72nd ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGIC MAPPING – "WALKABOUTS" IN CENTRAL PENNSYLVANIA:

1st-to 5th-Order Appalachian Mountain Folds; Folded Thrusts; Ordovician & Silurian Carbonates; Silurian Quartzites & Sandstones

Host: Pennsylvania Geological Survey

September 27-29, 2007
Burnham, Pennsylvania

Guidebook for the

72ND ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGIC MAPPING – "WALKABOUTS" IN CENTRAL Pennsylvania: 1st- to 5th-Order Appalachian Mountain Folds; Folded Thrusts; Ordovician & Silurian Carbonates; Silurian Quartzites & Sandstones

Editor:

John A. Harper, Pennsylvania Geological Survey

Contributors and Feld Trip Leaders:

Nathaniel C. Barta, Pittsburgh, PA
Paul T. Fagley, Greenwood Furnace State Park
Donald M. Hoskins, Pennsylvania Geological Survey, Retired
Thomas A. McElroy, Pennsylvania Geological Survey

September 27-29, 2007

Host: Pennsylvania Geological Survey

Headquarters: Quality Inn and Suites, Burnham, PA

Cover: Tom McElroy and Don Hoskins pause briefly during their "walkabout" of Kishacoquillas Valley and environs to check a map, while the spirits of geologists from years gone by roam the landscape looking for just one more outcrop to study. Cover by John A. Harper from a concept by Thomas A. McElroy and Donald M. Hoskins, based on the work of George Lehman, artist with the First Geological Survey of Pennsylvania, 1858.

Cartoons: John A. Harper

Guidebooks distributed by: Field Conference of Pennsylvania Geologists, Inc.
3240 Schoolhouse Road
Middletown, PA 17057

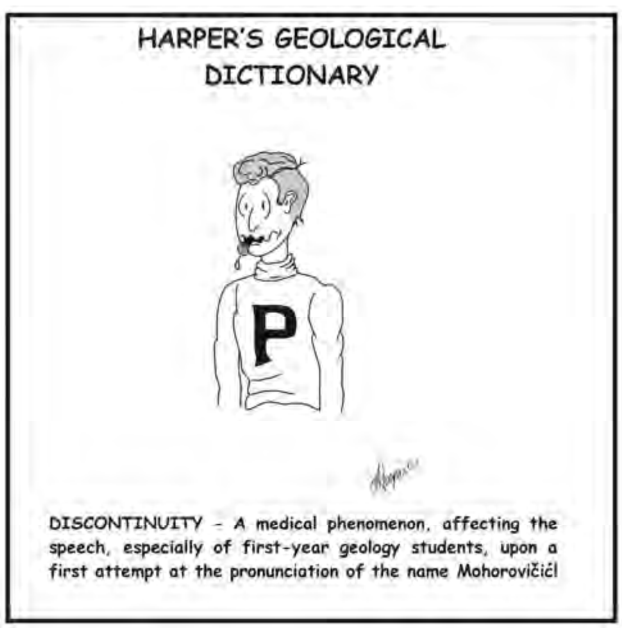
http://www.paonline.com/gfleeger/fcopg/

Frontispiece: Group photo of the 2006 Field Conference of Pennsylvania Geologists at the “red rocks” quarry (Stop 6).

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES



INTRODUCTION

The 72nd Annual Field Conference of Pennsylvania Geologists mainly presents the results of a portion of the field geologic mapping program of the Commonwealth's Bureau of Topographic and Geologic Survey, commonly referred to as the Pennsylvania Geologic Survey (or PaGS, if you like abbreviations). Preparing and publishing areal geologic maps has been a major activity of the Survey since its inception in 1836 and continues with its current geologic mapping program.

With two notable exceptions, the sites to be visited and examined are included in three 7½-minute topographic quadrangles mapped as part of the Survey's current geologic mapping program – Lewistown, Belleville, and Allensville (Figure 1). These quadrangles include complexly folded and faulted Ordovician to Devonian stratigraphy in two 1st –order fold structures with subsidiary 2nd – through 5th –order structures.

To the southeast is the complexly folded (with minor faulting) synclinal structure embraced by the Shade-Blue Mountain 2nd –order anticlines on the south and south-dipping Jacks Mountain on the north (Figure 1). Included in the synclinal structure are 3rd –order anticlines represented by Chestnut Ridge and the complexly folded and faulted structures of Big Ridge exemplified by the faulted and tightly overturned synclinal structures at "OZ."

To the northwest is Kishacoquillas Valley, a 1st –order breached anticlinal structure underlain by Ordovician carbonates (Figure 1). This pastoral valley, largely consisting of open fields farmed by Amish and Mennonites who maintain simplified life styles, contains major pre-Alleghanian detachment faults separating the carbonates from the overlying clastic rocks. On the north side of Kishacoquillas Valley splay faults extend upward from the detachment fault through the resistant clastic rocks that underlie the mountains into additional lower Silurian rocks. During the Alleghanian deformation these splay faults were folded producing complex geological fault patterns. The two notable exceptions to be visited are:

- The newly created, and rarely exposed, outcrops of the upper 1/3 of the Tuscarora Formation. At Macedonia, on the northeastward plunge of Blue Mountain, the exposures provide an unusual opportunity to examine in detail the sedimentary and paleontologic features of the Tuscarora's "western cross-laminated facies" (Cotter, 1982 and 1983), as well as a newly revealed zone of complex 4th – and 5th –order folds and faults not identified nor mapped by Conlin and Hoskins (1962) on the published geologic map of the Mifflintown quadrangle that includes this site.
- Extensive exposures of the Upper Ordovician carbonate rocks at Reedsville that include one of the rare exposures of structures interpreted by Nickelsen (1988) to be the result of the pre-Alleghenian detachment fault. Above these structures is the contact of the Coburn Formation with the rarely seen Antes Shale. In addition, this site provides nearly 100 percent exposure of Coburn to Salona carbonates, and, on nearby Old US Route 22, nearly complete exposure of the Nealmont to Loysburg sequence.

Both of these exposures, while not in the published mapped area, provide information and insights crucial to understanding and interpreting the geology of the area mapped.

Erosion of the region produced large-scale scenery that is mainly underlain by the resistant quartz arenite of the Tuscarora Formation. Sites that will be visited and traversed during the trip provide exceptional views of large scale geologic structures that are exemplary of

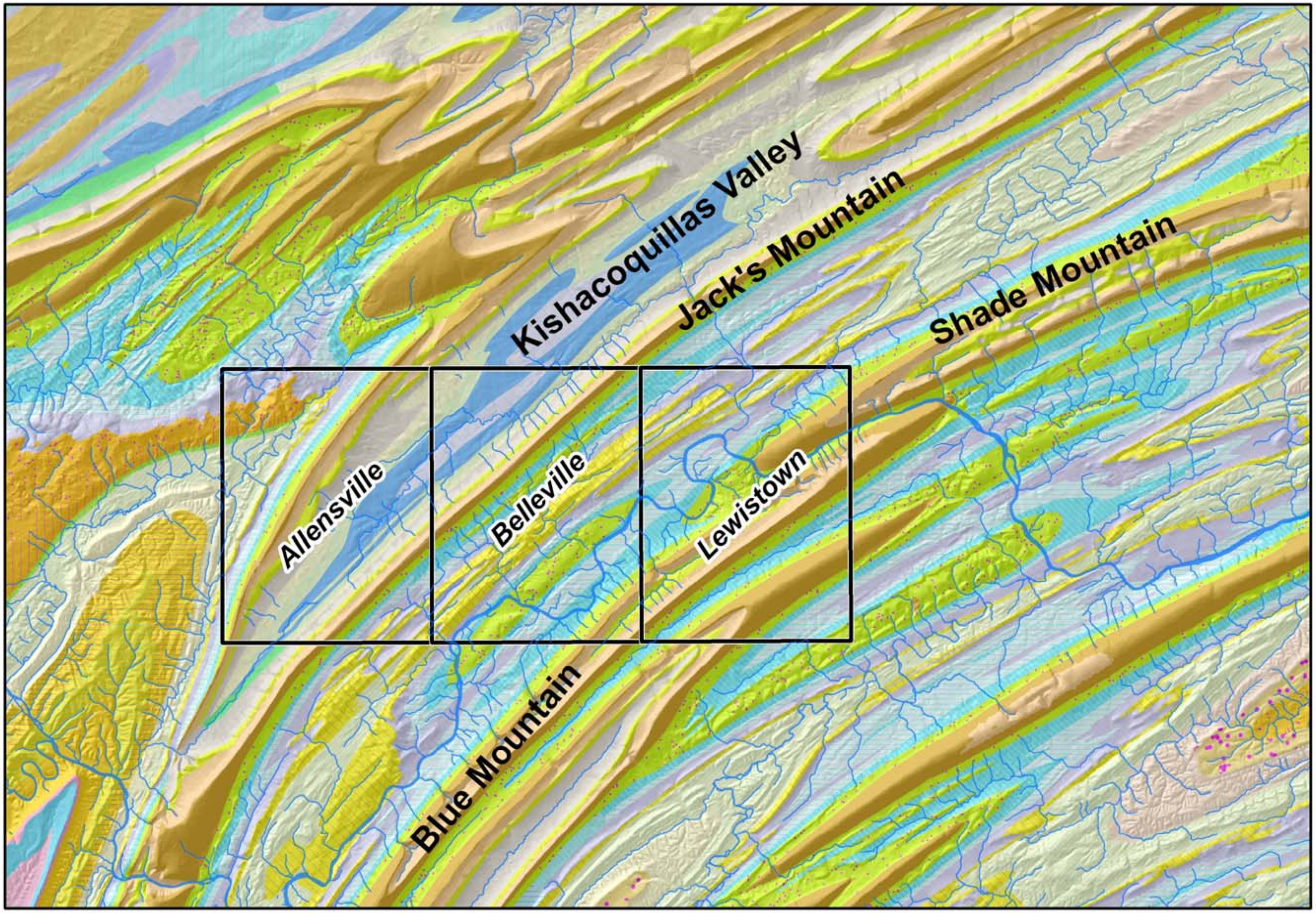


Figure 1. Shaded relief geologic map of a portion of central Pennsylvania showing the major physiographic features discussed in the text, and the locations of the Allensville, Belleville, and Lewistown quadrangles.

Pennsylvania's folded Appalachian Mountains.

The geological picture that we plan to present utilizes the result of the work of many geologists who preceded the current mapping program. Without their work, we would not have been able to produce, in the time allotted, the current series of maps that cover the area of the 72^{nd} Field Conference. For their work and understanding we are very grateful.

Of the geologists who have examined and mapped the area's geology, notably in the Kishacoquillas Valley, we have relied on the work of Morris Rones who, as a student at Pennsylvania State University, mapped much of the valley (and other carbonate valleys) in the 1950s. His field maps, prepared on topographic maps at the older scale of 1 inch to a mile are remarkably accurate. These maps were in the possession of the Survey during the flood that destroyed its offices in 1972. They were luckily recovered, preserved, and were used by us. Our mapping of the formational contacts is a refinement of his.

Similarly, the field notes collected by Richard Nickelsen, and field maps he prepared while examining the Kishacoquillas Valley, were graciously provided to us and used. Nickelsen's work resulted in his 1988 paper "Structural evolution of folded thrusts and duplexes on a first-order anticlinorium in the Valley and Ridge Province of Pennsylvania" (reprinted here as Appendix 1).

We adopted Nickelsen's interpretation of the geologic structure of the Kishacoquillas Valley as our framework for the geologic mapping of the detachment faults and splays in the valley. By re-examination of his mapped contacts of the carbonates and overlying clastic rocks, and doing extensive additional "walkabouts," we obtained additional data supporting that this contact is best represented as a detachment fault. To do so we have extended our mapping into areas bordering the Belleville quadrangle, most notably to the northeast into the Barrville quadrangle.

Few stratigraphic investigations have been made in the area we have mapped. This lack is due to the absence of outcrops sufficiently large enough to reveal the stratigraphy of mappable units. Most outcrops are small, particularly those exposing carbonates, and most often exhibit only the more erosionally resistant lithologies. Assembling these outcrops into a coherent geologic picture that can be presented as a geologic map is best resolved by combining outcrop data with stereographic aerial photographs.

Stratigraphic classification into mappable units in an area replete with complex structural features requires that the units exhibit characteristics clearly applicable to quadrangle field mapping. We have been unable to differentiate as mappable units the carbonate stratigraphic units immediately underlying the detachment fault. However, stratigraphers have subdivided these carbonates into formations and members. Researchers and students at the Pennsylvania State University and other state universities have described the stratigraphy of the Upper Ordovician carbonates. Nathanael C. Barta, M.S. (The Ohio State University), who has measured and studied the upper Black River and Trenton Groups at this section, volunteered to be the principal presenter of stratigraphic interpretations at Stop 6.

ACKNOWLEGEMENTS

David P. "Duff" Gold, Emeritus at Pennsylvania State University, and Arnold Doden, consultant, introduced us to the Ordovician Trenton and Black River carbonates at Reedsville that underlie the areas we mapped in the Kishacoquillas Valley. Tom Whitfield and Michael Moore provided exemplary help in producing the geologic maps used at the stop descriptions.

Gary Fleeger, in his inimitable mordant fashion, was very helpful in preparing digital images and scanning material for the appendices, providing advice in putting together the guidebook, and general information for running a field conference. Brent Custer, our intern, assisted in creating the road log, clearing stop sites of vegetation blocking views of the rocks, served as a scale for many photographs, and assembled montages of photos used in the guidebook, as well as the very large composite of the road cut on the east end of the Lewistown Narrows at Macedonia.

Charles Zugell, project manager for Walsh Construction, was very cooperative in providing repeated access to the Macedonia portion of the new Lewistown Narrows reconstruction project so that we could examine the geology during early and final periods of construction. Albert Mabus, of Eastern Industries, provided access and information on his company's quarries we will be visiting. Harry Barr allowed us ready access to his property for geologic mapping and core hole drilling. We thank the many fine families throughout the area, particularly in the Kishacoquillas Valley, who provided us with permission to do "walkabouts" in their farm fields during various portions of the growing season.

John Harper's editing of the guidebook and drawing for the cover significantly contributed to the guidebook's production and is greatly appreciated. Any remaining errors are the responsibility of the authors and not the editor. Bill Bragonier and Elizabeth Lyon provided logistical support in obtaining entry permissions for stop sites, advertisements, and registration of conferees.

References

Conlin, R. R. and Hoskins, D. M., 1962, *Geology and mineral resources of the Mifflintown quadrangle, Pennsylvania*, Pennsylvania Geological Survey,4th ser., Atlas 126, 46 p.

Cotter, Edward, 1982, *Tuscarora Formation of Pennsylvania*, Field Trip Guidebook, Society of Economic Paleontologists and Mineralogists, Eastern Section, 1982, Lewistown, Pa., 105 p.

Cotter, Edward, 1983, *Shelf, paralic, and fluvial environments and eustatic sea-level fluctuations in the origin of the Tuscarora Formation (Lower Silurian) of Central Pennsylvania*, Journal of Sedimentary Petrology, v. 53, no. 1, p. 25-49.

Nickelsen, R. P., 1988, *Structural evolution of folded thrusts and duplexes on a first-order anticlinorium in the Valley and Ridge Province of Pennsylvania*, Geological Society of America, Special Paper 222, p. 89-106.

LEWISTOWN NARROWS RECONSTRUCTION

Thomas A. McElroy
Pennsylvania Geological Survey

For decades, US Routes 22-322 through the Lewistown Narrows was known as a dangerous road in need of reconstruction. Reader's Digest dubbed it the second-most dangerous stretch of highway in the United States (Ecenbarger, 1995). It was, before construction began, lined with 39 crosses marking traffic fatalities. The road is a vital link between local and regional communities, with about 20,000 vehicles per day traveling through the Narrows, and many more on weekends when the Penn State football team is playing at home.

There were prior reconstruction plans. The 1973 guidebook for the Field Conference of Pennsylvania Geologists included one plan with a map. It utilized two bridges for the eastbound lanes. Costs and difficulties with getting environmental permits for bridges scotched that plan.

In the 1990's the Pennsylvania Department of Transportation (PennDOT) committed itself to the reconstruction of the Narrows. The design process ran from 1996 to 2003. In addition to design complications caused by the lack of suitable construction space, which is limited by the geology, PennDOT also decided to include a new Canal Park, utilizing the circa 1860 canal house as a museum/visitor center, a fishing/boating access area, and a trail and overlook at the Pennsylvania Canal. Tentative plans are to include a description of the geology of the Macedonia cut at the museum/visitor center.

The Narrows occupies a narrow (no surprise) 2nd –order syncline flanked by two 2nd –order anticlines, Shade Mountain anticline on the north, Blue Mountain anticline on the south. The structures are part of the 1st –order Shade Mountain anticlinorium. The predominantly shale Rose Hill Formation crops out along the axis of the syncline, and the underlying Tuscarora Formation is on the flanks of the anticlines.

The northern side of the roadway is flanked by marginally stable scree slopes on the side of Shade Mountain. The scree is derived from the Tuscarora Formation, and is the result of periglacial conditions. Depending on construction techniques, the scree is subject to massive landslides.

The south side of the roadway is flanked by the historic Pennsylvania Main Line Canal and the Juniata River. The Norfolk-Southern railroad, once the main line of the Pennsylvania Railroad, is on the south side of the river.

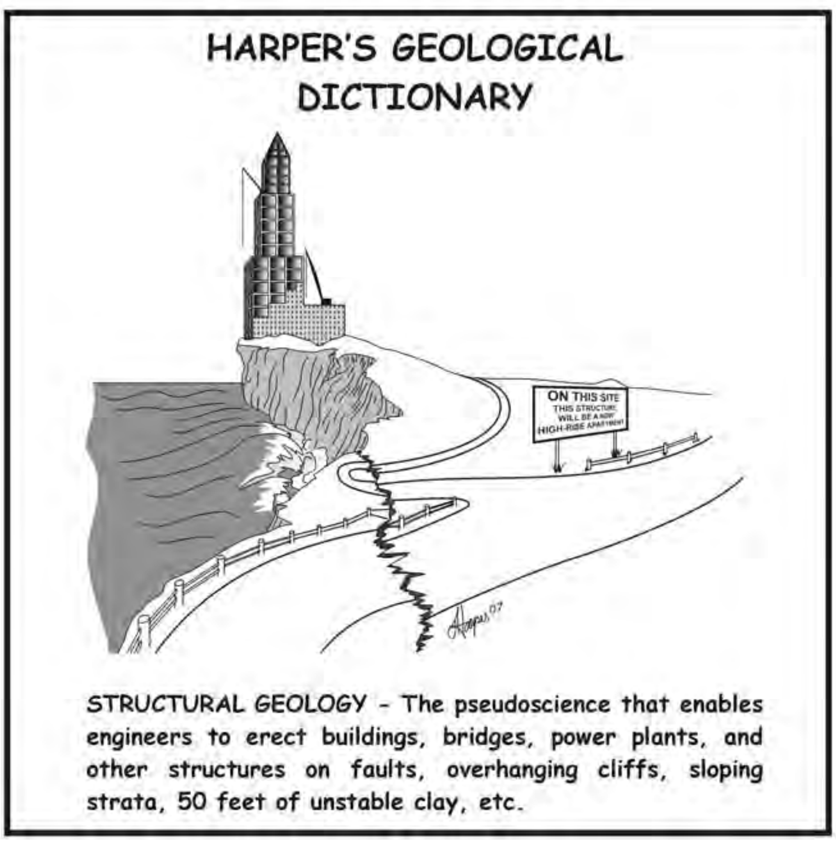
The challenges resulted in one of the most complex projects ever undertaken by the Pennsylvania Department of Transportation. Geotechnical work included more than 40,000 linear feet of core drillings as well as seismic and ground penetrating radar investigations. The design includes several unique features, including extensive elevational bifurcation of the roadway, in some cases elevating the west bound lanes over the scree in order to avoid cutting into the unstable mountain slope. Fill at the base of the slopes acts as a counterweight against the slopes of the mountain. Fill was obtained from the large cut through the plunging nose of the Blue Mountain anticline at the east end of the project that is Stop 1 of this Field Conference.

Micropiles installed in the early phase of construction were used to provide resistance to slope failure. The seven-inch diameter steel-pipe pilings range in length from 15 to 45 feet. They are drilled through surficial materials and imbedded six feet into the bedrock. They are filled with grout and are spaced one to two feet apart over a distance of three miles. Over 230,000 feet of the micropiles were installed. The scale of micropile utilization is the largest ever and was a multi-million dollar expense. The design also incorporates reinforced soil slopes, mechanically stabilized earth walls, steel H-piles, concrete cantilever walls, vibration monitoring, and rockfall protection ditches/fences. At the west end of the project, approximately 360 rock anchors were installed to prevent Tuscarora Formation quartzite dipping towards the roadway from slipping on interbedded shale that is lubricated by several springs.

Construction began in 2004 and is scheduled to be completed in the fall of 2008. The construction contract was more than $104 million, the second largest awarded in PennDOT history. When finished, travel will be on safe and fast highway through a previously very dangerous stretch of road, and there will be a wonderful exposure of the Rose Hill and Tuscarora formations that geologists will be inspecting for years to come.

Reference

Ecenbarger, William, 1995, *America's most dangerous highways*, Readers Digest, September, 1995, v. 147, no. 881, p. 78



THE GEOLOGY OF OZ —
AKA THE US ROUTE 22-522 INDUSTRIAL DRIVE INTERCHANGE

Thomas A. McElroy
Pennsylvania Geological Survey

Introduction

In July 2003, Tom McElroy and then Assistant State Geologist Sam Berkheiser first entered the portion of the US Route 22-522 Lewistown Bypass where it cuts deeply into Big Ridge in Granville Township, Mifflin County (Figure 2). This area lies in the Appalachian Mountains Section of the Ridge and Valley Province. At the time, excavation was underway for an exit ramp to the Mifflin County Industrial park, which is located to southeast of the area, and Tom and Sam had come to investigate the new exposure. They were surprised to see from a distance a broad band of black rock. It had to be the black shale of the Marcellus Formation, but only formations older that the Marcellus were shown on the existing geologic map for the area (Berg and Dodge, 1981). The site was a jumble of blasted rock that made contact and attitude determinations difficult. As Tom and Sam scrambled up the steep slope, they found more surprises. In the Old Port Formation, they noted the following: (1) a pod of black, deeply weathered rock that appeared to be a consequence of a fuel spill; (2) Shriver Chert having anomalous purple and yellow bands; and (3) three distinct variations of the Ridgeley Sandstone. These strange appearances caused Tom to remark, “Are we in Oz?” As blasting and removal of rock continued, the geology became clear, but the nickname stuck.

The construction project posed numerous geotechnical challenges, including, but not limited to, hillside failures in the clayey shales, old mine workings in sandstones and shales, and acid drainage generated by the pyritic black shales. Perhaps the most costly challenges were the hillside failures, which necessitated laying back the slope above the roadway from the original 1.5:1 to 2.25:1 horizontal-to-vertical ratio

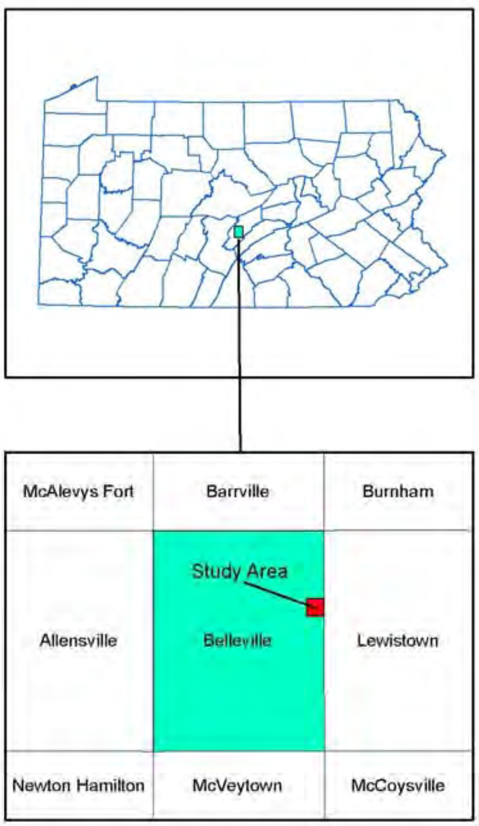
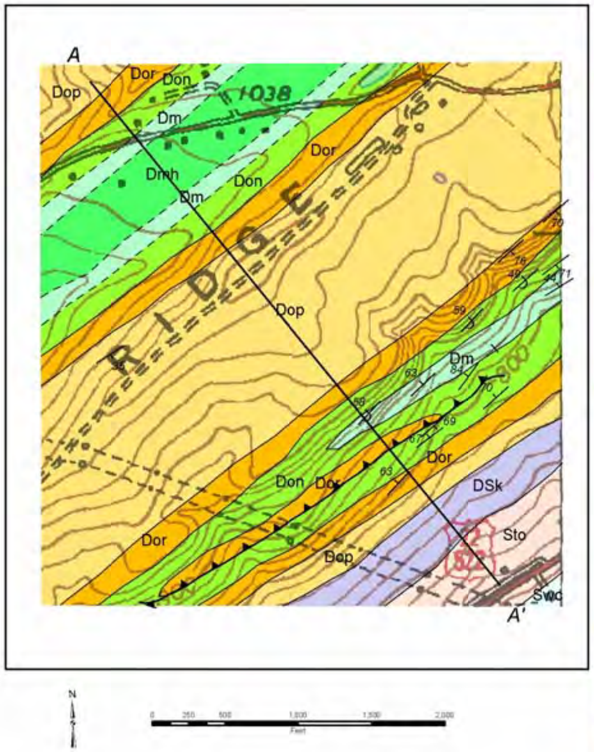


Figure 2. Location of the US Route 22-522 Industrial Drive Interchange (modified slightly from McElroy, 2006)

Stratigraphy

The stratigraphic relationship of rocks and their thicknesses at the Industrial Drive Interchange are shown and described in Figure 3, modified from McElroy and Hoskins, 2005. The oldest formation exposed at the bottom of the cut is the Early Devonian Old Port Formation, the underlying formations being covered by colluvium and construction materials. The youngest is the Middle



Commonwealth of Pennsylvania
Department of Conservation and Natural Resources
Bureau of Topographic and Geologic Survey
2005

Unit	Geologic Description
MAHANTANGO FORMATION Dmh	The Mahantango Formation is composed of medium-gray, olive-weathering, fine- to coarse-grained sandstone and numerous dark-gray to brown shale interbeds. It has well-developed, thin to flaggy bedding. Only about the lowermost 100 feet are present on the Belleville quadrangle.
MARCELLUS FORMATION Dm	The Marcellus Formation consists of grayish-black to black carbonaceous clay shale. It contains abundant pyrite. Several bentonites are contained within the formation. Its thickness is about 70 feet.
ONONDAGA FORMATION Don	The Onondaga Formation consists of olive-green-weathering, medium-gray limestone and calcareous shale. It contains claystone in its lower part. It has well developed, flaggy to thick bedding. The Selinsgrove Limestone Member is dark gray and fossiliferous. It is approximately 135 feet thick.
RIDGELEY MEMBER Dor	The Ridgeley Member consists of fine- to very coarse grained, pebbly, white and light gray to buff, fossiliferous sandstone. It is medium to thick bedded, with a thickness of 75 feet. It was formerly known as the Oriskany.
OLD PORT FORMATION Dop	The Old Port Formation contains diverse rocks types, including sandstone, chert, shale, and limestone. At the top the formation is the Shriver Member, a dark-gray to black chert that weathers to light gray to white or yellow brown or purple. Below the Shriver Member, the formation is dominantly a dark gray, massive limestone, with numerous interbeds of very fine grained sandstone, shale, chert, and siltstone. It is about 200 feet thick.
KEYSER FORMATION DSk	The Keyser Formation is a dark-gray, fossiliferous, crystalline to nodular limestone with thin bedded limestone at its top. It is well bedded, with beds flaggy to thick. Some beds are massive. It is about 170 feet thick.
TONOLOWAY FORMATION Sto	The Tonoloway Formation is a medium-gray finely laminated limestone. It is well bedded, with beds flaggy to thick. It is about 675 feet thick.
WILLS CREEK FORMATION Swc	The Wills Creek Formation is a greenish-gray shale containing local limestone and sandstone zones. Red shale and siltstone occur in the lower part of the formation. It is moderately well bedded, with fissile to thin beds. Its thickness is about 600 feet.

Figure 3. Bedrock geology at the Industrial Drive Interchange area (from McElroy and Hoskins, 2005). The Lewistown Bypass runs northeast-southwest through the area of excavation. Starting at the northeast end of the excavated area, the off-ramp swings northwest of the bypass, curving around to pass under the bypass and connect with Old Routes 22-522 and Industrial Drive in the southeast corner of the map. See Figure 5 for cross section A-A'.

Devonian Marcellus Formation.

The Old Port Formation consists of the limestones, shales, cherts, and sandstones overlying the Keyser Formation and underlying the Needmore Shale Member of the Onondaga Formation (Conlin and Hoskins, 1962). The dominant lithology of the Old Port Formation occurs in the lower part of the formation and consists of limestone with interbeds of very fine-grained sandstone, black chert, and shale. Almost all of the lower Old Port is covered by construction material at the excavation site. Above the limestone are the Mandata Member and the Shriver Member. The Mandata is olive black, thin-bedded, noncalcareous shale. In this area, it is not continuous, with thicknesses up to about 20 feet. The pod of black, deeply weathered rock mentioned in the introduction is the Mandata Member. The Shriver Member is fossiliferous, dark-gray to black chert that typically weathers to light gray to white or yellow-brown. At this location, weathered chert has striking thin purple and yellow bands. Typically, however, the Shriver Chert in this area has brown and yellow banding. The Shriver is continuous at the site, and its thickness varies from about 30 to 50 feet in the surrounding area. Table 1 is a measured section of the Old Port Formation taken 2½ miles northeast of the off ramp. Most of the measured section site is now paved over. The Ridgeley Member is at the top

Table 1. Measured section of the Old Port Formation at 40^{o}36’21”N, 77^{o}35’08”W.

Top	Bottom	Thickness	Description
0	29.5	29.5'	Weathered Shriver Member
29.5	34.3	4.8'	Dark-gray limestone
34.3	40.6	6.3'	Very-fine-grained sandstone, yellowish gray weathered to grayish yellow, non calcareous, brachiopods
40.6	72.1	31.5'	Dark-gray limestone
72.1	74.6	2.5'	Very-fine-grained sandstone, yellowish gray, noncalcareous, brachiopods
74.6	77.6	3'	Dark-gray limestone
77.6	83.6	6'	Very-fine-grained medium-dark-gray sandstone, thin bedded, noncalcareous, brachiopods
83.6	93.6	10'	Dark-gray limestone
93.6	93.9	4"	Limy, thin-bedded, brown-gray shale
93.9	95.4	18"	Black chert, brachiopods
95.4	95.8	4"	Highly weathered clastics, probably shale, yellowish brown, noncalcareous
95.8	139.8	44'	Dark-gray limestone
139.8	141.8	2'	Very thin-bedded, laminar limestone, light gray
141.8	143.3	18"	Thin-bedded, very-fine-grained, brown, sandstone
143.3	143.5	3"	Dark-gray chert
143.5	144.5	12"	Thin-bedded, very-fine-grained, brown, sandstone
144.5	145.5	12"	Gray siltstone
145.5	173.5	28'	Dark-gray limestone

of the Old Port Formation. It consists of white to very-light-gray, weathering to grayish-orange, quartz sandstone. It is about 70 feet thick. Robust brachiopods are common (Figure 4).

Cementation of the Ridgeley Member is highly variable at the site. Going up the slope of the excavation, the Ridgeley is exposed three times (Figure 3). The sandstone at the southeasternmost exposure is very friable and was deep-mined as a source of glass sand sometime in the 19th century. The mine's existence was not known to the contractors. They discovered it when a bulldozer fell into it. Collapses above the mine extend more than a half mile to the southwest. A fault-bounded, siliceous, very hard Ridgeley Member is exposed 175 feet to the northwest. The northeastern end of the outcrop is easily seen. The southwestern end of the outcrop is inferred from float. The third exposure of the Ridgeley Member, this one of well-indurated, fossiliferous sandstone, occurs higher on the ridge.

Overlying the Ridgeley Sandstone are the rocks of the Onondaga Formation. The Onondaga Formation consists of two members, the Needmore shale (lower) and the Selinsgrove limestone (upper) (Willard, 1935). The Needmore Member is a medium-gray to medium-light-gray, fissile, generally calcareous shale. It commonly displays pencil cleavage and contains a few pyritized brachiopods. The Selinsgrove Member is a dark- to medium-gray, dense, microcrystalline to very finely crystalline, fossiliferous, argillaceous, locally carbonaceous limestone. Bedding ranges from thin to thick. One of the Tioga ash beds is at the top of the Selinsgrove Member. It is a widespread deposit of crystal tuff, tuffaceous siltstone, and bentonitic shale. Way and others (1986) provide a detailed description of the lithologic character of these ash beds as well as a regional correlation throughout central Pennsylvania. The Onondaga Formation is about 135 feet thick.

The Marcellus Formation is a highly fissile, dark-gray to black shale (Faill and Wells, 1974). It is rarely fossiliferous, noncalcareous, slightly silty, and locally pyritic. The pyrite is the source of the acid drainages at the site. The formation contains the remaining Tioga ash beds at this site. At this location, there is an iron ore at its base that was deep-mined in the 19th century. The old mine lies under the roadway just to the east. At the Mifflin County landfill, seven miles to the northeast, measured thickness of the Marcellus Formation is 70 feet.

Structure

The US Route 22-522 Industrial Drive Interchange is located on the southeast flank of the northeast-southwest striking Big Ridge syncline. The syncline is a second-order fold with numerous faults and third-order folds within it. The third-order fold exposed at the excavation site is an overturned, faulted syncline, with beds dipping 60-80 degrees to the northwest. At the east side of the geologic map (Figure 3), beds are not overturned. The syncline plunges out about one mile southwest of the stop. The fault is on the southeast limb, and is interpreted as a north-dipping thrust fault (Figure 5). It is hypothesized that the Ridgeley Member exposed adjacent to the fault is siliceous because of hydrothermal fluids circulating through it.

Geotechnical Challenges

Slope Failure

Heavy rains from Hurricane Ivan, in 2004, caused extensive slope failure in the cut (Figure 6). The view is to the northeast, along strike.

Figure 4. Ridgeley Member brachiopods. Quarter for scale (from McElroy, 2006).

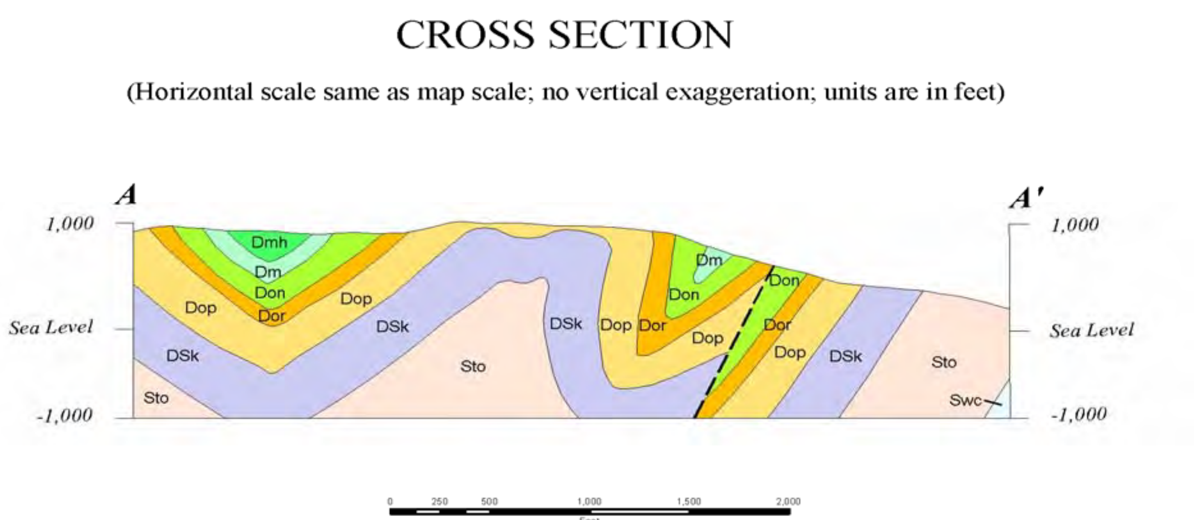


Figure 5. Northwest-southeast-trending geologic cross section for the vicinity of the US Route 22-522 Industrial Drive Interchange. See Figure 3 for the location of cross section A-A' and a key to the geologic units shown.

Figure 6. Slope failures at the US Route 22-522 Industrial Drive Interchange. Failures occurred after heavy rains associated with Hurricane Ivan had passed through the area. Construction for the Lewistown Bypass appears in the background of the photograph, and construction for the off-ramp to Industrial Drive appears in the foreground. The view is to the northeast from the southwest edge of the off-ramp roadcut. From McElroy, 2006.

Figure 7. Acid drainage from the Marcellus Formation at the US Rte. 22-522 Industrial Drive Interchange. Hard hat for scale.

Figure 8. Acid drainage flows out of an old iron mine in the Marcellus Formation at the excavation site. Photograph by Fred Waldner, Site-Blauvet Engineers, Inc., 2003.

Figure 9. Uncovered entrance to a Ridgeley sand mine encountered during excavation.

Figure 10. Mine opening with blown out cover.

There are numerous scarps parallel to the cut. The scarp at the top of the failure is about 20 feet high and is in the Shriver Member of the Old Port Formation. Failures extend downward (up section) through the Ridgeley Member, the Onondaga Formation and into the Marcellus Formation, which is the black rock at the toe of the cut. At the time of failure, the slope was 1.5:1. In the spring of 2006, the hillside was benched and cut back to a 2.25:1 slope.

Acid Water Generation

The road cut exposed the pyritic Marcellus Formation. As the formation lies on the axis of a syncline, the exposure is quite broad. Shortly after excavation exposed the formation, acidic, iron-rich water began to flow out of it (Figure 7). Pyrite, an iron sulfide formed under reducing (no oxygen) conditions, is the source of the acid drainages at the site. When it is exposed to air and water, it breaks down and forms sulfuric acid and iron hydroxide. A catch pond that the acidic drainage flowed into was drained, and sediment was removed and sequestered at the project spoil pile after being mixed with limestone to neutralize any acid.

The cut-back removed a large volume of the acid-water-generating Marcellus Formation, which may ameliorate the acid-water problems at the site. As with sediment from the catch pond, the material was mixed with limestone and sequestered. In addition, drains were installed above the Marcellus Formation to decrease the volume of groundwater passing through it, and the outcrop was covered to reduce its exposure to atmospheric oxygen.

Abandoned Mines

Two abandoned underground mines were dug into during excavation. The first was an iron mine underneath the main roadway just east of the off-ramp (Figure 8). The ore was at the top of the Marcellus Formation. The support timbers were still in place. The mine was filled in.

The second mine was a sand mine in the Ridgeley Member (Figure 9). Collapses above the mine extend more than a half mile to the southwest. A collapse adjacent to the mine opening exposed during excavation has repeatedly filled with water during storms until the pressure of the water was enough to blow out covers put over the opening (Figure 10). PennDOT plans on excavating from the mine opening to the collapse and piping storm water away.

References

Berg, T. M., and Dodge, C. M., compilers and editors, 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania, Pennsylvania Geological Survey, 4th ser., Map 61, p. 47.

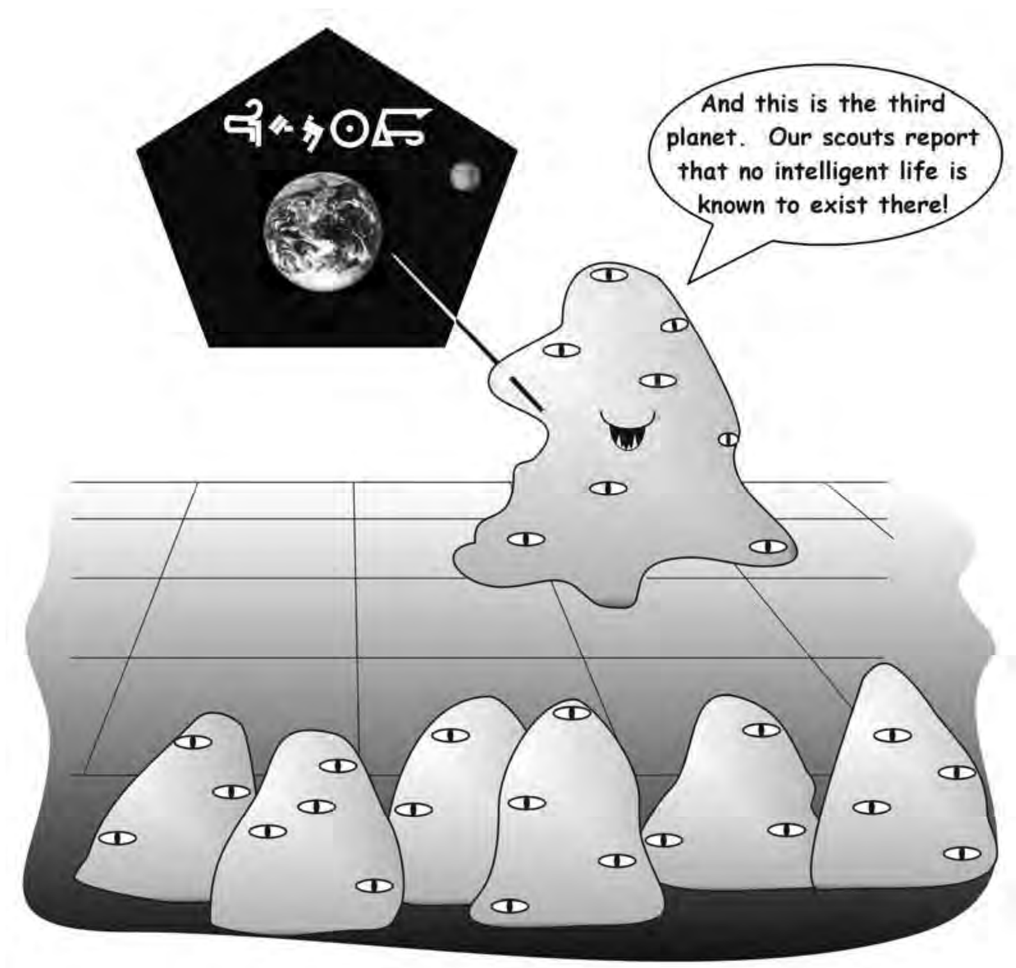
Conlin, R. R. and Hoskins, D. M., 1962, *Geology and mineral resources of the Mifflintown quadrangle, Pennsylvania*, Pennsylvania Geological Survey, 4th ser., Atlas 126, 46 p.

Faill, R. T. and Wells, R B., 1974, *Geology and mineral resources of the Millerstown quadrangle, Perry, Juniata, and Snyder Counties, Pennsylvania*, Pennsylvania Geological Survey, 4th ser., Atlas 136, 276 p.

McElroy, T. A., 2006, *Geology of Oz aka the U.S. Route 22-522 Industrial Drive Interchange*, Pennsylvania Geology, v. 36, no. 2/3, p. 2-9.

McElroy, T. A. and Hoskins, D. M., 2005, *Geology of the Belleville quadrangle, Pennsylvania*, Pennsylvania Geological Survey, 4th ser., Open File Report OFBG-05-7.0.

Way, J. H., Smith II, R. C., and Roden, Mary, 1986, *Detailed correlations across 175 miles of the Valley and Ridge of Pennsylvania using 7 ash beds in the Tioga zone,* Guidebook, 51st Annual Field Conference of Pennsylvania Geologists, Huntingdon, PA, p. 55-72
Willard, Bradford, 1935, *Hamilton Group in central Pennsylvania,* Geological Society of America Bulletin, v. 46, p 195-224.



STRATIGRAPHY OF THE LATE ORDOVICIAN CARBONATES AT US RTE. 322 AND RT. 76, REEDSVILLE, PA

Nathanael C. Barta, M.S.

Introduction

The Reedsville section at US Route 322 and Rt. 76 has been an important section for the study of Late Ordovician carbonates. Many workers have studied various aspects of the stratigraphy and structure of the outcrop. It is my hope that this section of the guidebook will give the reader a glimpse into some of the history and ongoing work at this section, as well as a good reference for various topics of interest.

I am also hoping to utilize this section to continue gathering input on the question of revising the lithostratigraphy of the upper Black River and Trenton Groups that I began investigating several years ago by integrating some of my interpretations and data from two presentations on the topic (Barta, 2004a; 2006).

Previous Work and Geologic Setting

The Reedsville section has been studied by many workers. The lithology of the outcrop has been studied by Thompson (1963), Rones (1969), and Slupik (1999). The K-bentonites that occur here have been studied by Cullen-Lollis and Huff (1986), McVey (1993), and Mitchell and others (2003). The carbon isotope stratigraphy of the section has been investigated by Patzkowsky and others (1997), Slupik (1999), and Barta (2004a, 2006). The former two investigators also included some comments on the sequence stratigraphy of the section.

Geologic Setting

The carbonate units exposed at Reedsville span the Turinian and Chatfieldian Stages of the Late Ordovician Mohawkian Series in North American nomenclature (Barta, 2004b) (Figure 11). The Mohawkian encompasses the same interval as the newly defined Sandbian and Katian Global Series (Bergström and others, 2006). The boundary between these global series occurs in the early Chatfieldian. Within the Reedsville section, the Turinian-Chatfieldian Stage boundary occurs at the Millbrig K-bentonite (#3 of Thompson 1963). The Trenton-Black River carbonates exposed at Reedsville belong within the British *Diplograptus foliaceus* Graptolite Zone and the North American *Climatograptus bicornis* and *Corynoides americanus* Graptolite Zones (Barta, 2004b) (Figure 11). The boundary of the new Global Series, the Sandbian and Katian, coincides with the *Cl. Bicornis–C. americanus* zonal boundary. The carbonates span several conodont zones. Here at Reedsville, the Nealmont through Coburn formations occur within the Midcontinent *Phragmodus undatus, Plectodina tenuis,* and *Belodina confluens* Conodont Zones and the North Atlantic *Amorphognathus tvaerensis* and *Am. superbus* Zones. (Richardson and Bergström 2003, Barta 2004a, 2004b, 2006).

These carbonates belong to the upper Black River and Trenton Groups. At the time of deposition, this part of North America was located 20E to 30E south of the equator (Witzke, 1990) (Figure 12). These Mohawkian carbonates were deposited on a passive carbonate bank that was activated by the Taconic orogeny to form the Taconic foreland basin. During the

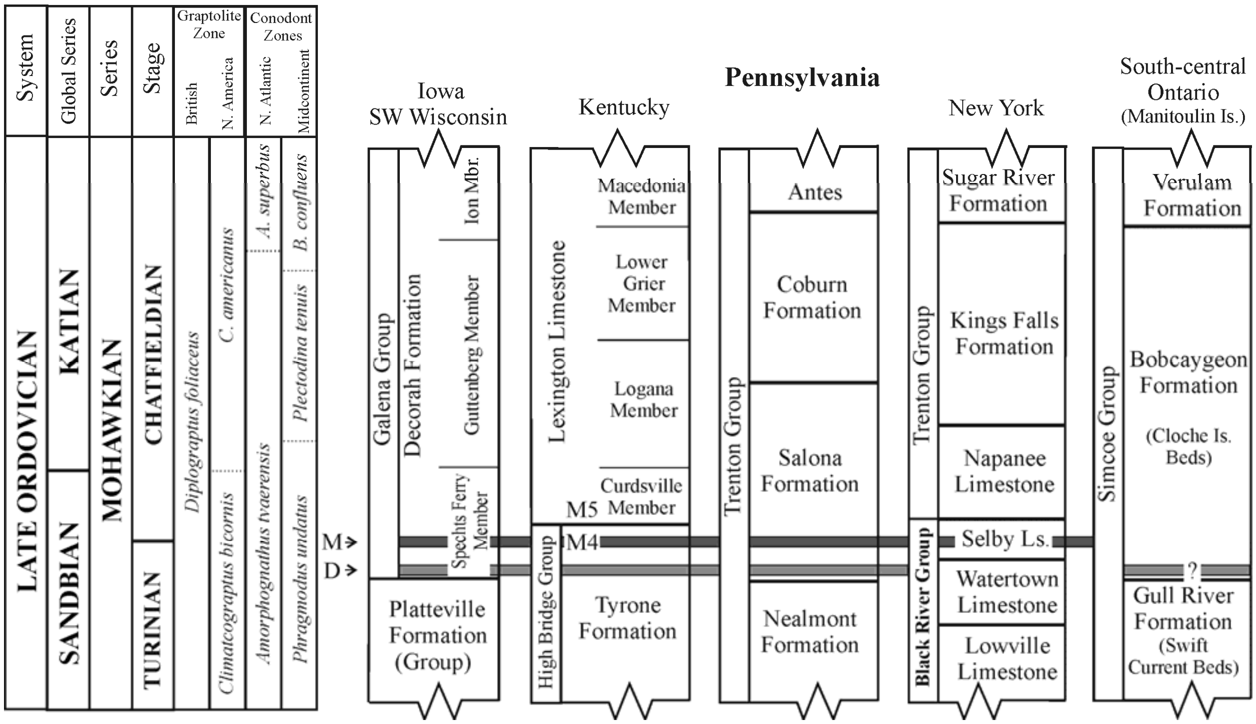


Figure 11. Chart showing general relationships for Mohawkain strata, modified from Leslie (2000). Global systems after Bergström and others (2006). Stadial terminology follows Leslie and Bergström (1995). Units are not to scale. Abbreviations: D - Deicke K-bentonite; M - Millbrig K-bentonite; B - *Belodina*. M4/M5 sequence boundary indicated for Kentucky (Holland and Patzkowsky, 1996). Modified from Barta (2004b).

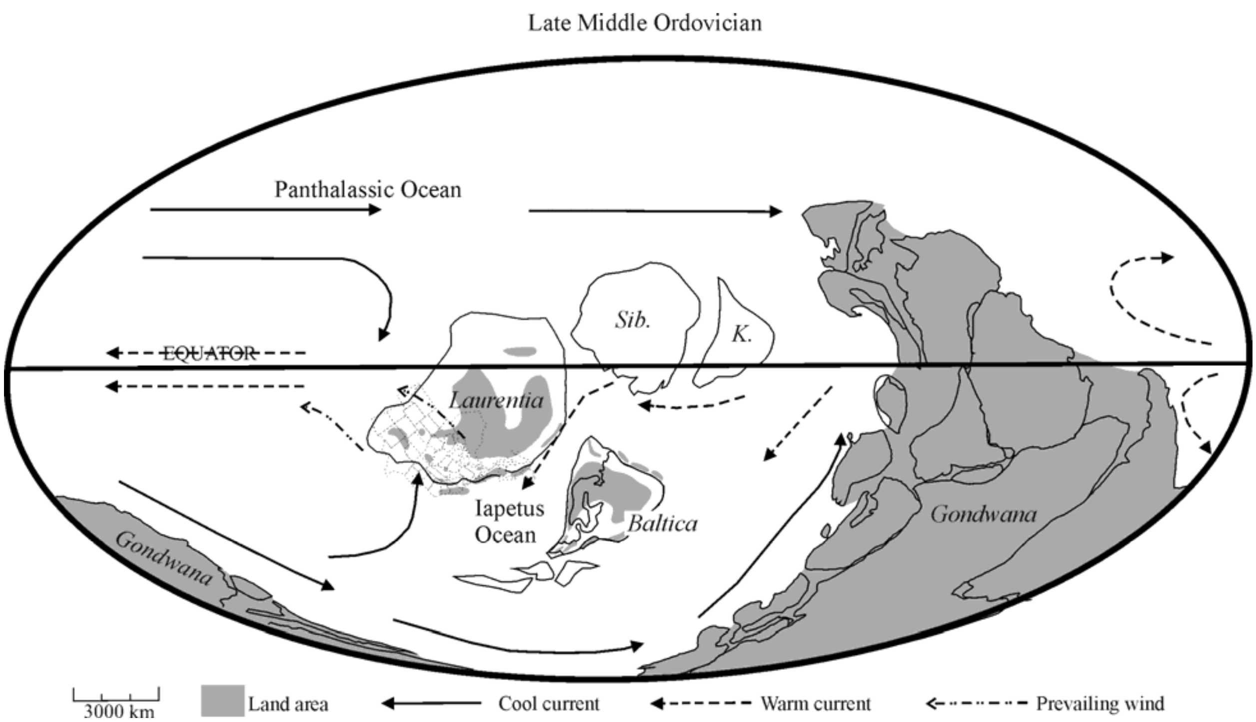


Figure 12. Late Ordovician paleogeographic reconstruction indicating inferred wind and ocean currents from Barta (2004b). Modified from Witzke (1991), Scotese and McKerrow (1991), and Pope and Steffen (2003). Abbreviations: Sib - Siberia; K - Kazakstania.

Taconic orogeny, the passive continental margin of Laurentia was steepened as microcontinents were sutured onto the passive margin (Kay, 1969). This suturing caused a significant amount of volcanic activity (Kolata and others, 1996). The Black River Group represents the last of the shallow, warm-water carbonate bank deposits and the Trenton Group represents the temperate or cool-water carbonates deposited during the progressive drowning of the carbonate ramp (Barta, 2004b). Overlying the Trenton carbonates, the Antes Shale represents the beginning of the siliciclastic infilling of the Taconic foreland basin.

Lithostratigraphy

It is important to note that there is a mixture of limestone-descriptive terminology in the following discussion. The studies by Thompson (1963) and Rones (1969) utilized clastic grain-size descriptions after Grabau (1924), and more recent workers utilize the terminology of Dunham (1962). I have found that the clastic terminology is most applicable for the description of the texture of weathered surfaces. Figure 13 shows the outcrop of the lower portion of the interval, along with the positions of the two major K-bentonites. Figure 14 is a stratigraphic column of the lower portion of the measured section.

Linden Hall Formation, Black River Group

The Linden Hall Formation was erected by Rones (1969) to encompass several formations named by previous workers. These include the Oak Hall, Valentine, Valley View, and Stover members, in descending stratigraphic order. The Linden Hall Formation, Oak Hall Member, has been provisionally recognized by the author as occurring at this outcrop due to the occurrence of two hardground layers in the first 2 m of the measured section, and lithology consistent with Rones' (1969) description of the Linden Hall in his measured section at Reedsville. The lithology of the Oak Hall Member is described below.

Figure 13. Photograph of the Center Hall to Salona interval at Reedsville, PA. Solid white lines indicate positions of the Deicke and Millbrig K-bentonites. The dotted line indicates transitional contact of the Center Hall (CH) Member and Rodman (R.) Member of the Nealmont Formation.

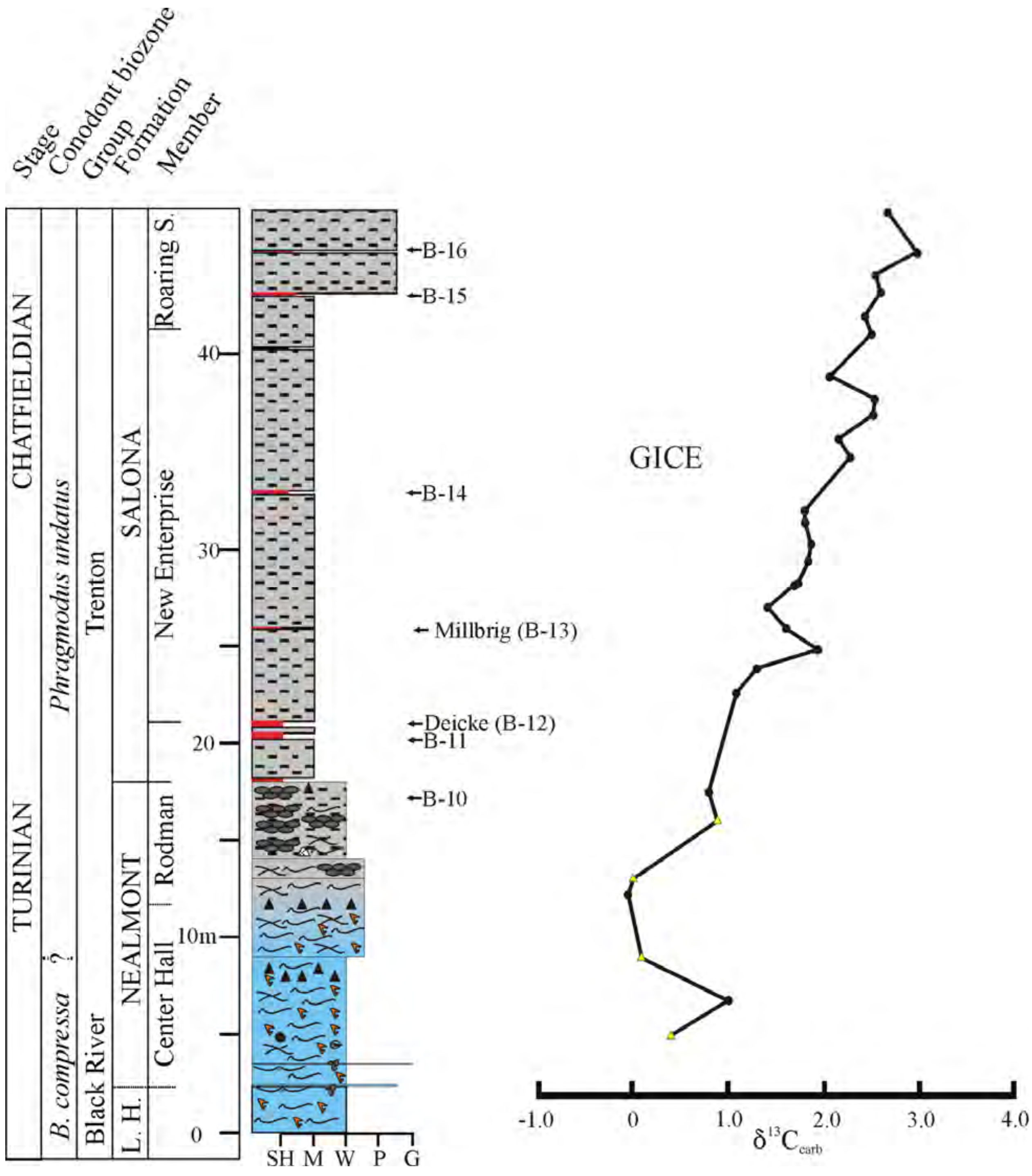


Figure 14. Stratigraphic section of the lower 25 m of the Reedsville, PA outcrop showing $\delta^{13}C_{carb}$ data plotted by Patzkowsky and others (1997) with additional data points of Barta (2004a, 2006) denoted as triangles. Additional data smoothes the sharper negative shift in $\delta^{13}C_{carb}$ values at the base of the Salona Formation.

Oak Hall Member – Formerly the lowest member of Kay's (1944) Nealmont Formation, the Oak Hall was removed from the Nealmont Formation by Rones (1969) as it was found to be an equivalent facies of the Valentine and Valley View limestones. The Oak Hall Member is defined as a medium-dark-grey, "3-foot to 5-foot bedded medium to course calcilutite [with] ...

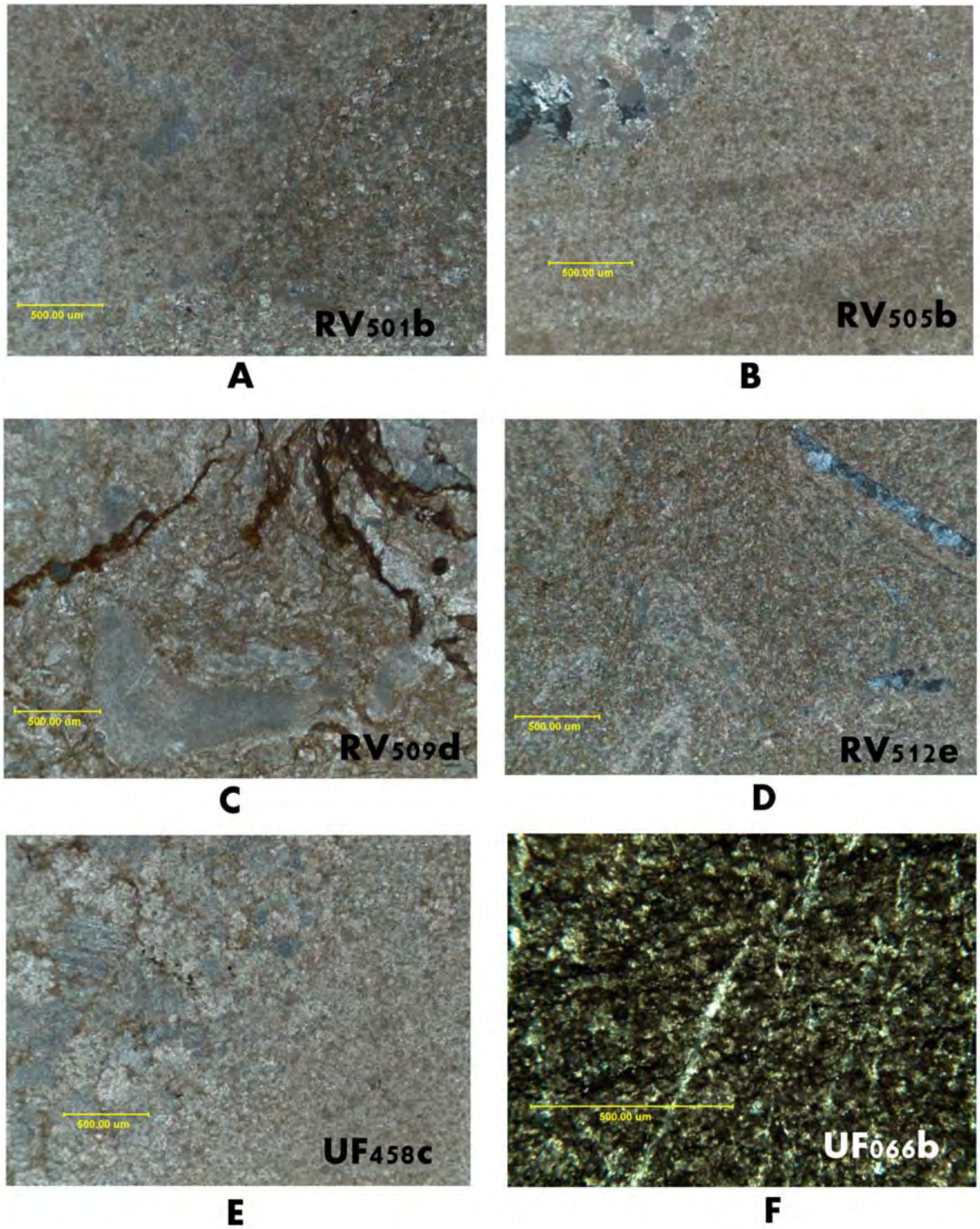


Figure 15. Photomicrographs of thin sections from 5 m, 9 m, 13 m and 16 m at Reedsville (A-D, respectively), compared with photomicrographs of thin sections of the Linden Hall (E) and Salona (F) formations at Union Furnace, Pennsylvania.

irregular dolomitic streaks....while in other layers the streaks develop into continuous bands" (Rones, 1969, p. 46). Here at Reedsville, the Oak Hall can be described as a medium- to dark-grey, bioturbated, bioclastic wackestone, with discontinuous laminae or lenses of light-grey to light-tan, very fine grainstone.

The contact of the Oak Hall and the overlying Nealmont is defined as the N_2 K-bentonite where it occurs. Rones' (1969) measured section at Reedsville, primarily lost due to highway widening, notes the presence of this K-bentonite. I have not found this K-bentonite in the existing section. The Nealmont and Linden Hall formations are reportedly separated by an unconformity as noted by Kay (1944). However, Rones found the contact to be conformable at Reedsville, Oak Hall, and Tusseyville.

Nealmont Formation, Trenton Group

The Nealmont Formation (Kay, 1944) originally included three members, The Oak Hall, Centre Hall, and Rodman limestones. Rones (1969) restricted the Nealmont to include only the Centre Hall and Rodman members. Here at Reedsville, both members of the Nealmont Formation are exposed.

Centre Hall Member – Initially defined by Field (1919), Rones (1969) defined two lithotypes within the Centre Hall Member. The first (Rones' Type 2a) is "2-inch to 4-inch irregularly bedded, fossiliferous, medium to coarse calcilutite [mudstone/wackestone]. . . some shaley or clayey surfaces appear and give the beds a slightly impure aspect . . . related to the presence of thin, closely spaced, irregular argillaceous and dolomitic bands along which parting develops" (Rones, 1969, p. 37).

Rones' second lithotype (Type 2b), a minor component of the member, is "1-foot to 3-foot even-bedded sparsely fossiliferous, coarse calcilutite to calcisiltite interbeds . . . occasionally contain scattered tubular to cylindrical structures indicative of worm borings" (Rones, 1969, p. 37). Rones noted two-inch crinoidal calcarenites (packstone/wackestones) in the upper part of the member. These were interpreted as the transition into the Rodman-type facies. Slupik (1999) described the unit at Reedsville as light- to medium-grey floatstone containing chert lenses. Protruding brachiopods can be found on weathered surfaces. See discussion above on placement of base of the member.

Rodman Member – The historically ambiguous and controversial Rodman Limestone (Butts, 1918) continues to be a problematic unit concerning its most efficient placement in the Black River or Trenton Group for mapping and other purposes (Faill and others 1989; Laughrey and others, 2003). This inspired me to start a study of the Linden Hall to Salona interval to bring this question into greater focus (Barta, 2004a, 2006). Portions of the data from Reedsville for that study appear here for the first time. The remaining data and my formal interpretations will follow in a formal paper in the near future.

Rones (1969) defined two lithologic types within the Rodman, "[Type 1] dominate and characteristic. . . is a medium to coarse grained, somewhat argillaceous, bioclastic calcarenite [packstone/grainstone]. The subordinate lithologic type[s] is a thin bedded, medium to coarse calcilutite [mudstone/wackestone] occurring as interbeds, predominately in the lower 10 feet [Type 2a, 2b]" (p. 32). Please note the subordinate lithologies are the same as those of the Centre Hall Member, and I have expanded the Centre Hall thickness at Reedsville to contain the

Type 2 lithologies. I regard the Rodman as consisting of only the Type 1 lithology. As such, it is not as thick as reported by other workers (30 feet or ~ nine m), but four m here at Reedsville. This differs from Rones' measurement of 35 feet here. I would describe the Rodman as cobbly, or nodular weathering, bioclastic wackestone/packstone with shaley interbeds.

Slupik (1999) described the Rodman as medium to massive bedded, bioturbated lime mudstones, wackestones, and floatstones containing bioclastic lenses and argillaceous laminations. Bryozoan debris is the most common bioclastic material found in the Rodman, but brachiopod and trilobite material is also common. Crinoid plates and columnals noted as diagnostic by previous workers (Field, 1919; Rones, 1969) are less common but stand out on weathered surfaces.

The top of the Rodman Member was originally placed by Butts (1918) at the base of the overlying Trenton Limestone (Salona Formation) I follow the placement of the (1934) top of the Rodman Member at the No. 0 K-bentonite bed (Rosenkrans, 1934). However, there commonly is a transition from Rodman-style to Salona-style lithologies above this level and may continue to the level of the No. 1 K-bentonite.

I have hoped to show in the descriptions of Linden Hall and Nealmont Formations that the lithologies of the two units are very similar. Four thin sections photomicrographs collected at five m, nine m, 13 m and 16 m in the measured section are shown on Figure 15 with thin sections of the Linden Hall and Salona formations from Union Furnace for comparison.

Salona Formation, Trenton Group

The Salona Formation (Field, 1919) consists of dark-grey to black, argillaceous lime mudstones and wackestones that are finely cross-bedded with large, symmetrical ripple marks in the upper part of the unit. The Salona has two members, the New Enterprise and Roaring Spring members (Thompson, 1963).

New Enterprise Member – Thompson (1963) defined the New Enterprise Member as black, structureless calcilutites [mudstone/wackestones] that are sparsely fossiliferous, lacking sedimentary structures, occurring in 6 inch to 1-foot beds. Lime mudstone beds are interbedded with argillaceous and highly argillaceous lime mudstones and calcareous shales (Thompson, 1963). Slupik (1999) re-described the New Enterprise Member as, "medium- to very thickly-bedded, sparsely fossiliferous, dark grey to black, homogenous, micritic lime mudstones with thin, calcareous shale or argillaceous limestone interbeds. . . [that have] gradational upper and lower boundaries" (p.20).

Most notably, the New Enterprise Member contains several K-bentonite beds . These were numbered 0 to 6 by Whitcomb (1932) and Rosenkrans (1934). The No. 2 and No. 3 K-bentonites are correlated with the Deicke and Millbrig K-bentonites of the North American Midcontinent, respectively (Kolata and others, 1996, Mitchell and others, 2003).

As noted above, the base of the New Enterprise Member, is placed at the No. 0 K-bentonite (Rosenkrans, 1934).

Roaring Spring Member – The Roaring Spring Member (Thompson 1963) is defined by laminated and cross bedded, fine grained calcarenites interbedded with argillaceous calcilutites and calcareous shale. Slupik (1999) described the unit as "thinly- to medium-bedded, planar and cross-laminated, recrystallized lime mudstones which occur in alternation with argillaceous lime mudstone and calcareous shales. . . many. . . with wavy tops and erosive bases (p. 29)." The Roaring Spring Member thickens to the southeast, perpendicular to strike, displacing the Milesburg member of the Coburn Formation (Thompson, 1963). Thompson (1963) placed the base of the Roaring Spring Member at the lowest bed of laminated fine-grained calcisiltite.

K-bentonites also occur in the Roaring Spring Member. Here at Reedsville, three K-bentonites and a possible fourth are exposed. Of greatest interest is the "R" K-bentonite (Thompson, 1963) exposed approximately 10 m from the top of the unit. Thompson utilized this K-bentonite as a datum in his study. The "R" K-bentonite also occurs in the Milesburg Member of the Coburn Formation. Thompson reported that this was due to the thickening of the Roaring Spring facies to the southeast.

Coburn Formation, Trenton Group

The Coburn Formation (Field, 1919) is "made up of alternations of crystalline, highly fossiliferous limestone and black shaly limestone" (Field, 1919, p. 421). Field described the contact of the Coburn with the overlying Antes Shale as gradational. Thompson (1963) divided the formation into the Milesburg and Coleville Members. The lithology of the two members is virtually the same, differing only by the most common bioclasts. Thompson (1963) did not measure the Coburn at the Reedsville outcrop, but did describe the lower 69 feet of the Coburn from a well drilled to the southeast side of Rte. 76, several miles east of the outcrop. I have chosen not to divide the members of the formation in my measured section, but have included the descriptions of the members below.

Milesburg Member – The Milesburg Member is characterized by bioskeletal calcirudites (packstones) containing the brachiopod *Sowerbyella* (Thompson, 1963). Thompson recognized two sub-lithotypes, pure *Sowerbyella* calcirudites and *Sowerbyella*-trilobite calcirudites, common in the upper part of the member. Packstones are interbedded with calcarenites, calcilutities, and calcareous shales. The Milesburg Member was described by Slupik (1999) to be "thinly- to medium-bedded, dark grey (weathered light grey), quartz-rich lime mudstones interbedded with thin, dark-grey, argillaceous lime mudstones. Some beds are weathered to a light tan color" (p. 31). Thompson (1963) found that dolomitic limestone (30% dolomite content) provided the tan color.

Coleville Member – Thompson (1963) defined the Coleville Member as "approximately 175 feet of ½ to 8 inch beds [at Bellefonte, PA] of interbedded *Dalmanella* bioskeletal calcirudite (packstone), *Dalmanella*-crinoid bioskeletal calcirudite" (Barta, 2004b, p. 269). Slupik (1999) described this unit to be, "thin-bedded, dark grey, planar laminated (and often cross-bedded), quartz-rich lime mudstone interbedded with thin, dark grey, argillaceous lime mudstone" (p. 32).

Interpretation of Depositional Environments

The Linden Hall and Nealmont Formations were interpreted by Newsom (1983) as being deposited in a high to moderate energy setting. Laughrey et al. (2003) interpreted the Linden Hall to represent deposition seaward of a barrier bank complex below normal wave base and above storm wave base. These authors interpreted the Nealmont Formation as deeper water environment than the Linden Hall, on the outer margins of a distally steepened ramp. The Rodman Member was interpreted as being deposited on the distal ramp in deeper water than the Center Hall Member. Both environments were above storm wave base. However, Arens and Cuffey (1989) interpreted the Rodman as a shallower water deposit citing evidence of biohermal growth and shoaling.

The Salona and Coburn Formations were interpreted by Newsom (1983) and Gardiner-Kursek (1988) as rhythmites caused by storm deposits. This cyclic style of deposition is also referred to as tempestites. Shale deposition is interpreted as deposition during tranquil periods. Gardiner-Kursek (1988) interpreted the shales as the result of storm surges. Newsom (1983) held that the Salona and Coburn formations were deposited between the near shore and outer shelf below fair weather wave base. Arens and Cuffey (1989) interpreted the Salona to be a restricted, high-salinity, inner carbonate bank deposit. Slupik (1999) and Laughrey et al. (2003) interpret the Salona to represent deposition on the deep water slope to basin margin below fair and storm wave base. The Coburn Formation was interpreted by Slupik (1999) to be storm deposition on a shallowing facies transitioning from deep ramp to middle ramp setting below fair weather wave base. Laughrey et al. (2003) interpreted the Salona and Coburn to represent a deepening then shallowing trend during transition from deep ramp to basin to more proximal deep ramp deposition.

Conodont Biostratigraphy

The conodont zones that occur in the Trenton carbonates have been mentioned previously (Figure 11). It is important to note a few items about the conodont zones at Reedsville. No investigations for conodonts have been undertaken at this outcrop. As such, the placement of conodont zonal boundaries have been extrapolated from other localities based on the conodont graphic correlation of Sweet (1995). This is true of the placement of the *Ph. undatus-Pl. tenuis* zonal boundary (Figure 16) at Reedsville by Patzkowsky et al. (1997) and Slupik (1999).

The exposure at Reedsville is dominated by the *Ph. undatus* conodont biofacies (Barta 2004b). This biofacies occurs in the depositional units representing deeper, cooler habitats of the late Mohawkian to Cincinnatian (Sweet, 1988). The frequent occurrence of North Atlantic realm conodonts (e.g. *Amorphognathus*) is indicative of cooler, deeper waters. Shallower, warmer water conodonts of the Midcontinent conodont realm are less common (Barta, 2004b). As such, the strict determination of the *Ph. undaus-Pl. tenuis* chronozone boundary (Sweet, 1995) cannot be determined (Richardson and Bergström, 2003; Barta, 2004b). Richardson and Bergström (2003) united these two conodont zones due to the rarity of the shallower water *Pl. tenuis* in the deeper, cooler water habitat of *Ph. undatus.*

The *Am. superbus* and *Belodina confluens* Conodont Zones occur in the uppermost Coburn Formation and the Antes Shale (Barta et al., *in press*; Barta 2004b). The *Am. superbus* Conodont Zone is found in the upper Coburn at Bellefonte, PA (Richardson and Bergström, 2003). The *Am. superbus* Conodont Zone begins a short stratigraphic distance below the beginning of the *B. confluens* Conodont Zone. Barta et al. (in press) found a correlation to the ending of the GICE and the beginning of the *B. confluens* Conodont Zone.

K-bentonite Event Stratigraphy

K-bentonites are diagenetically altered deposits of glass-rich volcanic ash. Diagenesis

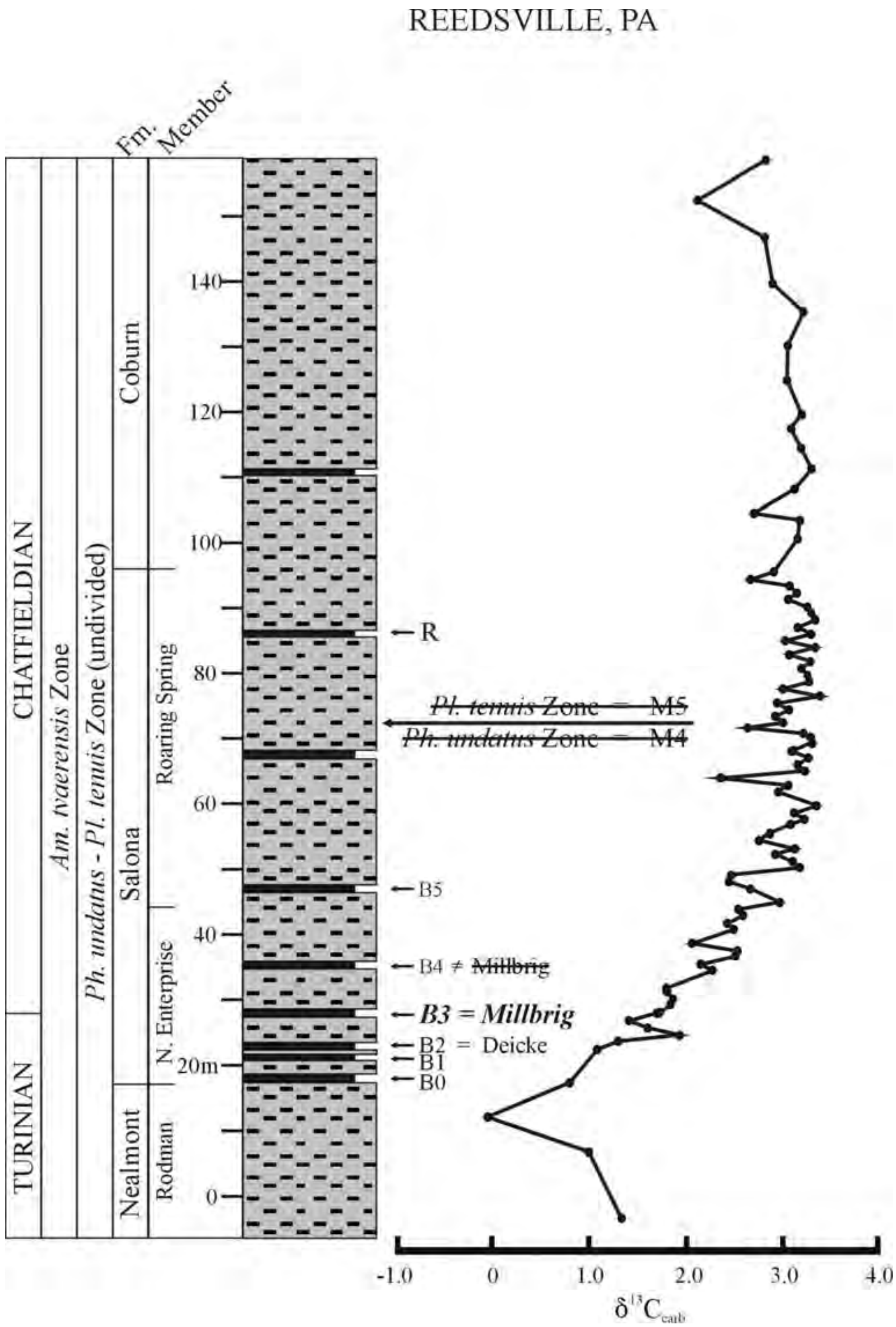


Figure 16. Plot of the $\delta^{13}C$ data of Patzkowsky and others (1997) and Slupik (1999) from Barta (2004b) on the measured section of this report. The GICE begins near the level of the Millbrig K-bentonite to reach maximum values near +3.5‰ in the Roaring Spring Member. $\delta^{13}C$ values drop blow +3.0‰ in the Coburn Formation but do not indicate the end of the excursion. Corrections of the positions of the Millbrig K-bentonite and assertions of the placement of the conodont zonal boundary and M4-M5 sequence boundary by Patzkowsky and others (1997).

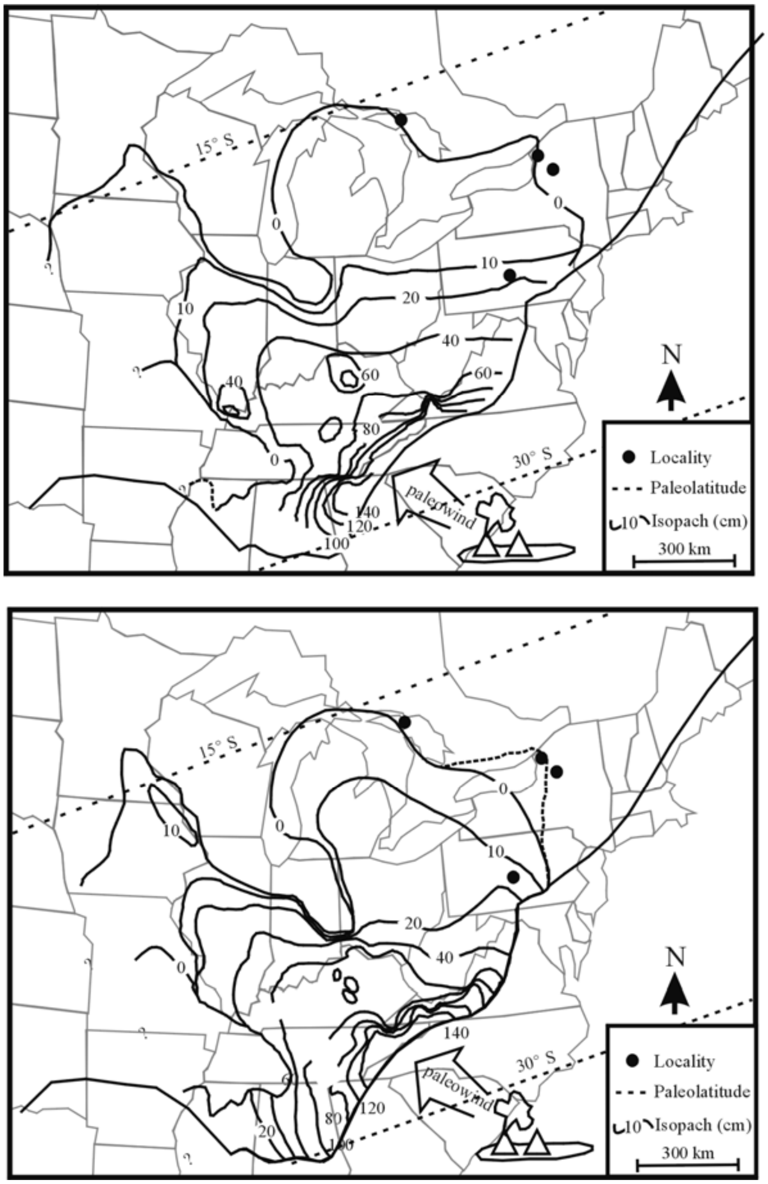


Figure 17. Geographic distribution with isopach representing thicknesses of the Deicke (top) and Millbrig (bottom) K-bentonites from Barta 2004b.

alters the ash into K-rich clay minerals, predominately mixed-layer illite/smectitie (Kolata and others, 1996). Early workers referred to the clays as “bentonite” or “metabentonite,” but these terms are inappropriate due the K content of the clays (Weaver, 1953). In the field, a K-bentonite has a shaly texture that fragments into small chips and can be orange, grey, yellow, green, or buff color. They are frequently located in reentrants that are often highly vegetated (Kolata and others 1996).

During the Late Ordovician many large volcanic eruptions occurred over a wide area of Laurentia and Baltica as a result of the Taconic Orogeny. Most K-bentonites are from local eruptions; however, two of the K-bentonites that occur at Reedsville, the Deicke and Millbrig K-bentonites, were deposited widely, up to 1.5 million km^2 (Kolata and others, 1996) (Figure 17). Due to their wide occurrence, individual chemical properties and deposition in a geological instant, K-bentonites are excellent tools for stratigraphic correlation.

At least eight K-bentonites are exposed at Reedsville. Of these, seven have been given numerical designations over the years for local correlation purposes (Whitcomb, 1932; Rosenkrans, 1934; Thompson, 1963; Rones, 1969; Cullen-Lollis and Huff, 1986). The majority occur with in the Salona Formation. Figure 18 shows a comparison of the K-bentonites at Reedsville and Union Furnace. Of greatest interest at this section is the #2 and #3 K-bentonites. Please note: the K-bentonites are numbered B-10 through B-16 for utility in comparison to the Union Furance section, and the second number conveniently corresponds to the number of the previously mentioned workers. These beds have been chemically fingerprinted using discriminant analysis of the trace metal constituents of multiple K-bentonite beds (either whole rock or more recently, fluid inclusions (Delano and others 1994; Kolata and others, 1996). The #2 and #3 K-bentonites at Reedsville have been chemically correlated with the widespread Deicke and Millbrig K-bentonites, respectively (McVey 1993; Kolata and others 1996; Mitchell and others

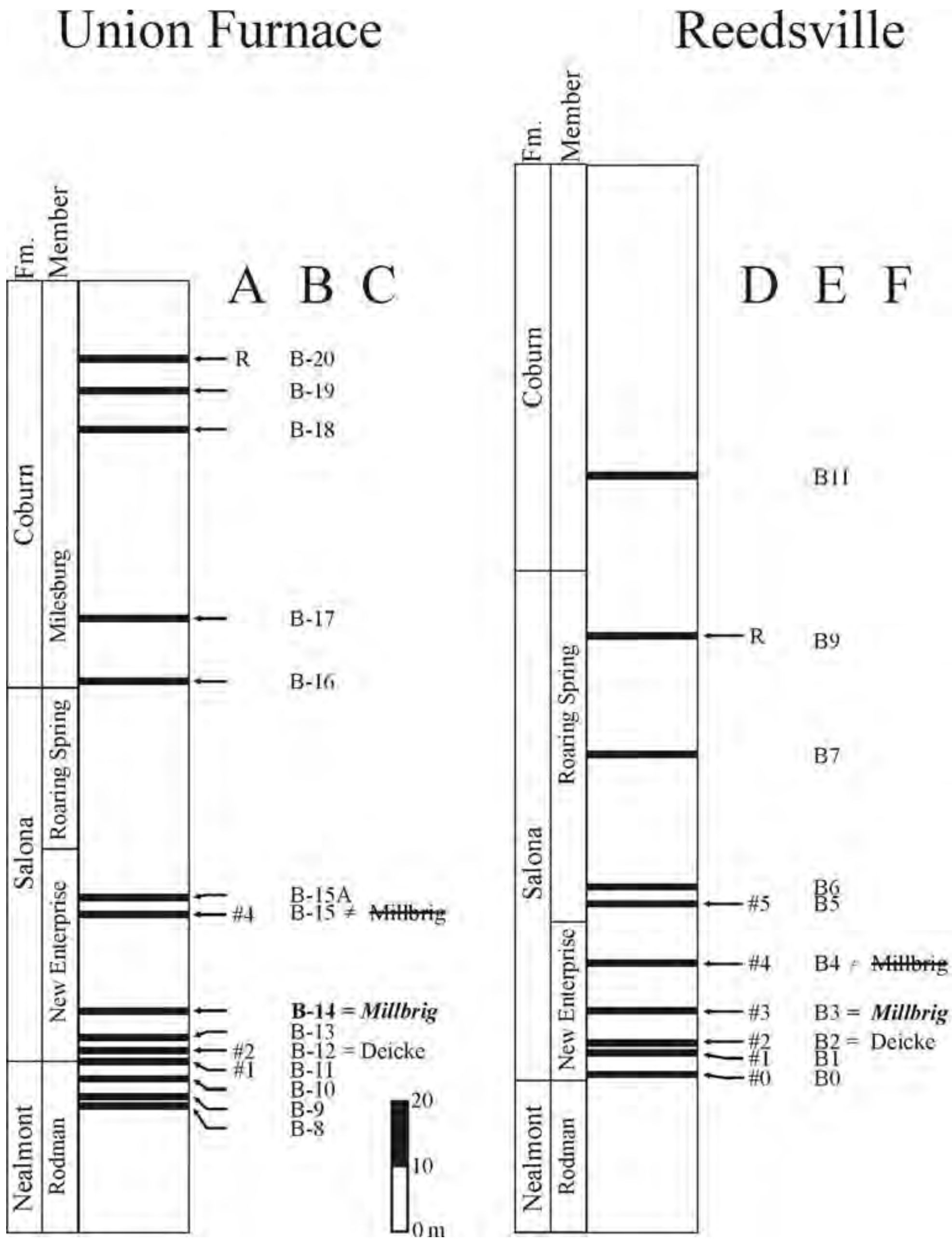


Figure 18. Comparison of the K-bentonite beds at the Union Furnace and Reedsville, Pennsylvania sections. Columns A through F indicate the designations for the K-bentonites by various authors and corrections from Barta 2004b. A—Thompson (1963); B—Berkheiser and Cullen-Lollis (1986); C, F—Deicke and Millbrig K-bentonites of McVey (1993) and Kolata et al. (1996) with the corrected position of the Millbrig in bold-italics; D—Thompson (1963) at Reedsville; E—Designations of Slupik (1999).

2003). An important item to note is that recent literature reports that the #4 K-bentonite in Pennsylvania is correlated with the Millbrig. This is true except at Reedsville. I found this to be a clerical error in McVey (1993) that has been duplicated (Barta 2004b). It is likely there were multiple eruptions from the same magma chamber that produced the Millbrig K-bentonite, and it is possible that several K-bentonite beds in Pennsylvania are "Millbrigs" (W. Huff, 2003, pers. comm..). Further investigation will test this. However, the lowest occurrence of the Millbrig is where the Turinian-Chatfieldian boundary is placed (Leslie and Bergström 1995). At Reedsville, that is at the #3.

$\delta^{13}C$ Chemostratigraphy

The Reedsville outcrop is an import section for work on stable C-isotope stratigraphy in the Late Ordovician. In the Middle Mohawkian, a positive excursion in the ratio of $^{13}C/^{12}C$ occurred. This excursion, known as the Guttenberg Carbon Isotope Excursion (GICE), is a regional and worldwide perturbation of the carbon cycle of +2.5 ‰ caused by upwelling of nutrient-rich waters that increased primary productivity coinciding with the eustatic sea level rise during the Trenton transgression (Young and others, 2005; Saltzman and Young, 2005; Barta, 2004b; Barta and others, in press).

Increased primary productivity preferentially removed ^{12}C, combined with rapid burial of organic matter at the beginning of Trenton deposition, caused the ratio of $^{13}C/^{12}C$ to increase. This trend is seen in both brachiopod and whole rock samples analyzed for $\delta^{13}C$ (Barta 2004b).

Patzkowsky and others (1997) and Slupik (1999) were the first to investigate the Trenton Group $\delta^{13}C$ chemostratigraphy in Pennsylvania. This outcrop is the dominant data source for their work. These authors sampled the entire measured interval here. Figure 16 shows the $\delta^{13}C$ values plotted against the measured section. I have integrated my measured section with their data (Barta 2004b). I collected several samples in the Linden Hall-Nealmont section (Figure 13) to clarify the data set of Patzkowsky and others (1997) for my work on the Nealmont question (Barta 2004a, 2006). The $\delta^{13}C$ data shows baseline values varying from 0.0 to +1.0‰, common in the Black River Group of New York (Barta and others, in press; Barta, 2004a, 2004b) within the Linden Hall to Nealmont interval. The $\delta^{13}C$ values become negative below the base of the Salona Formation then steadily increase to + 3.5‰ within the Salona, then continue with little decrease in value to the end of the measured section. This is remarkable because we have not been able identify the end of the GICE in Pennsylvania yet!

Several implications arise from the Reedsville dataset and other work at Union Furnace when compared to other datasets of the GICE from New York, Ontario, Tennessee, Kentucky and the Upper Mississippi Valley. First, the sedimentation rate in Pennsylvania was much greater than in the surrounding region during the excursion. This is logical since Pennsylvania was in much closer proximity to the Taconic Foreland basin. Second, since the GICE is a temporal event, it also has chronostratigraphic implications. Foremost among these is that the Trenton Group of Pennsylvania is older than many previous workers have reported . As a consequence of this, we have found that the Rocklandian and Kirkfieldian substages of the Chatfieldian are coeval (Barta et al., *in press*). Third, the GICE is a precise correlation tool when combined the K-bentonite event stratigraphy or conodont biostratigraphy. The correlation of the Trenton carbonates shown in Figure 11 is the result of the combination of these three methods. It is also another means to investigate disconformities for sequence work (Railsback et al., 2003; Barta et al, *in press*).

The work of Patzkowsky et al. (1997) has proved important in later studies of Late Ordovician paleoclimatoloy. Patzkowsky et al. (1997) also sampled the Reedsville section for organic matter $\delta^{13}C$ ($\delta^{13}C_{org}$). There is also a positive shift in $\delta^{13}C_{org}$ that begins after the $\delta^{13}C_{carb}$ excursion begins. Taking the difference of both datasets, the $\delta^{13}C$ was determined. This can be used a proxy for studying atmospheric carbon content or pCO_2. Patzkowsky et al.

(1997) suggested that increased primary productivity and organic matter burial resulted in significant pCO_2 decreases to ~ 8-10 times current levels and inferred climatic cooling throughout the interval. Late Ordovician pCO_2 levels were ~ 14-16 times preindustrial levels (Saltzman and Young, 2005). This inferred climatic cooling, has been further corroborated by the work of Young et al. (2005) and Saltzman and Young (2005). The drawdown of pCO_2 by marine organisms combined with a glacio-eustatic sea level drop coinciding the GICE around the globe (i.e. areas unaffected by Taconic tectonism and the Trenton transgression) would have enhanced global cooling by reducing poleward oceanic heat transport. The result would have been a glacial episode ~10 m.y. prior to the End Ordovician glacial event. Would you have imagined there would have been a glaciation going on during Trenton deposition?

Sequence Stratigraphy

Holland and Patzkowsky (1996) developed a sequence stratigraphic framework for the Mohawkian in which they defined 6 subsequences (M1-M6). The exposure here at Reedsville belongs within their M4 and M5 sequences (Figures 11 and 16). Patzkowsky et al. (1997) and Slupik (1999) placed the M4-M5 sequence boundary of Holland and Patzkowsky (1996) at or near the level of the *Ph. undatus-Pl. tenuis* Zone Boundary here at Reedsville. As mentioned above, this was an extrapolation from Sweet (1995).

A detailed sequence stratigraphic framework for the Reedsville section has not been attempted by the author. Laughrey et al. (2003) developed a sequence framework for the Snyder through Salona formations at Union Furnace and that work is suggested as a rough framework for Reedsville section also. Here is a general outline of their work:

> "Laughrey et al. (2003) suggested tentative 3rd Order sequences in the Union Furnace Route 453 Roadcut. In the middle Nealmont Formation, they suggest a Maximum Flooding Surface (MFS) over a Transgressive Systems Tract (TST) that began at a Sequence Boundary/Transgressive Surface (SB/TS) in the upper Linden Hall Limestone (Black River Group). The next SB was placed in the lower Salona between the Deicke and Millbrig, followed by a TST through the New Enterprise Member, a MFS in the Roaring Spring Member, and another SB at the base of the Coburn Formation."(Barta, 2004b, p. 103).

References

Arens, N. C. and Cuffey, R. J., 1989, *Shallow and stormy: late Middle Ordovician paleoenvironments in central Pennsylvania*, Northeastern Geology, v. 11, p. 218-24.

Barta, N. C., 2004a, *Does the Nealmont Formation belong in the Trenton Group of central Pennsylvania?* (abs.) American Association of Petroleum Geologists Eastern Section Meeting, Columbus, Ohio, October 4-5, 2004, abstracts.

Barta, N. C., 2004b, *Investigation of the correlation of the lower Chatfieldian (UpperMiddle Ordovician) strata of New York, Ontario and Pennsylvania using the Guttenberg carbon isotope excursion (GICE)*, Unpublished MS thesis, The Ohio State University, Columbus, OH, 288p.

Barta, N. C., 2006, *A new look at the lithostratigraphic and chronostratigraphic classification of the Upper Black River and Lower Trenton Group of central Pennsylvania* (abs.), Geological Society of America, Northeastern Meeting Program with Abstracts, Harrisburg, March 2006.

Barta, N. C., Bergström, S. M., Saltzman, M. R., and Schmitz, B., in press, *First record of the Ordovician Guttenberg* $\delta^{13}C$ *Excursion (GICE) in New York State and Ontario: Local and regional chronostratigraphic implications*, Northeastern Geology and Environmental Sciences.

Bergström, S. M., Finney, S.C., Chen Xu, Goldman, D., and Leslie, S.A., 2006, *Three new Ordovician global stage names*, Lethaia, v. 39, p. 287-288.

Butts, C., 1918, *Geologic section of Blair and Huntingdon Counties, central Pennsylvania*. American Journal of Science, Fourth Series, v. 196, p. 523-537.

Cullen-Lollis, J., and Huff, W. D., 1986, *Correlation of Champlainian (Middle Ordovician) K-bentonite beds in central Pennsylvania based on chemical fingerprinting*, Journal of Geology, v. 94, p. 865–874.

Delano, J. W., Tice, S., Mitchell, C.E., Goldman, D., 1994. *Rhyolitic glass in Ordovician K-bentonites: a new stratigraphic tool*, Geology, v. 22, p. 115–118.

Dunham, R. J., 1962, *Classification of carbonate rocks according to their depositional texture*, in Ham, W. E., ed., *Classification of Carbonate Rocks-a symposium*, American Association of Petroleum Geologists Memoir 1, p. 108-121.

Faill, R. T., Glover, A. D., and Way, J. H., 1989, *Geology and mineral resources of the Blandburg, Tipton, Altoona, and Beliwood quadrangles, Blair, Cambria, Clearfield, and Centre Counties, Pennsylvania*, Pennsylvania Geological Survey, 4 ser., Atlas 86, 209 p.

Field, R. M., 1919, *The Middle Ordovician of central and south central Pennsylvania*, American Journal of Science, 4th series, v. 48, p. 403-428..

Gardiner-Kuserk, M. A., 1988, *Cyclic sedimentation patterns in the Middle and Upper Ordovician Trenton Group of central Pennsylvania*, American Association of Petroleum Geologists, Studies in Geology No. 29, p. 55-76.

Grabau, A. W., 1924, *Principles of Stratigraphy*. New York, A. G. Seller, 1185 p.

Holland, S. M. and Patzkowsky, M. E. 1996, *Sequence stratigraphy and long-term paleooceanic change in the Middle and Upper Ordovician of eastern United States,* in Witke, B.J., Ludvigson, F.A., and Day, J.,eds., *Paleozoic sequence stratigraphy; views from the North American craton*, Geological Society of America Special Paper, v. 306, p. 117-129.

Kay, G. M., 1944, *Middle Ordovician of central Pennsylvania: Part II. Later Mohawkian (Trenton) formations,* Journal of Geology, v. 52, p. 97-116.

Kay, G. M., 1969, *Ordovician correlations between North America amid Europe*, in Kay, Marshall, ed., *North Atlantic geology and continental drift,* American Association of Petroleum Geologists Memoir 12, p. 563-571.

Kolata, D. R., Huff, W. D., and Bergström, S. M., 1996, *Ordovician K-bentonites of eastern North America*, Geological Society of America Special Paper 313, p. 84.

Laughrey, C. D., Kostelnik, J., Gold, D. P., Doden, A. G., and Harper, J. A., 2003, *Trenton and Black River carbonates in the Union Furnace area of Blair and Huntingdon Counties, Pennsylvania*, Field Trip Guidebook, American Association of Petroleum Geologists-Society of Petroleum Engineers, Eastern Meeting, Pittsburgh, 80 p.

Leslie, S.A., and Bergström, S. M., 1995, *Revision of the North American Late Middle Ordovician standard stage classification and timing of the Trenton transgression based on K-bentonite bed correlation,* in Cooper, J.D., Droser, M. L., and Finney, S. C., eds, *Ordovician odyssey: Short papers for the Seventh International Symposium on the Ordovician System*, Society for Sedimentary Geology, Pacific Section, Las Vegas, NV, June 1995, v. 77, p. 49-54.

McVey, D. E., 1993, *Timing of the Blount and Martinsburg foreland basin development during the Taconic orogeny based on the Deicke and Millbrig K-bentonite marker horizons*, Unpublished MS thesis, University of Cincinnati, Cincinnati, OH, 133 p.

Mitchell, C. E., Adhya, S., Bergström, S. M., Joy, M. P., and Delano, J. W, 2004, *Discovery of the Ordovician Millbrig K-bentonite bed in the Trenton Group of New York State: Implications for regional correlation and sequence stratigraphy in eastern North America*, Palaeogeography, Palaeoclimatology, Palaeoecology, v. 210, p. 331-346.

Newsom, S. W., 1983, *Middle Ordovician paleogeography of the Appalachian Valley and Ridge Rovince, central Pennsylvania*, Unpublished MS thesis, University of Delaware, Newark, DE, 166 p.

Patzkowsky, M. E., Slupik, L. M., Arthur, M. A., Pancost, R. D. and Freeman, K. H., 1997, *Late Middle Ordovician environmental change and extinction: Harbinger of the Late Ordovician or continuation of Cambrian patterns?* Geology, v. 25, p. 911-914.

Richardson, J. G., and Bergström, S. M., 2003, *Regional stratigraphic relations of the Trenton Limestone (Chatfieldian, Ordovician) in the eastern North American mid-continent*, Northeastern Geology and Environmental Sciences, v. 18, p. 93-115.

Railsback, L. B., Holland, S. M., Hunter, D. M., Jordan, E. M., Diaz, J. R., and Crowe, D. E., 2003, *Controls on geochemical expression of subaerial exposure in Ordovician limestones from the Nashville Dome, Tennessee, U.S.A.*, Journal of Sedimentary Research, v. 73, p.790-805.

Rones, M., 1969, *A lithostratigraphic, petrographic and chemical investigation of the lower Middle Ordovician carbonate rocks in central Pennsylvania*, Pennsylvania Geological Survey, 4th ser., General Geology Report 53, 224 p.

Rosenkrans, R. R., 1934, *Correlation studies of the central and south-central Pennsylvania bentonite occurrences*, American Journal of Science, v. 17, p. 113-134.

Saltzman, M. R., and Young, S. A., 2005, *Long-lived glaciation in the Late Ordovician? Isotopic and sequence-stratigraphic evidence from western Laurentia*, Geology, v. 33, p. 109-112.

Slupik, L. M., 1999, *Sedimentology and stable isotope chemostratigraphy of Late Middle Ordovician carbonates in central Pennsylvania*, Unpublished MS thesis, The Pennsylvania State University, State College, PA,135 p.

Sweet, W. C., 1988, *The Conodonta. Morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum*, Oxford Monographs on Geology and Geophysics No. 10. Clarendon Press, Oxford. 212 pp.

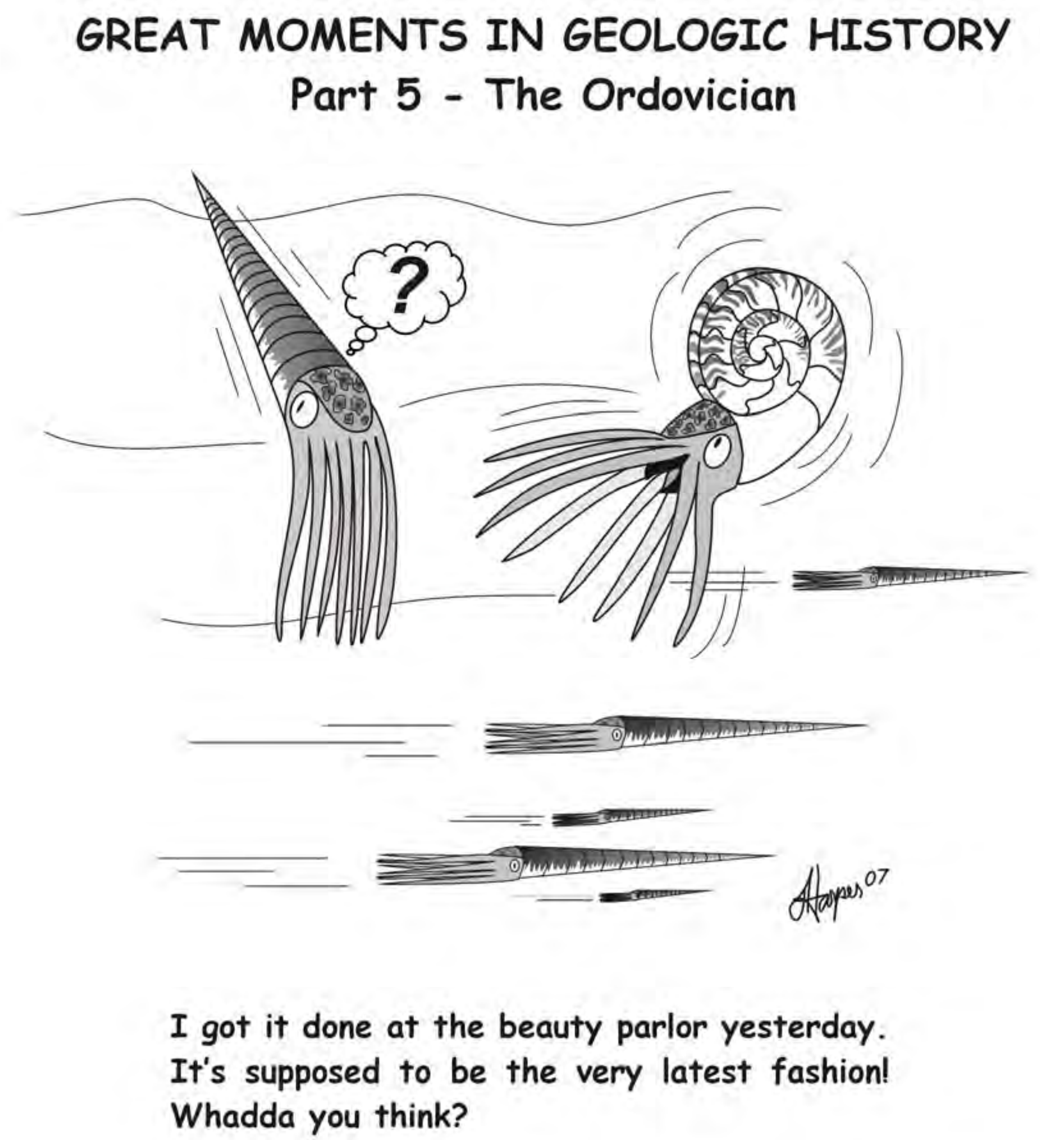
Sweet, W. C., 1995, *Graphic assembly of a conodont-based composite standard for the Ordovician System of North America*, Society of Economic Paleontologists and Mineralogists, Special Publication 53, p.139-150

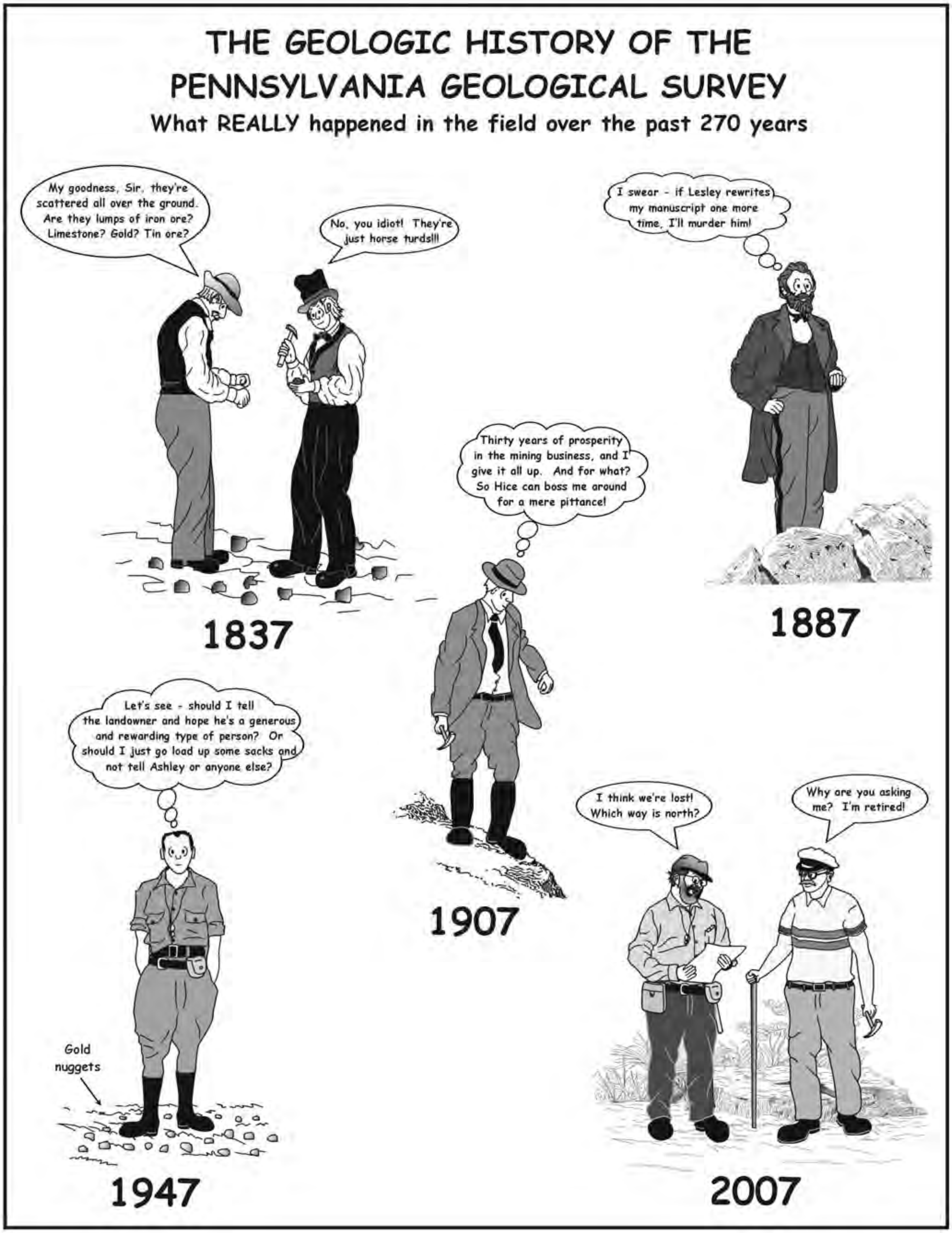
Thompson, R. R., 1963, *Lithostratigraphy of the Middle Ordovician Salona and Coburn formations in central Pennsylvania*, Pennsylvania Geological Survey, 4th ser., General Geology Report 38, 154 p.

Weaver, C. E, 1953, *Mineralogy and petrology of some Ordovician K-bentonites and related limestones*, Geological Society of America Bulletin, v. 64, p. 921-944.

Whitcomb, L., 1932, *Correlation by Ordovician bentonites*, Journal of Geology, v. 40, p. 522-

534.
Witzke, B. J., 1990, *Palaeoclimatic constraints for Palaeozoic palaeolatitudes of Laurentia and Euramerica*, in McKerrow, W. S., and Scotese, C. R, eds., *Palaeozoic palseogeography and biogeography*: Geological Society of London Memoir no. 12, p. 57-73.
Young, S.A., Saltzman, M. R. and Bergström, S.M., 2005, *Upper Ordovician (Mohawkian) carbon isotope ($\delta^{13}C$) stratigraphy in eastern and central North America: Regional expression of a perturbation of the global carbon cycle*, Palaeogeography, Palaeoclimatology, Palaeoecology, v. 222, p. 53-76.




THE GEOLOGIC HISTORY OF THE
PENNSYLVANIA GEOLOGICAL SURVEY
What REALLY happened in the field over the past 270 years
My goodness, Sir, they're scattered all over the ground. Are they lumps of iron ore? Limestone? Gold? Tin ore?
No, you idiot! They're just horse turds!!!
1837
I swear - if Lesley rewrites my manuscript one more time, I'll murder him!
1887
Thirty years of prosperity in the mining business, and I give it all up. And for what? So Hice can boss me around for a mere pittance!
1907
Let's see - should I tell the landowner and hope he's a generous and rewarding type of person? Or should I just go load up some sacks and not tell Ashley or anyone else?
Gold nuggets
1947
I think we're lost! Which way is north?
Why are you asking me? I'm retired!
2007

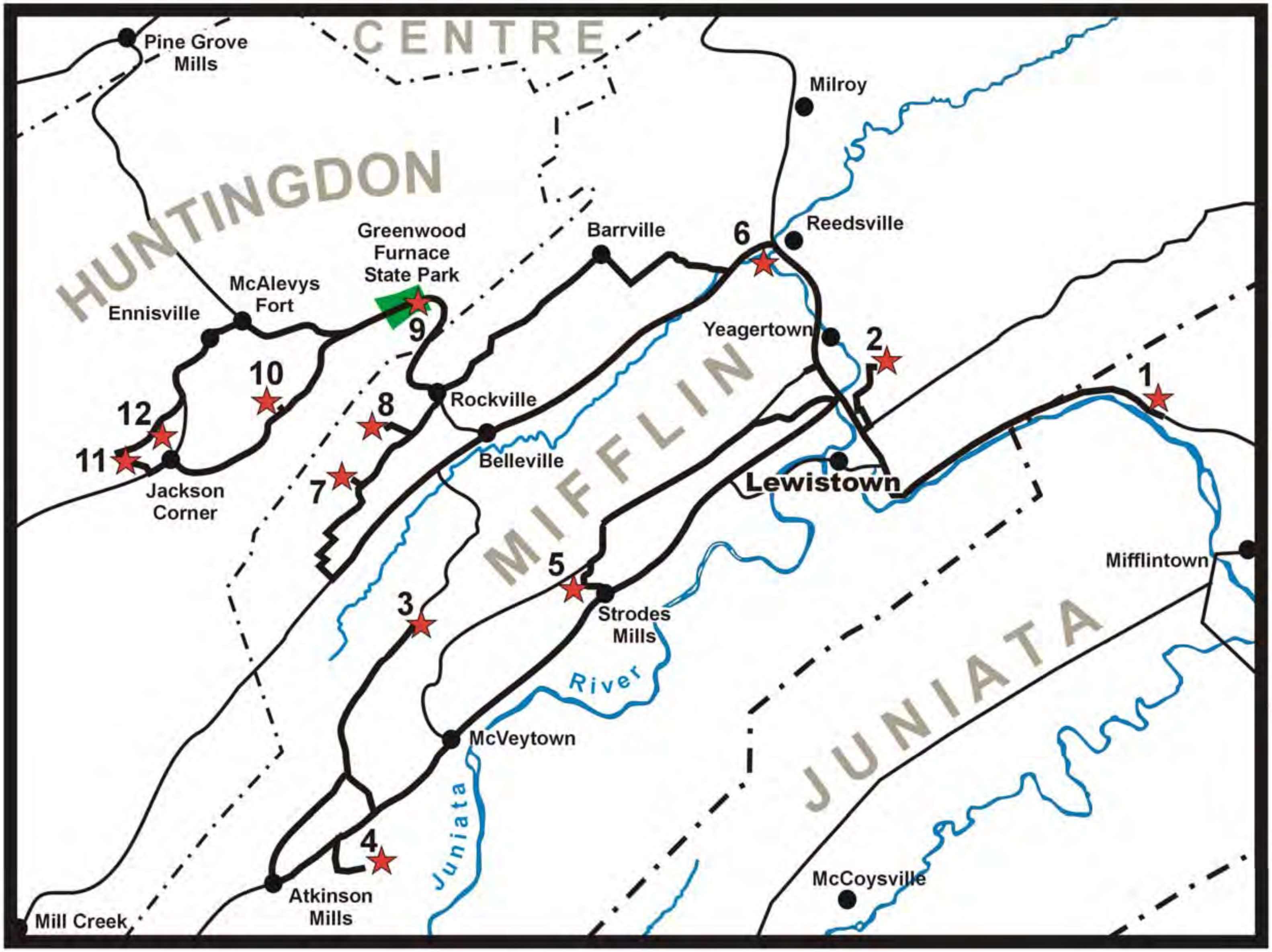


Figure 19. Map of field trip route and stops.

ROADLOG AND STOP DESCRIPTIONS

Day 1

Mileage		
Int	**Cum**	**Description**
0.00	0.00	Exit hotel parking lot. Turn left on Ferguson Valley Road. Jacks Mountain is to the right (north).
0.05	0.05	Stop sign; continue straight on Ferguson Valley Road.
0.10	0.15	"T" intersection; turn right on Ferguson Valley Road.
0.05	0.20	Bridge crossing over US Route 322.
0.05	0.25	Turn right onto access road for US Route 322 East.
0.15	0.40	Merge onto US Route 322 East.
0.10	0.50	Roadcut immediately south of bridge exposes south-dipping Wills Creek Formation.
0.20	0.70	Cross Buck Run.
0.10	0.80	Synclinal exposure of Tonoloway Formation; basal Keyser Formation is exposed at the uppermost portion of the roadcut.
0.30	1.10	View to southwest of “black” Marcellus Formation in lower part of new roadcut.
0.20	1.30	Intersection of US Routes 322 and 522; continue east (south) on US 322.
0.40	1.70	Quarry visible to left on steep hill slope. Exposed rocks are Keyser Formation.
0.30	2.00	Black shales of Marcellus Formation exposed to right.
0.10	2.10	Retaining wall to right. Behind this wall is the 'famous' Mt Rock exposure of Lower Devonian and Silurian rocks that was Stop No. 10 of the 1955 Field Conference (Swartz, F. M., 1955, p. SI-27 to SI-29) Listed as "exposed" were the "Hamilton" (Mahantango), Marcellus, "Onondaga" (Selinsgrove & Needmore), "Oriskany Group" (Ridgeley, Shriver), "Helderberg Group" (Mandata, "New Scotland", "Coeymans"), Keyser Limestone (Paintersville, Hollidaysburg & Mt. Rock members), and Tonoloway Limestone.
0.60	2.70	Exit to US Route 522 North (Walnut Street); continue on US Route 322.
0.20	2.90	Bridge over Kishacoquillas Creek that joins the Juniata River one mile downstream. Tonoloway Formation is exposed downstream along the stream bank.
0.50	3.40	Poorly exposed, reddish claystones on left marks location of Bloomsburg Formation. Non-red claystones to right are Rose Hill Formation.
0.40	3.80	Enter Derry Township and cross bridge over Jacks Creek. The stream course here marks the contact at the top of the Tuscarora Formation with the overlying Rose Hill Formation.
0.20	4.00	Low-angle, north-dipping Tuscarora Formation exposed on left.
0.40	4.40	Cross the axis of the west-plunging Shade Mountain anticline. The Tuscarora Formation plunges beneath ground surface (and the Juniata River) 0.15 miles to the southwest.
0.10	4.50	Low-angle, south-dipping Tuscarora Formation to left.

Figure 20. Rock anchors at mileage 4.70.

Figure 21. Scree slope in Lewistown Narrows at mile 7.00.

0.20	4.70	Rock anchors on slope to left stabilize the interbedded sandstone and shaly layers of the uppermost Tuscarora Formation to prevent slope failure (Figure 20). At this site, the rock layer dip angle is shallow (17 degrees) and less than that of the slope. At the east end of rock anchor emplacement the layers are "kinked" to a 40-degree south dip. Extensive jointing and lack of soil or scree cover permit easy entry of precipitation lubricating the shaly layers allowing slope failure without the engineered solution.
0.50	5.20	Enter the Lewistown Narrows. Small exposure of steeply south-dipping Tuscarora to the left. The Narrows is a steeply dipping syncline formed by the southwestward plunging Shade Mountain anticline and the northeastward plunging Blue Mountain anticline. The core of the syncline contains shales of the Rose Hill Formation that form the lower portion of the slopes along Blue Mountain on the south limb of the fold. These shales apparently also underlie the course of the Juniata River. Along the western 2/3 of the Narrows the Rose Hill shales form the lowermost slopes of Shade Mountain at only a few sites. The slopes along both limbs of the syncline are covered with Tuscarora scree colluvium. The steepness of the scree slopes, and the presence of large, vehicle-crushing boulders, forced the design for the reconstruction of US Route 22/322 through the Narrows to eliminate road cuts into the slopes and to elevate the new road above the trace of the prior highway.
1.20	6.40	Exposure of steeply south-dipping Tuscarora Formation on the left. This exposure appears to be "kink" folded at its uppermost part. However, the visibly north-dipping layers extend outward over the south-dipping layers and may be a result of slope failure.
0.40	6.80	View to south of Hawstone. This small village was a mining town. On the slopes of Blue Mountain, at approximately midslope, observant eyes may see parallel embankments that were the slopes along which the miners "mined" ganister rock, a high-quality sandstone used in lining high-temperature furnaces. Observant eyes may also be treated to embankments seen along the north side of the Juniata River. These

		embankments are the remnants of the Pennsylvania Mainline Canal, Juniata Division, the first significant development of public transportation. Construction took from 1826 to 1840.
0.20	7.00	Prominent scree slopes occur from this mileage point for the next one-half mile (Figure 21). Note larger scree boulders with painted numbers. These boulders were marked for removal during construction to avoid later potential failure impacting the newly constructed highway. During removal of one of these marked boulders it "slipped" destroying the then in-place "Jersey barrier."
0.70	7.70	Cross the Mifflin / Juniata County line.
1.80	9.50	Walsh concrete plant on left. View to the southeast shows the beginning of the northeastward plunge of Blue Mountain.
1.10	10.60	Cross Macedonia Run. Macedonia Gap is located along one of the regional cross-strike features interpreted as relating to fractures. The zone continues across the nose of the plunging Blue Mountain anticline allowing the Juniata River to erode along the zone rather than beyond the plunge of the Tuscarora Formation.
0.10	10.70	Cross the axis of eastward plunging Blue Mountain anticline. This marvelous new exposure is Stop 1.
1.20	11.90	Bear right onto access road for Arch Rock road.
0.30	12.20	South-dipping Wills Creek Formation is exposed on slope of road bank to right.
0.10	12.30	Stop sign; turn right on Arch Rock Road.
0.20	12.50	Stop sign; turn right on SR 3002 West (old US 22-322).
0.80	13.30	Mifflintown and Keefer formations are exposed on right. The outcrop exposes a 3rd -order anticline, with 4th -order folds within it, which plunges out on the other side of the Juniata River.
0.10	13.40	The Rose Hill Formation is exposed on the right at road level, the Keefer Formation just above it.
0.20	13.60	Mifflintown Formation exposed on right.
0.85	14.45	**STOP 1: BLUE MOUNTAIN ANTICLINE AT MACEDONIA** Leaders—Thomas A. McElroy and Donald M. Hoskins See p. 71 for expanded stop illustrations and a measured section.

This road cut was opened for the Lewistown Narrows four-lane highway construction project. Maximum depth of the cut is 155 feet. In addition to providing the substantial amounts of fill needed for the project, it also allowed the preservation of the Pennsylvania Canal Lockmasters building, where a park commemorating the Pennsylvania Mainline Canal will be constructed. Tentatively planned is an explanation of the engineering and geologic aspects of the road cut to be co-located with the historical description of the canal. The safest access to the cut is from the parking area near the Lockmasters building, crossing Macedonia Creek, walking eastward beneath the bridge, and climbing the steep and very rubbly slope. The cut exposes the lower 173 feet of the Rose Hill Formation and the upper 186.5 feet of the Tuscarora Formation (approximately 1/3 of its total thickness in this area). A measured section is included on pages 71-76.

Figure 22. Complex lower order folds, chevron folds, and overturned layers at Stop 1.

Figure 23. Low-angle thrust fault and back thrust in Tuscarora Formation western cross-laminated lithofacies.

The cut crosses the axis of the northeast plunging Blue Mountain 2nd order anticline. Encountered first, the northwest dipping limb of the Blue Mountain anticline provides an exceptional view of the complex interbedding and lensing of both quartz arenite and dark shaly layers, including erosional features, that are characteristic of the Tuscarora Formation's western cross-laminated lithofacies (Cotter, 1982). The southeast limb of the anticline displays complex, lower order folds, including spectacular chevron folds, overturned layers, and slickensides (Figures 22 and 23). The published geologic map (Conlin and Hoskins, 1962) of the site does not explain these features. Are they the result of faulting, local folding of the type seen at other, nearby (Lewistown Reservoir) exposures of the Tuscarora Formation, or some other cause?

During construction, on the west side of the cut, on the northwest limb of the Blue Mountain anticline, we found brachiopod molds in shale interbeds within the quartz arenites, which may be a first for the Tuscarora Formation. Burrows of *Arthrophycus* may be seen in many shaly layers, particularly in lower units of the measured section. Vertical burrows (*Skolithos?*), along with an inarticulate, chitinous, linguloid brachiopod are seen in one unit.

If you look up, you may see a bald eagle or two. Their nest is nearby.

		Depart Stop 1. Turn around, go east on SR 3002.
1.95	16.40	Turn left on Arch rock Road.
0.40	16.80	Turn left on access ramp to US 22-322. Reddish claystones on sloping road bank to right marks the contact of the south-dipping Bloomsburg Formation, overlain by the gray claystones of the Wills Creek Formation.
0.20	17.00	South-dipping Mifflintown Formation to the right consists of interbedded layers of gray shale and limestone.
0.50	17.50	South-dipping Rose Hill Formation exposed on slope of road bank to left. The Keefer Sandstone caps the crest of the slope and is exposed at its uppermost portions.
40	19.90	To the south, crossing the slope of Blue Mountain, is PA Route 333, a transportation route with its own history. The Works Progress

		Administration constructed the road in 1936. Prior to that, the only way to access the village of Hawstone was by way of the Juniata River. Hawstone was founded in the early 1900's by the Haws Refractories Company, which decided to build a silica brick factory there. Bricks were made using scree from the Tuscarora Formation. The brickyard closed in the late 1960's.
0.10	20.00	Steeply south-dipping Rose Hill Formation in gully course draining Roaring Run. Rose Hill also exposed in small borrow pit on east side of gully.
1.30	21.30	Steeply southeast dipping Rose Hill Formation exposed to right. The outcrop is almost entirely shale, with a few thin, non-continuous very fined grained sandstones. This formation underlies the prominent scree slope to the west.
2.30	23.60	Historical Marker reads: *Travel History - Five stages of travel can be recalled here. Concrete covers the old turnpike. Opposite are the ruins of the old canal. The Juniata was once filled with river craft. Across the river is the Pennsylvania Railroad.*
1.20	24.80	Enter Lewistown Borough.
0.10	24.90	Exit the Juniata Narrows. Steeply dipping Tuscarora to right. Continue on US Route 322.
1.40	26.30	Exit US Route 322 to US Route 522 North (Walnut Street); continue straight.
0.20	26.50	Turn right on US Route 522 North and cross Kishacoquillas Creek.
0.10	26.60	Traffic light; turn left onto Spring Street.
0.40	27.00	Turn left onto Banks Avenue.
0.10	27.10	Turn right onto Bridge Street.
0.10	27.20	Enter Derry Township. Kishacoquillas Creek parallels the roadway on the left.
0.10	27.30	To the right is an inactive quarry exposing south-dipping Keyser Formation limestones. Similar small, inactive quarries are present along the route to mileage 27.8, where the inactive quarry includes a bat cave that is a protected site.
0.70	28.00	Turn right onto Quarry Road.
0.50	28.50	**STOP 2: EASTERN INDUSTRIES QUARRY (INACTIVE)** Leaders—Thomas A. McElroy and Donald M. Hoskins See p. 77 expanded stop illustrations.

Derry quarry is located on a doubly plunging 3rd –order syncline that is about 3,000 feet long. The southwest working levels of the quarry reveal the axis of the syncline, which demonstrates the non-concentric, asymmetric folding of planar beds typical of the Ridge and Valley Physiographic Province (Faill and Wells, 1974, p. 132).

The Silurian-age Tonoloway and the Devonian-Silurian age Keyser Formations are exposed here. The Tonoloway Formation is a medium-gray, thinly laminated limestone, with occasional thin to medium thickness beds of dense, gray, microcrystalline limestone. On weathered surfaces the laminated appearance results from the alternation of micrite or calcisiltite in argillaceous and silt layers. Clear calcite crystals may be found near its top. Mud cracked polygons, characteristic of the Tonoloway, are common and beautifully exposed here

Figure 24. Mud polygons and possible algal mats at Stop 2.

Figure 25. Nodular lithology in lowermost Keyser Formation is restricted to one layer at Stop 2.

(Figure 24). On the polygonal surfaces are roughly circular features that may be algal mats. The Tonoloway in this area is about 675 feet thick, of which approximately 20 feet are exposed in the quarry. Deeply grooved, cross-strike slickensides are present in the uppermost northwest dipping Tonoloway layers exposed along the access road to the quarry bottom, and on the nearly horizontal Tonoloway layers in the quarry bottom.

The Keyser Formation is a dark- to medium-gray, fossiliferous, crystalline to nodular limestone, with thin beds in the uppermost exposed layers that resemble the Tonoloway Formation. Beds are flaggy to thick. Some are massive. The most abundant fossils in the Keyser Formation are crinoids, which in some massive layers appear to constitute a crinoidal arenite. Brachiopods, crinoids, bryozoans, mollusks, and ostracodes also are found. The formation is about 175 feet thick. Unlike Keyser exposures in the Susquehanna and lower Juniata River valleys, the characteristic nodular lithology of its lower Byers Island Member is seen in only one layer in this quarry (Figure 25). Secondary solution and deposition features are exposed along strike and cross strike fracture zones in the north side high wall.

The Keyser Formation, which has a higher purity than the Tonoloway Formation, was the target of quarrying. The pit is about 85 feet deep and 1,800 feet long. The highest elevation of the high wall on the north side is 690 feet. Original topography showed the elevation of the hilltop at slightly more than 740 feet, and the axis of the syncline is at the bottom of the pit, so approximately 150 feet of Keyser Formation was removed. Three different owners operated this now-inactive limestone quarry from the late 1960s to the early 1990s.

		Depart Stop 2. Seen to the west (straight ahead) is a prominent hilltop that is a tightly folded syncline forming part of Big Ridge.
0.50	29.00	Turn left onto Bridge Street. Kishacoquillas Creek is on the right.
0.10	29.90	Turn left onto Banks Avenue.
0.10	30.00	Turn right onto Spring Street. View to south is of the west-plunging Shade Mountain anticline.

Figure 26. Syncline with Mahantango Formation on axis seen at mileage 31.70.

Figure 27. Ridgeley Member crag at mileage 33.20.

0.30	30.30	Traffic light; turn right onto Walnut Street (US Route 522).
0.20	30.50	Cross Kishacoquillas Creek; turn right onto access roadway to US Route 322 West.
0.60	31.10	Exit left from US Route 322 to US Route 522 South on newly constructed highway.
0.10	31.20	South-dipping Marcellus Formation exposed on right.
0.50	31.70	Mahantango Formation exposed on right marks the axis of syncline seen at departure of Stop 2 (Figure 26).
0.10	31.80	North-dipping Marcellus Formation exposed on right.
0.10	31.90	Lower portion of Old Port Formation exposed on right. The new highway cuts the regional strike at a very oblique angle allowing the relatively thin Old Port Formation to be exposed along the highway for the next 0.75-mile.
0.40	32.30	Cross bridge over local road. Additional lower Old Port Formation exposures are present on steep roadcut banks below highway.
0.50	32.80	Sandstones of Ridgeley Member of Old Port Formation exposed to the right and continuing for the next mile along Big Ridge. US Route 522 south now parallels the regional strike.
0.40	33.20	Crag exposure of Ridgeley sandstones provides excellent foundation for house with magnificent view south of the Juniata River valley and Blue Mountain (Figure 27).
0.60	33.80	Additional Ridgeley crags exposed where power line crosses US Route 522.
0.90	34.70	View ahead is of the deep cut for exit ramp to Business Rt. 22. While under construction this site was deemed to be "OZ" because of the complexity of geologic features exposed during construction. The unsuspected site geology forced expensive engineering changes during construction. Since construction covered over critical exposures almost as fast as it exposed new data this site was a puzzlement. The site was visited many times during construction. Each visit provided a bit more information that allowed for an eventual interpretation of a very tight,

		slightly overturned faulted syncline, with 19th century sandstone and sedimentary iron ore mine workings, bordering one of the many anticlines along Big Ridge's predominant syncline. If the site designers had examined published maps and reports of the mine workings, they might have been better prepared for events that occurred during construction. For a full description of this site including geologic map and photos taken during construction see pages 7-15.
0.20	34.90	Marcellus Formation black shales exposed to the right at the entrance to "OZ".
0.50	35.40	View of depressions to the right (along power line). These depressions are collapse features over the openings to mined-out portions of the Ridgeley sandstones which here can be dug with hand tools. Similar depressions were present in the excavated portions of "OZ". These allowed rapid drainage into the almost strengthless bedrock permitting easy excavation but little support for embankments. During construction the depression closest to the “OZ” excavation filled and "blew out" the constructed "plug" exposing the ancient adit and rocks.
0.80	36.20	Keyser and Tonoloway formations exposed to right on road bank above the end of the newly constructed highway.
0.60	36.80	View to southwest of northeastward plunging anticline of Rose Hill and Keefer Formations forming Chestnut Ridge.
0.30	37.10	Low road cut through northwest-dipping Tonoloway Formation limestones.
0.35	37.45	Historical Marker reads: *Three Locks. Preserved here are three locks of the Pennsylvania Canal, Juniata Division. Unique in that three locks and levels were adjacent. Stonework and the old bed of the canal can be seen.*
0.05	37.50	Enter village of Strodes Mills.
0.90	38.40	Intersection with Strodes Run Road to right and Middle Road to left; cross Strodes Run. Strodes Run's reach follows a linear trend crossing Big Ridge to the north, and cuts across Chestnut Ridge anticline to the south near its northeastward plunge. This trend is interpreted to represent a fracture zone and likely is the cause for the gap through Chestnut Ridge Gap near its northeast plunge.
0.20	38.60	Low ridge to the left that parallels our route for the next four miles is underlain by the Wills Creek Formation claystones.
1.50	40.10	Open-pit mines in the Ridgeley sandstones visible to the right (west) (Figure 28). Much of the sand excavated from these mines was used for glass making, including the lens for the 200-inch Mt. Palomar telescope. The first lens cast cracked and is now on display at the Corning Glass Museum.
0.60	40.70	Cross Wakefield Run, a drainage feature cross-cutting the regional structures nearly perpendicularly, similar to Strodes Run.
0.50	41.20	View of Chestnut Ridge to left (Figure 29). This ridge is mantled by the Keefer sandstones overlying Rose Hill shales. Visible is a "borrow pit" excavation in the Rose Hill. The very wide gap eroded

Figure 28. Open-pit mine in Ridgeley sandstone at mileage 40.10.

Figure 29. Water gap through Chestnut Ridge at mileage 41.20.

		through this ridge by the Juniata River is likely controlled by interpreted fractures along the extension of a linear zone also related to the course of Wakefield Run.
2.20	43.40	Enter McVeytown.
0.10	43.50	Cross Town Run.
0.05	43.55	Historical Marker reads: *Joseph T. Rothrock. Born here April 9, 1839. Conservationist and father of the State Forest idea in Pennsylvania. Pioneer in development of forest fire control, reforestation, and scientific forestry.*
0.05	43.60	Traffic light; continue straight.
0.40	44.00	Cross Musser Run.
0.40	44.40	North-dipping Tonoloway limestones exposed in road bank to the left.
0.20	44.60	North-dipping Tonoloway limestones exposed in road bank to the right.
0.50	45.10	Cross Musser Run. Exposure of Mahantango Formation sandstones on road bank to right beyond bridge crossing.
0.30	45.40	Exposure to left in "borrow" pit is steeply north-dipping (60 degrees) Mahantango sandstones & siltstones.
0.50	45.90	"T" intersection; turn right on Jacks Mountain Road.
0.20	46.10	Ridgeley sandstones exposed to right along, and defining, the axis of southwestward plunging anticline.
0.40	46.50	North-dipping Ridgeley sandstone.
0.10	46.60	South-dipping Ridgeley sandstone exposed on right. From this point to mileage 46.7, though the gap in Orebank Ridge cut by Musser Run, the exposure includes nearly 100 percent of the Old Port Formation (excepting the Shriver Member) and 100 percent of the underlying Keyser Formation limestones to the contact with the underlying Tonoloway Formation. *As with most such exceptional exposures traffic along this winding road is frequent and almost no walking space exists between the pavement and exposure. Visitors are cautioned to exercise great care in examining this site.*
0.30	46.90	Tonoloway Formation limestones exposed inn small outcropping to right in series of very tight 5th order folds.

0.20	47.10	Intersection with Ferguson Valley Road. Vertically to steeply north-dipping and overturned Keyser Formation limestones exposed to right.
0.10	47.20	Ridgeley sandstone float to right. At mileage 47.2 and 43.6 Ridgeley sandstone float define a very tightly folded syncline along Dunmire Ridge.
0.70	47.90	Intersection with Kansas and Little Kansas Roads; continue straight.
1.10	49.00	South-dipping Rose Hill shales in small pit to left.
1.60	50.60	South-dipping Tuscarora Formation sandstones exposed semicontinuously to left for the next 0.75-mile.
0.80	51.40	**STOP 3: CREST OF JACKS MOUNTAIN—RAPTORS AND LUNCH** Leaders—Thomas A. McElroy and Donald M. Hoskins

This, where LR 4033 crosses the crest of Jacks Mountain, is our “arm-waving” stop. While eating lunch, participants can drink in magnificent views to the north and south and watch migrating raptors. Those interested in examining the exposures adjacent to the parking areas can refer to Appendix 1, which provide a description of the Tuscarora Formation’s western cross-laminated facies at this site (Cotter,1982).

To the north, the Kishacoquillas Valley (Figures 30 and 31) lies about 1,200 feet below us, bounded on the south by Jacks Mountain and on the north by Stone Mountain. The valley is a breached, first-order anticline, with Ordovician carbonates exposed at its core. The carbonates produce very fertile soil, which the numerous Amish and Mennonite farming families in the valley have exploited for about 200 years. In traversing this valley on the second day, and today, if you are sharp-eyed, you may notice that, in addition to the usual black buggies, some of the Amish utilize black and white and black and yellow buggies.

The Lower Silurian Tuscarora Formation underlies the crests of the bounding mountains (Figure 32), with an easily seen lower ridge underlain by the Ordovician Bald Eagle Formation. North of Stone Mountain is the Sideling Hill syncline, which we will visit on the second day.

To the south, Ferguson Valley is immediately below us. South-dipping Silurian-and-Devonian rocks underlie it. Big Ridge adjoins the south side of the valley. The ridge, which is synclinal, is structurally complex, with numerous 3rd – and 4th –order folds, and faults. The Lower Devonian Ridgeley Member of the Old Port Formation underlies most of the ancillary ridges within Big Ridge. The Ridgeley Member has very variable resistance to erosion. In some places on Big Ridge it forms 100-foot high tors. Elsewhere on the ridge, it is topographically below the underlying Shriver chert. Farther south is a water gap where the Juniata River cut through the anticlinal Chestnut Ridge. The thin but highly resistant Lower Silurian Keefer Formation underlies most of Chestnut Ridge. Blue Mountain is on the horizon. To the southeast, Shade Mountain plunges out at the west entrance to the Lewistown Narrows. The Tuscarora Formation caps both of these mountains.

		Depart Stop 3. Return down south slope of mountain. On a clear day the view to the southwest includes a view of the southwest plunge of Blue Mountain anticline.
3.50	54.90	Intersection with Little Kansas and Kansas Roads.
0.70	55.60	Intersection with Ferguson Valley Road; turn right.
0.20	55.80	Steeply north-dipping Ridgeley sandstone to right on south limb of

Figure 30. View of Kishacoquillas Valley, north of Jacks Mountain.

Figure 31. View to south of Jacks Mountain.

Figure 32. Tuscarora Formation outcrop at crest of Jacks Mountain at Stop 3.

		Dunmire Ridge syncline.
0.20	56.00	Ridgeley sandstones underlie slope to left.
0.30	56.30	North-dipping Marcellus Formation black shales exposed in abandoned borrow pit to left.
0.90	57.20	Cross under power line.
0.50	57.70	Ridgeley sandstone outcrop on north limb of Dunmire Ridge syncline visible in tree line north of field.
0.80	58.50	From mileage 56.3 to here, the roadway closely parallels the Ridgeley-Needmore contact.
0.30	58.80	Intersection with Cookson Road.
0.20	59.00	Old Port Formation exposed in old abandoned pit to left.
0.10	59.10	T" Intersection at Atkinson Mills; turn left onto US Routes 22/522.
0.50	59.60	"White House" (a place of liquids) on right.
0.70	60.30	Selinsgrove limestones exposed in road bank on left.
0.50	60.80	Turn right onto Fairview Road; enter Oliver Township.
0.30	61.10	Turn left onto Irvin Hill Road.
0.10	61.20	Wayne Church on right.
0.40	61.60	**STOP 4: EASTERN INDUSTRIES QUARRY (INACTIVE)**
		Leaders: Thomas A. McElroy and Donald M. Hoskins
		See p. 80 for expanded stop illustrations.

This inactive limestone quarry is owned by Eastern Industries. It was operated from the 1950's to the early 1970's. *Trash was illegally dumped in the pit. Please be careful!*

As at Stop 2, the Upper Silurian Tonoloway and the Devonian-Silurian Keyser Formations are exposed here. Stratigraphy of the Tonoloway Formation exposed is similar to the Tonoloway at Stop 2. However, polygonal mud cracks and slickensides are not as evident. Along the south high wall the Tonoloway exhibits sedimentary cycles identified by a thin calcareous claystone at a cycle's top.

The Keyser Formation exposed in the access to the main quarry contains black chert and some basal nodular limestone. The nodular limestone is not continuous. There are silicified fossils, dominantly crinoids in some of the large blocks that have fallen into the quarry access.

The quarry is located on the northwest flank of the here-named Horningford anticline, a 2^{nd} –order fold. Strike is N55E. Dips are generally to the northwest. At an exposure of the Ridgeley Member northwest of the quarry, dip of the beds is 67 degrees. Near the entrance to the quarry floor, the Keyser Formation dips 41 degrees. Dip of the Keyser Formation on the southeast highwall is 17 degrees.

Of particular interest in this quarry are beautifully displayed 4^{th} –order disharmonic and kink folds, some with vertical and overturned dips. The 4^{th} –order folds do not appear to include the overlying Keyser Formation.

Figure 33. Cave in vertical to overturned Tonoloway layers at Stop 4.

There are also several caves (Figure 33). Most are on the highwall and are small. The largest is at the quarry floor, and has two openings a small, determined caver could enter. To our knowledge, it has not been explored, but the cool air coming out of it indicates a significant length of passageway. A water well drilled about 1/3 mile to the northeast along strike entered a 50-foot cavern.

		Depart Stop 4 via Irvin and Fairview Roads. View to north is of high hills of Gearhart Ridge.
0.50	62.10	Shallow north-dipping Mahantango Formation siltstones exposed in small borrow pit to right.
0.10	62.20	"T" intersection with US Routes 22/522; turn right.
0.20	62.40	Steeply south-dipping masonry composed of Ridgeley sandstone blocks obscures the underlying Marcellus black shales exposure.
0.50	62.90	Nearly horizontal Selinsgrove limestones exposed in road bank to left. To right along power line is “borrow” pit with 45-degree south-dipping Marcellus black shales, also exposed on stream bank. At ridge crest along power line are Ridgeley sandstone exposures.
0.50	63.40	"T" Intersection with Jacks Mountain Road; continue straight.
0.70	64.10	Cross Musser Run.
1.40	65.50	Cross Musser Run.
0.40	65.90	McVeytown traffic light; continue straight.
1.70	67.60	View of Juniata River watergap through Chestnut Ridge on right.
0.30	67.90	Wills Creek exposed in hillside pit on right.
0.50	68.40	View to upper left of large abandoned quarries in Ridgeley sandstone.
1.70	70.10	Enter Strodes Mills.
0.60	70.70	Historical Marker. *"Juniata Iron" Along the streams of this region are ruins of many charcoal iron furnaces and forges built between 1790-1850. Juniata iron was the best in America. Its reign ended with the rise of coal and coke iron making."*
0.20	70.90	Intersection. Turn left on Strodes Road.
0.10	71.00	To the left, at the sharp blind turn, north-dipping Keyser limestones are exposed under and along the stream and in an abandoned quarry. At this site unusual geologic and topographic features are present. Here a low waterfall occurs with an approximate 15-foot drop from the crest of the waterfall that is supported by Keyser Formation limestones (Figure 34). Along the lower part of the waterfall are a series of potholes eroded into the limestones, indicating turbulent flow (Figure 35).
0.10	71.10	Cross Strodes Run and enter Oliver Township. Ridgeley sandstones exposed to right on steep bank.
0.20	71.30	Cross Strodes Run and enter Granville Township.
0.40	71.70	Strodes Mill quarry entrance. Turn left.

STOP 5: OLD PORT QUARRY AND FOSSILS

Leaders: Thomas A. McElroy and Donald M. Hoskins

See p. 83 for expanded stop illustrations.

This is an active sand quarry, operated by Eastern Industries. Sandstone from the Early Devonian-age Ridgeley Member of the Old Port Formation is crushed for industrial uses.

Figure 34. Waterfall over Keyser Formation at mileage 71.00.

Figure 35. Potholes in Keyser Formation at mileage 71.00.

The Ridgeley Member here consists of fine- to very coarse-grained, white and light-gray to buff sandstone. It is highly fossiliferous, and is noted for the robust brachiopods it contains. It is about 75 feet thick. Layering in the active quarry is nearly absent except in the northerly exposures (Figure 36).

The Ridgeley's distinctive lithology makes it an excellent marker unit in geologic mapping. It is cemented by either silica or calcite (James Casselberry, Pers. Comm.). Consequently, hardness of the member is highly variable. Where it is cemented by silica, it is exposed as rocky crags (Figure 37), some up to100 feet high, that can be seen along the slopes north of the active quarry. Where it is cemented by calcite, as in the active quarry, it is easily erodable. In nearby mapped areas it may be found topographically below the underlying Shriver Chert.

The quarry is located on a 4th –order syncline within the structurally complex 2nd –order Big Ridge syncline. Wavelength is about 500 feet. The tight folding has disrupted

Figure 36. Photo showing difficulty in discerning bedding in Ridgeley Member at Stop 5.

Figure 37. Steeply dipping Ridgeley Member adjacent to quarry at stop 5.

bedding to the extent that it is difficult to discern in most of the quarry (Figure 36). It also created a broad outcrop of the Ridgeley Member that makes it commercially viable as a sand source.

While the sand quarried here is only used for industrial purposes, the high purity of the Ridgeley Member makes it valuable as a source of glass sand. It was the source of silica used to cast the Mount Palomar 200-inch lens, and is currently quarried at Mapleton Depot for glass sand. In the last ten years, it has become a target aquifer for public water supplies, with sustained yields of up to 400 gallons per minute (James Casselberry, Pers. Comm.). In western Pennsylvania, it is an important source of natural gas.

		Depart Stop 5.
0.00	71.70	Turn left on Strode Road at "T" intersection.
0.10	71.80	Steeply north-dipping, overturned Ridgeley sandstone exposed in right road bank.
0.30	72.10	Cross Ridgeley outcrop trace on north side of steeply sided syncline.
0.30	72.40	Turn right on Ferguson Valley Road at "T" intersection. View to north of scree slopes along south slope of Jacks Mountain.
0.50	72.90	Low ridge to north (left) is underlain by Keefer sandstones.
0.20	73.10	Wills Creek Formation exposed in low banks of road cut on left and right.
0.80	73.90	Upper sandy unit of Bloomsburg Formation exposed on right; road follows near the contact with the Wills Creek Formation. View to south is of Big Ridge.
0.80	74.70	Wills Creek Formation exposed on left in road bank.
1.20	75.90	Steeply south-dipping Tonoloway Formation exposed on left. To the right is the site of one of the large 19th century iron mines described in d'Invilliers, 1891.
0.70	76.60	Tonoloway limestones exposed to left. To right in vegetated area is Keyser Formation limestones exposed along small thrust fault.
0.30	76.90	Keyser Formation limestones exposed in small pit to right.
0.70	77.60	Turn right on Ort Valley Road at "Y" intersection.
0.40	78.00	To left along the power line is a fine view of Manns Gap and Jacks Mountain
0.40	78.40	Enter Ort Valley, a "dry" valley, at a sharp left turn. In this valley there is no surface drainage even though the USGS topographic map depicts a stream. The bedrock is the Tonoloway Formation.
0.50	78.90	Enter Derry Township.
0.10	79.00	View of road excavation piles to right resulting from new Lewistown bypass construction.
0.60	79.60	Junction with US Route 522 South.
0.50	80.10	Traffic light; turn left onto Electric Avenue.
0.10	80.20	Turn left onto US Route 322 West access ramp.
0.30	80.50	Join US Route 322 West.
1.10	81.60	Exit US Route 322 onto Burnham / Yeagertown Exit.
0.10	81.70	Turn left onto Ferguson Valley Road.
0.10	81.80	Turn right into hotel parking lot.
		End of Day 1 field trip.

ROADLOG AND STOP DESCRIPTIONS

Day 2

Mileage		
Int	**Cum**	**Description**
	0.00	Exit hotel parking area. Turn left on Ferguson Valley Road; immediately turn right at stop sign onto access road entering US 322 West.
0.10	0.10	View of Manns Narrows through Jacks Mountain straight ahead (Figure 38). Erosion by Kishacoquillas Creek in Manns Narrows exposes extensive steep-slope (and infrequently seen elsewhere) outcrops of the Ordovician-Silurian sequence that normally underlies the many mountains of Pennsylvania's Appalachian Mountain Section. Well exposed in Manns Narrows are the Tuscarora, Juniata and Bald Eagle formations. Although these Formations will not be examined in Manns Narrows, prior field trips have examined them. As noted below, stop descriptions from prior field trips are included in appendices.
0.50	0.60	North-dipping, multi-hued Wills Creek Formation claystones on left. This outcrop is on the north limb of minor local anticline reversing the regional south dip.
0.40	1.00	South-dipping reddish Bloomsburg Formation claystones on left.
0.50	1.50	South-dipping Rose Hill Formation shaly claystones on left.
0.10	1.60	Steeply south-dipping sandstone layers of the Tuscarora Formation on right. These exposures were extensively described in Thompson's (1970, Stop 2C) and in Cotter's (1982) field trip guides (Appendices 3 and 4, respectively).
0.10	1.70	Steeply south-dipping reddish sandstone layers of Juniata Formation on left.
0.10	1.80	Cross Kishacoquillas Creek. The reddish Juniata Formation is well

Figure 38. View of Mann Narrows at mileage 0.10.

Figure 39. Contact of Antes Member with underlying Coburn Formation at mileage 3.00.

		exposed on the right (northeast) bank of Manns Narrows and is accessible for examination at the exposures along the visible local road (old US 322). These exposures were extensively described in Thompson's 1970 field trip guide, Stop 2A (Appendix 3)
0.40	2.20	South-dipping cliff exposures of Bald Eagle Formation on right and left. These exposures were also extensively described in Thompson's (1970) field trip guide, Stop 2B. (Appendix 3)
0.20	2.40	Exposed basal contact of the Bald Eagle Formation with the Reedsville Formation at road level. The contact is designated as the lowest quartzose sandstone layers underlain predominantly by shaly layers. Based on an preliminary geologic map of the east side of Mann Narrows prepared by Arnold Doden (2004), the Bald Eagle is estimated as 700 feet thick at this exposure. The Reedsville formation is estimated at 1,800 feet thick at this locality.
0.40	2.80	Bear to the right onto exit lane for PA Route 655.
0.20	3.00	Contact of the Antes Member of the Reedsville Formation with the underlying Coburn Formation on the right (Figure 39). The dark black iron-stained (pyritic?) shales of the Antes Member are more completely exposed on the left (west) side of the extensive road cuts at this exit on US 322 West. Note complex 3rd order folding and faults in the limestones exposed along the exit lane.
0.20	3.20	Turn left onto PA 655 at traffic light.
0.20	3.40	Turn left into parking lot.

STOP 6: REEDSVILLE AND DETACHMENT FAULT

Leaders—Thomas A. McElroy, Donald M. Hoskins, and Nathanael C. Barta

See p. 85 for expanded stop illustrations and measured section. See p. 16 for additional information on the Ordovician carbonates at the Reedsville locality.

This stop provides excellent exposures of the Antes Member of the Reedsville Formation at the southernmost portion of the outcrop, as well as the Coburn Formation, the Salona Formation and the upper member of the Nealmont Formation. All of the stratigraphic units are upper Ordovician in age. The carbonate portion of the outcrops also displays 4th –order folding in the Coburn Formation interpreted to be caused by a pre-Alleghanian detachment fault.

The Antes Member is a dark-gray to black, fissile, thin-bedded shale. It contains pyrite. At this site, calcium carbonate coatings are common on joint planes, and elemental sulfur deposits are also common.

All of the units exposed at Stop 6 below the Antes are predominantly limestone. The Coburn Formation is medium- to very dark-gray, fossiliferous (including tempestites), and shaly. The Salona Formation is dark-gray to black, fossiliferous, and contains chert nodules. The upper Rodman Member of the Nealmont Formation is medium-gray, coarsely crystalline, and fossiliferous. The lower Centre Hall Member of the Nealmont, which will not be examined here, is thin-bedded, finely crystalline, and shaly.

The most striking geologic feature seen at the exposure is a zone of southeast-verging 4th –order folds within the Coburn limestones. These were interpreted by Nickelsen (1988) as evidence for a fault he named the Antes-Coburn detachment fault (Figure 40). For a sketch of

Figure 40. View of Antes-Coburn detachment fault zone at Reedsville at Stop 6.

the folded portion of the outcrop see Nickelsen 1988, p. 96. The zone of folding is about 300 feet wide. Because of the intense folding, the actual thickness of the Coburn portion of the section cannot be determined. Gwinn (1970, fig. 3) recognized that the underlying carbonate sequence had been shortened twice as much as the overlying rocks.

We have found additional evidence for the detachment fault at several sites in the Kishacoquillas Valley. Directly on strike from Stop 6, approximately 5.8 miles to the south, and 0.5 miles south of Union Mills, the Reedsville Formation shales, minus the Antes Member lithologies, are in contact with the fossiliferous limestones of the Coburn Formation. On the northwest side of the KishacoquillasValley, at a site 0.6 miles south of Soft Run between Rockville and Belleville, the detachment fault cuts downward, removing about half of the carbonates. Along strike northeastward from this site, mainly evident on the Barrville quadrangle, the detachment fault cuts upward, removing about half of the Reedsville Formation.

		Exit Stop 6 parking area and turn left onto PA 655 South.
0.30	3.70	Sinkholes with exposures of south-dipping lowermost (Milroy Member) Loysburg Formation are prominent in the pasture to the right (northwest) along PA Route 655.
0.30	4.00	On the left (south) is Jack's Mountain with the Bald Eagle Formation underlying the prominent bench below the ridge crest, underlain by the Tuscarora Formation. The Juniata Formation, rarely seen in outcrop along the ridge, underlies the slope between the ridge crest and the bench. The Reedsville Formation underlies the slope below the mid-slope bench.
0.30	4.30	The ridge to the right (north) also is underlain by the Tuscarora Formation. It terminates abruptly at a promontory called Milligan's Knob (Figure 41). At Milligan's Knob the Tuscarora Formation-traces the northeastern portion of the southwestern-plunging syncline formed by Stone and Broad Mountains. This syncline expands into the Sideling Hill Synclinorium to the southwest.

Figure 41. View of Milligans Knob at mileage 4.30.

Figure 42. Tiger striped lithology exposed at mileage 4.80.

0.50	4.80	Along PA Route 655 from mileage 4.8 to mileage 5.1 the outcrops are of the Milroy Member of the Loysburg Formation, composed of interbedded gray limestone and dolostone layers. Present at this locality are layers of intermixed dolomite and limestone possessing a "tiger-stripe" lithology characteristic of this portion of the Loysburg Formation (Figure 42). Present also are layers with fragments of fossils. Approximately 150 feet of outcrop is exposed at this locality. *Caution must be exercised if this locality is visited. The extreme narrowness between the outcrop and the pavement, coupled with the frequent high-speed traffic, including frequent trucks, makes this a very dangerous road for geologic examination and should be visited only a few persons at any time.*
0.20	5.00	"T" Intersection of Coffee Run Road with PA 655 West at Cedar Hill; continue straight. The well-exposed south-dipping contact of the Loysburg and Bellefonte formations occurs approximately 100 feet north of the "T" intersection on Coffee Run Road.
1.30	6.30	"T" Intersection with Barrville road to right; continue straight.
0.50	6.80	Kishacoquillas, a small, unincorporated community, named for the valley (or from which the valley is named).
0.60	7.40	Small pasture exposures in tree line to right are the Axemann Formation. At this locality the Axemann Formation and the eastward plunge of the Belleville anticline is cut out along a local fault. This fault likely continues along the regional strike eastward to localities mapped by Morris Rones on an unpublished (1950s) geologic map of Kishacoquillas Valley.
0.30	7.70	To the left, at Sam's Backhoe Service, is an exposure of Bellefonte dolostones. At the east end of the excavations newly exposed dolostone layers contain vugs with secondary mineralization.
0.20	7.90	Cross Spring Run (which flows along Frog Hollow in its reaches above the spring). The principal flow of Spring Run derives from a spring immediately to the right of PA Route 655.

0.20	7.90	Cross Spring Run (which flows along Frog Hollow in its reaches above the spring). The principal flow of Spring Run derives from a spring immediately to the right of PA Route 655.
0.40	8.30	To the right is Kishacoquillas Valley's sole winery. Local wines are produced from a vineyard growing on soils derived from the Axemann Formation and from locally grown fruits. Small Axemann outcrops at the winery define a low-dip, eastward-plunging anticline that traces into the fault at mileage 7.5.
0.20	8.50	Low-angle, south-dipping Axemann Formation dolostone exposed on right.
1.10	9.60	"T" intersection with Front Mountain Road to left; continue straight. Valley View Medical Center to left.
1.50	10.00	Village of Belleville community sign.
1.10	11.10	Cross bridge over Little Kishacoquillas Creek in Belleville. Although not visible from PA Route 655, an abandoned quarry with approximately 55 feet of Bellefonte Formation is present approximately 250 yards northwest of the stream crossing.
0.20	11.30	"T" Intersection with PA Route 305; continue straight.
0.20	11.50	PA Route 655 follows the regional strike of low-angle, north-dipping upper Bellefonte Formation along the north limb of the Belleville anticline. The lower part of the slope north of the highway and the adjacent lowland is underlain by the Loysburg Formation. The southerly slopes of the low hills to the north are underlain by limestones of Nealmont to Hatter Formations with Salona and Coburn formations present at higher elevations (Figure 43).
0.70	12.20	"T" intersection with Wills Road, leading over Jacks Mountain to US Route 22; continue straight.
0.70	13.60	"T" intersection with Knepp Road to right; continue on PA Route 655.
0.30	13.90	Enter Whitehall, labeled Menno on USGS Allensville topographic map.

Figure 43. Terrain underlain by Coburn through Loysburg Formation carbonates at mileage 11.50.

Figure 44. Quarry described by Rones (1969) at mileage 16.80.

1.60	15.50	"T" intersections with Long Lane on right and Waynesburg Road on left; continue on PA Route 655.
0.50	16.00	Small north-dipping Bellefonte Formation outcrop in field to left.
0.30	16.30	"T' Intersection with West Back Mountain Road; turn right.
0.30	16.60	Very large sinkhole in Nealmont to Hatter Formation carbonates present to left (west) marked by grove of trees to the left of the farm.
0.20	16.80	Small abandoned quarry to left (Figure 44). Exposed here are approximately 125 feet of limestones belonging to the Upper Ordovician Nealmont to Snyder Formations. The section is described in Rones (1969). For detailed description of these rocks see Appendix 5.
0.10	16.90	Cross uppermost reach of Kishacoquillas Creek draining King's Hollow. To the northwest can be seen a prominent Bald Eagle Formation outcrop in King's Hollow gap. Outcrops to the right in farmed field are laterally equivalent to the rocks at mileage at 16.8.
0.10	17.00	Sinkhole visible to left in Coburn-Salona Formations.
0.10	17.10	Additional view of Kings Hollow Gap framed by shallow, northwest-dipping Bald Eagle Formation on the lower bench of Stone Mountain. Unlike areas to the northeast and southwest along this bench, the dip here is relatively shallow, dipping northwestward at 20 degrees. King's Hollow Gap, an unnamed gap 1.8 miles south, and Hostetler Gap 1.7 miles north all exhibit deep reentrants resulting from the locally shallow dips.
0.60	17.70	Reedsville Formation shales exposed in farmer's borrow pit on hill slope to left.
0.40	18.10	Junction of West Back Mountain Road with Long Lane on right; continue with sharp left turn. The contact of the Coburn Formation with the Reedsville Formation occurs shortly north of the turn at the topographic break in slope. To the right, about 250 yards along Long Lane approximately 50 feet of fossiliferous Nealmont-Hatter limestones are exposed in a ditch northeast of the pavement.
0.20	18.30	Continue with sharp right turn on West Back Mountain Road.
0.20	18.50	To left, along private lane, are discontinuous north-dipping exposures of Reedsville Formation.
0.40	18.90	To right is small borrow-pit exposure of Reedsville Formation.
0.80	19.70	Stop sign; turn left onto West Back Mountain Road at junction with Knepp Road.
0.70	20.40	Contact of Reedsville and Coburn formations is situated midway to turn at Hickory Grove Road in farmed field on right.
0.30	20.70	Turn right then left onto Hickory Grove Road; turn left into Peachy shale pit.

STOP 7: PEACHY SHALE PIT

Leaders: Thomas A. McElroy and Donald M. Hoskins

See p. 91 for expanded stop illustrations.

The Reedsville Formation shale is extracted from this active pit. It is located on the

Figure 45. Low-angle dip in Peachy Shale Pit on northwest side of Kishacoquillas Valley, Stop 7.

northwest flank of the Jacks Mountain anticline, in the Kishacoquillas Valley. The Reedsville Formation here consists of dark-gray shale containing thin sandy to silty shale interbeds. It is moderately well bedded, commonly displaying pencil cleavage. The shale beds are thin. Sandy interbeds may be up to two feet thick.

At the present working face of the pit, joints with secondary mineralization are prominent. Dips in the pit are to the northwest and gentle, averaging about 18 degrees (Figures 45 and 46).

Fossils have not been found to date at Stop 7. However at a nearby "borrow pit" immediately to the west the Reedsville is fossiliferous in its uppermost layers, where sandy beds are more common.

Our mapped contact of the uppermost Coburn limestones and the lowermost Reedsville Formation occurs 1,000 feet southeast of the exposed rocks at the Peachy pit. Nickelsen, 1988, p. 105, states that at the Peachy pit "… locally well-developed spaced cleavage and fourth-order folds may mark the position of the detachment." We agree that this contact is the Antes-Coburn detachment fault. However, we observed no 4^{th} –order folds at this pit. Can you find any?

Visible north-northeast from Stop 7 is Bearpen Hollow which is formed between two low ridges along Stone Mountain. The Bald Eagle Formation underlies both these two ridges. Bearpen Hollow contains the Bearpen Hollow thrust fault (Nickelsen, 1988, p. 92-97). Nickelsen's figure 2, a geologic map of the area including Stop 7, portrays that the Bearpen Hollow fault traverses south from Bearpen Hollow through the northwestern part of Stop 7, connecting with the detachment southwest of Stop 7. No structural features were observed at Stop 7 or in Reedsville outcrops southwest of Stop 7 that we can interpret as related to the Bearpen Hollow fault, leading us to the conclusion that an alternate map explanation is required.

About 1.25 miles northeast of Stop 7, and approximately 0.4 miles southeast of the termination of the Bald Eagle Formation along the Bearpen Hollow thrust fault, a small pit exposes a 4^{th} order anticline whose axis dips steeply to the south. The Reedsville shale at this site is strongly cleaved, with cleavage paralleling the fold axis. This outcrop and

Figure 46. Reedsville Formation exposed along working face at Stop 7, Peachy Pit. Note the low-angle, northwest dip of layers and numerous vertical joints with secondary mineralization.

limited other nearby outcrops in the Reedsville support an interpretation that the Bearpen Hollow thrust has a map pattern similar to the Potlicker Flat thrust fault of Nickelsen (1988, p. 92) that was originally mapped in the 1800s (Billin, 1885a) and known as the "Z" fault.

		Depart stop 7. Turn left onto Back Mountain Road.
0.50	21.20	Enter Union Township.
0.30	21.50	To the right, (southeast), beyond the small forested patch, the upper Ordovician limestones (Coburn-Salona) are mapped as absent and are interpreted to be missing along the Antes-Coburn detachment fault. This is the sole area in the Allensville quadrangle where detailed field mapping data supports an interpretation that the detachment fault cuts downward into the carbonate formations as opposed to cutting upward to remove the Reedsville Formation shales in other areas.
0.50	22.00	Turn left onto Rockville Lane.
0.10	22.10	Cross Soft Run. The slope north of Soft Run is wholly covered by colluvium, largely derived from the Bald Eagle Formation on the low ridge to the northwest.
0.50	22.60	Turn left, staying on Rockville Lane.
0.05	22.65	Turn right into Rockville Fellowship Church parking lot.

STOP 8: BEARPEN HOLLOW GAP

Leaders: Thomas A. McElroy and Donald M. Hoskins

See p. 91 for expanded stop illustrations.

Stop 8 provides exposures of the Bald Eagle Formation through a gap in the ridge that leads to Bearpen Hollow. At this site the Bald Eagle is steeply overturned, dipping over most of the visible outcrop 40 degrees to the southeast (Figure 47). The outcrops on the northeast side of the gap also exhibit an overturned syncline that rotates the bedding to 180 degrees overturned. The lithology of the exposed portion of the Bald Eagle is similar to that seen in outcrops bordering the Kishacoquillas Valley. Here it is thick to massively bedded sandstones and conglomeratic sandstones.

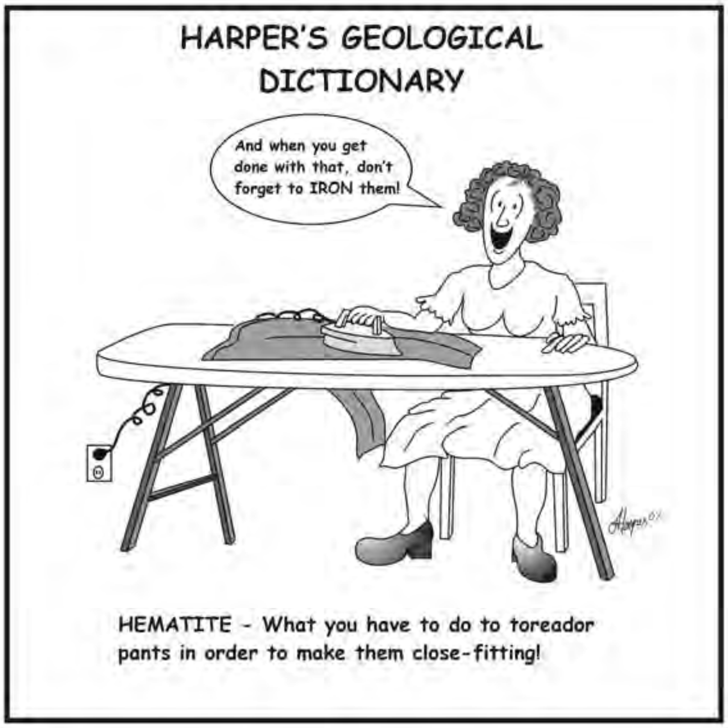
Figure 47. Overturned bedding on the Bald Eagle Formation, Stop 8 (refer to Nickelsen, 1988, fig. 11 bottom for additional images of this outcrop).

Nickelsen (1988, pp. 92-97, also provided here in Appendix 1) describes and interprets this outcrop in detail with photographs. Included in Appendix 1 is one of the photographs in Nickelsen's description whose image is reversed in his article for purposes of demonstrating "structures down plunge toward the southwest" (Nickelsen, 1988, fig. 11 caption). The photograph is included in its original format because it provides a clearer picture than can be seen today due to extensive growth of vegetation in the gap.

Geologic issues that we faced in mapping this area include recovering all of the outcrops used by Nickelsen in reaching his conclusions, in addition to attempting to find additional outcrops or other evidence of the trace of the Bearpen Hollow thrust fault. The area underlain by the Bald Eagle extends approximately 3,000 feet west of the gap at Stop 8. No Bald Eagle outcrops providing measurable attitudes exist southwest of the gap. A problem that we faced was to determine the trace of the Bearpen Hollow thrust fault beyond the end of the ridge supported by Bald Eagle conglomeratic sandstones. The question we asked was, "Is the westerly termination of the Bald Eagle on the Bearpen Hollow fault similar to mapped terminations of the Tuscarora Formation on the Potlicker Flat thrust fault, or does the Bearpen Hollow thrust fault join with the Antes-Coburn detachment as postulated by Nickelsen (1988, fig. 2)". Our mapping best resolves the question by depicting the trace of the Bearpen Hollow thrust fault as abruptly curving eastward and then northeastward at the termination of the Bald Eagle ridge.

The gap exposing Stop 8 outcrops was eroded by Soft Run along a fracture zone that trends northwest and extends across the Bearpen Hollow fault into the north-dipping Bald Eagle Formation on the south facing slope of Stone Mountain. A question we would ask is how such a small stream could produce the deep gap with cliff exposures of the Bald Eagle.

		Depart Stop 8. Turn left out of Church parking lot into Rockville Lane. Then turn right staying on Rockville Lane.
0.65	23.30	Turn left onto Back Mountain Road.
0.50	23.80	In streambed on left are distorted limestone layers, marking interpreted trace of the splay fault from the Antes-Coburn detachment fault that extends southwestward and then curves to join with Bearpen Hollow thrust fault.
0.30	24.10	Turn left onto PA 305 West.
0.40	24.50	Overturned, steeply south-dipping Reedsville Formation in shale pit on right. While at quick glance the dip inclination appears to be north and right side up, close inspection of fossiliferous layers in the shales shows the dip to south and overturned similar to the Bald Eagle rocks at Stop 8 and in the gap 0.1 miles to the north.
0.10	24.60	Overturned, steeply south-dipping Bald Eagle Formation outcrops exposed along stream in gap northwest of sharp bend in highway.
0.50	25.10	Blocks of Bald Eagle Formation float mantle slopes on left and right.
0.80	25.90	Enter Rothrock State Forest and Huntingdon County.
0.10	26.00	Cross the trace of Stone Mountain Fault; slopes to right of highway are mantled by Bald Eagle and Tuscarora float.
1.70	27.70	Enter Greenwood Furnace State Park. The park boasts a 19th century iron furnace that processed locally mined sedimentary iron ores from the Rose Hill Formation. **STOP 9: GREENWOOD FURNACE STATE PARK: LUNCH AND HISTORICAL PRESENTATION** Leader: Paul T. Fagley See p. 95 for discussion.



0.60	28.30	Depart lunch stop, continuing on PA 305 West. Outcrops on cut bank adjacent to dam are Keefer Sandstone underlain by Rose Hill Formation north along the lakeshore.
1.50	29.80	Mounds in the woods to the right are tailings from 19th century iron mines in the Rose Hill Formation.
0.10	29.90	Bear left onto East Branch Road toward Jackson Corners.
0.50	30.40	To the left, along the farm entry road below the farm building are exposures of the steeply south-dipping upper sandy and resistant layers of the Bloomsburg Formation. The visible farm fields are underlain by shales of the Wills Creek Formation.
0.80	31.20	South-dipping, upper resistant layers of Bloomsburg Formation exposed in pit on right (Figure 48).
0.10	31.30	Cross East Branch of Standing Stone Creek. Outcrops to right along stream bank are south-dipping Wills Creek Formation.
0.30	31.60	Small steep bank on left at field edge southeast of road contains an emerging spring and exposes the Tonoloway Formation along the axis of the Sideling Hill syncline.
0.80	32.40	Bridge crossing East Branch of Standing Stone Creek. Lowermost Devonian Old Port Formation limestone with silicified brachiopod fossils is exposed south along highway from bridge; Devonian-Silurian Keyser Formation is exposed along the steep stream bank to the north of the bridge and along road banks to south along the paved road. Gated road a few yards northeast of bridge leads to site of aborted research core hole located on or near to the axis of an overturned syncline.

0.10	32.50	Turn right onto Barr Road.
		STOP 10: KEYSER AND OLD PORT FORMATION STATIGRAPHY
		Leaders: Thomas A. McElroy and Donald M. Hoskins
		See p. 101 for expanded stop illustrations.

Lowermost Old Port Formation (Figure 49) and uppermost Keyser Formation limestones are exposed at this stop. One outcrop of the Keyser Formation is visible on Barr Road, and the Old Port Formation outcrops are abundant along East Branch Road. Chert and silicified fossils, including brachiopods, coral, ostracodes and bryozoans are found here in lowermost Old Port limestones. Bedding is thin to massive. The top of the Keyser Formation is thinly laminated, and no fossils were found.

The stop is located near the beginning of the Sideling Hill syncline, which plunges to the southwest. Folding in this syncline is very tight and steep. About 800 feet southeast of East Branch Road, on the southeast limb of the syncline, the Ridgeley is overturned, dipping 26 degrees to the southeast (Figure 50).

Discerning the Old Port Formation from the Keyser Formation is problematic in this area as they appear very similar in field outcrops. For mapping purposes, we defined the base of the Old Port Formation to be the lowest stratigraphic layer with chert and silicified fossils because it is a recognizable bed and we, at this stop, found thinly laminated limestone typical of upper Keyser adjacent to the cherty, fossiliferous limestone.

In hopes of better defining the formations, and learning about the Keyser-Tonoloway contact (the nodular bedding typical of lower Keyser is missing in this area), we attempted to drill a core hole on the axis of the syncline in August 2007. The hole went through 74 feet of unconsolidated sand before it went into very weak Ridgeley Member sandstone. The sandstone was too incompetent to keep the hole open, so we had to cease drilling at 97 feet.

		Depart Stop 10. Turn right on East Branch Road
0.50	33.00	Cross East Branch of Standing Stone Creek. Ridgeley Member of Old Port Formation is exposed on vegetated stream bank on left at bridge. Ridgeley sandstones underlie hill slopes to right, south of bridge, where they form steep dip slopes and massive (crag) outcrops.

Figure 48. Shale pit in upper Bloomsburg Formation at mileage 31.20.

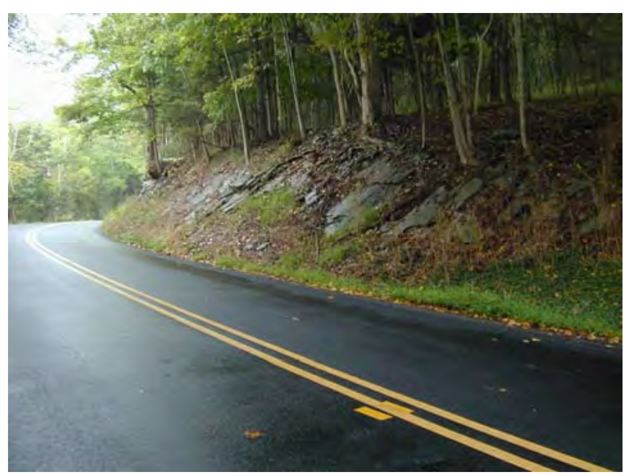


Figure 49. Lowermost Old Port limestone at Stop 10.

Figure 50. Overturned Ridgeley Member at Stop 10.

0.70	33.70	"T" intersection with Allensville Road, continue straight.
0.10	33.80	Dirt lane on left leads to a large exposure of the Marcellus Formation in a shale pit along East Branch Creek.
0.05	33.85	Cross East Branch Creek.
0.25	34.10	Enter Miller Township.
0.20	34.30	Road bank outcrop of Marcellus Formation on left.
0.20	34.50	Shale pit exposing south-dipping Marcellus Formation on right. The Marcellus is faulted and folded nearest the paved road. Overlying the Marcellus exposure is approximately five feet of colluvium principally composed of weathered Ridgeley Formation sandstone.
0.20	34.70	Poorly exposed, south-dipping, limy shales of Needmore Member occur in low road banks over the next 0.3-mile.
0.60	35.30	"T" intersection with Gensler Run Road to left; continue straight. Enter Village of Jackson Corner. The Marcellus Formation is exposed at the bend in Gensler Run Road.
0.20	35.50	Cross Standing Stone Creek. Turn left at stop sign onto PA 26 South. Outcrops of Ridgeley sandstone are exposed at base of steep slope across PA 26.
0.20	35.70	Outcrop of south-dipping Selinsgrove limestone on right.
0.20	35.90	Outcrop of south-dipping Marcellus Formation on right, along field access road.
0.30	36.20	Turn right onto Wesley Chapel Road. Hills seen to south of the Chapel are underlain by the Mahantango Formation

0.30 36.50 **STOP 11: RIDGELEY MEMBER OF THE OLD PORT FORMATION**

Leaders: Thomas A. McElroy and Donald M. Hoskins

See p. 103 for expanded stop illustrations.

Stop 11 provides excellent exposures of the Ridgeley Member of the Old Port Formation. Here the rocks form a dip slope, so you see a 75-foot thick unit exposed for 200 vertical feet along Wesley Chapel Road. Because of the much gentler folding at this locality, (dips average 15 degrees to the southeast), bedding that is difficult to impossible to see at Stop 5 is easily discerned at this stop.

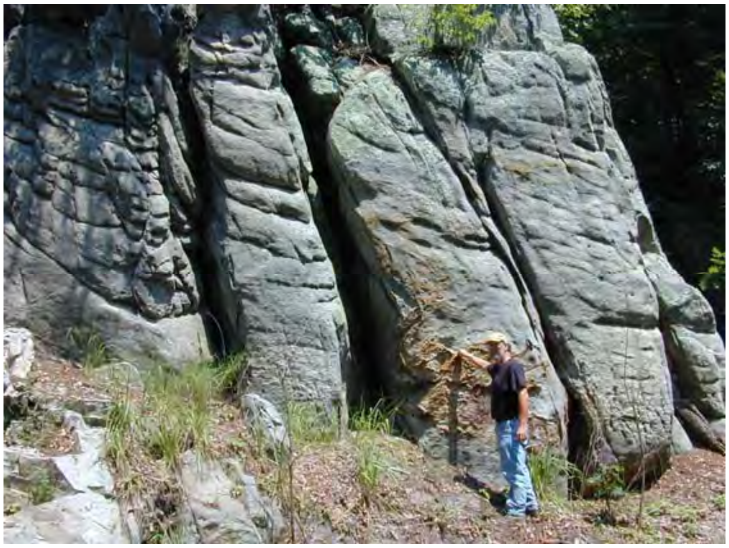


Figure 50. Deeply weathered jointing in Ridgeley Member with surficial secondary mineralization at Stop 11.

The Ridgeley displays wide variation in hardness (p. 104). At this locale, in places, the rock is soft enough to push a pencil into it. Joints are well exposed at these outcrops. At the lowest outcrop, in addition to the joint set perpendicular to bedding, there are three other sets, with orientation of: N80W, dip 86S; N60E, dip 70NW; and N5E, dip 77W. Some joints are deeply weathered (Figure 51). Zones of differing hardness seem to be related to jointing that is perpendicular to bedding, giving the first impression that bedding is very steep and dipping to the northwest.

The most outstanding portion of this outcrop is the high, beautifully cross-bedded, differentially weathered crag (Figure 52). Cross bedding of this type is rarely observed in Ridgeley Member outcrops. Ridgeley crags of this type, rising to significant heights are common in this area, some of which are favorite bouldering (free-style rock climbing) sites.

Unlike Stop 5, fossils can be found, but they are not as abundant. Molds of brachiopods have been found in the lowermost updip layers.

Figure 52. Ridgeley Member crag exhibiting cross bedding at Stop 11.

0.30	36.80	Walk up to buses at Chaney Spring Road and leave Stop 11.
0.10	36.90	Ridgeley sandstones exposed in road bank to left for 0.1 mile. In swale to right sandstone boulders are likely "let-down" colluvium from eroded Ridgeley or from Ridgeley outcropping at hilltop to north.
0.40	37.30	"T" intersection; turn right onto Summit School Road.
0.10	37.40	On hilltop to the right are Ridgeley boulders and abandoned pits signifying that the hilltop is underlain by Ridgeley Member.
0.20	37.60	Exposed to the left is approximately 20 feet of nearly horizontal to shallowly south-dipping, thickly-bedded to platy limestones of the upper Old Port Formation. Some layers are fossiliferous.
0.10	37.70	To the right, in tree area, are Ridgeley boulders and apparent outcrop.
0.10	37.80	To the left, in the forested area is an extremely large sinkhole assemblage. The depressed surfaces in the forested area follow linear patterns suggesting that they follow local jointing fractures. This sinkhole assemblage drains an area of one-half square mile.
0.70	38.50	**STOP 12: VIEW OF GIANT SINKHOLE, MURPHY HOLLOW, AND WESTWARD PLUNGING ANTICLINES OF THE SEVEN MOUNTAINS** Leaders: Thomas A. McElroy and Donald M. Hoskins

Our last stop of the Field Conference provides an overlook of three examples of the geology of the area.

Behind us is a huge closed depression (Figure 53). It covers a half square mile. Most of the closed depression is on the Donation quadrangle, which was last mapped for the 1980 State Geologic Map. That map lumps the Keyser and Tonoloway formations together. Mapping by McElroy and Hoskins of the adjacent Allensville quadrangle indicates the Keyser Formation underlies much of the closed depression.

Within the closed depression is a very large sinkhole. It is about 30 feet deep and 200 yards long. It has a sinuous shape that appears to follow joint patterns, and occupies the lowest part of the large closed depression. According to the landowner, heavy rains will fill it up.

Figure 53. Immense closed depression with sinkhole in trees on right side of image, looking northeast, Stop 12.

Figure 54. Murphy Hollow in center of photo – view from Stop 12, looking east-northeast.

Figure 55. Southwest-plunging anticlines, looking northeast, near Stop 12.

Intriguingly, a 92-year old resident told us that his grandfather told him that prior to 1875 there was a lake here.

Murphy Hollow (Figure 54), site of one of Thursday's pre-conference trip, is directly ahead. Along the hollow are sandstone boulders derived from the Ridgeley Member that range in size up to that of a semi-truck tractor, but there is no outcrop of the Ridgeley Member upslope from which to derive the boulders, only carbonates older than the Ridgeley. The crest of the hollow's drainage basin is underlain by Old Port limestones. That implies the Ridgeley boulders have been sitting in the hollow for a very long time. How long is a question we hope someone will answer.

On the horizon to the northeast, Tuscarora Formation crested anticlines that plunge southwestward from the Juniata culmination are seen (Figure 55). The Juniata culmination is a transverse zone encompassing the structurally highest portions of all of the anticlines in the Ridge and Valley structural province (Faill and Nickelsen, 1999, p. 271). The area is known as the Seven Mountains. Interestingly, there is no consensus on which seven mountains the name refers to.

		Depart Stop 12.
0.20	38.70	Note riprap limestone in road gutter to left. This area received torrential rains during the 2004 Hurricane Ivan event causing extensive erosion along the roadway.
0.30	39.00	Limestone outcrops to the left are Tonoloway Formation. The outcrops continue along the valley, including along the steep banks that are, in part, the result of the Hurricane Ivan deluge that extensively flooded local properties along the road.
0.40	39.40	"T" intersection with PA Route 26; Turn left. Tonoloway limestones exposed on steep bank to right. *Note: this is a very dangerous intersection for traffic entering PA 26. To the right is a 'blind' curve. Traffic coming from the south is frequent, fast, and cannot see entering traffic. Turning right at this intersection is safer. A short distance to the south is a small business with a parking area that permits making a "U" turn to progress north on PA Route 26.*

0.10	39.50	Steeply dipping Tonoloway limestones exposed on left (Figure 56) are an example of the complexly folded rocks common along the banks of Standing Stone Creek.
0.20	39.70	Shallowly north-dipping Tonoloway limestones exposed to the left.
0.30	40.00	"T" intersection with Cunningham Road; continue straight. This road provides access to the geologic phenomena along Murphy Hollow described at Stop 12 and access to viewing the 3rd order folds along the banks of Standing Stone Creek.
0.20	40.20	The steep bank and slopes to the right are underlain by limestones of the Tonoloway, Keyser and Old Port Formations folded into tight 3rd and 4th order folds.
0.90	41.10	"Y" intersection of Pa Routes 26 and 305 at Ennisville; turn right on joint PA 26 & 305.
0.10	41.20	Cross Standing Stone Creek.
0.10	41.30	Enter McAlevy's Fort.
0.60	41.90	"T" intersection; turn right onto PA Route 305.
0.20	42.10	South-dipping Wills Creek Formation exposed to left.
0.10	42.20	North-dipping Wills Creek Formation exposed to left.
0.10	42.30	Complexly folded Tonoloway limestones exposed to left.
0.50	42.80	Wills Creek shales are exposed behind storage building to right and along road bank.
0.60	43.40	North-dipping, upper resistant layers of Bloomsburg Formation exposed in left road bank.
0.20	43.60	Enter Rothrock State Forest.
0.30	43.90	Tailing piles from 19th century iron miles visible on left.
0.90	44.80	"Y" intersection where East Branch Road connects with PA Route 305; continue on PA Route 305.
1.10	45.90	Enter Greenwood Furnace State Park.
0.70	46.60	Greenwood Furnace Historical Marker: *Built around 1837 to supply iron to Freedom forge near Lewistown. Restored stack, the Church,*

Figure 56. Complexly folded Tonoloway limestones.

Figure 57. Thick and Strong Mountains, eastern Kishacoquillas Valley.

		Big House and store common to iron making communities remain. Works closed in 1904, the last to operate in this region.
2.10	48.70	Leave Rothrock State Forest; enter Mifflin County.
1.80	50.50	Turn left on East Back Mountain Road towards Barrville. The route course toward Barrville almost immediately crosses the trace of the Reedsville-Coburn detachment fault. At the turn, Reedsville shales underlie the field to the left and limestones underlie the field and dry stream course to the right. The juxtaposition of Reedsville and Coburn-Salona Formations in the mapped area are interpreted to show that the detachment fault traverses the mapped area and includes a splay fault that is interpreted to be contiguous with the Stone Mountain Fault.
0.60	51.10	At Stone Barn Road a north-dipping Reedsville Formation exposure is visible on hill slope to the left near the tree line.
0.20	51.30	Small road bank exposure of Coburn-Salona limestone on left.
0.40	51.70	Large "swallow" hole and sinkhole to the right opposite Shady Lane leading to Smith Gap. Sink and 'swallow' holes linearly related to gaps and 'hollows' in the Bald Eagle are repeated at several sites on

the route along Stone Mountain. The linear arrangement of the sinkholes associated with vegetated, colluviated stream courses, frequently exhibiting large colluvial boulders, is interpreted to relate to solution along a local fracture that is perpendicular or at an oblique angle to the regional strike. Visible erosion and solution affects the Bald Eagle, Reedsville and Coburn-Salona / Nealmont-Hatter groups of formations. The underlying Loysburg and Bellefonte Formations do not exhibit visible solution topography along extension of the fracture trace. Also visible in aerial photography and site topography are additional sinkholes present at the prominent break in slope that parallels the regional strike. These strike-parallel sinkholes are interpreted to be located along the Reedsville-Coburn detachment fault. Additionally, in this area, the Reedsville Formation is also only half of its 1,800-feet regional thickness.

0.10	51.80	Limestones now fully underlie the north slope (left) up to the tree line and break in slope.
0.10	51.90	Small road bank exposure on left of northwest striking Coburn-Salona limestone perpendicular to regional strike indicating presence of local $3^{rd}/4^{th}$ -order fold.
0.20	52.10	"Y" junction with Yoder Road; turn left and continue on East Back Mountain Road.
0.20	52.30	View of Tuscarora exposure on mountain crest to left through unnamed gap.
0.60	52.90	In the forested area to the left are a series of large and small sinkholes and "swallow holes" along the extension of Hartzler Hollow. This site repeats the solution features connected with Smith Gap.
0.50	53.40	Note sinkhole at farm to left in forested area.
0.40	53.80	In the forested area to the left, below Pollyann Gap, are discontinuous outcrops of the Coburn-Salona/Nealmont-Hatter formations along a steeply banked stream course that terminates in a "swallow hole" and the Barrville cave. This cave has been mapped and described by the Mid-Appalachian Region of the national Speleological Society (Dayton and others, 1981). It has 250 feet of mapped passage. The steep-banked stream course appears principally to be a solution feature along a linear fracture similar to the features observed opposite Smith Gap and Hartzler Hollow. At the north end of the steep-banked stream course the Reedsville Formation is exposed in abandoned borrow pits. The Bald Eagle Formation also is exposed in Pollyann Gap.
0.30	54.10	Tuscarora scree slope is visible on the left on Stone Mountain through Pollyann Gap.
0.10	54.20	Forested area to left contains linearly arranged sinkholes associated with unnamed hollow.
0.90	55.10	Very large sinkhole visible in dry stream course on left. Upslope from this site along the same dry stream course, along Barrville

Figure 58. Coffee Run spring.

Figure 59. Axemann Formation.

		Road, is a very large "swallow hole". The trace of this linear juxtaposition of sinkholes is oblique to the regional strike and is associated with an unnamed hollow.
0.40	55.50	Enter Barrville.
0.20	55.70	Turn right on Barrville Road. The gap visible in Jacks Mountain to the upper left is Manns Narrows.
0.40	56.10	Axemann Formation limestones exposed to the right in small pit dips steeply south from vertical to 80 degrees. 150 feet south of the pit exposure similar rocks in an additional exposure dip to the north at 45 degrees identifying a 3rd/4th -order fold. To the left, the low hilly area is complexly faulted and folded as mapped by Morris Rones in the 1950's.
0.70	56.80	Stop sign; turn left on Green Lane. Approximately 300 feet east of the intersection low-angle, south-dipping Axemann Formation is exposed in the left road bank.
0.30	57.10	View of east end of Kishacoquillas Valley and the eastward plunging Thick Mountain and Strong Mountain synclines that outline the east horizon (Figure 57). Long Lane Amish Cemetery on right. The simply shaped headstones are made from a variety of rock types, including locally quarried sandstones of Tuscarora and Juniata Formations.
0.50	57.60	Stop sign; turn right on Coffee Run Road.
0.20	57.80	Horizontal to low-angle, south-dipping Axemann Formation exposed in road bank to left.
0.10	57.90	Cross Coffee Run. To the left, visible in a cliff exposure of the Axemann Formation, is a flowing spring (Figure 58). Measurements in 1934 and 1972 recorded flow as 520 and 1230 gallons per minute. Exposures to the right along the paved road are south-dipping Axemann exposures (Figure 59), which occur nearly continuously south for approximately 0.2 miles and intermittently for an additional 0.2 miles. Stratigraphy of the Axemann Formation along Coffee Run is described by Lees (1967). Plate 18 of this publication includes an illustrated diagram of the Coffee Run outcrops (Section 28) showing

		the Axemann and underlying Bellefonte formations. Macaulay (1952) provides a text description of the Axemann Formation along Coffee Run. *<u>Caution is advised for visitors while examining these rocks. Coffee Run road has a narrow berm. Additionally, there are several blind curves throughout the extent of the Axemann and Bellefonte Formation exposures.</u>*
0.30	58.20	South-dipping Axemann Formation exposed to right in old, abandoned pit. The exposed rocks are limestone and are interpreted as marking the top of the Axemann Formation.
0.10	58.30	South-dipping Bellefonte Formation dolostones exposed in right road bank.
0.10	58.40	Cross Coffee Run. South-dipping Bellefonte Formation dolostones exposed in left road bank.
0.10	58.50	Cross Coffee Run. Very-low-angle, nearly horizontal Bellefonte Formation exposures in right road bank. A reverse fault within the Bellefonte Formation has been mapped following and paralleling the course of Coffee Run at this point for 0.2 miles. The change in rock layer attitude is interpreted to be drag on the south dipping fault.
0.20	58.70	Dip returns to regional south dip to next road crossing over Coffee Run.
0.10	58.80	Cross Coffee Run. South-dipping Bellefonte Formation exposed along left road bank to within 150 feet of intersection with PA Route 655 at Cedar Hill. The contact between the Bellefonte and Loysburg Formations is well exposed at this outcrop (Figure 60).
0.20	59.00	"T" intersection with PA Route 655; turn left.
1.60	60.60	Turn right onto ramp to US 322 East.
0.80	61.40	Enter Manns Narrows. Reedsville-Bald Eagle contact is exposed to right.
0.70	62.10	Cross Kishacoquillas Creek.
1.60	63.70	Bear right onto Burnham exit road; turn left onto Ferguson Valley Road crossing over US Route 322.
0.20	63.90	Turn left staying on Ferguson Valley Rd.

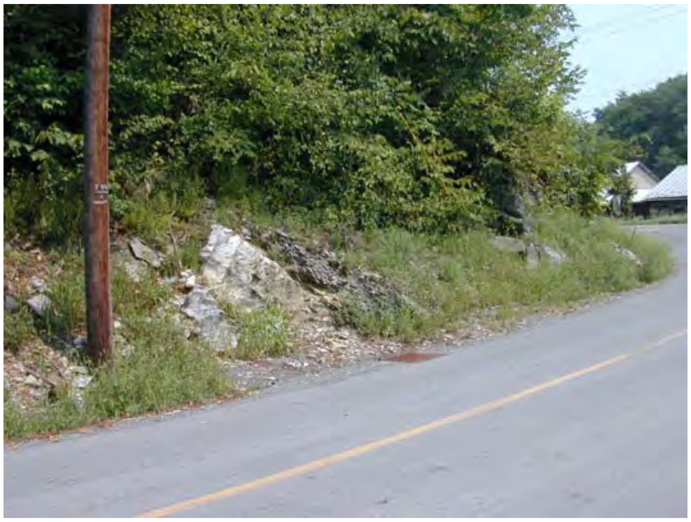
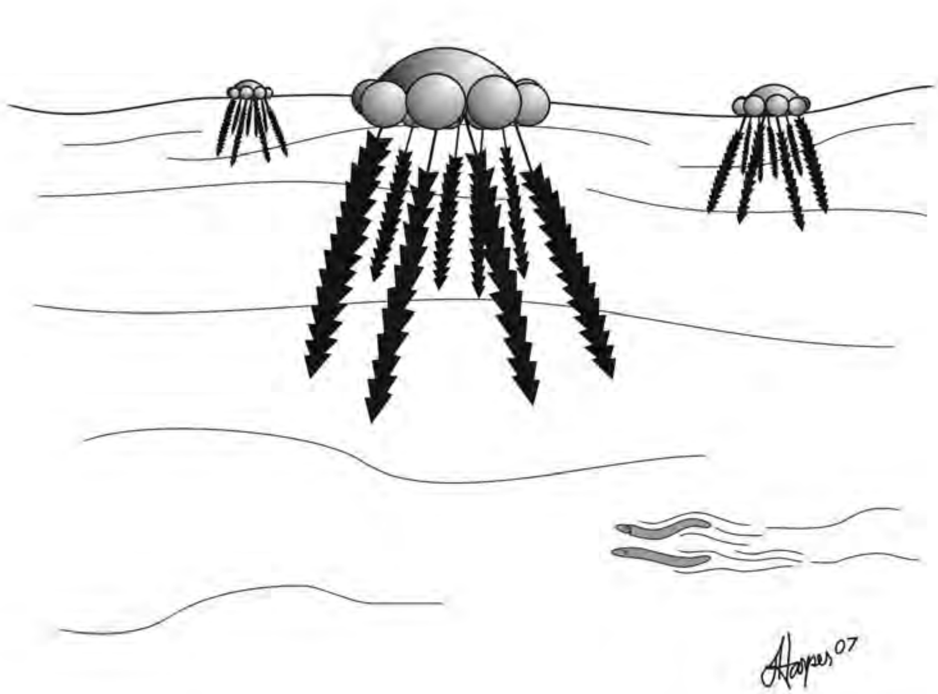


Figure 60. Bellefonte-Loysburg Formations contact.

0.30 64.20 Turn right into hotel parking lot.
End of Field Conference. Be safe going home.

GREAT MOMENTS IN GEOLOGIC HISTORY
Part 4 - The Lower Silurian



I've ALWAYS wanted to move into one of those new low-rise apartments!

STOP 1: BLUE MOUNTAIN ANTICLINE AT MACEDONIA

Thomas A. McElroy and Donald M. Hoskins

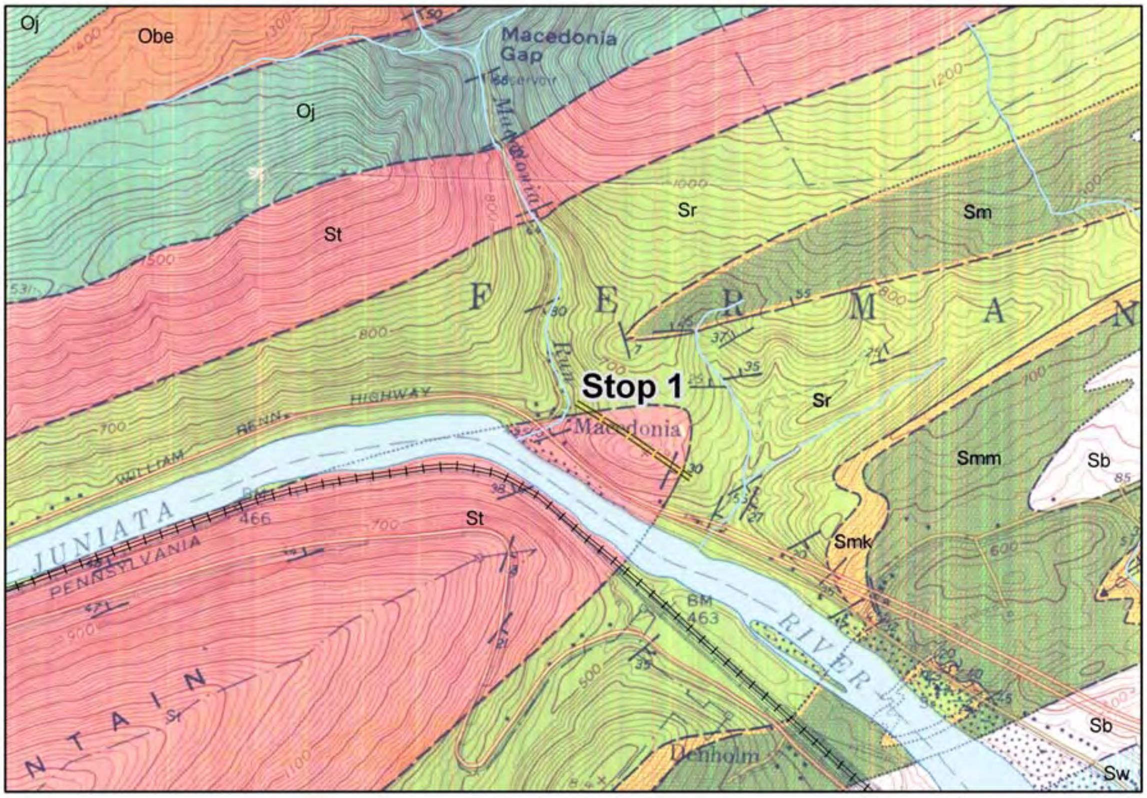


Figure 61. Geologic map of the area encompassing Stop 1 – Blue Mountain anticline at Macedonia (from Conlin and Hoskins, 1962). Sw-Wills Creek Fm., Sb-Bloomsburg Fm., Sm and Smm-Mifflintown Fm., Smk-Keefer Member of Mifflintown Fm., Sr-Rose Hill Fm., St-Tuscarora Fm., Oj-Juniata Fm., Obe-Bald Eagle Fm.

Thickness measurements at this outcrop are only accurate at road level. Throughout the outcrop individual layers thin and thicken within short distances and lithologies vary so that following specific units across the observable anticlinal fold are difficult. The stratigraphic units were measured in the continuously exposed section north of the principal anticline axis. Objectives were: determine the maximum thickness of the exposed Tuscarora Formation by tracing units across the anticline; and assess whether the complexly folded southern portion of the outcrop included a fault. Stratigraphic unit boundaries and numbers are labeled on a mosaiced digital image available on the CD-ROM version of this guidebook.

Unit	Thickness (feet)	Lithologic Description
		ROSE HILL FORMATION
1	160.0	Olive-gray to brownish-gray shaly claystone with minor, thin, non-continuous layers of quartz arenite. Randomly scattered on the outcrop are ground water seepages producing iron staining.
2	11.0	Light-gray to medium-dark-gray siltstone to very-fine-grained quartz arenite with indistinct bedding in lower 7'; upper 4' contains thin (2-3") interbeds of quartz arenite. Bases of interbeds are planar, tops are rippled with included shaly clasts.

Figure 62. Contact between the Rose Hill and Tuscarora formations at Stop 1 – Blue Mountain anticline at Macedonia.

TUSCARORA FORMATION

1	9.0	Medium-light-gray, very-fine-grained quartz arenite. Bedding ranges from 4"-16". Includes thin (2.5"-3") interlayers of grayish-orange, shaly/silty, very-fine-grained quartz arenite. Iron staining on joints.
2	4.8	Interbedded dark-gray, shaly siltstone and thin (2.5" to 3") very-fine-grained quartz arenites with shaly interclasts. Also includes interbeds of shaly, laminated, quartz arenite pods randomly scattered in medium-dark-gray shale. During construction, molds of brachopods were observed in this unit (Figure 63). *Arthrophycus* present (Figures 64 and 65).
3	6.6	Pale-red to pale-yellowish-brown, very-fine-grained to fine-grained quartz arenite. Bedding ranges from 2"-24." Cross bedded. Includes interbeds of medium-gray claystone. Tops and bottoms of layers are mostly planar, a few are rippled. Reddish coloration is not continuous but mottled.
4	1.5	Dark-gray claystone interbedded with medium-dark-gray siltstone including two layers of variable thickness (1.5 to 4"), pale-red to grayish-pink quartz arenite. Claystone is poorly consolidated.
5	3.5	Pale-red to grayish-pink, very-fine-grained quartz arenite Bedding ranges from 3" to 2'. Unit thins updip to about 2' at top of cut.. Cross bedded. Includes thin, olive-gray ,shaly interbeds.
6	1.8	Medium-gray to medium-light-gray, very-fine-grained quartz arenite. Bedding ranges from 4.5" to 1'.

Figure 63. Brachiopod (*Eocoelia?)* external molds in uppermost Tuscarora Formation units at Stop 1 – Blue Mountain anticline at Macedonia.

Figure 64. *Arthrophycus* burrows at Stop 1 – Blue Mountain anticline at Macedonia.

Figure 65. Lateral view of *Arthrophycus* burrows in layer below coin. Similar layers are a common lithologic feature in dark, shaly lithologies from unit 17 to unit 23 at Stop 1 – Blue Mountain anticline at Macedonia.

7	5.3	Medium-gray to medium-dark-gray, very-fine-grained quartz arenite (Figure 66) unbedded except for minor bedding features. Contains vertical burrows (*Skolithos*?) from top to bottom . Contains widely dispersed chitinous 'blebs'. One such bleb retrieved from the outcrop contained growth line around the umbo, thus establishing the blebs as a linguloid brachiopod. Vertical burrows are filled with very-light-gray, very-fine-grained arenite.
8	3.0	Very-light-gray, very-fine-grained arenite, with randomly scattered medium- to medium-dark-gray, shaly clasts in upper 3', lower 2' includes thin (.5"-2.5") finely laminated, small cross bedding arenite layers. At top of unit is a 1" bed of medium-light-gray, very-fine-grained quartz arenite that appears to be composed of clasts.
9	8.7	Interbedded light- to medium-dark-gray, very-fine-grained quartz arenite and shaly siltstone. Some layers are cross bedded. One foot below the top is 10" burrowed layer. Shaly interbeds include pods of medium-light-gray quartz arenite that appear as if deformed while as soft sediment. Some layers thin within short distance updip.
10	6.5	Predominantly medium-dark-gray, shaly, laminated, very-fine grained quartz arenite with thin interbeds of quartz arenite. One arenite layer thickens within a distance of 35' on outcrop face from 0" to 18" and appears to infill a pre-deposition depression in the underlying shaly unit.
11	5.0	Light- to medium-gray quartz arenite interbedded with grayish-black to dark-gray, shaly claystone. Some quartz arenite layers are cross bedded and upper parts include shaly clasts. Unit thins significantly updip.
12	6.0	Dark-gray, laminated, very-fine-grained quartz arenite grading down into unbedded arenite. Fracture surfaces in lower part of unit are rounded.
13	6.0	Interbedded very-pale-orange to yellowish-gray to medium-dark-gray quartz arenite and thin (2" to 6") grayish-black to dark-gray shale. Bedding ranges from 1" to 2' in large waves. *Arthrophycus* occurs at tops of some shaly layers.
14	8.8	Very-pale-orange to light-gray, massively bedded, very-fine grained quartz arenite. Base irregular.
15	1.2	Medium-dark-gray, shaly siltstone with no internal layering. Base irregular. Unit pinches out up higher on cut face.
16	42.3	Pale-orange to light-gray, massively bedded (up to 5'), cross-bedded, very-fine grained quartz arenite with clasts of dark-gray claystone. Includes discontinuous interbeds of grayish-black claystone. Shaly interlayers pinch and swell within short distances.

Figure 66. Stratigraphic unit number 7 at Stop 1 – Blue Mountain anticline at Macedonia. This stratigraphic unit contains extensive vertical burrows (*Skolithos*?) and rare linguloid brachiopods. During construction, exposures of this unit exhibited a non-systematic fracture pattern.

Figure 67. Complex 4^{th} - to 5^{th} -order folds in upper Tuscarora Formation at Stop 1 – Blue Mountain anticline at Macedonia. Slickensides, which extend across the lower portion of the outcrop, indicate lateral movement. What does the slickensides' motion indicate?

Figure 68. Close-up of lateral movement slickensides at Stop 1 – Blue Mountain anticline at Macedonia.

17	8.2	Dark-gray shale with interbeds of pale-orange to yellowish-gray, cross bedded quartz arenite up to 18" thick. Shaly portions appeared burrowed.
18	5.0	Pale-orange to yellowish-gray, very-fine-grained quartz arenite, in one bed with indistinct layering. Unit thins to extinction about 60' updip.
19	2.8	Interbedded very-fine-grained quartz arenite and dark-gray shale, upper surface appears eroded cutting off layers within the unit up section. At road level this unit is replaced by infilling of mixed clasts of medium-light-gray arenite and dark-gray claystone.
20	14.0	Very-light-gray to dark-gray, cross bedded, fine-grained quartz arenite with dark-gray shale interbeds and grayish-black to dark-gray shale clasts. Surfaces have "iron" weathering mineral-filled pits. Base includes *Arthrophycus* burrows.
21	9.1	Medium-dark-gray, shaly quartz arenite with interbeds of very light-gray quartz arenite. Laminated in portions. Upper foot and throughout the unit are layers of *Arthrophycus* burrows.
22	19.8	Very-light-gray to dark-gray, massively bedded and cross-bedded, fine-grained quartz arenite with dark-gray shale interbeds and grayish-black to dark-gray shale clasts. Surfaces have "iron" weathering mineral filled pits.
23	2.8	Interbedded grayish-black to dark-gray, shaly arenite with interbeds of thin, cross-bedded, light-gray, burrowed quartz arenite.
24	5.0	Very-light-gray to dark-gray, massively bedded and cross-bedded, fine-grained quartz arenite with dark-gray shale interbeds and grayish-black to dark-gray shale clasts. Surfaces have "iron" weathering mineral-filled pits.
Total	**186.6**	

STOP 2: EASTERN INDUSTRIES QUARRY (INACTIVE)

Thomas A. McElroy and Donald M. Hoskins

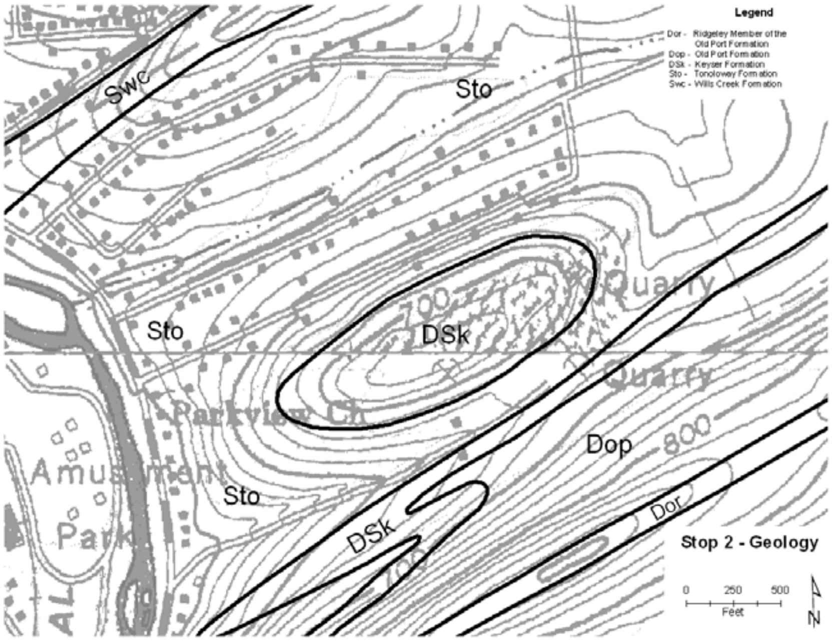


Figure 69. Geologic map of the area encompassing Stop 2. Lower half of map from McElroy (2004).

Figure 70. Prominent slickensides in uppermost layers of Tonoloway Formation at Stop 2 – Derry Quarry. These slickensides are located at or very close to the contact of the Tonoloway and the overlying Keyser Formation. Secondary minerals coat the slickenside surfaces. Note the mudcracked polygons on the northwest dipping Tonoloway shown in the upper portion of the photo. Is there deformation of these polygons representing early stage deformation as concluded by Faill and Nickelsen (1973)?

Does the following quote apply? “The other interesting aspect of these mud crack polygons is that they are not equi-dimensional. Measurements at several localities show that they are preferentially elongated in the direction of the fold axis, with length to width ratios on the order of 2:1. Assuming that these mud crack polygons were initially equi-dimensional, this reflects a strain within the mud crack polygons normal to the fold axis. Whether this distortion of the mud cracks was accomplished by solution at its edges or by bulk deformation of the entire polygon is not known with certainty. The carbon-clay enrichment between the polygon suggests that some of the elongation was accomplished by solution at the polygon margin.” (Faill and Nickelsen, 1973, p.31.)

Figure 71. Deeply grooved slickensides in quarry floor at Stop 2 – Derry Quarry. What causes such deep grooves? Were the slickensides created before folding?

Figure 72. Crinoidal “conglomerate” at Stop 2 – Derry Quarry. On the west portion of the Derry quarry, above the lower working face of the Keyser Formation, the Keyser lithology consists of very thick layers of crinoidal “conglomerate” and arenites.

Faill and Nickelsen (1999) p. 278-282, observed that fossils have been distorted from their initial shapes. At this locality, where the crinoid components of the rock show less dispersion during sedimentation, does this observation hold?

Figure 73. View of Keyser Formation layers along southwest working face at Stop 2 – Derry Quarry. At quick glance the layering appears to be a smooth curve, but close inspection shows that the syncline has a flat bottom with north dipping layers connecting at a very obtuse angle.

The southwest end of the quarry reveals the axis of the syncline and the non-concentric, asymmetric folding with planar beds typical of the Ridge and Valley physiographic province (Faill and Wells, 1974, p. 132). Radius of curvature of the fold is about 200 feet and wavelength is about 1,400 feet. Dip on the southeast limb measure 45 degrees, dips on the northwest limb 13 degrees. With an interlimb angle of 123 degrees, the fold is a tight one (interlimb angle of 45 to 125 degrees), although it is close to being an open one (interlimb angle of 125 to 175 degrees).

Figure 74. Nearly intact crinoid calyx at Stop 2 – Derry Quarry. Careful examination of the exposed crinoidal “conglomerates” include portions of crinoids rarely seen. The crinoidal “conglomerates” can be seen in place above the lower working face of the Keyser Formation and in many of the very large blocks strewn about in the lowermost portion of the quarry.

STOP 4: EASTERN INDUSTRIES QUARRY (INACTIVE)

Thomas A. McElroy and Donald M. Hoskins

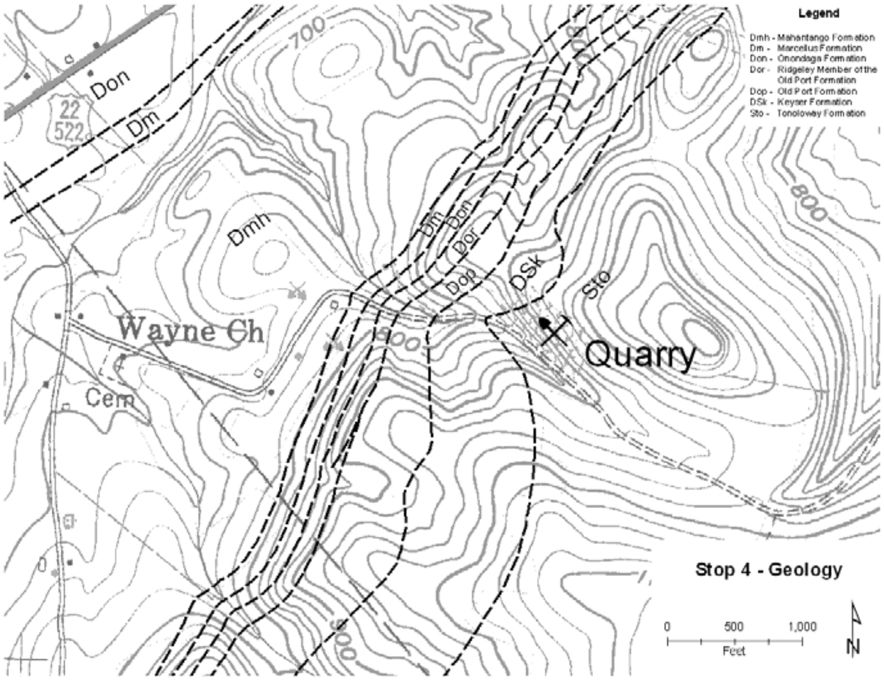


Figure 75. Preliminary geologic map of the area encompassing Stop 4.

Figure 76. Concentric and disharmonic kinked folds in Tonoloway Formation at Stop 4 – McVeytown quarry**.**

Figure 77. Close-up of kinked anticline in Tonoloway Formation at Stop 4 – McVeytown quarry.

Figure 78. Close-up of concentric anticline in Tonoloway formation at Stop 4 – McVeytown quarry.

Figure 79. Mud crack polygons in Tonoloway Formation at Stop 4 – McVeytown quarry. Here polygons appear to be limited to this layer, and do not extend downward.

Figure 80. Concentric syncline and anticline along southwest face of quarry at Stop 4, McVeytown quarry. Photo taken during leaf-off season. Cotter and Inners (1986, fig. 16 and p. 167-169) described sedimentary cycles in the Tonoloway at Allenport, seven miles to south-southwest of Stop 4. The uppermost part of the cycle is characterized by distinctive yellow-brown, vuggy, supratidal dolostones and dolomitic limestone. Does the prominent yellow-brown strata in this photo indicate the top of one of the subtidal to supratidal cycles?

Figure 81. Finely-laminated Tonoloway Formation in uppermost portion of quarry at Stop 4 – McVeytown quarry (_for those that want to climb, NOTE: do not go close to the highwalls of the main quarry. It is a long ways down!!_).

STOP 5: OLD PORT QUARRY AND FOSSILS

Thomas A. McElroy and Donald M. Hoskins

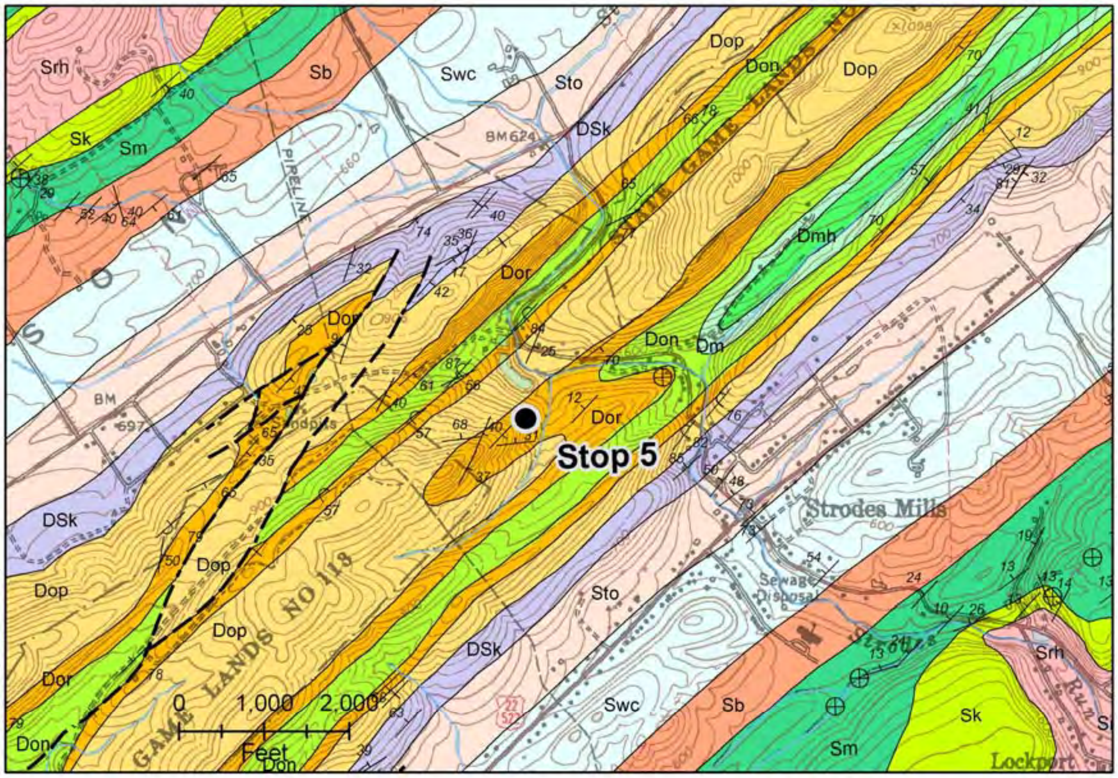


Figure 82. Geologic map of the area encompassing Stop 5.

Figure 83. Ridgeley Member sandstone exposed in southwest up-plunging syncline at Stop 5 – Strodes Mills quarry. Stratigraphic layers in this quarry are difficult to find, but fossils abound.

Figure 84. Close up of large, robust spiriferid and rhipidomellid brachiopods in Ridgeley sandstone in quarry at Stop 5 – Strodes Mills quarry.

Figure 85. Large spiriferid brachiopod and platycerid gastropod fossils in quarry at Stop 5 – Strodes Mills quarry.

Figure 86. View east of stop 5 showing western entrance to Lewistown Narrows in center of photo.

STOP 6: REEDSVILLE AND DETACHMENT FAULT

Thomas A. McElroy, Donald M. Hoskins, and Nathanael C. Barta

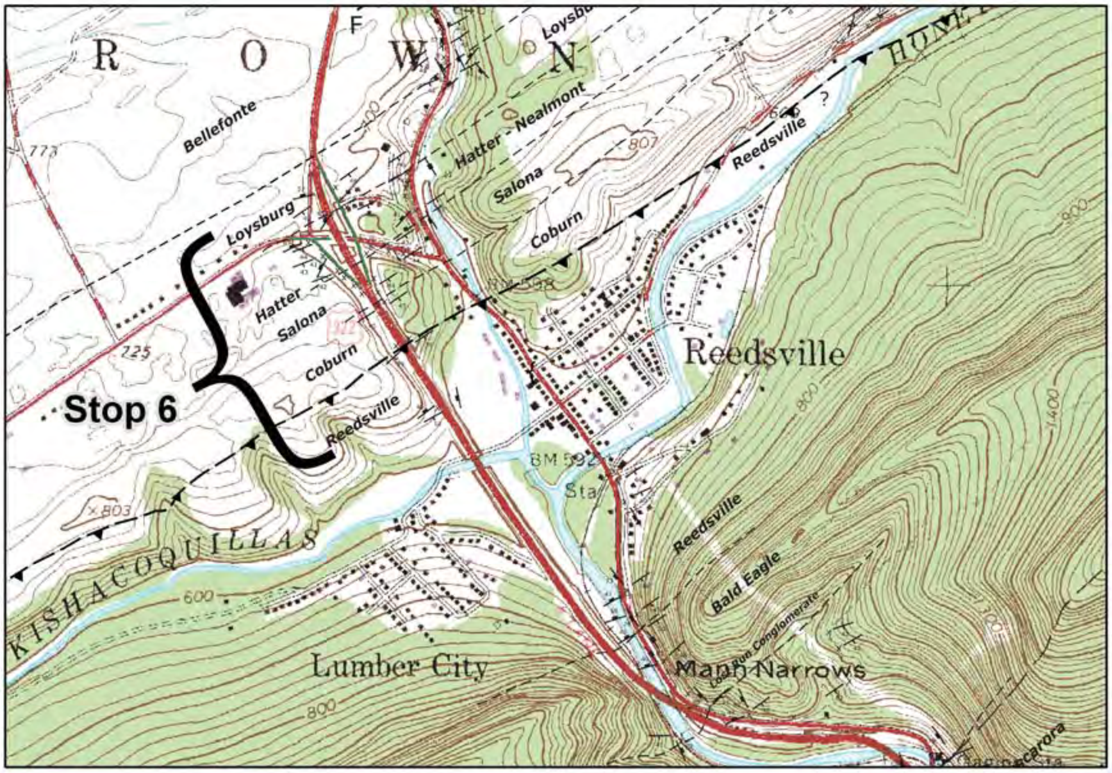


Figure 87. Preliminary geologic map (from Doden, 2004) of area encompassing Stop 6.

Figure 88. Exposure of Salona and Nealmont formations at north end of exposure along US 322 at Stop 6 – Reedsville exit.

Figure 89. Exposure of Salona and Coburn formations adjacent to and overlapping Figure 88 at Stop 6 – Reedsville exit.

Figure 90. Exposure of Coburn Formation adjacent to and overlapping Figure 89 at Stop 6 – Reedsville exit, including 4th -order folds representing the lowermost deformation associated with the Antes-Coburn detachment fault.

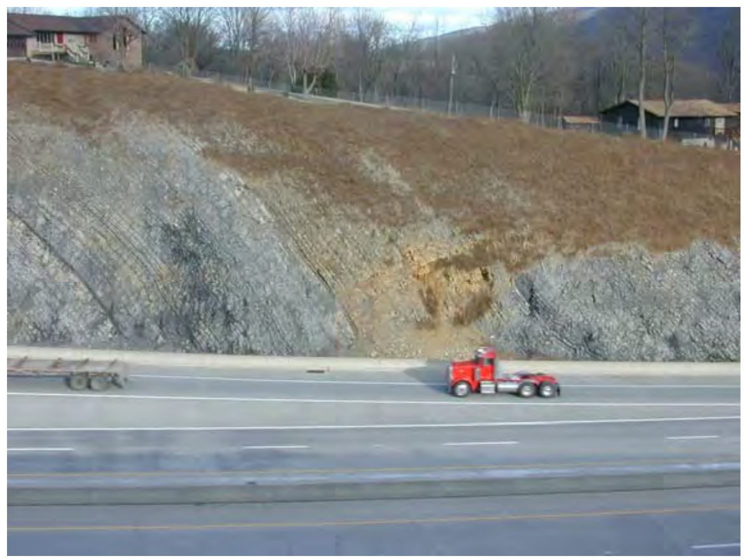


Figure 91. Exposure of Coburn Formation adjacent to and overlapping Figure 90 at Stop 6 – Reedsville exit, including additional 4th -order folds representing increased deformation associated with the Antes-Coburn detachment fault.

Section of Late Ordovician carbonates at the US Rte. 322 and Rte. 76 roadcut at Reedsville, PA (Stop 6) measured by Nathanael C. Barta.

Interval	Lithologic Description
	LINDEN HALL FORMATION
	("Provisional" 2.35 m)
0.0-2.35 m	Bioclastic wackestone, medium- to dark-grey, with discontinuous laminae or lenses of very fine grainstone, light-grey to light-tan. Bioturbation is common and two thin hardgrounds visible. Gastropods and brachiopods are found.
	NEALMONT FORMATION
	Centre Hall Member (11.65 m)
2.35-2.45 m	Bioclastic wackestone/packstone with limestone lithoclasts. Grey. Some Hematite staining.
2.45-3.50 m	Bioclastic wackestone, medium- to dark-grey, medium to thick bedded with discontinuous laminae or lenses of very fine grainstone, light-grey to light-tan.
3.50-3.54 m	Grainstone with limestone lithoclasts (rip-up clasts?), grey.
3.54-9.0 m	Bioclastic wackestone, grey, 2 to 6 cm irregularly bedded with argillaceous lamina and lenses of tan colored grainstone and horizons of black chert lenses. Chert lenses at 8.0 and 8.4 m. Small cave opening in 6-7 m interval.
9.0-13.0 m	Wackestone/packstone, grey, gradational change from continuous to discontinuous 1 to 7 cm beds with argillaceous partings and fine grainstone laminae and/or lenses. Bioturbation less common. Chert lenses or nodules at 11.25 and 11.68 m. Rare bryozoans, brachiopods, gastropods.
13.0-14.0 m	As below, but bedding becoming more irregular and more nodular in appearance.
	Rodman Member (4.05 m)
14.0-16.85 m	Bioclastic wackestone, dark-grey to grey, in 3 to 8 cm irregular, wavy bedded, becoming more regular thin to medium beds with argillaceous partings or lamina upsection, but appearing nodular on more weathered surfaces. Limestone appears to be massive in outcrop. Some planar laminations in shaly laminae. Bryozoan skeletal material common. *Prasopora* sp. at 14.72 m. White calcite veins in joints perpendicular to bedding.
16.85-18.05 m	Same as above except thicker argillaceous laminae. More nodular in appearance. Chert nodules at 17.75 m.
	SALONA FORMATION (75.35 m)
	New Enterprise Member (23.06 m)
18.05-18.14 m	**K-Bentonite #0** (Thompson, 1963). Base is black, then 9 cm of buff to yellow K-bentonite, then 1cm of black shale, 3 cm of yellow-brown K-bentonite, then 1 cm of black shale.
18.14-21.20 m	Bioclastic wackestone, dark-grey, thick to thinly bedded, with 1 to 7 cm argillaceous mudstone beds.

21.20-21.30 m	Fissile, calcareous shale, black to dark-grey.
21.30-21.45 m	**K-bentonite #1** (Thompson, 1963). Grey to olive-grey with yellow-orange layers.
21.45-21.50 m	Calcareous shale, black.
21.50-21.80 m	Mudstone/wackestone, black to dark-grey.
21.80-22.0 m	**Diecke K-bentonite** (#2 of Thompson, 1963). Yellow-orange, white to grey at base becoming tan with orange mottling. Overlain at top by 5cm of black shale.
22.0-26.70 m	Mudstone/wackestone, dark-grey, thin to medium bedded, interlayered with argillaceous mudstone. Hematite nodules from 23.9 to 24.5m. Fossiliferous layers from 24.5 to 26.7 m
26.70-26.88 m	**Millbrig K-bentonite** (#3 of Thompson, 1963; McVey, 1993). Greyish-purple overlain by 2-3 cm black shale.
26.88-33.71 m	Mudstone/wackestone, dark-grey, thin to thickly bedded, interlayed with argillaceous mudstone. Fossiliferous wackestone bed at 27.5 m. Cave opening at 31.5-33.0 m.
33.71-33.93 m	**K-bentonite** (#5 of Thompson, 1963). Grey to white with yellow-orange mottling at base.
33.93-41.11 m	Mudstone/wackestone, dark-grey, thin to thickly bedded, interbedded with shaly laminae.
	Roaring Spring Member (54.29 m)
41.11-42.0 m	Calcareous shale, dark-grey to black.
42.0-43.70 m	Mudstone/wackestone, dark-grey, thin to thickly bedded, interbedded with 2-5 cm argillaceous mudstones.
43.70-43.85 m	**K-bentonite** (#6 of Thompson, 1963).
43.85-45.90 m	Same as 42.0-43.70 m.
45.90-46.05 m	**K-bentonite.** 3 cm calcite layer at base then tan, becoming orange-brown, 2 cm black layer, overlain by orange-brown clay and 3cm of black shale.
46.05-62.10 m	Wackestone, dark-grey, thin to thickly bedded, with argillaceous mudstone interbeds. Planar bedding apparent in some beds. Beds weathering tan.
62.10-67.35 m	Wackestone, dark-grey, thin to medium bedded, with argillaceous mudstone or calcareous shale interbeds becoming more numerous, and thicker. Weathering of beds does not display tan color as below.
67.35-67.47 m	Calcareous shale, grey-black, with possible 2 cm K-bentonite at base.
67.47-85.60 m	Wackestone, dark-grey, fossiliferous, thin to thickly bedded. Grainstone interbeds 2-4 cm thick, weathering tan. Planar bedding and potential rippled bedding surfaces. Bioturbation rare in beds above 70 m. 10 to 15 cm calcareous shale beds at 71.35, 74.70 and 77.20 m. Dip varies from 35ES, becoming shallower near 20ES then steepening to 38ES.
85.60-85.83 m	**K-bentonite** (**R** of Thompson, 1963). Grey to white with yellow-orange mottling near base and tan-brown toward top. Excellent bedding plane

	surface exposed with the bryozoan *Prasopora* sp., brachiopods and bioturbation.
85.83-95.40 m	Wackestone, dark-grey, massive to thin bedded, interbedded with argillaceous mudstone laminae. Planar bedding and bioturbation common. Most bioturbation is horizontal with less common vertical burrows. This is notable at 88 m. Lenses of fossiliferous packstone at 93.5 m. Wackestone typically have a weathered texture of very fine grainstone. No grains visible in freshly cleaved samples. This is common throughout the Coburn Formation also.
	COBURN FORMATION (62.1 m) ***(Members undifferentiated)***
95.40-95.60 m	Calcareous shale or very argillaceous mudstone, dark-grey to black, with platy calcite layer (vein?) at base and 10 cm above. Wackestone/ grainstone, thickly bedded becoming thinly bedded interlayered with very argillaceous mudstone or calcareous shale.
95.60-110.40 m	Cross bedding and planar bedding common. Rip-up clasts rare (110.9 m).
110.40-110.54 m	Shale, potential K-bentonite? Platy calcite at base, 4 cm of clay, another platy calcite, then black, brown shale.
110.54-110.67 m	Calcareous shale, dark-grey.
110.67-126.88 m	Very fine grainstone, dark-grey, thin to thickly bedded, interbedded with 3 to 15 cm calcareous shales/argillaceous mudstones. Shales are highly weathered and fissile. Dip increases from 58ES to 68E S through this interval.
126.88-131.75 m	Grainstone and fossiliferous packstone, grey, thin to thickly bedded, interbedded with argillaceous wackestone or grainstone. Bioturbation, planar bedding, cross bedding common. Grainstone/packstone beds display fining-upward graded bedding commonly. Typical bed is fossliferous packstone grading into fine grainstone then wackestone to argillaceous wackestone. This is displayed at 127.5 m. Tan weathering of interbeds.
131.75-139.80 m	Same as below except 2 to 9 cm highly weathered interbeds. Dip 45E S.
139.80-139.95 m	Calcareous shale, black with 1-2 cm grainstone at center.
139.95-141.90 m	Same as 131.75 to 139.75 m.
141.90-142.05 m	Fossiliferous packstone, grey.
142.05-142.20 m	Calcareous shale, black to dark-grey. Calcite layer near top.
142.20-158.50 m	Grainstone, dark-grey, thin to thickly bedded, with planar bedding and cross bedding, with some packstone laminae. Interbedded with 5 to 15 cm argillaceous wackestone or shales, black. Top of grainstone beds weathering tan especially upsection. 20 cm grainstone bed at 153.6 m.
	End of Measured Section

- Synform fold begins near 157 m. Beds traceable into plunging limb of corresponding antiform below grade. Beds untraceable beyond this point.
- Deformed Coburn section continues for approximately 265 linear feet (as measured on Jersey barrier).

- Antes Shale (approximately 5-10 m exposed) at end of disturbed zone.
- Linear distance of measured section (measured on Jersey barrier): 731 feet.
- Total length of outcrop (measured on Jersey barrier): 1,100 feet.

Figure 92. Close-up of Salona and Nealmont formation contact seen in Figure 88.

Figure 93. Close-up of K-bentonite number 16 in Salona Formation seen in Figure 88.

STOPS 7 and 8: PEACHY SHALE PIT AND BEARPEN HOLLOW GAP

Thomas A. McElroy and Donald M. Hoskins

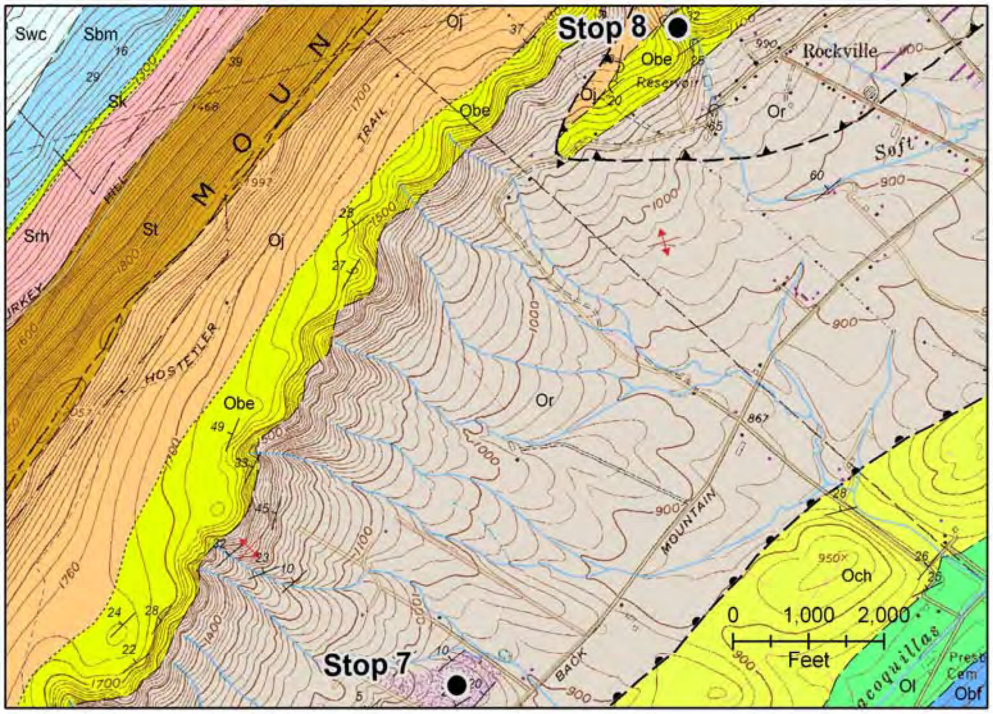


Figure 94. Geologic map of the area encompassing Stops 7 and 8.

Figure 95. Close-up photo of the Reedville Formation exposed at Stop 7 – Peachy pit. Note the intersecting joint surfaces with secondary mineralization.

Figure 96. “Pencil” shale fragments at Stop 7 – Peachy pit, produced by cleavage, jointing and layering.

Figure 97. Close-up of Reedville Formation outcrop at Stop 7 – Peachy Shale pit. Note apparent multiple joint sets, offset of layering along vertical joints, and secondary mineralization along vertical joints and on a surface closely paralleling layering.

Figure 98. Overturned, 40 degrees south-dipping Bald Eagle Formation along southwest face of Bearpen Hollow Gap at Stop 8 – Bearpen Hollow.

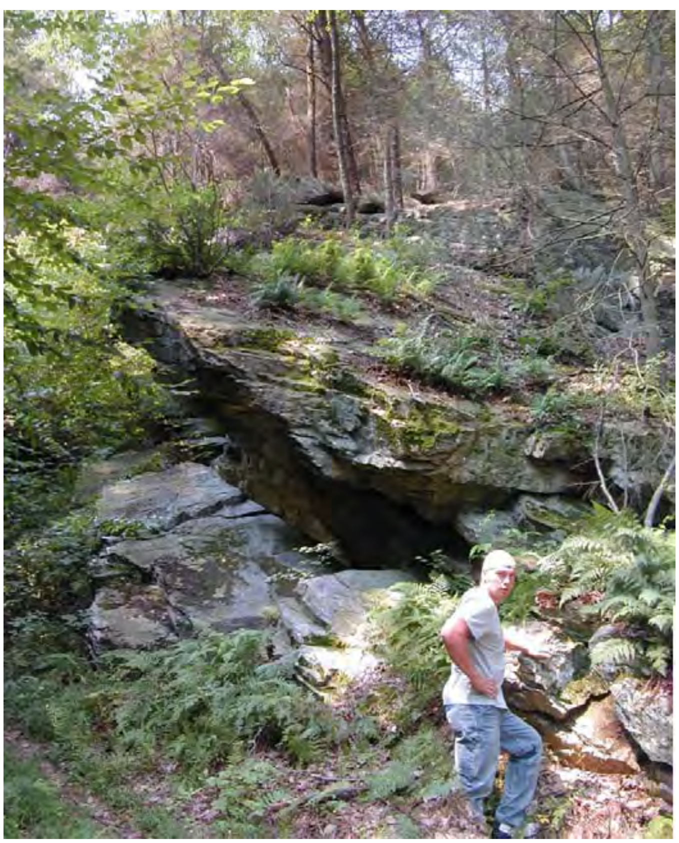


Figure 99. Overturned, south-dipping Bald Eagle Formation on pathway along northeast face of Bearpen Hollow Gap, Stop 8 – Bearpen Hollow.

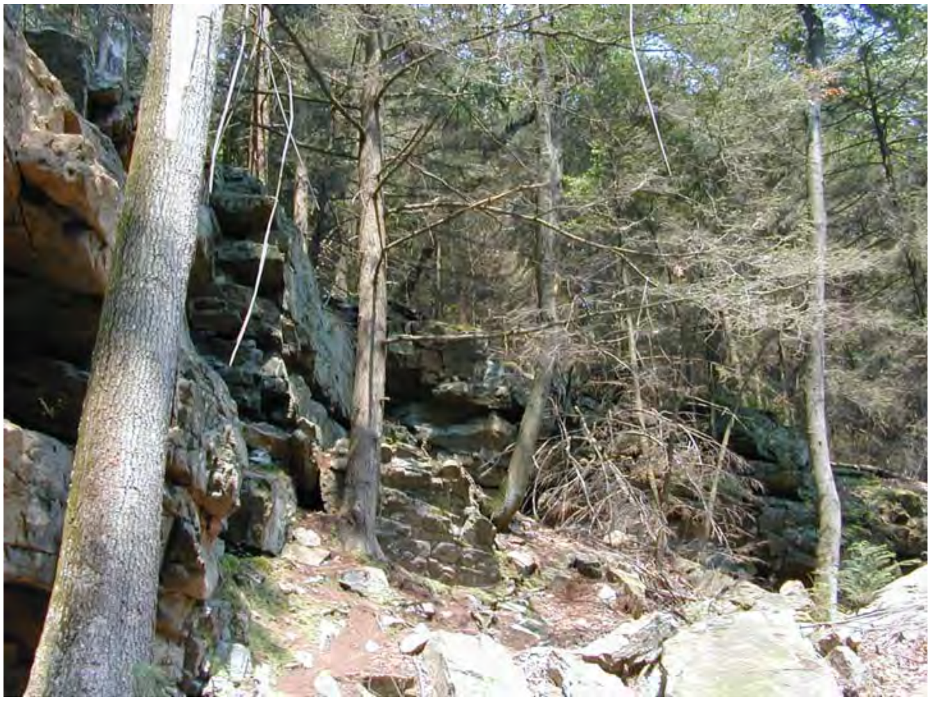


Figure 100. Overturned, south-dipping Bald Eagle Formation at northeast face Bearpen Hollow Gap, Stop 8 – Bearpen Hollow. Note prominent vertical jointing.

Figure 101. Bald Eagle Formation 180 degrees overturned at Stop 8 – Bearpen Hollow.

STOP 9: IRON ORES OF GREENWOOD FURNACE

Paul T. Fagley
Greenwood Furnace State Park

In the early days of ironmaking in Pennsylvania, charcoal-fueled furnaces dotted the landscape. Unlike the steel industry of the last century and a half that was located in urban areas, these charcoal furnaces were often located in remote areas. As transportation systems were not well developed, these furnaces had to be situated near to their raw materials – namely wood for charcoal, limestone (or equivalent), and of course, iron ore. Uncounted ore workings were scattered around the countryside in a roughly 5 mile diameter from the furnace. They were worked by pick and shovel. Some were open cuts into the ground, while others were underground shafts with little more than the dim flicker of candles to light the mine.

During most of the first half of the 19th century, the Juniata Valley of south-central Pennsylvania was the principle iron-producing centre of the nation, making as much as one-fifth of the national output! Much of this can be attributed to the high quality of the iron from the Juniata, which was considered some of the best in the world. In order to produce this high quality product, the raw materials had to be of high quality as well.

Figure 102. Photograph of Greenwood Furnace, circa 1902.

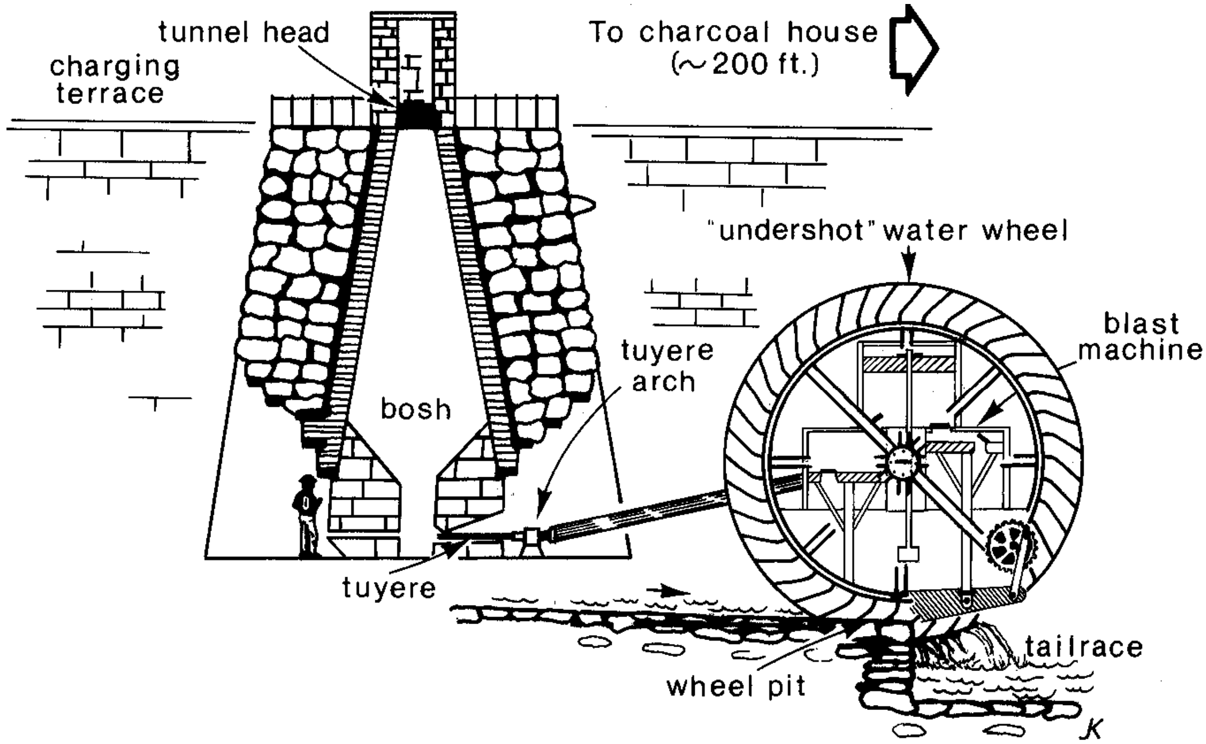


Figure 103. Generalized illustration of a typical 19th century iron furnace. From Inners (1986, fig. 4).

The iron ores of the Juniata Valley were well-known for their quality as far back as colonial America, when samples intrigued Philadelphia area ironmasters in the 1760s. Following the American Revolution, many would erect ironworks in the Juniata, which in turn laid the economic and manufacturing foundation of the fledgling iron and, later, steel industry of that mighty industrial city of Pittsburgh.

Greenwood Furnace

Located in the northeast corner of Huntingdon County, Greenwood Furnace State Park is the site of an important ironmaking industry and village. It operated for 70 years, from 1834 to 1904. The remote location was dictated by the need to be close to the raw materials necessary for iron smelting – wood for charcoal, limestone, and iron ore. Greenwood Furnace (Figures 102 and 103) used ore from two principal deposits that are typical of the ores found in the Juniata Valley.

The Greenwood Ore Banks

The iron ores of Kishacoquillas Valley (aka Big Valley) of Mifflin County were mined during much of the 19th century. They were discovered around 1800, and supplied numerous iron furnaces and forges in the area, including Brookland Furnace at McVeytown, Hope Furnace at Strodes Mills, Freedom Iron Works (forerunner of Standard Steel) in Burnham, all in Mifflin County, and Greenwood Furnace in Huntingdon County. During the first half of the century, numerous small workings were found in the valley, but these had essentially been abandoned by mid-century. Few signs of these old working remained in the 1880s when the area was investigated by the Second Geological Survey of Pennsylvania.

One bank proved more productive, and was used for many years later to supply the Freedom and Greenwood works. Known as the Greenwood ores, they were located south west of the village of Belleville.

These ores were classed as limonite ores, and were formed during the Ordovician period. They were of excellent quality, nominally assayed at about 65% iron content, according to the Second Geological Survey. The ore was located in irregular nests along the anticlinal lines of strata along the fissures created by the upheaval and bending when they were elevated eons ago. The deposits were found in the clay and loam filling the fissures. All of the mining was done by open cuts. In the Greenwood Banks, once mining reached a depth of fifty feet, the ore assumed a different structure. At this point, distinct stalactitic formations of ore were found. These were termed “pipe ores,” and were a rich source of iron. There were irregular beds of white sand measuring from 18 to 36 inches in thickness associated with the pipe ore. Under the sand, yellow limestone was found.

By the late 1880s, the expense of hauling the ore increased, and the amount of iron ore was shrinking. Absent a railroad line, the workings ceased. It is unknown how much ore remains in the valley, and no mining has taken place in 120 years. Ironically, just a few short years after the mines closed, a railroad was built in the valley.

Today, the Greenwood Ore banks are largely filled in and forgotten, and little remains to mark their importance. The owner of the Ore Banks Farm recently donated samples of ore from the banks to Greenwood Furnace State Park, for educational purposes. Additionally, one story of interest of the days of mining is preserved in the name of the road to the “Ore Banks Farm.” It is known as “Jericho Road.” According to local legend, the miners were mostly Irish and prone to getting drunk. It was common for them to rob and beat up passersby on this road. In one instance, they beat and robbed an Amish man. As he lay along the road, another Amish man came to his aid. The incident reminded them of the Biblical story of the Good Samaritan, so the Amish started calling this “Jericho Road.” Today, that is the official name of the road.

The Brush Ridge Ore Banks

When Greenwood Furnace first went into blast on June 5, 1834, the ore used came exclusively from the Greenwood Ore Banks. However, the original owners, James Hall and Francis W. Rawle, suspected that they might find ore in Stone Valley, where the furnace was located. In 1835 they began searching for ore, without success. Then in 1839, a deposit was discovered on the crest of Brush Ridge, along a coaling road. Mining commenced immediately in the area, and a good, rich ore was found. The ore was easily mined by pick and shovel (Figures 104 and 105) by stripping the soil and layers of decomposed shale off the ore vein. Until 1850, all of the ore was taken out of open cuts. As the mining moved down slope, it became deeper in the ground. In 1850, the first underground mines were cut, by tunneling in horizontally until the veins were reached, then digging laterally from the main shaft. As mining increased following the Civil War, a tramway was built to carry the ore to the furnace. This crude railroad consisted of four to five mine cars, each holding 11 tons of ore, pulled by mules along a wooden rail track. The wood rails were topped with iron strapping to reduce wear and tear. By the time of the Second Geological Survey in 1879, over 90,000 tons of ore had been taken from these banks.

Mining continued until the close of the furnace on December 7, 1904. At that time, all

Figure 104. Photograph of a drift mine at the Brush Ridge Ore Banks.

Figure 105. Photograph of a mining family at the Brush Ridge Ore Banks. The photograph is out of focus, probably the result of someone bumping the camera as the film was being exposed.

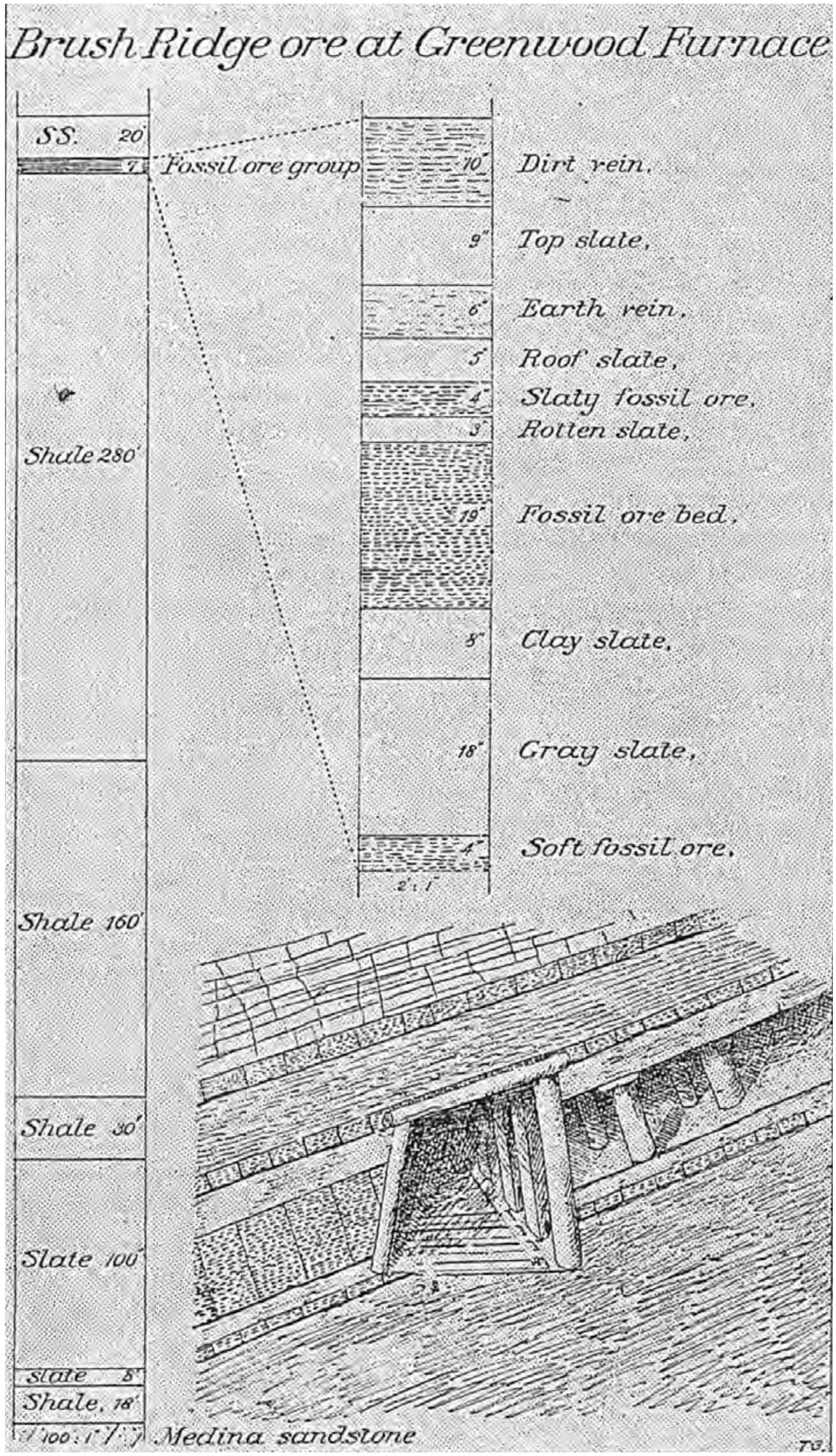


Figure 106. Sections at Greenwood Furnace. From Billin, 1885, Plate XLIII. "Medina sandstone" = Tuscarora Formation.

mining ceased, and the area today remains in a remarkable state of preservation. Approximately 220 acres of the mining area is included in the Greenwood Furnace National Historic District, forever protecting this once important area for future generations.

The ores of the Brush Ridge Ore Banks are classed as red fossiliferous hematite, and are part of the Clinton ore group. There is some debate about whether they belong to the Rose Hill Formation, or the Keefer Formation, as some geologists are favoring. The main fossil ore vein averages 18 inches in thickness, while the soft fossil vain is about 6 inches (Figure 106). They are separated by a layer of shale, and set atop a layer of white sandstone of the Tuscarora Formation. They were laid down in the Silurian Period, approximately 400 to 430 million years ago. A distinct feature of this ore is that it is full of fossils. In the collection at Greenwood Furnace State Park, examples of coral, brachiopods, crinoids, and even a cephalopod can be found.

Conclusion

The ores from the Greenwood Ore Banks and the Brush Ridge Ore Banks were instrumental in the westward expansion of the railroads in America. Smelted Greenwood Furnace iron was used at the Freedom Iron Company to manufacture locomotive tires, wheels, and other parts. For a time, Greenwood iron was critically regarded as some of the best iron in the world. Not bad for the iron ores of the picturesque Juniata Valley!

References

Billin, C. E., 1885, *Ranges of fossil ore through Barree and Jackson Townships*, in Lesley, J. P., ed., *The geology of Huntingdon County*, Pennsylvania Geological Survey, 2nd ser., Report T3, p. 239-255.

Inners, J. D., 1986, *Mount Etna iron furnace plantation, Blair County*, Pennsylvania Geology, v. 17, no. 2, p. 2-6.

Additional Reading

Billen, C. E., 1877, *Letters on Geology – No. 6,* One of a series of articles on geology, published in the Huntingdon Journal, Huntingdon, Pa. March 16, 1877.

d'Invilliers, E. V., 1891, *Report on the Geology of the Four Counties Union, Snyder, Mifflin, and Juniata*, Pennsylvania Geological Survey, 2nd ser., Report F3, p. 237-238.

Lesley, J. P., 1892, *A Summary description of the Geology of Pennsylvania*, Pennsylvania Geological Survey, 2nd ser., Volume 2, p. 831-836.

Rogers, Henry Darwin, 1840, *Fourth Annual Report on the Geological Survey of the State of Pennsylvania*, p. 107-108.

Rogers, Henry Darwin, 1858, *The Geology of Pennsylvania*, Volume 1, p. 479.

STOP 10: KEYSER AND OLD PORT FORMATION STATIGRAPHY

Thomas A. McElroy and Donald M. Hoskins

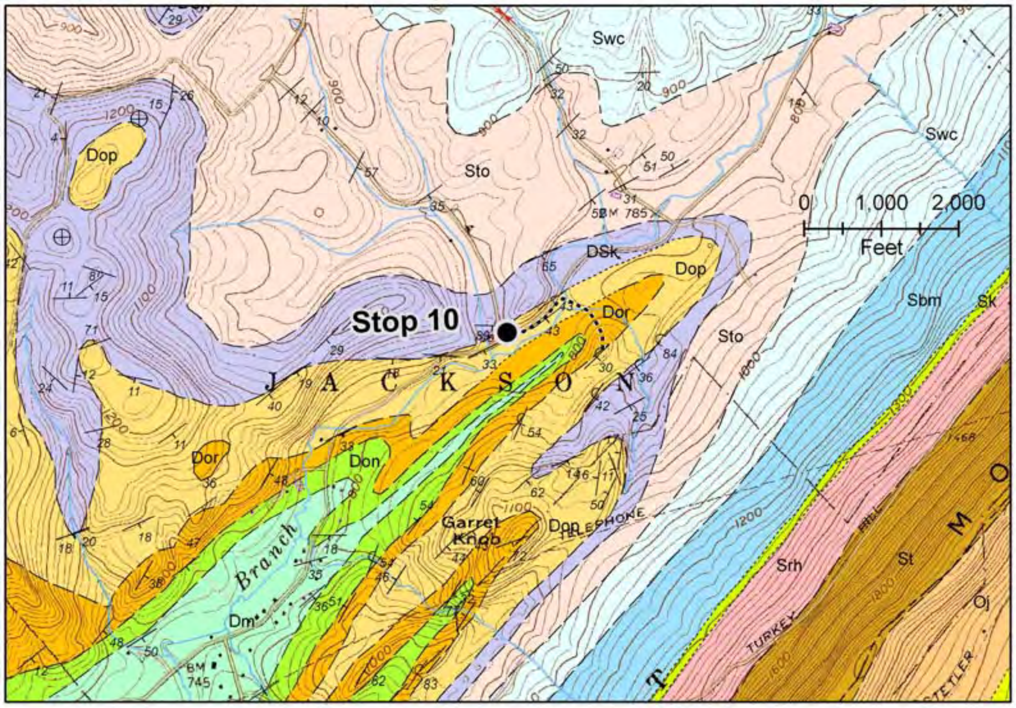
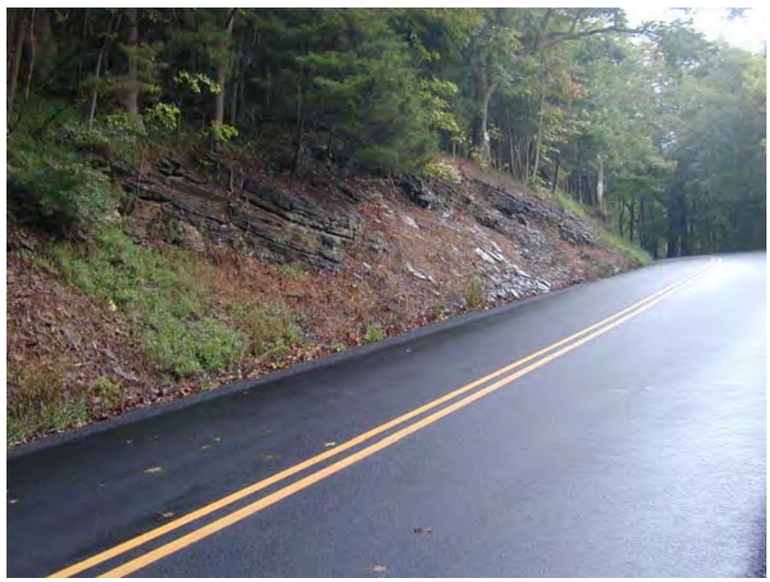


Figure 107. Geologic map of the area encompassing Stop 10. For the enterprising 'walkabouter,' the dotted line locates a traverse to an exposure of overturned, southeast dipping Ridgeley sandstone, providing an experience of geologic mapping difficulties where deadfalls provide conclusive data.

Figure 108. Lower Old Port Formation bedding plane with silicified fossils exposed at Stop 10 – East Branch Road.

Figure 109. South-dipping Lower Old Port Formation limestone, on northwest limb of overturned syncline. View to southwest, Stop 10 – East Branch Road.

Figure 110. South-dipping Lower Old Port Formation limestone, on northwest limb of overturned syncline. View to northeast, Stop 10 – East Branch Road.



STOP 11: RIDGELEY MEMBER OF THE OLD PORT FORMATION

Thomas A. McElroy and Donald M. Hoskins

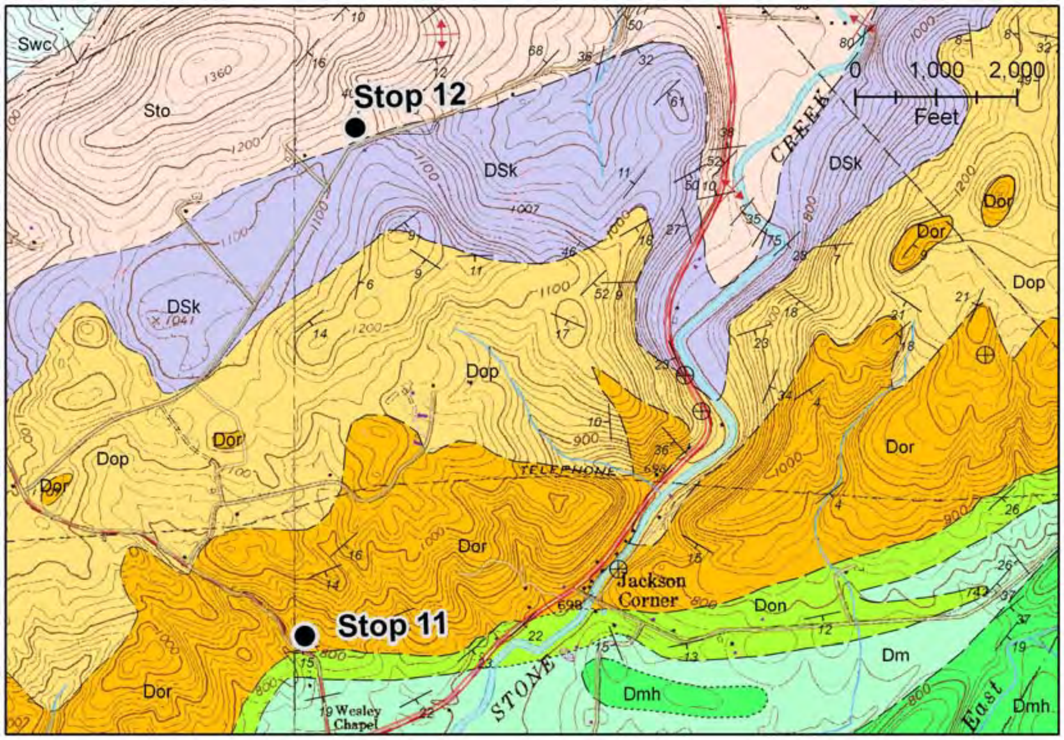


Figure 111. Geologic map of the area encompassing Stops 11 and 12.

Figure 112. Ridgeley Sandstone outcrop along Stop 11 – Wesley Chapel Road. Note nearly vertical jointing and dip slope.

Figure 113. Highly weathered Ridgeley Sandstone outcrop along Stop 11 – Wesley Chapel Road. Push your pencil here!

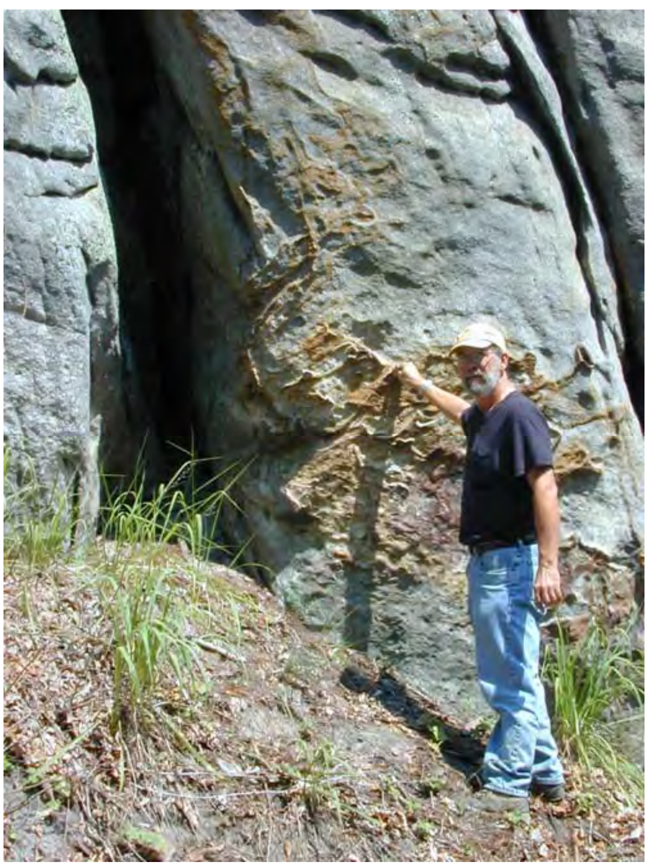


Figure 114. Close-up of secondary mineralization on Ridgeley Sandstone joint surface, Stop 11 – Wesley Chapel Road.

ROAD LOG AND STOP REFERENCES

Billin, C. E., 1885, *Map of adjoining portions of Huntingdon, Mifflin, Centre, and Union Counties, Sheet 25*, in Lesley, J. P., State Geologist, Geological Survey of Pennsylvania, 2nd ser., Grand Atlas, Division V, Part I, Central and Southeastern Pennsylvania, 2 miles/inch.

Conlin, R. R. and Hoskins, D. M., 1962, *Geology and mineral resources of the Mifflintown quadrangle, Pennsylvania*, Pennsylvania Geological Survey,4th ser., Atlas 126, 46 p.

Cotter, Edward, 1982, *Tuscarora Formation of Pennsylvania*, Field Trip Guidebook, Society of Economic Paleontologists and Mineralogists, Eastern Section, 1982, Lewistown, Pa., 105 p.

Cotter, E. and Inners, J. D, 1986, Silurian Stratigraphy and Sedimentology in the Huntingdon County Area, *in* Selected Geology of Bedford and Huntingdon Counties, Guidebook, 51st Annual Field Conference of Pennsylvania Geologists

Dayton, G. O., and others, 1981, *The caves of Mifflin County*, Mid-Appalachian Region of the National Speleological Society, Bulletin #12, p. 9-11.

d'Invilliers, E. V., 1891, *Report on the geology of the four counties-Union, Snyder, Mifflin and Juniata, Pennsylvania Geological Survey, 2nd Ser., Report F3, 420 p.*

Doden, Arnold, 2004, Preliminary geologic map of the Burnham quadrangle, Pennsylvania.

Faill, R. T. and Nickelsen, R. P., 1973, *Structural geology*, in Faill, R. T., ed., *Structure and Silurian-Devonian stratigraphy of the Valley and Ridge province, central Pennsylvania*, Guidebook, 38th Annual Field Conference of Pennsylvania Geologists, Camp Hill, Pa., p. 30-31.

Faill, R. T. and Nickelsen, R. P., 1999, *Chapter 19, Appalachian Mountain section of the Ridge and Valley province*, in Shultz, C. H., ed., *Geology of Pennsylvania*, Pennsylvania Geological Survey,4th ser., and Pittsburgh Geological Society, Special Publication 1, p. 269-286.

Faill, R. T. and Wells, R. B., 1974, *Geology and mineral resources of the Millerstown quadrangle, Perry, Juniata, and Snyder Counties, Pennsylvania*, Pennsylvania Geological Survey,4th ser., Atlas 136, p. 132

Gwinn, V. E., 1970, *Kinematic patterns and estimates of lateral shortening, Valley and Ridge and Great Valley provinces, central Appalachians, south-central Pennsylvania*, in Fisher, G. W., and others, eds., *Studies of Appalachian geology: central and southern*, New York, Interscience Publishers, Figure 3.

Lees, J. A., 1967, *Stratigraphy of the Lower Ordovician Axemann Limestone in Central Pennsylvania*, Pennsylvania Geological Survey,4th ser., General Geology Report 52, 78 p.

Macaulay Jr., G. R., 1952, *Stratigraphy and paleontology of the Lower Ordovician Axemann Limestone of Kishacoquillas and Nittany Valleys, Central Pennsylvania*, Unpublished MS thesis, Pennsylvania State College, University Park, PA, p. 17-36.

McElroy, T. A., 2004, *Bedrock geology of the Lewistown quadrangle, Mifflin and Juniata Counties, Pennsylvania*, Pennsylvania Geological Survey,4th ser., Open-file Report OFBM 04-02.0, 5 p., Portable Document Format (PDF).

McElroy, T. A., and Hoskins, D. M., in press, *Bedrock geology of the Allensville quadrangle, Huntingdon and Mifflin Counties, Pennsylvania*, Pennsylvania Geological Survey,4th ser.

Nickelsen, R. P., 1966, *Fossil distortion and penetrative rock deformation in the Appalachian Plateau, Pennsylvania*, Journal of Geology, v. 74, p. __.

Nickelsen, R. P., 1988, *Structural evolution of folded thrusts and duplexes on a first-order anticlinorium in the Valley and Ridge Province of Pennsylvania,* Geological Society of America, Special Paper 222, p. 89-106.

Rones, Morris, 1952, *Areal geologic mapping, 1951-1952*, unpublished map prepared in support of Ph.D. dissertation, Pennsylvania State University, Geology Department.

Rones, Morris, 1969, *A lithostratigraphic, petrographic and chemical investigation of the lower Middle Ordovician carbonate rocks in central Pennsylvania,* Pennsylvania Geological Survey,4th ser., General Geology Report 53, 224 p.

Swartz, F. M., 1955, *Stratigraphy and structure in the Ridge and Valley area from University Park to Tyrone, Mount Union and Lewistown,* Guidebook, 21st Annual Field Conference of Pennsylvania Geologists, University Park, PA, p. SI-27 to SI-29

Thompson, A. M., 1970, *Sedimentology and origin of Upper Ordovician clastic rocks, central Pennsylvania,* Field Trip Guidebook, Society of Economic paleontologists and Mineralogists, Eastern Section, 88 p.

Thompson, R. R., 1963, *Lithostratigraphy of the Middle Ordovician Salona and Coburn formations in central Pennsylvania*, Pennsylvania Geological Survey, 4th ser., General Geology Report 38, 154 p.

Geological Society of America
Special Paper 222
1988

Structural evolution of folded thrusts and duplexes on a first-order anticlinorium in the Valley and Ridge Province of Pennsylvania

Richard P. Nickelsen
Department of Geology, Bucknell University, Lewisburg, Pennsylvania 17837

ABSTRACT

The Jacks Mountain anticlinorium is a high, continuous structure in the Pennsylvania Valley and Ridge Province midway between the Blue Mountain and Allegheny structural fronts. Evolution of its northwest limb proceeded through a number of structural stages that may be characteristic of the first-order anticlines of the middle Appalachians.

Prior to major folding, faults rising to the northwest off the proposed Antes-Coburn detachment developed in sequence as the Stone Mountain duplex, the Bearpen Hollow thrust and the Potlicker Flat thrust, all cutting Silurian rocks. These were later passively folded to northwest dips during growth of the anticlinorium above the contracting and imbricating Cambro-Ordovician duplex. The northwest limb near the Stone Mountain duplex underwent later-stage layer-parallel extension and steep out-of-sequence reverse or strike-slip faulting, which were caused by the larger amounts of limb rotation and fold flattening at this part of the anticlinorium. Faults associated with this later event have mineralized pressure-solved breccias, suggesting that different deformation conditions prevailed.

Evaluation of the poorly exposed Antes-Coburn detachment has not provided structural evidence of a systematic transport direction, but allows interpretation of this zone as both an early floor thrust for imbricates rising to the northwest into overlying Silurian rocks and a later boundary zone between parts of the stratigraphic section undergoing unequal layer-parallel shortening.

INTRODUCTION

The Jacks Mountain first-order anticlinorium is a distinctive structure in the Pennsylvania Valley and Ridge Province, lying midway between the Blue Mountain and Allegheny structural fronts and persisting along strike farther than most other first-order anticlinoria (Fig. 1). It comprises en echelon, left-stepping, second-order anticlines that can be traced 250 km from the Anthracite region in the northeast, where it separates the Northern and Middle Anthracite synclinoria, to the Broad Top coal field in the southwest, where it defines a steep southeast margin. At both its northeast end, where regional plunges are northeast, and its southwest end, where regional plunges are southwest, the Jacks Mountain anticlinorium remains structurally high while adjacent synclines deepen. The Jacks Mountain anticlinorium plunges south near the Broad Top coal field into the axial depression of the Transylvania fault (Root and Hoskins, 1977), but rises again as the Cacapon Mountain anticlinorium that can be traced for another 145 km into Maryland and West Virginia. Rodgers (1970, Table 1) correlates the Cacapon anticlinorium to the Saltville fault system, an important mid-province structural front in Tennessee. Such great structural relief and continuity along strike, that is found elsewhere only along the Nittany–Wills Mountain anticlinorium to the northwest, suggests that the Jacks-Cacapon Mountain structure was built by stacking imbricates of the underlying duplex of Cambro-Ordovician carbonates. This paper about folded thrusts and duplexes occurring along 35 km of the northwest limb of the Jacks Mountain anticlinorium, at its structurally highest point in central Pennsylvania, will demonstrate that this belt was defined early in the history of deformation as a

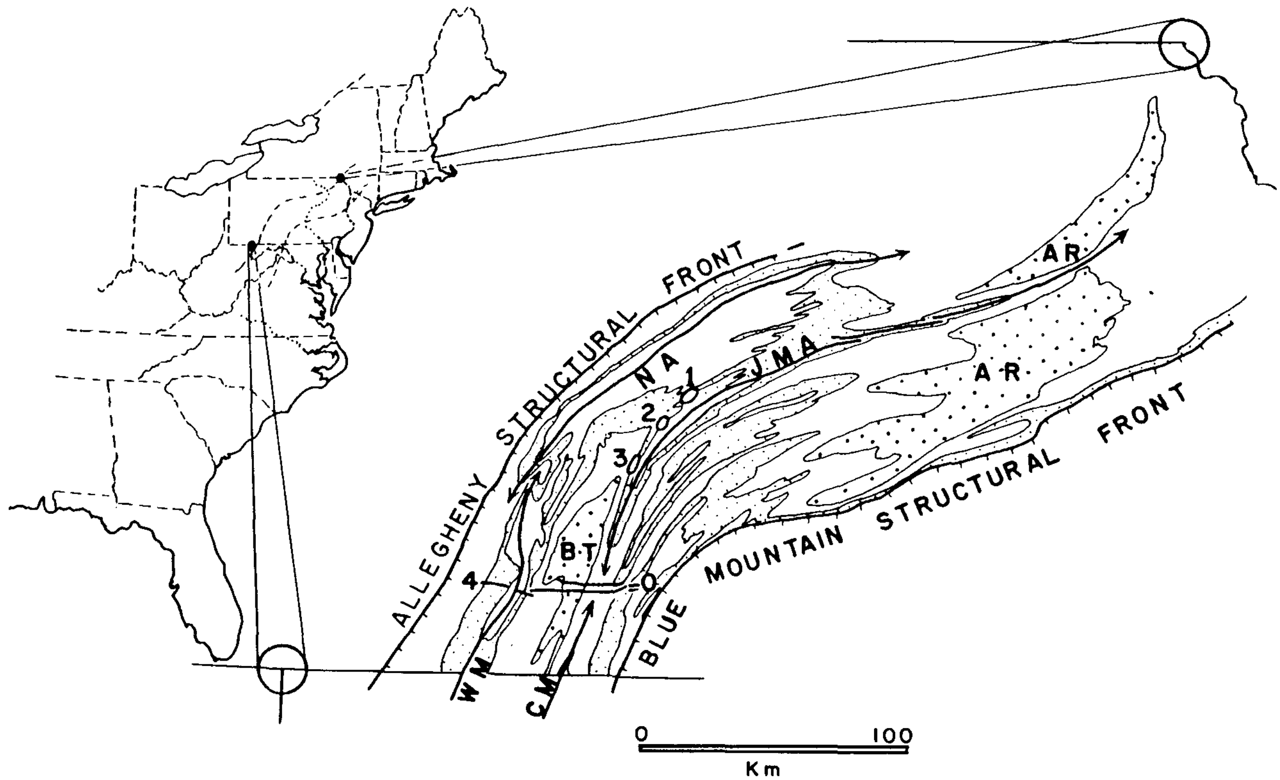


Figure 1. Index map showing major tectonic features of the study area. JMA = Jacks Mountain anticlinorium. 1 = Potlicker Flat thrust; 2 = Bearpen Hollow thrust; 3 = Stone Mountain duplex; AR = Anthracite region; BT = Broad Top coal field; CM = Cacapon Mountain anticlinorium; NA = Nittany anticlinorium; WM = Wills Mountain anticlinorium; 4-0 = Transylvania fault.

zone of thrusting and greater than normal layer-parallel strain confined within a fault duplex. In contrast to the northwest limb, ramp thrusting and duplex formation has not been recognized on the southeast limb of the Jacks Mountain anticlinorium.

General description of thrust faults and detachment horizons in the middle Appalachian foreland

With a few exceptions surface thrusts are not an obvious feature of the Pennsylvania Valley and Ridge Province and this has retarded the development of a modern synthesis. As demonstrated below, many are blind or folded, and subparallel to layers, appearing only as enigmatic zones of strain disharmony, some of which have recently been interpreted as duplexes (Nickelsen and Cotter, 1983; Nickelsen, 1986).

The small thrusts on the northwest limb of the Jacks Mountain anticlinorium fit the regional picture of the distribution of ramps and detachments that is emerging for the northern part of the middle Appalachians. These thrusts seem to be rooted in a detachment at the contact between the Cambro-Ordovician carbonates and the overlying Upper Ordovician to Silurian clastic rocks, a horizon variously described as the basal Reedsville or Martinsburg Shale, or Antes Shale, or the upper part of the Trenton Limestones (Coburn or upper Salona Limestones in Pennsylvania). Exposures of the supposed detachment in Pennsylvania are marked either by strong cleavage in the Antes Shale or by fourth-order disharmonic folding in the upper part of the Trenton Limestones, so the surface has been named the Antes-Coburn Detachment (Faill and Nickelsen, 1988). Above the detachment, thrusts ramp through stiff units such as the upper Reedsville sandy shales, the Bald Eagle Sandstone and Lost Run Conglomerate, or the Silurian Tuscarora quartz sandstone, but in places, they flatten and become parallel to bedding in ductile units such as the shales of the Ordovician Juniata Formation or the Silurian Rose Hill Formation. They are not thought to extend above a bed-parallel detachment (roof thrust?) in the Silurian Wills Creek Formation because huge exposures of the Lower Devonian Ridgely Sandstone in the Pennsylvania Glass Sand Quarries near Mapleton Depot, Pennsylvania, show no thrusting or imbrication. It should be noted that bed-parallel detachment

TABLE 1. STRATIGRAPHIC COLUMN FOR THE STUDY AREA
IN THE PENNSYLVANIA APPALACHIANS

Kilometers: 0, 1, 2, 3, 4, 5; Ft x 10^3: 0, 5, 10, 15, 20

Devonian		Df	Foreknobs
	M	Ds	Scherr
		Dbh	Braillier, Harrell
		Dh	Hamilton Group
	L	Doo	Onondaga, Old Port, Ridgely
Silurian	U	DSKt	Keyser, Tonoloway
		Swc	Wills Creek
	M	Sbm	Bloomsburg, Mifflintown
		Srh	Rose Hill
	L	St	Tuscarora
Ordovician	U	Oj	Juniata
		Obe	Bald Eagle, Lost Run
		Or	Reedsville, Antes
	M	Ocl	Coburn -- Loysburg
	L	Ob	Bellefonte
		Oa	Axeman
		On	Nittany
		Om	Mines
Cambrian	U	Є g	Gatesburg
		Є Wa	Warrior
	M	Є ph	Pleasant Hill
		Є Wo	Waynesboro

horizons are visible in these quarries within the Marcellus Shale but they show no evidence of being connected to thrusts below the Ridgely Sandstone.

It has been apparent since the work of Gwinn (1964, 1970) and Rodgers (1963, 1970) that the floor thrust beneath the Pennsylvania Valley and Ridge Province is in the Middle Cambrian Waynesboro Formation and that ramping of this blind thrust to either the Ordovician Reedsville-Martinsburg Formation or the Upper Silurian Wills Creek–Salina Formation beneath the Appalachian Plateau has created the Nittany anticlinorium. The regional distribution and relative importance of the two upper detachments is not certain. At the northeastern plunge out of the Nittany anticlinorium, it appears that ramping proceeds directly from the Middle Cambrian under the Valley and Ridge to the Salina detachment of the Appalachian Plateau (Faill and Wells, 1977; James Farley, personal communication, 1982). The Salina detachment under the Appalachian Plateau extends at least as far north as the Firtree Point anticline (Prucha, 1968), or the end of penetrative strain in surface rocks (Geiser and Engelder, 1983). The Salina detachment may then ramp up to the Middle Devonian Union Springs Shale and continue north at least to the vicinity of the Mohawk River Valley (Bosworth, 1984). To the southwest along the Allegheny Front in central Pennsylvania, both detachments apparently exist (Faill, 1981, Fig. 3), but farther southwest in Maryland, Virginia, and West Virginia, Perry (1978, Figs. 2, 8, and 9) recognized ramping only to the Ordovician Martinsburg Formation at the eastern edge of the Appalachian Plateau. However, Rodgers (1963, Fig. 2) and Gwinn (1964, Fig. 16) both predict progressive ramping from Cambrian to Ordovician to Silurian detachment horizons toward the northwest across Virginia and West Virginia, and Perry's work only encompasses the region of Cambrian to Ordovician ramping.

The thrusting above the Antes-Coburn detachment described in this paper occurs near the central Pennsylvania Allegheny Front, where both upper detachments are believed to exist. Though Hoskins (1979) called attention to thrusting and sequential deformation in this area, this is the first interpretation of thrusting within the Valley and Ridge southeast of the Allegheny Front that shows a possible relationship to the two detachments. These thrusts have little transport (maximum of 3,000 m stratigraphic separation) and are the northeastern limit of thrusting recognized in the middle Appalachians at this stratigraphic interval. The mid-province Jacks Mountain anticlinorium may be the first structure in a southeast-to-northwest profile where ramping rises to the Silurian.

Perry (1978, Figs. 8 and 10) recognized that the Antes-Coburn detachment is the folded roof thrust of the underlying

Cambro-Ordovician carbonate duplex, an interpretation adopted by Boyer and Elliott (1982, Fig. 16) and expanded upon by Herman and Geiser (1985). Herman and Geiser have shown that the Antes-Coburn detachment is a boundary zone between the greatly shortened carbonate duplex below and the less-shortened Upper Ordovician–Devonian section above. The present work was begun in 1984 to find field evidence of the detachment in Pennsylvania and to discover how it was related to the folded thrusts on the northwest limb of the Jacks Mountain anticlinorium (Fig. 2).

STRUCTURES OF THE NORTHWEST LIMB OF THE JACKS MOUNTAIN ANTICLINORIUM IN CENTRAL PENNSYLVANIA

Due to a southwest plunge within the region of study, the mutual relations of faults affecting its northwest limb can be viewed in downplunge projection by drawing all sections (Figs. 4, 5, 8, 9, 10, 12, and 15) and printing all outcrop photographs (Figs. 7 and 11) to be viewed toward the southwest. Thus, from lowest to highest in the stack are: (1) the Potlicker Flat thrust at the northeast end of the zone; (2) the Bearpen Hollow thrust, which crops out 10 km to the southwest; and (3) the Stone Mountain duplex, which crops out from 15 to 25 km farther to the southwest (Figs. 1 and 2).

All of these thrusts dip northwest less than the dip of beds, thus cutting up-section in a down-dip direction, an important criterion for recognizing folded thrusts (Dahlstrom, 1970, Fig. 7). When rotated with bedding until bedding is horizontal, thrusts dip to the southeast. Hence, it is inferred that faults formed as ramp thrusts and duplex zones, through what was to become its northwest limb, before the growth of the anticlinorium.

Potlicker Flat thrust

Faulting that has been interpreted here as a folded thrust appeared on the earliest geologic maps of the region (Billin, 1885a), was part of the compilation of the Barrville 7½-min Quadrangle by D. M. Hoskins for the 1980 Pennsylvania Geologic Map (Berg and Dodge, 1981), and was partially mapped by Devlin (1983). The fault is illustrated on Figures 2, 3, 4, and 5, rising off the Antes-Coburn detachment. The inferred existence of the Antes-Coburn detachment is based on scattered small nearby exposures and one good road cut on the southeastern limb of the Jacks Mountain anticlinorium (southeast end Figs. 6 and 4; see discussion of the Antes-Coburn detachment). The Potlicker Flat thrust is a texbook example of a folded thrust as seen on standard aerial photography and, especially, on high-altitude infrared color photography (Fig. 3). Despite this fine physiographic expression, exposures of the fault or rocks adjacent to the fault are rare. One exception is the huge outcrop of highly contorted but essentially vertical Rose Hill, Tuscarora, and Juniata Formations at Laurel Creek Reservoir, which is in the footwall of the Potlicker Flat thrust, 100 to 200 m below the fault (Fig. 7). The high strain of this steep southeast limb of an asymmetric second-order syncline seems related to the fault because the same stratigraphic units on the northwest limb, only 0.6 km away, show little strain. On the northwest limb, beds dip 45° southeast and have few small-scale structures except for incipient wedge and wrench faults of small displacement. In contrast, at the Laurel Creek Reservoir a complex structural sequence, including prefolding and postfolding stages of the Alleghany orogeny (Nickelsen, 1979), has resulted in one of the most structurally complex outcrops of the Valley and Ridge Province. The structural sequence has been described by Faill and others (1973, p. 78–88) and O'Keefe (1977), and is illustrated in Figure 8.

Layer-parallel shortening by Stage IV wedging and conjugate kink folding occurred while beds were horizontal to slightly dipping (<20°). Conjugate kink folds formed at large angles (>60°) to bedding during this stage. All prior structures were then rotated through more than 90°, and the enveloping bedding and the S-shaped kink folds of Figure 7 became dominant because they were properly oriented to grow during flexural-slip folding. Evidence for the early formation of conjugate kinks is provided by the preservation of a few relict kinks of a Z shape that were not obliterated during Stage V folding. Stage VI layer-parallel extension, seen as wedge-shaped fault blocks cutting beds at large angles, occurred after the enveloping bedding attained steep dips. Extension faults bounding wedge-shaped blocks dip either steeply northwest (>60°) or are horizontal to slightly northwest dipping. The horizontal extension faults parallel the Potlicker Flat thrust and are thus better developed than the conjugate, steeply-dipping faults.

This structural sequence, which contrasts so dramatically with the structure of the northwest limb of the syncline, indicates prefolding concentration of wedging and kink folding near the incipient Potlicker Flat thrust, followed by large-scale folding, layer-parallel extension, and continued thrusting. Presumably the structural development began as a splay off the Antes-Coburn detachment and continued through the folding of that detachment by the growth of the underlying Cambro-Ordovician carbonate duplex. If this is true, the location of the southeast steep limb of the asymmetric syncline and its associated thrust was established early in the sequence of Alleghanian deformation and continued to be a focus of higher strain throughout the structural evolution of this locality.

Although this discussion has dealt mainly with the excellent exposures of the Tuscarora and Juniata Formations at Laurel Creek Reservoir, the Bald Eagle Sandstone on the crest of Little Mountain, 0.6 km to the southeast, shows many of the same structural features. It is inferred to be immediately beneath the Potlicker Flat thrust and is overturned, intensely folded, and shows evidence of late layer-parallel extension.

Bearpen Hollow thrust

The Bearpen Hollow thrust, first named the Stone Mountain fault (Billin, 1885b), has appeared on subsequent mapping by

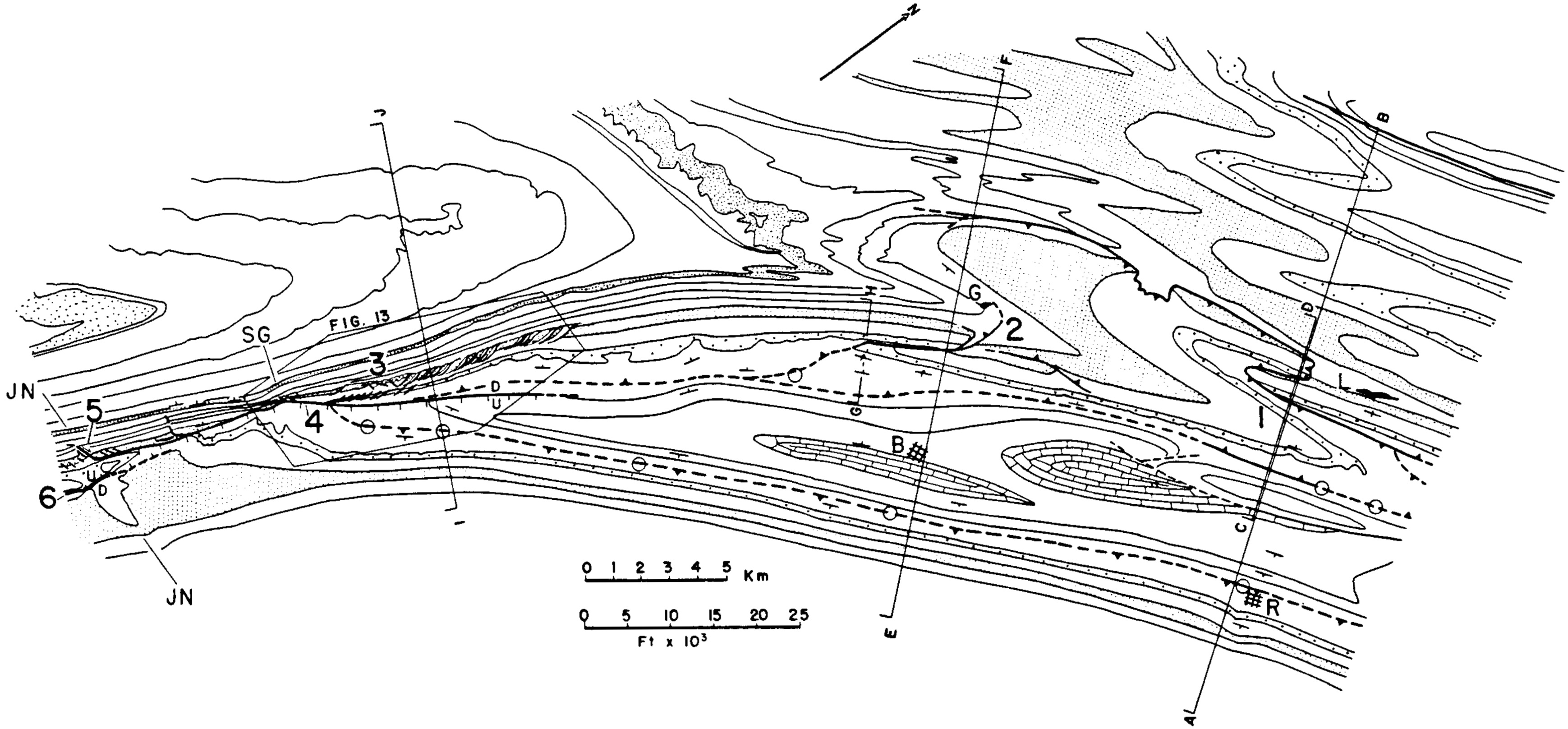


Figure 2. Geologic map of the Jacks Mountain anticlinorium in central Pennsylvania, including the Kishacoquillas Valley, Seven Mountains, and Stone Valley areas. Geology is modified from the reduced 7½-min quadrangles compiled for the 1980 Geologic Map of Pennsylvania by D. M. Hoskins (Berg and Dodge, 1981). Legend: 1 = Potlicker Flat thrust; 2 = Bearpen Hollow thrust; 3 = Stone Mountain duplex; 4 = Saddler Gap fault; 5 = Jacks Narrows fault; 6 = Jacks Mountain fault; L = Laurel Creek Reservoir; R = Reedsville; B = Belleville; G = Greenwood Furnace State Park; SG = Saddler Gap; JN = Jacks Narrows; Section A-B = Figure 4; Section C-D = Figure 5; Section E-F = Figure 9; Section G-H = Figure 10; Section I-J = Figure 12; outline of Figure 13. Fine dot patterns on geologic units are: Mississippian Pocono Formation, Devonian Ridgely Sandstone, and Silurian Tuscarora Formation. Coarse dot pattern is the Ordovician Bald Eagle Sandstone. Block pattern is Lower Ordovician Axeman Limestone. Open circles are localities for viewing the Antes-Coburn detachment. See Table 1 for identification of stratigraphic units.

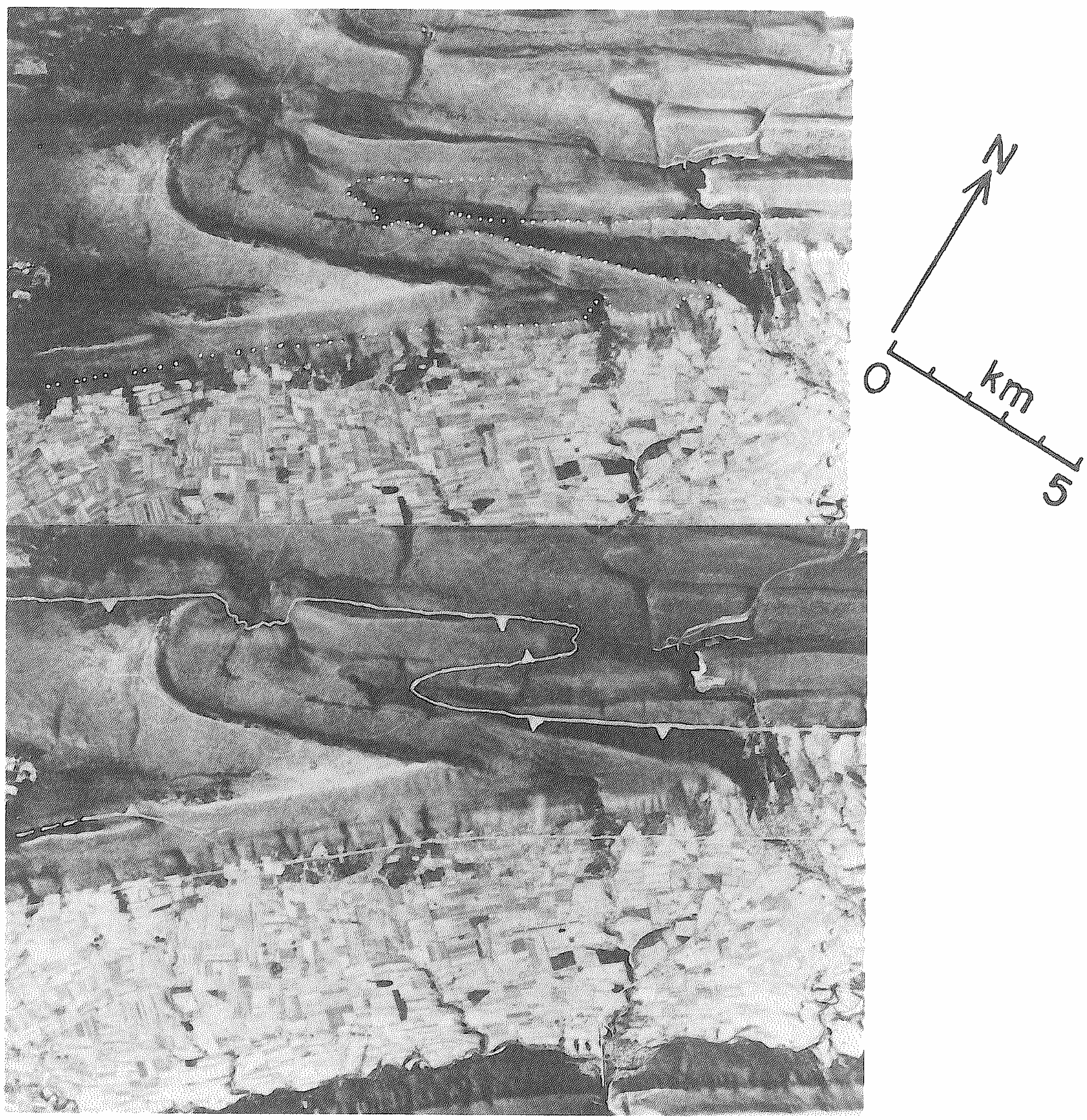


Figure 3. Stereo air photo pair of the northwest limb of the Jacks Mountain anticlinorium showing the folded Potlicker Flat thrust and the Barrville Gap back thrust and lateral ramp. Dots mark the outcrop of the Bald Eagle Sandstone ridgemaker.

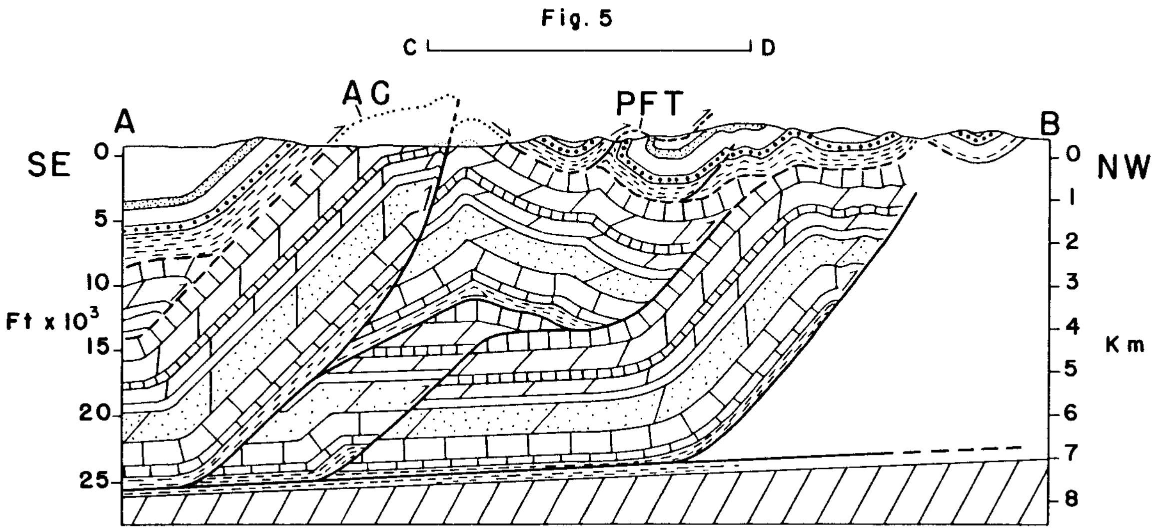


Figure 4. Laurel Creek–Reedsville profile, Section A-B, showing the Potlicker Flat thrust (PFT) and Antes-Coburn detachment (AC). See Figure 2 for location of the profile and Table 1 for identification of stratigraphic units.

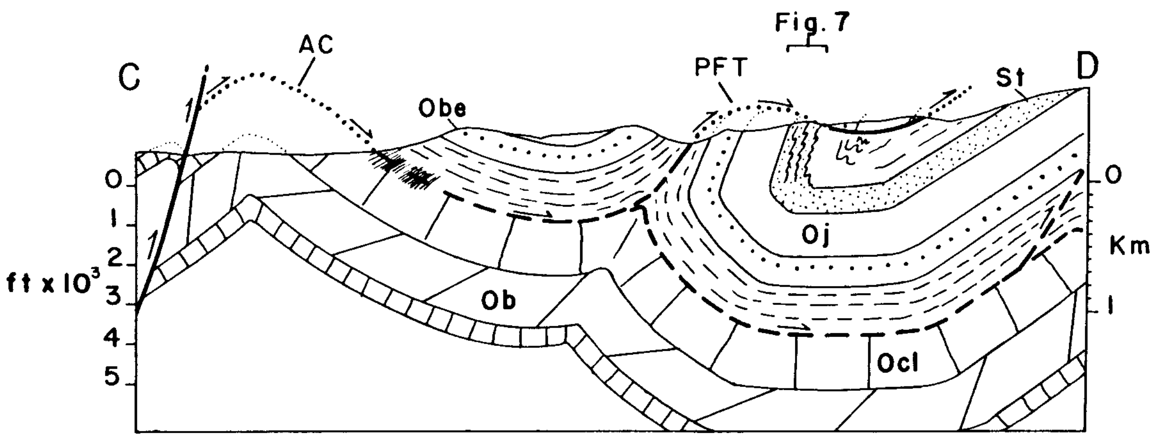


Figure 5. Section CD, an enlarged profile of the Laurel Creek area, in the central part of Section A-B to show the Potlicker Flat thrust (PFT) rising off the Antes-Coburn detachment (AC). See Figures 2 and 4 for location of the profile.

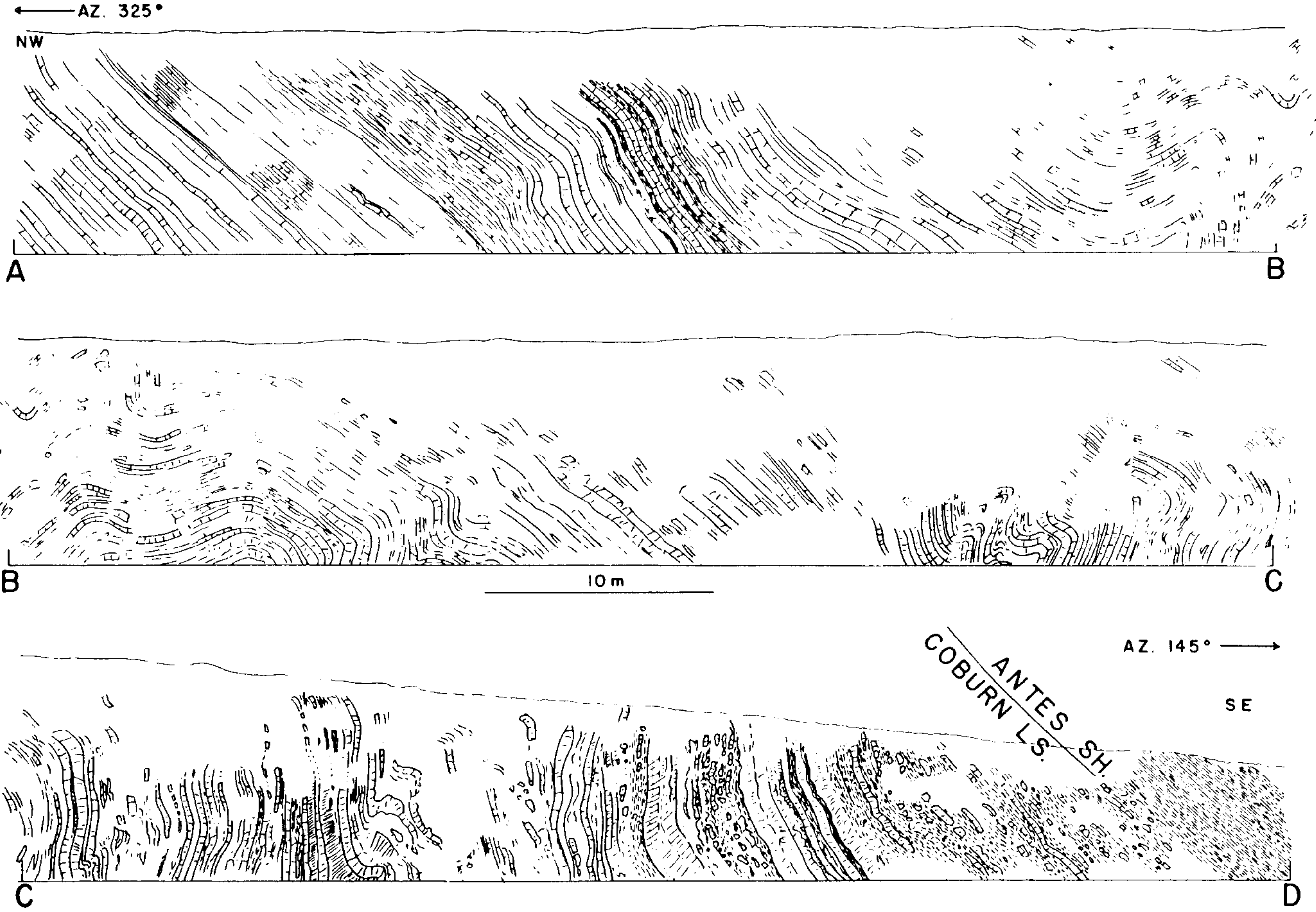


Figure 6. Drawing of the Antes-Coburn detachment exposed on the northeast side of Route 322 at Reedsville, Pennsylvania.

D. M. Hoskins (Berg and Dodge, 1981, Allensville, Barrville and McAlevys Fort 7½-min Quadrangles), who interpreted it as a thrust. It is illustrated on Figures 2, 9, and 10.

The right-lateral separation of topography and outcrop belts by this fault suggests that it is a dextral strike-slip fault, but the direction of bedding drag against the fault does not support this view. The best evidence of slip is provided by the changing dip of Bald Eagle Sandstone in the lower bench of Stone Mountain throughout the 16 km (10 mi) between Straley Knob near Milroy (northeast end, Milroy 7½-min Quadrangle) and Bearpen Hollow (southwest end, Allensville 7½-min Quadrangle) (Figs. 2 and 10). Dip of the Bald Eagle Sandstone gradually changes with distance southwest from Straley Knob: 0 mi, bedding horizontal; 1.5 mi, dip 10° northwest; 5 mi, dip 60° northwest; 7.5 mi, dip 63° southeast, overturned; 8.5 mi, Route 305, dip 82° southeast, overturned; 10 mi, Bearpen Hollow, dips range from 0° to 40° southeast, overturned, to 30° northwest overturned. Northwest dips in Bearpen Hollow have been rotated more than 180° and, if viewed down plunge toward the southwest, define a recumbent syncline beneath the Bearpen Hollow thrust that is related to slip on the fault (Figs. 9 and 10). The hinge of this syncline in the footwall parallels the azimuth 45° strike of the ridge, and slip on the overlying Bearpen Hollow thrust is assumed to have been perpendicular to the hinge (azimuth 315°). The fault dips 30° northwest parallel to the overturned beds in the footwall but climbs section through the more steeply northwest-dipping beds in the hanging wall (Fig. 10). A photograph of the overturned Bald Eagle Sandstone in Bearpen Hollow gap shows minor folds verging to the northwest that owe their asymmetry to the shear on the overlying Bearpen Hollow thrust (Fig. 11). The thrust now dips northwest because it has been rotated 45° to 60° on the northwest limb of the Jacks Mountain anticlinorium, but it probably originated in horizontal beds as a ramp from the Antes-Coburn detachment. The thrust seems to terminate in a

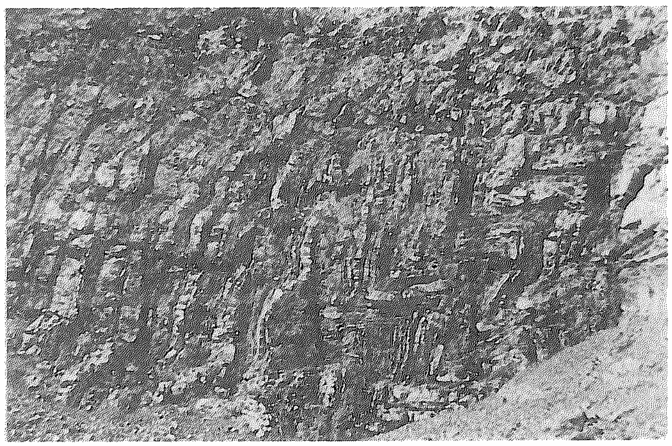


Figure 7. Fourth-order kink folds at Laurel Creek Reservoir in the footwall of the Potlicker Flat thrust. The photograph is printed in reverse to view structures down plunge toward the southwest. See Figure 5 for location of photograph. Height of exposure 30 m.

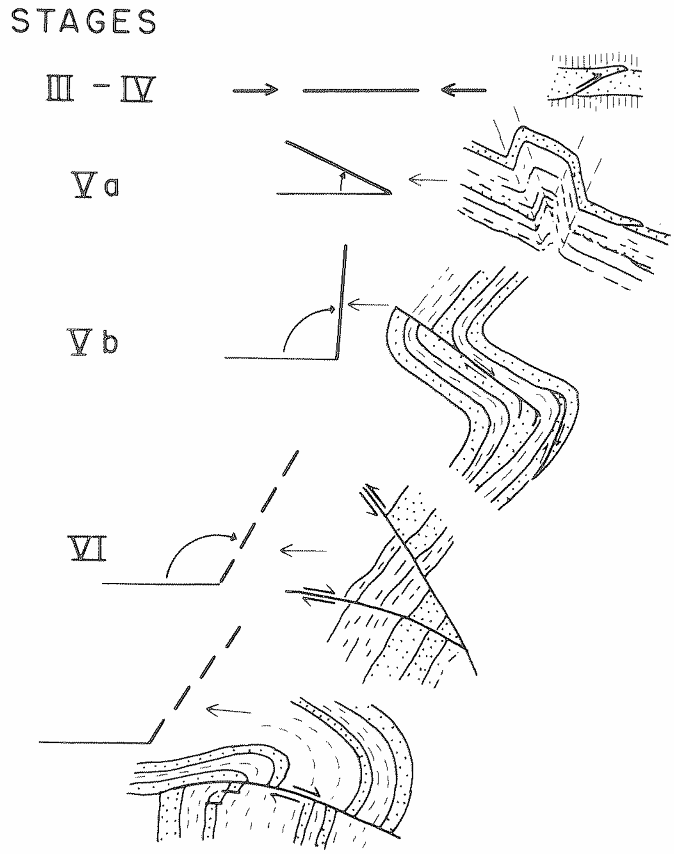


Figure 8. Interpretive diagram of structural stages in the evolution of the footwall of the Potlicker Flat thrust. Roman numerals refer to structural stages of the Alleghany orogeny defined in Nickelsen (1979).

well-exposed zone of fourth-order folds and spaced cleavage in a shale pit and jeep road through the Rose Hill shale, 1 km east of Greenwood Furnace State Park (GFSP). It is possible that with better exposures to the west of the park it could be traced approximately 4 km to the outcrop belt of the Wills Creek Shale to join the Potlicker Flat thrust at a leading branch line (Butler, 1982). A trailing branch line is inferred where the Bearpen Hollow thrust leaves the Antes-Coburn detachment (Fig. 9, TBL). The Potlicker Flat and Bearpen Hollow thrusts partially define a horse (Boyer and Elliott, 1982) that can be seen on Figure 9 but is incompletely segregated because the Bearpen Hollow thrust cannot be traced to a juncture with the Potlicker Flat thrust.

Two other small thrusts are present in this area. Southeast of GFSP, a small thrust rises off the Bearpen Hollow thrust, placing the Tuscarora Formation on the Rose Hill Formation. Three km east of GFSP a back thrust, bounded on the northeast by a lateral ramp that passes through Barrville Gap (southwest 9th, Barrville 7½-min Quadrangle), repeats the Tuscarora Formation (Figs. 2 and 3). This back thrust disappears to the southwest beneath the Bearpen Hollow thrust and can be traced to the northeast only as far as a local bedding detachment(?) in the Juniata Formation between the Bald Eagle Sandstone and the Tuscarora Formation.

Though none of the faults in this area are large, they all demonstrate geometric relationships that (1) prove their origin as thrusts that can be described and interpreted accordingly to newly assembled thrust concepts and terminology (Boyer and Elliott, 1982; Butler, 1982), and (2) support the view that thrusting largely preceded rotation of the northwest limb of the Jacks Mountain anticlinorium to its present dip.

Stone Mountain duplex

A 6½-mi segment of Stone Mountain extending north from Saddler Gap is structurally different from previously discussed parts of the northwestern limb of the Jacks Mountain anticlinorium. This segment differs because: (1) the whole stratigraphic

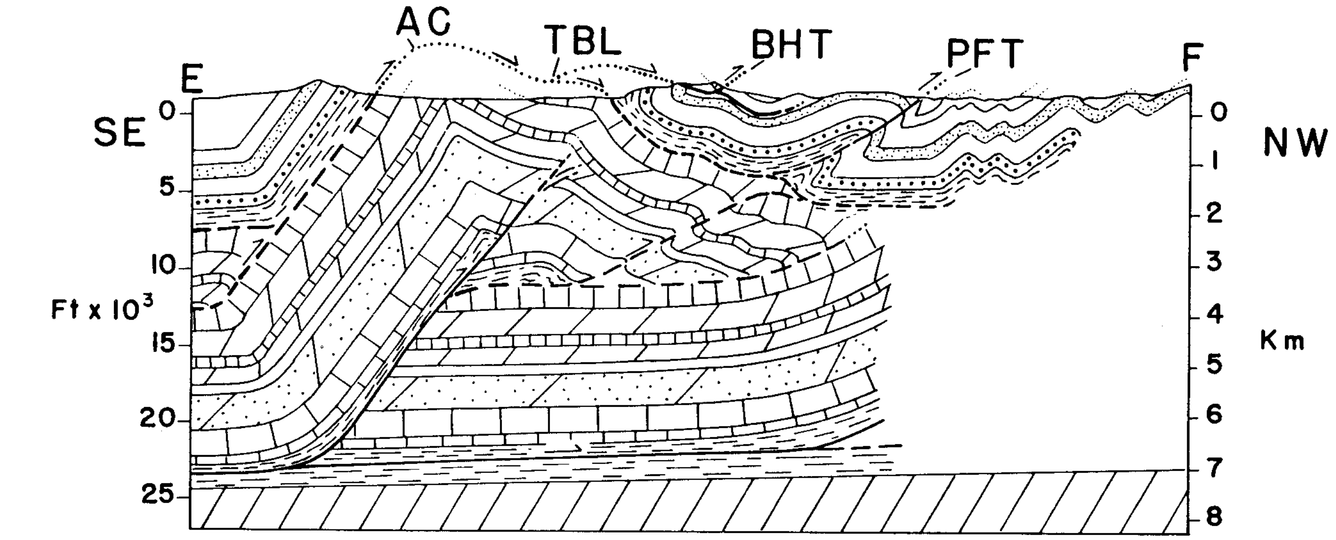


Figure 9. Belleville-Greenwood Furnace Profile, Section E-F, showing Bearpen Hollow thrust (BHT) and Antes-Coburn detachment (AC). TBL is the trailing branch line where BHT leaves AC. See Figure 2 for location of profile and Table 1 for identification of stratigraphic units.

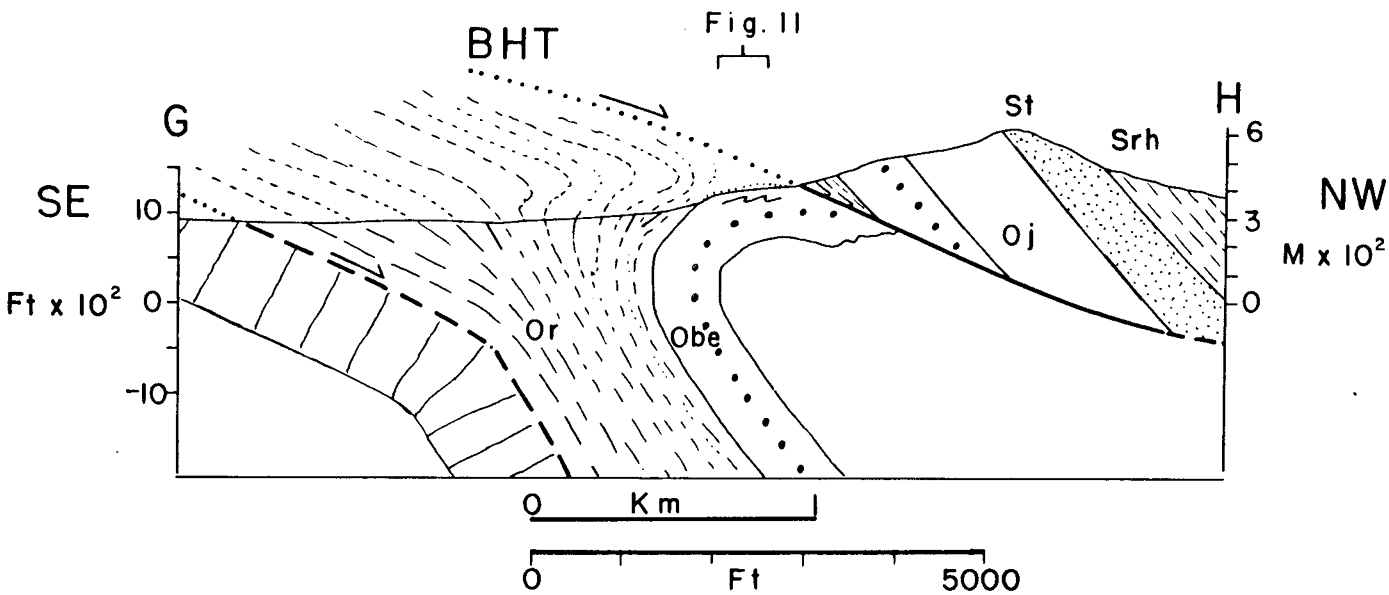


Figure 10. Enlarged profile of Bearpen Hollow thrust (BHT), Section G-H. See Figure 2 for location of the profile.

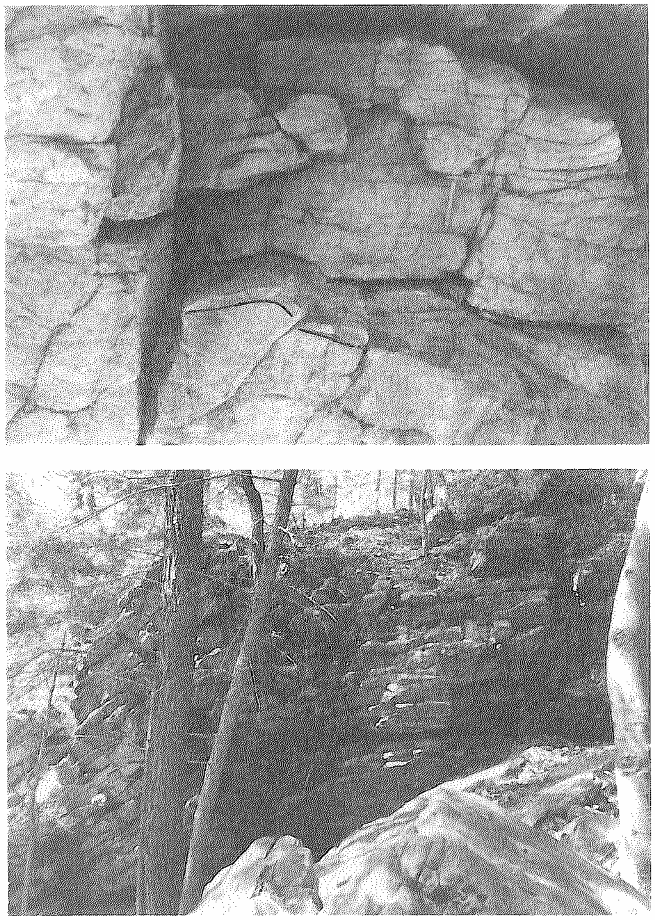


Figure 11. Overturned bedding in the Bald Eagle Sandstone dips southeast (left of picture) or is horizontal (right of picture). Enlarged photo shows parasitic fold verging right (northwest) in horizontal overturned beds beneath the Bearpen Hollow thrust. Both photos are printed in reverse to view structures down plunge toward the southwest. See Figure 10 for location of the photos. Length of hammer 0.4 m.

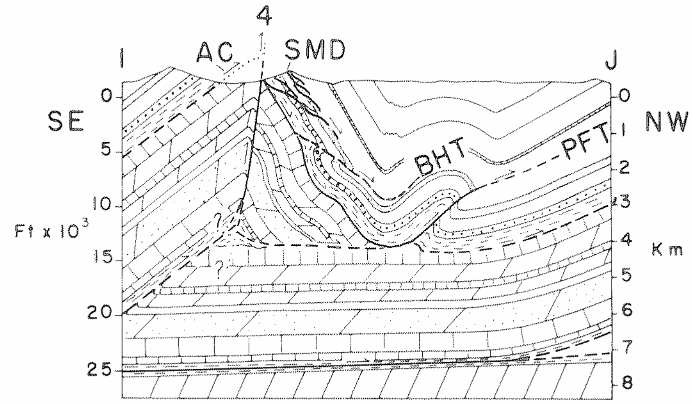


Figure 12. Stone Mountain duplex profile, Section I-J, across the southwestern end of the Kishacoquillas Valley. Profile shows the Stone Mountain duplex (SMD) and the down-plunge projections of the Bearpen Hollow thrust (BHT) and Potlicker Flat thrust (PFT). A steep out-of-sequence reverse fault (4) cuts earlier structures. See Figure 2 for location of the profile and Table 1 for identification of stratigraphic units.

section of enveloping bedding (Ordovician to Devonian) dips more steeply than elsewhere, averaging 60° northwest; (2) bedding within the Tuscarora Formation dips less than the enveloping bedding, averaging 30°; (3) small-scale faulting of two different generations and genetic classes has occurred; (4) the stratigraphic section has been tectonically thinned; and (5) formations along the southeast slope are progressively truncated toward the southwest by an obliquely intersecting, steep reverse fault. These features are illustrated on Figures 2, 12, 13, 14, and 15. The assemblage of structures is thought to have resulted from the following sequence of structural events: (1) imbrication, prior to major folding, into a duplex, which propagated toward azimuth 320°; (2) folding around an axis trending azimuth 15 to 25°; (3) thinning by late folding, Stage VI flattening; and (4) faulting and truncation of already folded beds by transverse strike-slip faults and a late reverse fault. Although referred to as the Stone Mountain duplex, it is apparent that the duplex is only a small, early part of the structural development of this segment of Stone Mountain. A description of structural relations and evidence for the structural sequence proposed are presented below.

Evolution of the Stone Mountain duplex. This structure consists of 16 imbricate slices of Juniata Formation over Tuscarora Formation that occur in the 8 km (5 mi) along the crest of Stone Mountain between 2.4 km (1.5 mi) and 8.5 km (6.5 mi) north of Saddler Gap (Figs. 2 and 13). Two to 3 mi north of Saddler Gap, several north-plunging, fourth-order folds also occur within the duplex. Stone Mountain trends azimuth 15° or azimuth 25°, but most bedding and all imbricate thrust faults in the Tuscarora Formation strike north to northwest and dip west to southwest. Consequently the duplex is exposed along the ridge crest in a number of minor knobs and saddles that result from differential erosion of the different rocks encountered. Knobs are formed of Tuscarora Formation, while saddles occur where less resistant Juniata Formation has been either folded or faulted above the Tuscarora (Fig. 13). Structural interpretation of this duplex hinges upon observations in the imbricated stiff unit, the Tuscarora Formation, because shale horizons where floor and roof thrusts are likely to occur are not exposed on the rubble-covered slopes of Stone Mountain.

Figure 14 is an enlargement of the map of several imbricates along the ridge crest in the center of Figure 13, and Figure 15 is a

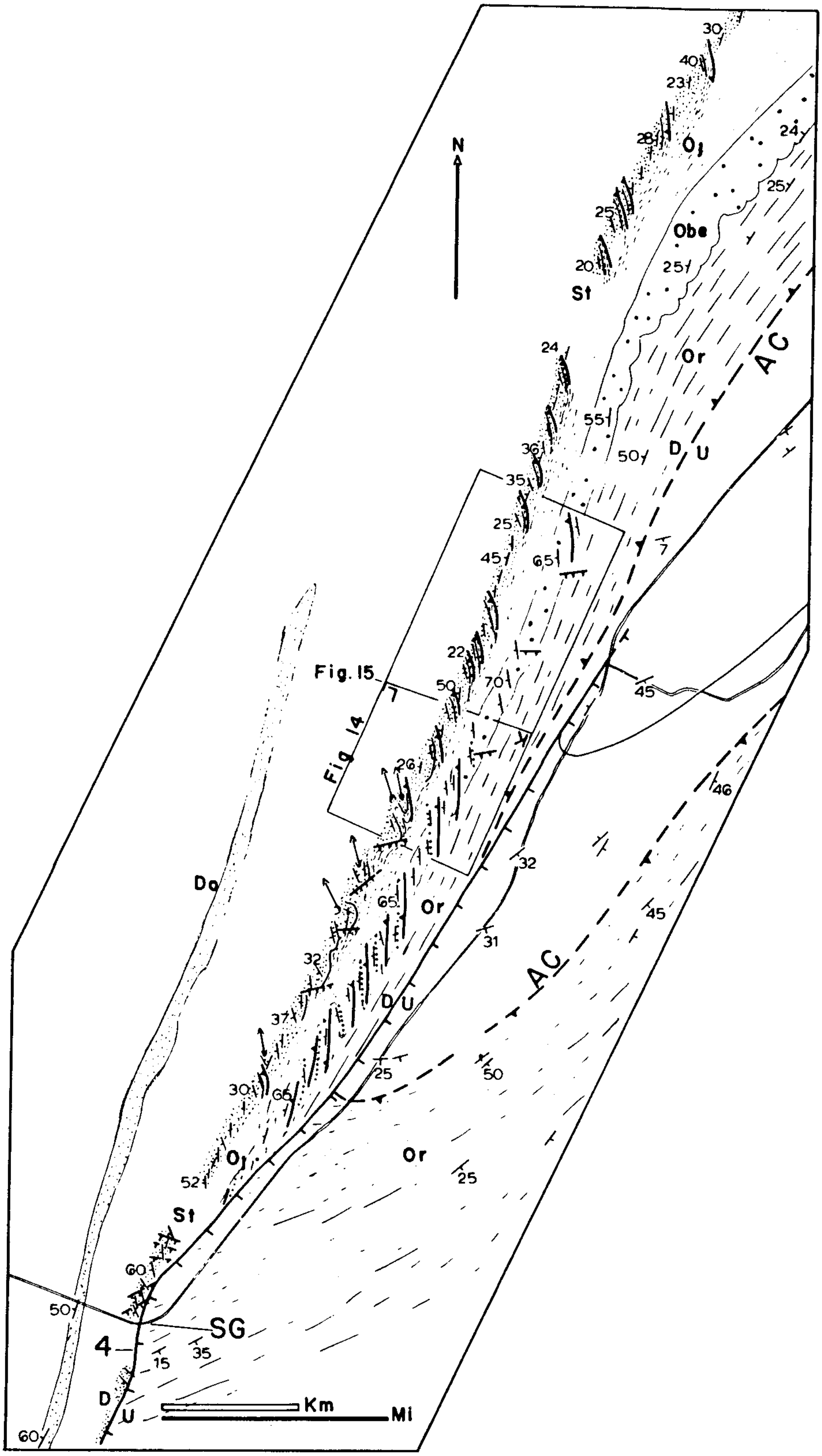


Figure 13. Geologic map of the Stone Mountain duplex. See Figure 2 for location. Saddler Gap fault (4) and Saddler Gap (SG). Antes-Coburn detachment (AC).

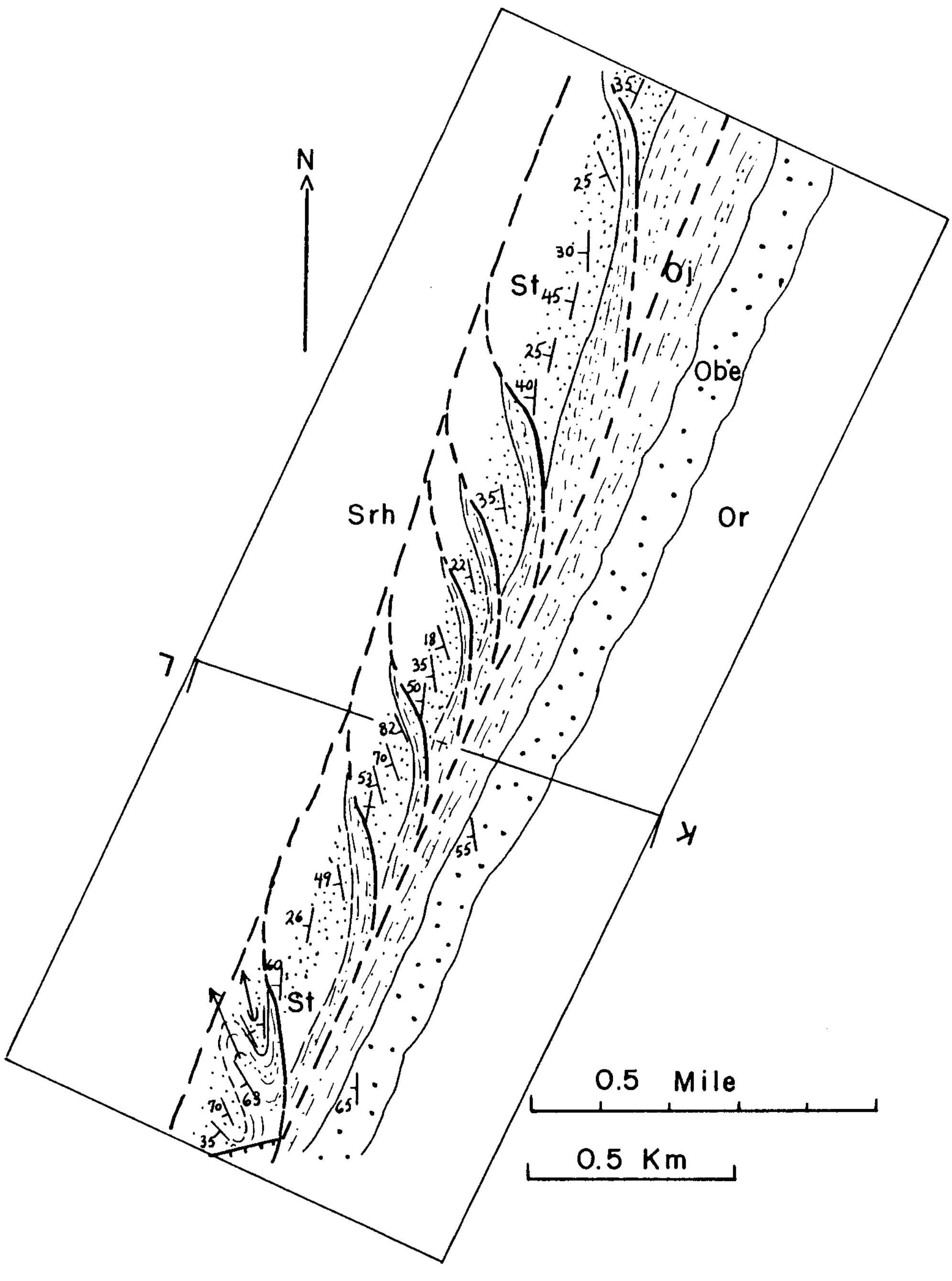


Figure 14. Enlarged geologic map of the central portion of the Stone Mountain duplex. See Figure 13 for location.

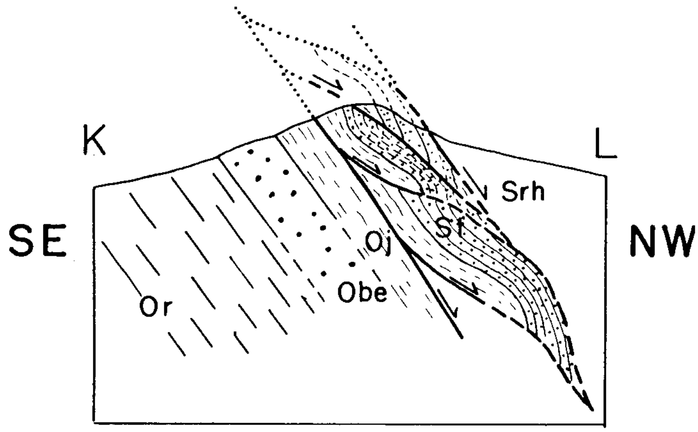


Figure 15. Enlarged profile of the Stone Mountain duplex, Section K-L. See Figures 13 and 14 for location of profile.

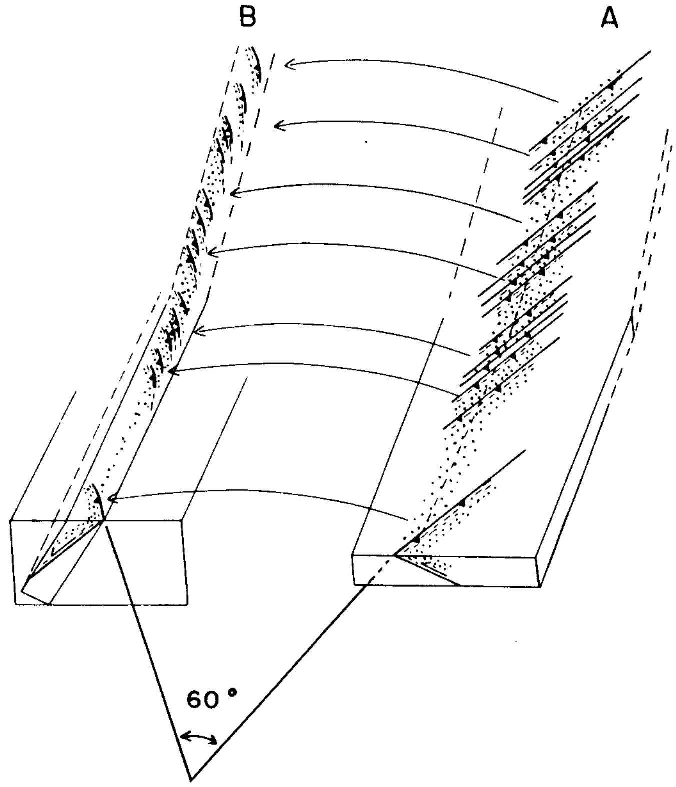


Figure 16. Interpretation of the origin of the structural attitudes in the Stone Mountain duplex by 60° counterclockwise rotation of a prefolding northeast-striking duplex (A) around an azimuth 15 to 25° axis. B is the attitude of the duplex after rotation.

section showing mutual relationships between the faulted Tuscarora and Juniata Formations. The section is interpreted as a downward-facing duplex between a floor thrust in the shales of the Juniata Formation and a roof thrust in the Rose Hill Shale. This duplex is thought to have originated in flat-lying beds as a series of imbricates that had an original strike northeast of the future azimuth 15 to 25° trend of Stone Mountain (Fig. 16a). After later rotation of 60° by folding around this trend, the outcrop pattern of the Stone Mountain duplex was created (Fig. 16b). Evidence for prefolding transport toward azimuth 320° is provided by data on the orientation of the acute bisectors of conjugate wrench faults in both the Tuscarora Formation along the crest of Stone Mountain and the Ridgely Sandstone to the southwest. Huge exposures of bedding planes dipping 50 to 70° northwest have been uncovered in the Devonian Ridgely Sandstone of the Pennsylvania Glass Sand Quarries between the northern Butler Knob Quadrangle and the central Mount Union Quadrangle, a strike distance of 6.5 mi. Conjugate sets of prefolding, early wrench faults (Stage IV, Bear Valley sequence, Nickelsen, 1979) with the slickenlines parallel to the fault-bedding intersection are prominent in all quarries. Figure 17 is a composite of these faults as seen on bedding planes viewed toward the southeast. They formed initially perpendicular to bedding as strike-slip faults intersecting in acute dihedral angles of 30 to 40°. After rotation with bedding to their present attitude, the right-lateral faults are nearly vertical and left-lateral faults dip 35 to 55° northeast. The least strain axis (λ_3) for these conjugate wrench faults lies in the bedding, bisecting the acute dihedral angle and plunging northeast. When bedding is rotated back to horizontal, λ_3 for the conjugate wrench faults strikes between azimuth 310 and 327°, 10 to 27° north of the perpendicular to the former strike of bedding. Figure 18 compares the attitude of rotated, Stage IV, λ_3 axes in the Tuscarora and Ridgely Formations to the present strike of bedding. This prefolding stress system is inferred to have been perpendicular to the northeast-striking imbricates in Figure 16a, and is an indication of the likely transport direction at that time.

Poor exposures of repeated sequences of Bald Eagle Sandstone, Lost Run Conglomerate, and Juniata Formation that occur on the southeast slope of Stone Mountain may be interpreted as another duplex at a lower stratigraphic level than the Stone Mountain duplex (Fig. 13). Similar to that duplex, bedding strikes here are consistently west of both the trend of the ridge and the belt of outcrop of the Bald Eagle Sandstone. Unlike the

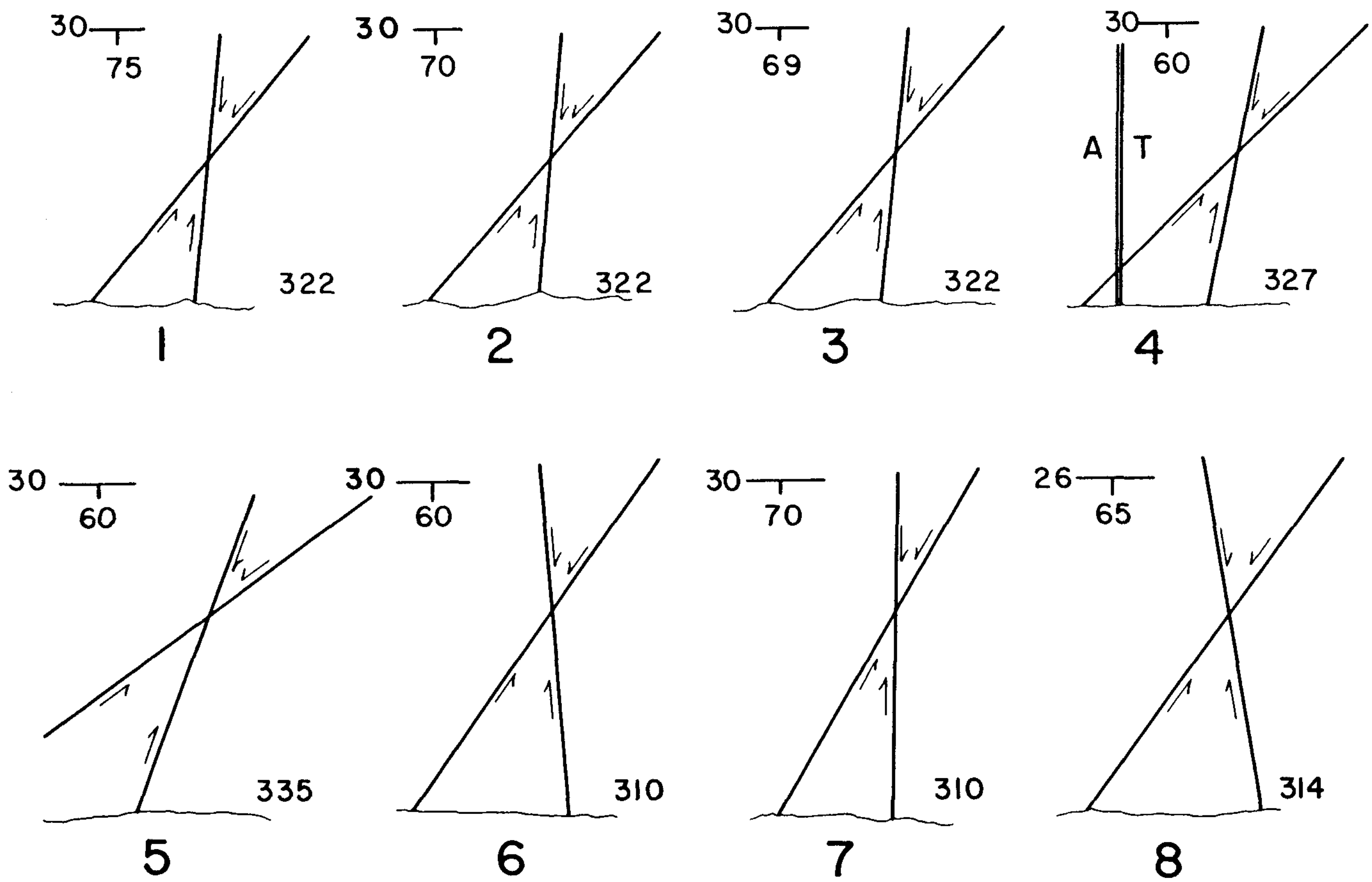


Figure 17. Summary of the orientation of conjugate early wrench faults as viewed looking southeast on to steeply dipping bedding planes of the Devonian Ridgely Sandstone in Pennsylvania Glass Sand Quarries north of Mapleton, Pennsylvania. Bedding plane attitudes are drawn in the upper left corner of each panel. The azimuth in the lower right is the orientation of the acute bisector of the wrench faults after rotation with bedding to horizontal. Panel 4 shows a vertical, late, strike-slip fault that overprints the early wrench faults. T = toward; A = away from observer.

Stone Mountain duplex, bedding dips average more than 60°, approximating the dip of the enveloping bedding. A few transverse, late, right-lateral, strike-slip faults cut these outcrops but are not numerous enough to explain all of the repeated sequences of stratigraphic units. Hence, the structure is shown as a duplex with a floor thrust in the Reedsville Shale and a roof thrust in the Juniata Formation. Better outcrops are needed to interpret this structure.

Steepening and thinning of the stratigraphic section adjacent to the Stone Mountain duplex. Following formation of the Stone Mountain duplex the northwest limb of the Jacks Mountain anticlinorium was rotated as the fold grew, due to ramping and contraction within the underlying Cambro-Ordovician duplex. The progressive rotation of the limb is depicted by Figure 4 (Section A-B), Figure 9 (Section E-F), and Figure 12 (Section I-J). Although they are present-day sections through the structure, taken in sequence from northeast to southwest, they show the steepening and flattening toward the southwesternmost section (Fig. 12), which is inferred to represent the temporal development of the fold. Progressive steepening from 20 to 60° takes place along the northwest limb as one proceeds toward the southwest. However, the greatest change in dip (from 25 to 50°) occurs at a change in trend of Stone Mountain (azimuth 15° to azimuth 30°) near the northern end of the Stone Mountain duplex (Figs. 2 and 13). At the same place, thinning of stratigraphic section starts and becomes more intense toward the southwest until, near Saddler Gap, the section is half the map width of a normal section. This thinning is a characteristic feature of the steepest portions of steep limbs of folds in the Valley and Ridge Province and results from domainally isolated, Stage VI, layer-parallel extension during the later stages of the Alleghany orogeny (Nickelsen, 1979). Some thinning here resulted from stretching parallel to strike, which was accommodated by vertical, right-lateral, strike-slip faults that are oblique to

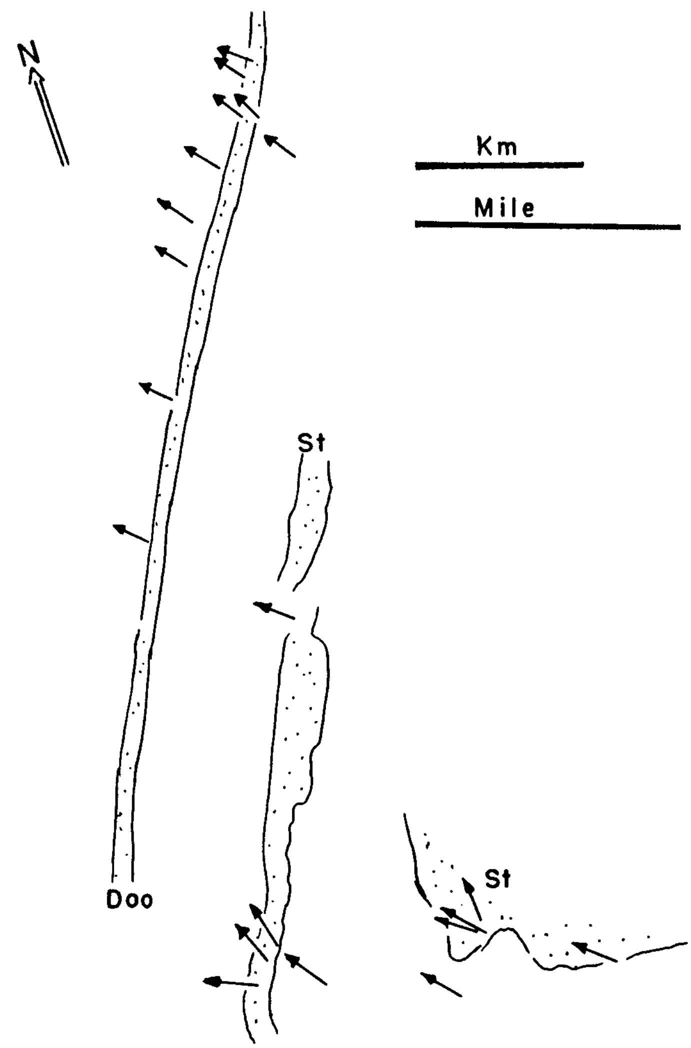


Figure 18. Map of rotated orientations of λ_3 (least principal strain axis) derived from acute bisectors of conjugate early wrench faults in the Tuscarora Formation (St) and Ridgely Sandstone (Doo). The acute bisectors were rotated to horizontal with bedding before plotting on this map.

the structure. Bedding attitudes within blocks consistently strike to the northwest of the trend of the ridge, and the diamond-shaped blocks are strung out along the trend of the ridge. Similar strike-slip faulting and related northeast-southwest extension was described by Schasse (1978) at the south border of this map area, and such faults increase in frequency and separation in that direction. It is not known whether northeast-southwest extension accommodated by strike-slip faults is the only mechanism responsible for the considerable thinning of section in the Stone Mountain duplex–Saddler Gap area. Exposures are limited to the Tuscarora, Bald Eagle, and Ridgely Sandstones, and no other extensional structures are apparent in these stiff units. The strike-slip faults that can be observed do not seem adequate to accommodate the 50 percent (?) thinning required. D. M. Hoskins (Mount Union 7½-min Quadrangle compilation for the 1980 Geologic Map of Pennsylvania, Berg and Dodge, 1981) faulted out Silurian stratigraphic units in the northwest side of Stone Mountain with a steep upthrust that has not been shown on Figure 2 or Figure 12 of this paper. Although this is a valid suggestion for reducing the outcrop width of Silurian units above the Tuscarora Formation on the northwest side of Stone Mountain, it cannot be mapped in the field and it does not explain the drastic reduction in thickness within the Juniata Formation on the southeast side of the mountain between the Tuscarora and Bald Eagle Formations.

Relationships between the Stone Mountain duplex and later, right-lateral, strike-slip faults. The above, right-lateral, strike-slip faults have different physical properties, orientation, and age, and overprint the faults of the Stone Mountain duplex. Fault surfaces formed at the time of the duplex are smooth, polished, and slickensided with fine cataclastically pulverized quartz and excellent slickenlines. The comminuted quartz is a layer usually less than 1 mm thick that grades into normal clastic quartzite fabric laced with anastomosing strain bands. In contrast, the second-generation fault surfaces are rougher, softer, and commonly free of slickenlines. One finds coarse breccias, with pressure solution interlocking of clasts and abundant sulfide mineralization, now commonly weathered to iron oxide minerals that fill the voids between breccia fragments. These faults are vertical, with horizontal slip that occurred after bedding had attained a steep dip. In some cases they overprint the nearly vertical set of early wrench faults (Fig. 17), and two sets of slickenlines may be visible—the first parallel to the fault-bedding intersection, the second perpendicular to that intersection. They are clearly much later, and formed under different environmental conditions and strain mechanisms, perhaps less-confining pressure, greater strain rate, more fluid mobility, and more pressure-solution creep. Description and interpretation of differences between these two generations of faults is continuing.

Out-of-sequence reverse fault southeast of Stone Mountain. Another late structural event was the Saddler Gap fault, a steep reverse fault that obliquely truncated the steeply dipping stratigraphic units along the southeast slope of Stone Mountain, bringing Reedsville Shale into contact with the Juniata, Tuscarora, and Rose Hill Formations (Figs. 2 and 13, fault 4). It is shown as an out-of-sequence fault cutting the Antes-Coburn detachment (Fig. 12, fault 4).

At its south end on Figure 2, the fault terminates in the right-lateral, strike-slip, Jacks Narrows fault of Schasse (1978). Thus, the Saddler Gap fault (Fig. 2, fault 4) and Schasse's Jacks Narrows fault (Fig. 2, fault 5) are interpreted here to be the same age, because unlike Schasse and Hoskins (in Berg and Dodge, 1981), I have joined them in my mapping (Fig. 2). Since the Saddler Gap fault is restricted to the area of steepest dip and tectonic thinning along the Jacks Mountain anticlinorium, it appears to have formed in response to the bed rotation and late flattening that occurred only here.

Adding to the complexity of the Jacks Narrow area is the

Jacks Mountain fault (6 on Fig. 2), which Schasse (1978) traced for 24 km northward along Jacks Mountain to its termination, 2 km north of Jacks Narrows. This northwest-dipping, steep, reverse fault was interpreted by Schasse as a chisel fault rising off his Martinsburg (Reedsville) decollement. Additional field work will be required to integrate this interpretation with the geology known to the north.

THE ANTES-COBURN DETACHMENT

An initial objective of this study was to describe and evaluate the Antes-Coburn detachment. Eight outcrops in either the Antes Shale or Trenton Limestones were judged to show structures, either fourth-order folding or strongly developed spaced cleavage, that may be related to the formation of this detachment (see circles plotted on Fig. 2 for location). Only the southeast-dipping exposure near Reedsville on the northeast side of route 322 (Fig. 6) shows the complete structure of the detachment. It is a zone of southeast-verging fourth-order folds within the Coburn and Salona Limestones embedded in a 2-km-thick, tabular, stratigraphic section extending from the Ordovician Bellefonte Dolomite to the Silurian Tuscarora Formation. The detachment zone is the only departure from a constant 40 to 50° dip. No cleavage or small-scale folds are visible in the overlying Antes Shale, so the detachment here seem]s restricted to the Coburn and upper Salona Limestones.

Two roadcut outcrops of the detachment on the northwest limb of the anticlinorium, 5 km north of Reedsville, are marked by spaced cleavage in the Antes Shales and minor folding and overturning of Coburn Limestone beds. Cleavage seems restricted to the zone of the proposed detachment, but this could be a result of rock type, not concentrated strain.

In a large borrow pit in the Antes-Reedsville Shale, 5 km west of Belleville, locally well-developed spaced cleavage and fourth-order folds may mark the position of the detachment.

Four other borrow pits in Antes or Reedsville Shale dipping southeast also show well-developed cleavage and/or fourth-order folding. These localities are south or southwest of Belleville along the southeast limb of the Jacks Mountain anticlinorium.

In summary, except for the exposure at Reedsville, the evidence for the existence of the Antes-Coburn detachment is hardly impressive. Even at Reedsville it is not clear what has occurred to produce the disharmonic smaller-scale folds. There is no evidence at any locality of differential slip between units above and below the proposed detachment, and it is possible that the cleavage and small folds seen are related to lithologic differences. On the other hand, large-scale considerations of section balancing (Herman and Geiser, 1985) or rooting of thrusts (this paper) seem to demand a detachment and northwesterly transport at the Antes-Coburn level. Perhaps we are discovering what such detachments look like here at the northeastern end of large-scale Alleghanian overthrusting. The evidence suggests that they are boundary zones separating stratigraphic sequences that have undergone locally different amounts of layer-parallel shortening, which may have resulted in opposed senses of differential transport but no regionally uniform sense of large-scale overthrusting. This view is supported by: (1) absence of evidence for the Coburn-Antes detachment at some reasonably well-exposed localities; (2) different shear sense suggested by vergence of rock cleavages and asymmetry of fourth-order folds in different exposures of the Coburn-Antes detachment zone; and (3) different strains at different places in the Coburn-Antes detachment, as indicated by different intensity of rock cleavage or different tightness of fourth-order folding. These apparent differences may well be due to the poor quality of exposures in the detachment zone. Only the locality depicted in Figure 6 is well exposed.

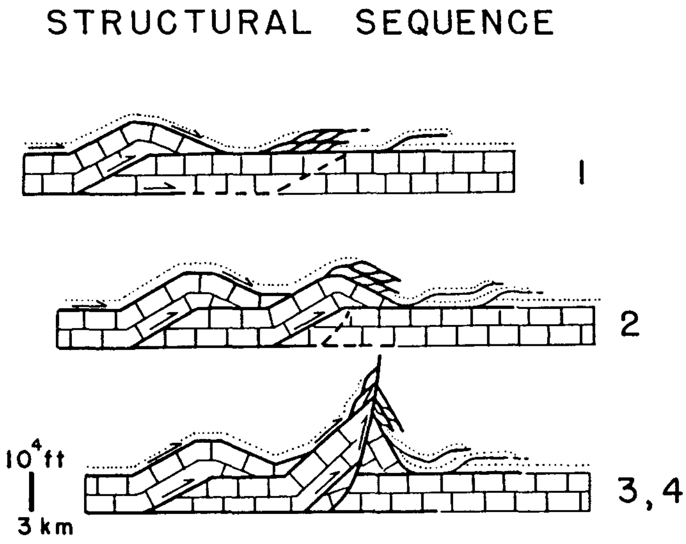


Figure 19. (1) Northwest-directed ramp faulting of the first-order Cambro-Ordovician carbonate duplex. Roof thrust is the Antes-Coburn detachment from which second-order duplexes (e.g., Stone Mountain duplex) rise into Silurian Formations. (2) Rotation of the second-order duplex by a first-order ramp anticline in the underlying Cambro-Ordovician carbonate duplex. (3) Further rotation, flattening, and faulting by a steep out-of-sequence upthrust (Saddler Gap fault) of both the second-order duplex and the first-order ramp anticline.

CONCLUSIONS

The northwestern limb of the Jacks Mountain anticlinorium in central Pennsylvania has three small folded thrusts or duplexes that originated in horizontal beds as imbricates rising toward the northwestern foreland from the Antes-Coburn detachment. They later were folded by ramping in the underlying Cambro-Ordovician carbonate duplex so that, in many places, they now dip northwest in the direction of their initial transport. These thrusts may be the northeasternmost limit of surface thrusting at the Ordovician to Silurian stratigraphic level in the middle Appalachians. Viewed down plunge to the southwest, the Potlicker Flat thrust is the lowest thrust in the stack, overlain successively by the Bearpen Hollow thrust and Stone Mountain duplex. If a forward or foreland-directed sequence of thrusting is accepted, these faults formed in the following order. (1) Stone Mountain duplex, (2) Bearpen Hollow thrust, and (3) Potlicker Flat thrust. The Stone Mountain duplex propagated obliquely toward the northwest (transport azimuth 310 to 324°), and the strike of its folds and faults trended east of the future axis of rotation (Fig. 16A). Because of a later rotation around an axis striking azimuth 15 to 25° parallel to Stone Mountain, the duplex is now viewed on edge, and its structures now strike west of the mountain (Fig. 16B). The structurally advanced Stone Mountain duplex in the southwest underwent the most structural development as subsequent ramping, folding, and flattening occurred. Both enveloping beds and the duplex were rotated to a dip of 60°, extended, and faulted by a steep out-of-sequence upthrust (Saddler Gap fault) and by many transverse, right-lateral, strike-slip faults (e.g., Jacks Narrow Fault). The sequence of structural events that is revealed in the northwest limb of the Jacks Mountain anticline is schematically shown in Figure 19.

ACKNOWLEDGMENTS

Thanks to Donald Hoskins for introducing me to the geology of Stone Mountain and the Kishacoquillas Valley; Paul Devlin for mapping several areas; Jake Hossack for help in interpreting the folded thrusts; Robert Sadosky for a guided tour of the Pennsylvania Glass Sand Quarries; Rodger Faill, William Bosworth, and Donald Hoskins for manuscript reviews; and the Pennsylvania Geological Survey for the loan of air photos and unpublished maps. Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research.

REFERENCES CITED

Berg, T. M., and Dodge, C. M., eds., 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th Series, approximately 1:62,500.

Billin, C. E., 1885a, Map of adjoining portions of Huntingdon, Mifflin, Centre, and Union Counties, Sheet 25, *in* Lesley, J. P., State Geologist, Second Geological Survey of Pennsylvania, Grand Atlas, Division V, Part I, Central and Southeastern Pennsylvania, 2 miles/inch.

——, 1885b, Geological map to illustrate the Stone Mountain fault, Sheet 27, *in* Lesley, J. P., State Geologist, Second Geological Survey of Pennsylvania, Grand Atlas, Division V, Part I, Central and Southeastern Pennsylvania, 1600 feet/inch.

Bosworth, W., 1984, Foreland deformation in the Appalachian Plateau, central New York; The role of small-scale detachment structures in regional overthrusting: Journal of Structural Geology, v. 6, p. 73–81.

Boyer, S. E., and Elliott, D., 1982, Thrust systems: American Association of Petroleum Geologists Bulletin, v. 66, p. 1196–1230.

Butler, R.W.H., 1982, The terminology of structures in thrust belts; Journal of Structural Geology, v. 4, p. 239–245.

Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains: Bulletin of Canadian Petroleum Geology, v. 18, p. 332–406.

Devlin, P. A., 1983, Thrust faulting in the Burnham, Barrville, Allensville, and McAlevys Fort Quadrangles, central Pennsylvania [Senior thesis]; Lewisburg, Pennsylvania, Bucknell University, 24 p.

Faill, R. T., 1981, The Tipton block; An unusual structure in the Appalachians: Pennsylvania Geology, v. 12, p. 5–9.

Faill, R. T., and Nickelsen, R. P., 1988, Valley and Ridge, *in* Shultz, C. H., ed., The geology of Pennsylvania; Part III, Structural geology and tectonics: Pittsburgh Geological Society (in press).

Faill, R. T., and Wells, R. B., 1977, Geology and mineral resources of the Linden and Williamsport Quadrangle, Lycoming County, Pennsylvania: Pennsylvania Geological Survey, 4th Series, Atlas 134ab.

Faill, R. T., Wells, R. B., Nickelsen, R. P., and Hoskins, D. M., 1973, Structure and Silurian–Devonian stratigraphy of the Valley and Ridge Province, Central Pennsylvania: Guidebook for the 38th Annual Field Conference of Pennsylvania Geologists, Harrisburg, Pennsylvania, Pennsylvania Geological Survey, 168 p.

Geiser, P., and Engelder, T., 1983, The distribution of layer parallel shortening fabrics in the Appalachian foreland of New York and Pennsylvania; Evidence for two non-coaxial phases of the Alleghanian orogeny, *in* Hatcher, R. D., Jr., and others, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 161–175.

Gwinn, V. E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge Provinces of the central Appalachians: Geological Society of America Bulletin, v. 75, p. 863–900.

——, 1970, Kinematic patterns and estimates of lateral shortening, Valley and Ridge and Great Valley Provinces, central Appalachians, south-central Pennsylvania, *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian geology, central and southern: New York, Interscience Publishers, p. 127–146.

Herman, G. F., and Geiser, P. A., 1985, A "passive roof duplex" solution for the Juniata culmination; Central Pennsylvania: Geological Society of America Abstracts with Programs, v. 17, p. 24.

Hoskins, D. M., 1979, Sequential faulting during Alleghanian orogenesis, Seven Mountains, Pennsylvania: Geological Society of America Abstracts with Programs, v. 11, p. 16.

Nickelsen, R. P., 1979, Sequence of structural stages of the Alleghany orogeny at the Bear Valley Strip Mine, Shamokin, Pennsylvania: American Journal of Science, v. 279, p. 225–271.

——, 1986, Cleavage duplexes in the Marcellus Shale of the Appalachian foreland: Journal of Structural Geology, v. 8, p. 361–371.

Nickelsen, R. P., and Cotter, E., 1983, Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge; Guidebook for the 48th Annual Field Conference of Pennsylvania Geologists: Harrisburg, Pennsylvania, Pennsylvania Geological Survey, 192 p.

O'Keefe, F. X., 1977, Structural analysis of the Rose Hill, Tuscarora and Juniata Formations at Laurel Creek Reservoir [Senior thesis]: Lewisburg, Pennsylvania, Bucknell University, 40 p.

Perry, W. J., Jr., 1978, Sequential deformation in the central Appalachians: American Journal of Science, v. 278, p. 518–542.

Prucha, J. J., 1968, Salt deformation and decollement in the Firtree Point anticline of central New York: Tectonophysics, v. 6, p. 273–299.

Rodgers, J., 1963, Mechanics of Appalachian foreland folding in Pennsylvania and West Virginia: American Association of Petroleum Geologists Bulletin, v. 47, p. 1527–1536.

——, 1970, The tectonics of the Appalachians: New York, Wiley-Interscience, 271 p.

Root, S. I., and Hoskins, D. M., 1977, Latitude 40°N fault zone, Pennsylvania; A new interpretation: Geology, v. 5, p. 719–723.

Schasse, H. W., 1978, The geology and mineral deposits of Jacks Mountain, in the Butler Knob and Mount Union 7½-minute Quadrangles, central Pennsylvania [M.S. thesis]: University Park, Pennsylvania State University, 175 p.

Manuscript Accepted by the Society October 29, 1987

Appendix 2: From Thompson, A. M., 1970, Sedimentology and origin of Upper Ordovician clastic rocks, central Pennsylvania, Field Trip Guidebook, Society of Economic Paleontologists and Mineralogists, Eastern Section, p. 19-27

63.7		Junction U.S. 22-west and U.S. 322-west. Turn right onto U.S. 322-west-522-north, and proceed northwest.
	2.4	
66.1		U.S. 522-north exit off U.S. 322. Continue west on U.S. 322.
	0.7	
66.8		Electric Avenue exit off U.S. 322-west. Continue west on U.S. 322.
	0.3	
67.1		Exposures on right of Oriskany sandstones.
	0.6	
67.7		Exposures on both sides of highway of Middle Silurian shales, probably McKenzie and Wills Creek.
	0.4	
68.1		Exposures on both sides of highway of Bloomsburg red beds.
	0.1	
68.2		Burnham exit off U.S. 322-west. Turn right onto off-ramp. At end of exit ramp, in front of Holiday Inn, turn left and proceed north along road into Yeagertown.
	0.7	
68.9		Exposures on right of Bloomsburg red shales and silt-stones.
	0.1	
69.0		Access road terminates at bottom of hill on South Main Street in Yeagertown. Turn left onto South Main Street and proceed north through the town.
	1.0	
70.0		Entering Kishacoquillas Gap.
	0.2	
70.2		Bridge over Kishacoquillas Creek.
	0.1	
70.3		Beginning of lithofacies-D exposures of stop 2.
	0.4	
70.7		STOP 2. REEDSVILLE. Three to four hours.

Stop 2 is at exposures in Kishacoquillas Gap, ½-1 mile southeast of Reedsville. Exposed in road cuts along the old U.S. 322 and the new U.S. 322 bypass are much of lithofacies A, complete sections of lithofacies B, C, D and F, and a small interval of lithofacies E. Because of the difficulties of negotiating two highways, three separate stops will be made (see Fig. 5 for locations). Stop 2A will examine lithofacies A, C and D on the east side of the gap along old U.S. 322; 2B will consider lithofacies A, B, C and D along U.S. 322 bypass; and 2C will examine lithofacies F and the overlying Tuscarora sandstones on the bypass.

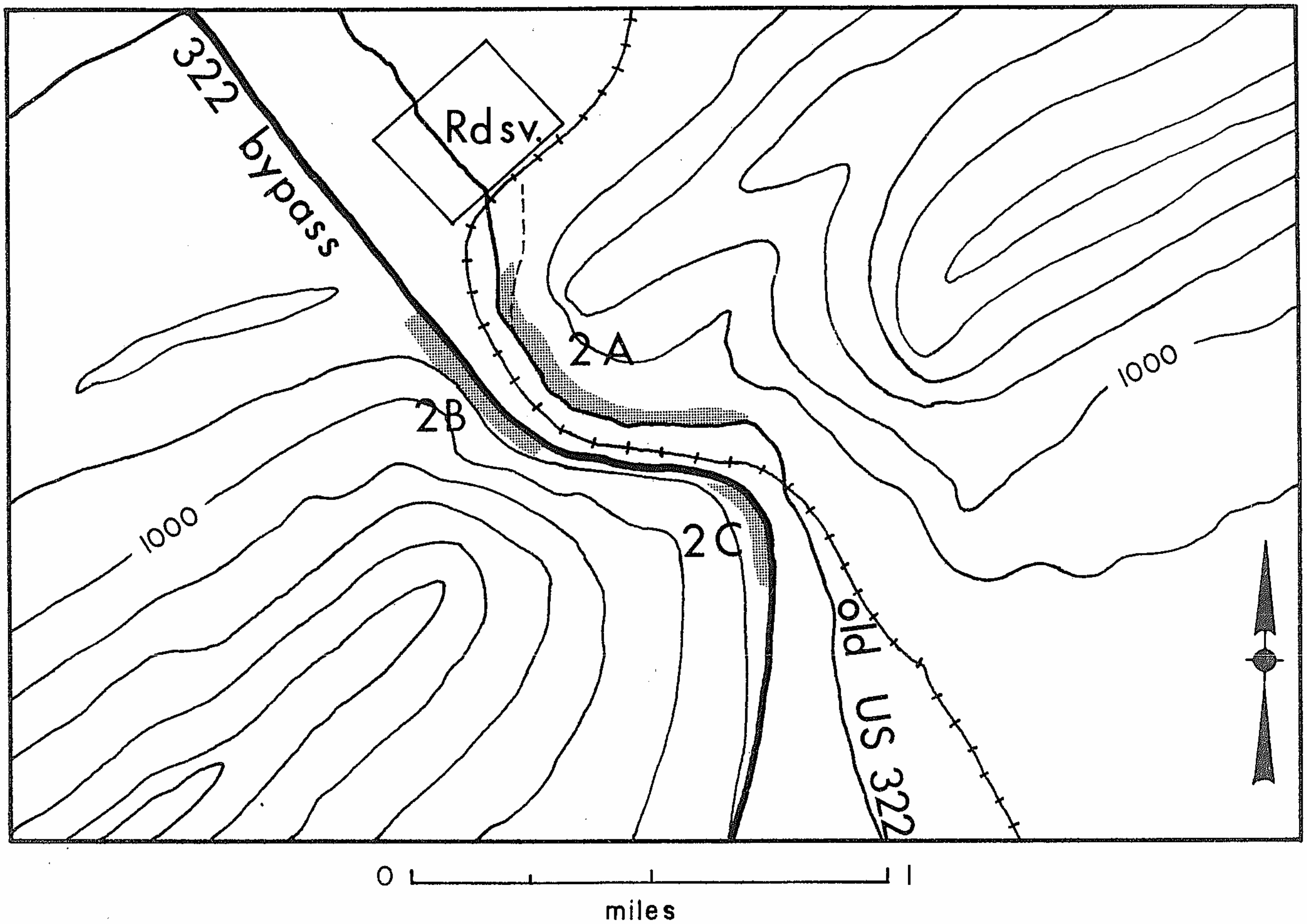


Figure 5. Topographic map of Reedsville region showing locations of stops 2A, 2B and 2C. Contour interval = 200 feet.

STOP 2A. LITHOFACIES A, C, D.

Two hours.

Pull off old U.S. 322 onto widest point of right shoulder, opposite center of bypass bridge on curve. The massive, reddish sandstones and conglomerates exposed at this point belong to lithofacies D. Stratigraphic tops are to the southeast. Ahead of you bends down-section, to lithofacies C, B and A. Begin with lithofacies D, and work down-section.

The total thickness of lithofacies D is exposed in this outcrop. The bus is parked near the middle of the coarse-grained, conglomeratic zone, 75 to 90 meters above the base of the lithofacies and 150-175 meters below the top. The grain-size maximum provides a convenient starting point for examination of the unit. The conglomeratic zone is roughly 110 meters thick, and in this coarsest portion contains subequal numbers of lithic (sandstone and chloritic greenstone) pebbles up to 20 cm. long and siliceous (white quartz and chert) pebbles averaging three to four cm. in length. Thick-bedded intervals up to three meters thick are common in this zone, as are thick (up to two meters) planar cross-strata. Scour surfaces, separating nearly all bedding types, and low-angle channel structures are conspicuous; many channel-fill sandstones are

are not conglomeratic.

Proceeding up-section from the grain-size maximum, medium- and fine-grained sandstones gradually replace the coarse, conglomeratic sandstones as the major rock type. The abundance and size of pebbles decrease upward; the last pebbles seen are a centimeter or less in length, widely scattered, and well rounded. They are siliceous, and reflect the increasing maturity of the pebble suite caused by the gradual disappearance of unstable, lithic types. The major bedding type in these upper parts is large-scale trough cross-bedding, with sets reaching two meters in thickness. A few solitary sets of planar cross-strata occur in the upper parts; they are usually less than a meter thick. Pebbly layers are often found along the bases of sets; these probably formed by selective pebble accumulation along the bases of foresets. Many other sedimentologic features are found in the upper parts of lithofacies D. Mud cracks are well exposed near the 224-meter level. Linguloid ripples occur on bedding planes at the 210-meter level. Parting lineations frequently occur on the erosion surfaces at the tops of cross-bed sets.

Proceeding downward from the grain-size maximum, the same sequence of variations is repeated. Pebbles become smaller, less abundant, better rounded and more siliceous farther below the grain-size maximum; the last pebble occurs 25 meters above the base of the unit. Rocks below the conglomeratic interval are greenish-gray; the color boundary is gradational over at least two meters. Cross-bedding is mostly of the trough type, with 15-25^{o} inclinations of foresets. Trough cross-bedding is more abundant near the bottom of the interval; planar cross-stratification becomes more abundant upward into the conglomeratic zone, in sets up to 80 cm. thick. Scour features are everywhere, and recognizable channels are very low-angle. Parting lineations characterize the upper surfaces of cross-bed sets in rocks close to the conglomeratic interval.

The great predominance of sand-size and larger sediments in the lithofacies as a whole is well shown by this outcrop. The thin, widely separated shaly beds are usually less than five cm. thick, although thickness increases markedly in the uppermost 15 meters of the lithofacies. Lower contacts of fine-sediment layers are often gradational over a centimeter or less; upper contacts are consistently erosional in nature.

Lithofacies C in this exposure contains thin alternations of clean, thin-bedded and cross-bedded sandstone and gray to black silty shale. Attention should be given to the predominance of sandstone over shale in this section; the same interval at stop 2B will be seen to contain much more interbedded shale. An arbitrary zero mark at the base of lithofacies C is indicated by a yellow paint stripe on the outcrop. Throughout the 50 meters of continuous exposure the sandstones consistently show thin-bedding and parallel laminations as one major bedding type; parting lineations and primary current lineations are abundant on bedding planes. Current crescent casts are observable one meter above the base of the unit. The other major bedding type is trough cross-bedding; most sets are 20-50 cm. thick. Linguloid ripples are found on several sandstone bedding planes. Distinct scour features are seen at many places in the sandstones; thin-bedded or cross-bedded sandstones are scoured down into other sandstones or into silty sequences. Convolute bedding and slump structures are visible in a 30-cm.-thick sandstone bed 30 meters above the base.

The shaly intervals are basically similar throughout the unit with respect to both lithologic and sedimentologic properties. They consist of thinly interbedded silty shale and fine- to very-fine-grained sandstone, on a scale of two or three cm. Boundaries between laminae are erosional, with a maximum relief of three to four cm. Both sandstone and shale layers are micro-cross-laminated to parallel-laminated; more sandstones than shales are cross-laminated. Many layers of both sandstones and shales are burrowed. In several instances, as at 16 meters above the base, the thicker sandstones are load-casted down into underlying shales. The homogeneous, thin-bedded sandstone sequences often truncate the shaly sequences irregularly, with as much as 1.5 meters of relief on the scour surfaces.

Lithofacies B is only partially exposed at this stop. It consists of seven meters of fine-grained sandstone extending from the arbitrary zero marker north to the large covered interval. The gray sandstones are micro-cross-laminated to thin-bedded, and are fossiliferous with <u>Orthorhynchula linneyi</u>, <u>Lingula nicklesi</u>, <u>Tancrediopsis</u> sp., <u>Zygospira modesta</u>, <u>Lophospira</u> sp., and other forms. The upper two meters are bioturbated, and contain one- to two-cm. coquinoid layers rich in lingulid brachiopods and gastropods. Basal surfaces of these coquinoid beds are generally erosional, and upper contacts are gradational.

The covered interval north of this exposure of lithofacies B contains the rest of that unit plus its contact with underlying lithofacies A. North of the covered interval, turbidites and interbedded sandstones and shales of lithofacies A are continuously exposed for at least 125 meters at the top of the small talus slope. The stratigraphically lowest rocks, well exposed at the junction of the major highway with the northeast-trending secondary road, consist of thin, fine-grained, probably distal turbidites. The graded character is well displayed on the many joint surfaces. These turbidites contain fine- to very-fine-grained sandstones at the base, and grade up into silty shales and shales usually in less than 10 cm. Whole and comminuted remains of shallow-water fossils, mainly brachiopods and crinoids, are common in the sandy parts of these turbidites. Several thicker (up to 1.5 meters) turbidites contain significantly coarser-grained basal layers; lag conglomerates are frequently observed. One good example of turbidite erosion is shown at the road junction by a 40-cm.-long rounded shale clast contained in a basal sandstone but very probably derived from the underlying shale.

Higher in lithofacies A the average turbidite thickness increases somewhat, to 30-40 cm, and the frequency of continuously graded beds decreases; proportionally more sandstone-shale contacts are erosional. The erosional contacts are usually relatively smooth, with one or two centimeters of relief. The sandstones are less visibly size-graded than those below, and frequently lack skeletal debris at the base. Near the top of the exposed section, behind the utility pole, the number of sandstone layers decreases sharply, and the section consists largely of shale beds. In these shales several smooth surfaces of discontinuity separate shale beds; these may be scour surfaces. Channeling of sand beds is evident in this interval.

Return to bus; <u>continue north</u> along old U.S. 322.

	0.2	
70.9		Access road departs to right.
	0.2	
71.1		Entering Reedsville.
	0.5	
71.6		<u>Turn left</u> onto Pa. 655 and <u>proceed west</u>. Outcrops at this point are in lower formations of Trenton Group.
	0.3	
71.9		<u>Turn left</u> onto on-ramp leading to U.S. 322-east, and <u>proceed east</u> on U.S. 322. Outcrops here and in the next quarter mile are Nealmont Limestone (top of Trenton Group), and contact with overlying Reedsville Shale is exposed.
	0.9	
72.8		STOP 2B. LITHOFACIES A, B, C, D. Two hours.

This stop is located on the southwest side of the gap, at exposures of lithofacies A, B, C and D in the road cut along the new U.S. 322 bypass. Park along widest part of shoulder, fairly close to bridge. Stratigraphic tops are ahead, to the southeast.

Lithofacies A is less well exposed at this stop than at stop 2A; several small faults and springs tend to obscure bedding and other sedimentologic relationships. The same trends are visible in these rocks as were seen in the exposure across the gap. The lower parts of the lithofacies contain thin, laterally persistent turbidites which grade from fine-grained sandstones upward into shales. Shallow-water faunal elements occupy the lower parts of sandy layers. Scour features are evident but are not strongly developed.

This section affords a better exposure of the upper regions of lithofacies A. In this interval, sandstones are often erosionally bound both above and below. This is particularly true of the thicker sandstones, which tend to be coarser-grained also. Thinner, fine-grained sandstones most often show good grading upward into pelagic shales. The sandstones in these upper parts are usually unfossiliferous; the shales yield rare graptolites and trilobite fragments with persistent searching. Scouring is evident in these upper parts, and many sandstones pinch out in outcrop distances. Several sandstones fill shallow channel structures. Sole markings are hard to see because of the flatness of the outcrop face and rarity of exposed bedding planes.

Lithofacies A grades up into lithofacies B by increase in abundance of fine-grained sandstone, loss of graded bedding, and appearance of an indigenous fauna. The transition zone contains six to seven meters of thin-bedded sandstone and siltstone, with minor interbedded shale. Erosion surfaces abound through this section, but few well-developed channels or truncating structures are visible.

Above the transition zone, lithofacies B extends upward for 20 meters. The lower 12 meters consist predominantly of fine-grained fossiliferous sandstone, with minor, thin silty shale beds. The sandstones are small-scale trough cross-bedded in the lower four meters, and show abundant scour surfaces and truncation of sets. The next eight meters consist of thin-bedded to parallel-laminated sandstones showing abundant parting lineations and primary current lineations on the flat bedding surfaces. Current crescent casts frequently occur on bedding planes, and in several instances have formed around fossil fragments. This parallel-laminated sequence is scoured downward into the cross-bedded rocks below; the visible relief is 50 cm. Small, dark clasts are oriented in the bedding. Although resembling intraformational shale clasts, many of these are phosphatic.

The fauna of this lower part consists primarily of strophomenid (Rafinesquina alternata, Sowerbyella sp.), rhynchonellid (Orthorhynchula linneyi) and spiriferid (Zygospira modesta) brachiopods, bryozoans, crinoids and rare sponges. Most skeletal remains are disarticulated but relatively unabraded.

The uppermost seven to eight meters of lithofacies B, while fossiliferous, differ markedly from underlying rocks. Significant amounts of siltstone and shale are interbedded with the sands; these are laminated to micro-cross-laminated and erosionally bound. The erosion surfaces show up to 10 cm. of relief. Several shale beds are burrowed. The sandstones in this interval are slightly finer-grained than those below, and contain smaller-scale bedding features. They are predominantly small-scale cross-bedded and micro-cross-laminated. The uppermost two meters consist of highly burrowed sandstone; another, thinner burrowed zone occurs 60 cm. below it. Most sandstones, and particularly the burrowed sandstones, contain thin coquinoid layers. Basal contacts are usually sharp; upper contacts are gradational, with gradual disappearance of shell material. These layers are often discontinuous, and show pronounced pinch-and-swell along single horizons.

Faunas in these layers consist mainly of Lingula nicklesi, Orthorhynchula linneyi, Tancrediopsis sp. and common small gastropods (c.f. Lophospira sp.). The faunas in rocks other than coquinoid layers include Orthorhynchula and Lingula, and also pectinid and mytilid bivalves (Ambonychia sp., Modiolopsis sp.). These species are more often whole and articulated than those in the coquinoid layers.

Lithofacies C at this stop is characterized by significantly higher proportions of siltstone and shale layers than the same interval on the east side of the gap. Individual sandstone and shale beds rarely exceed a meter in thickness. Significant portions of the total thickness contain thinly and delicately interbedded fine-grained, micro-cross-laminated sandstones and cross-laminated to parallel-laminated shales; beds in these sequences are usually less than two to three cm. thick and are laterally persistent. Current and linguloid ripples are common bedding-plane features in these sequences, and nearly all lithologic boundaries are erosional. A typical sequence of this type occurs five meters above the base of the lithofacies.

The middle 10 meters are predominantly sandy, and contain thin-bedded and parallel-laminated sandstones which show parting lineations on several bedding planes. Large channel scours cut these sandstones; relief on some reaches 1.5 meters in outcrop distances. Shale partings become more numerous near the top of these sandstones, and are extensively burrowed.

The upper parts of the lithofacies, 12 meters thick, contain more fine-grained sediment than the sandstones just beneath. This interval contains thinly interbedded sandstone-shale sequences similar to those near the base of the lithofacies, with micro-cross-laminated, rippled sandstones and laminated to micro-cross-laminated siltstones and shales. These major siltstone-shale units, up to two meters thick, are erosionally bound, both above and below. Several thicker sandstone beds (up to a meter) are large-scale trough cross-bedded. Most rocks are burrowed; the infaunal element constructed isolated, vertical borings which are filled with mud. The first true intraformational shale clasts appear five meters below the top, and increase in abundance upward.

The lowest 40 meters of lithofacies D are exposed at this stop. These greenish-gray sandstones are fine- to medium-grained, and coarsen slightly upward. Small white quartz pebbles are encountered near the top, as the unit becomes very slightly conglomeratic. The sandstones are large-scale trough cross-bedded, with set thicknesses reaching 1.5 meters. Occasional planar sets are present, in greater numbers toward the top of the section. Scour features are abundant. CAUTION: beware of the overhang at the top of the lithofacies-D outcrop; potentially dangerous rock falls are known to originate there.

Return to bus; continue east along U.S. 322 bypass.

0.7

73.5 STOP 2C. LITHOFACIES F.

One half to one hour.

This stop is on the northwest flank of the main ridge of Jacks Mountain in a road cut on the new U.S. 322 bypass (see Fig. 5). Pull off onto right shoulder about 100 meters beyond the second highway bridge; outcrop is on right.

Exposed at this stop are lithofacies F and the Ordovician-Silurian contact above it. Lithofacies F consists of 113 meters of generally medium- to coarse-grained sandstones, relatively rich in intraformational shale clasts. Beds of siltstone or shale are rare, and where present are usually less than 30 cm. thick. They tend to occur in restricted zones of relatively high concentration, where they are thinly interbedded with sandstones. They are micro-cross-laminated to laminated, and are erosionally bound; occasionally bedding is destroyed by bioturbation.

Shale clasts constitute the only pebble-size sediment in these rocks; lithic conglomerates are absent. Shale-clast conglomerates average 15-20 cm. in thickness, and often occur just above shale beds. Many clasts are quite angular, and probably have been transported only short distances. A few examples of direct derivation of shale clasts from erosion of shale beds are visible 30-35 meters above the base of the exposure.

Nearly all sandstones are cross-bedded. Although trough cross-stratification is the more common type, significant planar cross-bedded rocks are present. The planar sets reach a meter in thickness, are bordered above and below by erosion surfaces, and occur both as solitary sets surrounded by trough cross-bedded rocks, and as grouped cosets of two to three meters thickness. Foresets are inclined at generally low angles.

Trough cross-bedded sets are usually less than 50 cm. thick, and are grouped into cosets which range up to a meter. Directions of foreset inclination are similar throughout the unit.

Scour features are abundant in this lithofacies, but are limited to boundaries between sets and cosets of cross-strata. Substantial channels, with relief of more than 30-40 cm., are rare to absent.

The lithofacies is separable into lower and upper red, and middle green-gray, units. The nature and size of bedding and other sedimentologic properties show no visible variations between these color units.

The contact between lithofacies F and the overlying Silurian Tuscarora Formation is marked by a color change from dark red to white, and involves interlayering of beds of progressively lighter colors. The color lightening (to various shades of buff, tan and pink) is due to dilution of the available red hematite pigment.

No significant differences in the kinds of sedimentary structures are apparent across the boundary. However, abundances of various structures do show differences. The Tuscarora contains more planar cross-strata, in generally thicker sets, than lithofacies F. Also, the relative abundance of fine-sediment beds is less in the Tuscarora. The differences are relatively subtle, and question whether the two units represent different depositional environments is not totally answered at this outcrop.

Appendix 3: From Cotter, Edward, 1982, Tuscarora Formation of Pennsylvania, Field Trip Guidebook, Society of Economic Paleontologists and Mineralogists, Eastern Section, p. 76-83.

STOP 5. JACK'S MOUNTAIN CREST

Western cross-laminated lithofacies.

Jack's Mountain is a homoclinal ridge, made up of the Tuscarora Formation dipping to the southeast. From this point one can look to the southeast to Blue Mountain (Blacklog Mountain). As Blue Mountain trends to the northeast (left) it gradually descends as the anticline plunges. This is one of the two offset, oppositely plunging anticlines between which the Juniata River passes south of Lewistown (refer to mile 5.2 of morning road log). On the other side of Jack's Mountain, one can look to the northwest across Kishacoquillas Valley (Big Valley) to Stone Mountain.

Lithology

Only sandstone is exposed; most is medium- to coarse-grained quartz arenite; small percentage of chert and rock fragments; moderately well sorted. Granule and pebble lags common at the tops of many sandstone beds (Fig. 28B). Some surfaces show numerous intraclasts of very fine sandstone or siltstone.

Bed Geometry and Sedimentary Structures

Upper surfaces show elongate, sharp crests and broad swales (similar to those of Stop 4); orientation approximately NW-SE; cannot be tectonic flexures (internal laminae not flexed).

Upper surfaces also show the arcuate patterns of trough cross lamination; many indicate transport to the NW, but all other quadrants also noted. Thus, much sediment transport was parallel to direction of crestal elongation (NW).

Some cross lamination is more planar, with transport also to the northwest.

Within some thicker beds showing surface crests cross lamination is lower angle and directed to the NE; several beds show structures under the crests similar to the "chevron upbuilding" of deRaaf and others (1977).

A number of beds are penetrated by the vertical shafts of *Skolithos* (see Fig. 28A); *Arthrophycus* is uncommon here.

General Procedure for Examination

A. Within 50 meters of parking area:

Number of sharp crests and broad swales elongated to NW. Note directions of transport indicated by arcuate patterns: some normal to crests; some parallel

Laterally extensive cross laminae in bed burrowed by Skolithos (above two white dots on outcrop); also has gravel lag on upper surface. Note bipolar cross lamination:

Skolithos-burrowed bed cross laminae inclined to NW
Bed below this is thicker and inclined to SE.

About 20 m along (near 3 white dots), more distinct Skolithos shafts into bed with laminae inclined to NE; superimposed on this (see upper surface) is cross lamination directed NW.

B. Near highway sign warning trucks of steep hill:

Many upper surfaces show bed-top gravel lags.
Complexity of upper surface forms (including sharper crests and broader swaley troughs).

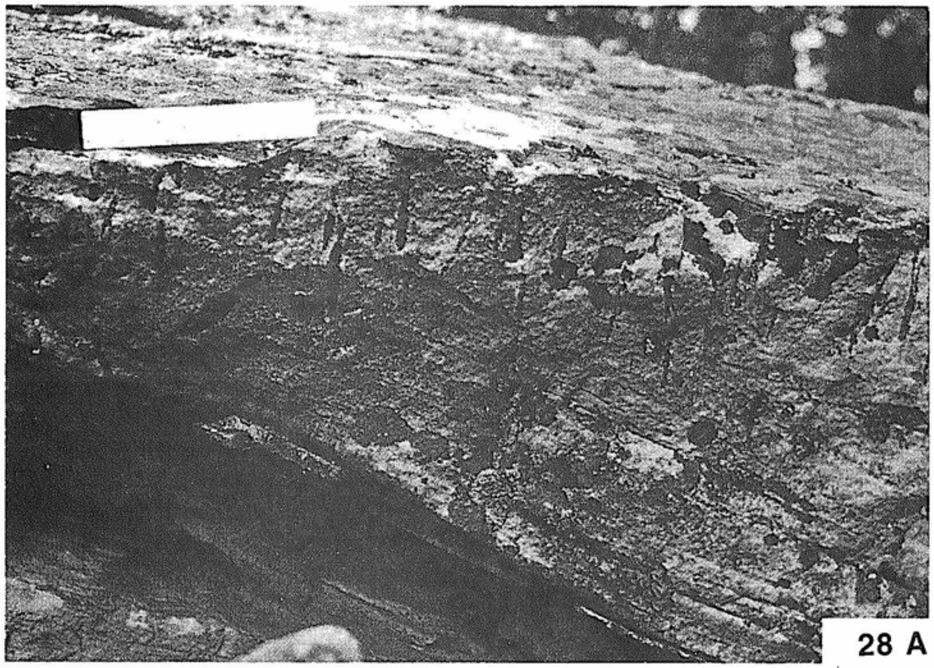
Varied directions of sediment transport shown by patterns of arcuate laminae.

C. About 50 m beyond highway sign to just before dwelling:

Complex upper surfaces, with some sharper crests and elongate swales.

Gravel lags on the tops of beds, some appear streaked out in direction parallel to trough axes and/or along crests. (see near one and two painted white dots)

Dominant direction of sediment transport was toward NW; does the part near the four white dots indicate bipolar transport?



28 A

28 B

Figure 28. Features at crest of Jack's Mountain southwest of Belleville, Pa. (Stop 5). Scale is 15.2 cm long.

28A. **Skolithos** vertical shafts into top of cross-laminated sandstone; western cross-laminated lithofacies.

28B. Gravel lag on upper surface of sandstone bed; western cross-laminated lithofacies.

STOP 6. KISHACOQUILLAS GAP IN JACK'S MOUNTAIN

Basal horizontally laminated lithofacies intercalated with eastern cross-laminated lithofacies.

CAUTION! Very narrow margin of busy highway. Please stay off the road pavement.

The significance of the Juniata-Tuscarora transition zone here can be considered in three parts. First of these is the evidence for the development of beach depositional conditions at the beginning of Tuscarora time. At the proximal locations of Stops 2 and 3 we considered the importance of this evidence of basal transgression to a reinterpretation of the origin of the Tuscarora. This is the first of three stops today at which we shall find that beach conditions occurred at the base of the Tuscarora at distal localities also. In fact, at essentially every exposure of the base of the Tuscarora in central Pennsylvania there is clear evidence of coastal deposition that took place during the basal transgression.

A second significant aspect of this section is the demonstration of the interrelationships between braided fluvial systems and the wave-dominated beaches. River deposition began the accumulation of the Tuscarora, but the transgressing beach system modified the sublitharenitic sand into quartz arenitic horizontally laminated deposits with symmetrical ripples. The rivers again prograded over these beaches, only to be reworked another time into horizontally laminated, symmetrically rippled quartz arenite. The distal, near-coastal location of the braided rivers is shown by the presence of Skolithos burrows and an occasional SE-directed set of cross laminae. The compelling drama of this story cannot be brought to a climax, for the depositional environment of the strata immediately above the second beach unit is not certain. The decision to identify it as of shelf sand wave origin was based on the relative compositional and textural maturity and on analogy with the situation at Seven Mountains (Stop 7). However, the evidence at this locality is inconclusive.

The third sedimentological significance of this section is the evidence that the uppermost Juniata Formation was influenced by marginal marine conditions. Skolithos, and possibly another, larger vertical biogenic structure (Diplocraterion?), occur over a significant stratigraphic range of the Juniata. The lowest noted is down near the bridge (Bed 11), but as the contact with the Tuscarora is approached (contact placed between Beds 70 and 71), occurrences of Skolithos are more common and profuse (for example, see Bed 66). These biogenic structures in the Juniata Formation are likely to have formed in coastal bodies of water just landward of the coastline. As in the present situation of Holocene transgression, rising sea level results in inundation of low-lying parts of the coastal plain landward of the beaches. Conditions of river flooding can introduce braided fluvial sediment into these marginal coastal areas. Between river floods, the Skolithos-making organisms recolonize the very shallow coastal ponds. It would be very difficult to explain the origin of the biogenic structures in a terrestrial river flood plain setting, both because of the filter-feeding nature of the Skolithos-making organisms, and because of the absence of known land animals in Early Silurian time.

This measured section shows the basic relationships of the section at the base of the Tuscarora. Some diagnostic features are labeled on the diagram and a number of others are stated below. The bed numbers referred to below are those painted in white by some earlier worker on this sequence.

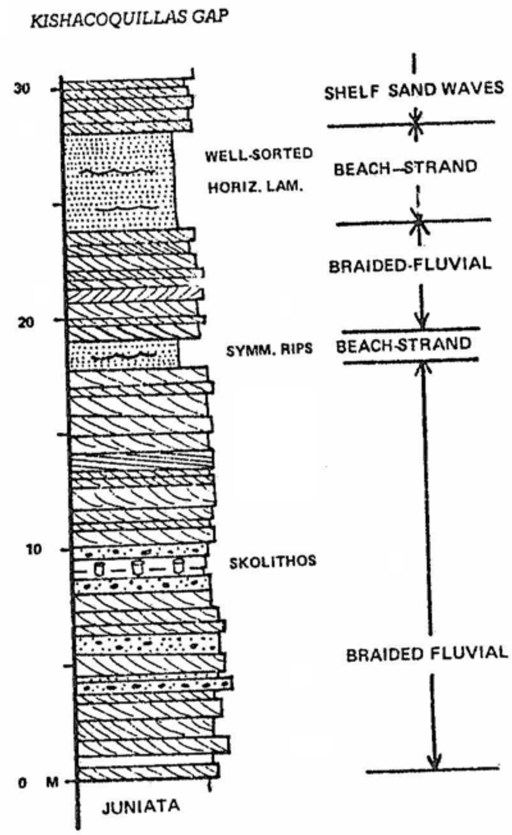


Figure 29. Stratigraphic section of basal Tuscarora at Kishacoquillas Gap (Stop 6).

Lowest Tuscarora Cross-Laminated Unit (Beds 71-81)

The contact with the Juniata Formation was placed at the base of Bed 71 because at that point the sandstone takes on the characteristics of the strata below and above the horizontally laminated unit (Bed 82), and the thin interbedded shales become nonred. This lowest unit consists of medium- to coarse-grained sublitharenite (Fig. 30A). A number of beds are very coarse, and granule sizes are present along set boundaries and cross laminae. There is a suggestion of broad channeling. Shale interbeds are few and poorly exposed, and some of the sandstone beds contain scattered shale intraclasts. Well-developed Skolithos burrows occur in Bed 77. No southeasterly-directed cross laminae were noted in this unit.

Lower Horizontally Laminated Unit (Bed 82)

Bed 82 is largely fine- to medium-grained quartz arenite with horizontal lamination, wavy lamination, and symmetrical ripples. The changes in composition, texture, and structures parallel those noted at Waggoner's Gap (Stop 2) and at Roxbury (Stop 3). Depositional processes were of sufficiently high energy to generate the upper flow regime lamination typical of the beach swash zone, as well as to modify the texture and composition toward greater maturity. However, thin sections of this unit (Fig. 30B) reveal that there is not as extensive a modification of the sedimentological maturity as at those earlier stops. This thin unit was deposited in a beach depositional system. How much thicker the depositional record of this beach system was cannot be determined. It is possible that contemporaneous shoreface erosion during the temporary transgression truncated it.

Middle Cross-Laminated Unit (Beds 83 and 84)

This unit returns to the coarser grained, cross-laminated sublitharenite typical of Beds 71 to 81. Sorting is poor (Fig. 30C). Cross laminae indicate that the dominant direction of sediment transport was to the northwest. However, one set of cross laminae just at the base of Bed 83 was generated by flow toward the southeast (sourceward). Features of this unit are consistent with deposition in distal braided fluvial environments close to the beach systems. The sourceward-directed paleocurrent testifies to the influence of storm-generated surge upriver or possibly some tidal flow. It would not be surprising to find Skolithos burrows in this marginal-marine fluvial sequence.

Upper Horizontally Laminated Uniot (Beds 85 , 86 and 87)

Nearly 4 meters of fine- to medium-grained, well-sorted quartz arenite (Fig. 30D) marks the second record of beach deposition. Lamination is mostly horizontal (even parallel) to slightly wavy. Symmetrical ripples can be seen in cross section. There are no coarse sand or gravel sizes and no intraclasts. The modified composition, the finer grain size, the better sorting, and the particular sedimentary structures all mark this as of beach origin, not a matter of upper flow regime fluvial flow origin.

Upper Cross-Laminated Unit (Beds 88 and Higher)

Above the second beach unit the section consists of medium to thick beds of cross-laminated medium, coarse, and very coarse-grained sandstone. Very thin shales are interbedded in places. There are no criteria to determine whether this unit is of fluvial or of shelf origin, however, by comparison with Stops 7 and 8, and because of somewhat better sorting and compositional maturity (Fig. 30E) than underlying cross-laminated units, this unit is labelled shelf in origin.

Figure 30. Photomicrographs of sandstones at base of Tuscarora at Kishacoquillas Gap (Stop [illegible]); see Fig. 29 for units. Scale for all photos: narrow dimension is 3.7 mm.

30A. Lowest cross-laminated sandstone just above Juniata Formation (Bed 80).

30B. Lower horizontally laminated sandstone (Bed 82).

30C. Middle cross-laminated sandstone (Bed 84).

30D. Upper horizontally laminated sandstone (Bed 85).

30E. Upper cross-laminated sandstone (Bed 88).

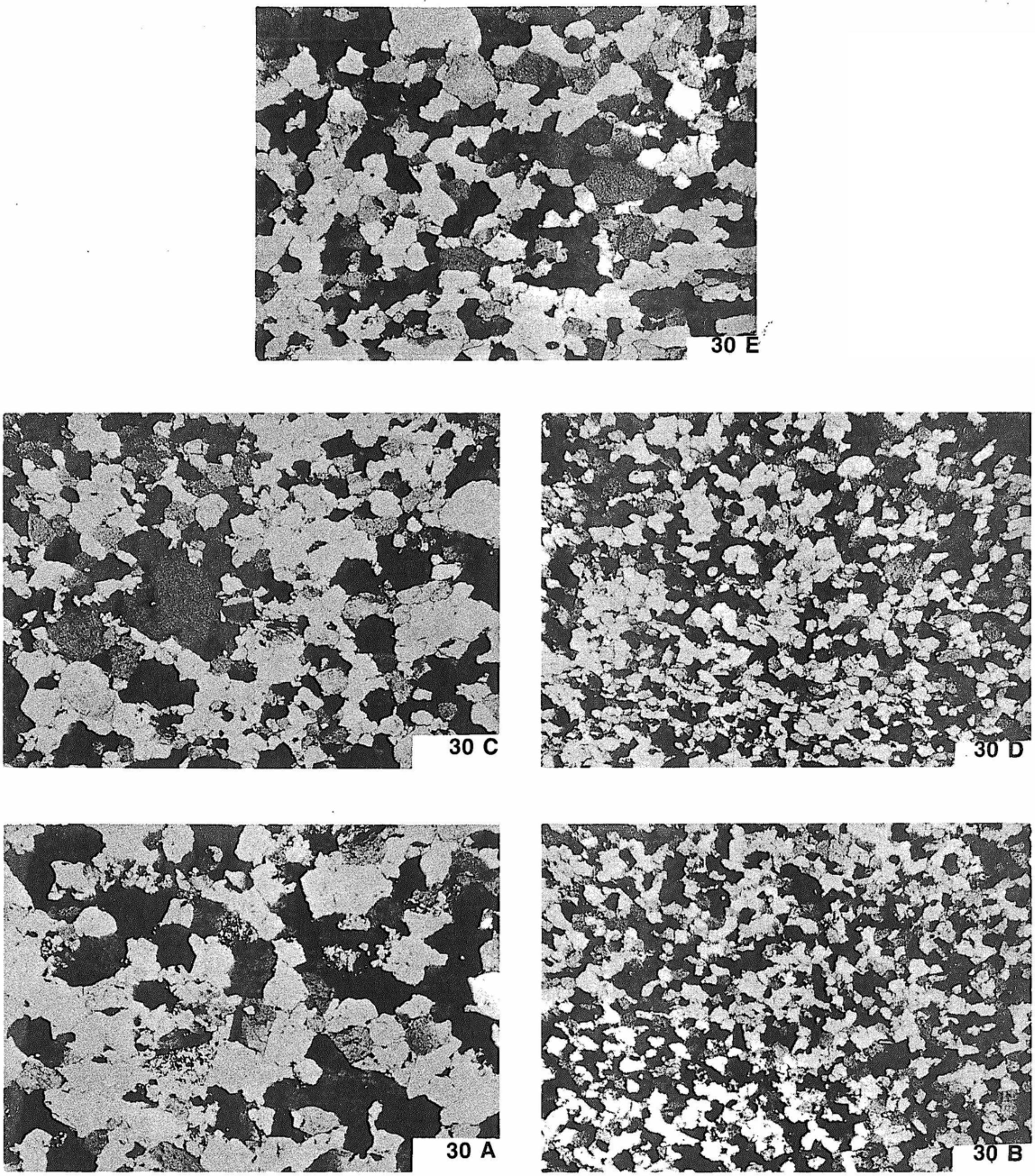


Figure 30

Appendix 4: From Rones, Morris, 1969, A lithostratigraphic, petrographic and chemical investigation of the Lower Middle Ordovician carbonate rocks in central Pennsylvania, Pennsylvania Geological Survey, 4th ser., General Geology Report 53, 224 p.

SECTION 37—ALLENSVILLE

Section is on the Allensville, Pennsylvania, map (scale 1/62,500), 9,000 feet south of 40°35′ latitude and 8,500 feet east of 77°50′ longitude. The exposures are in an abandoned roadside quarry at the first right-angle bend in the road approximately 2,500 feet north of the intersection with Route 76. Allensville is 9,000 feet further southwest from the intersection but along Route 76. The measured part of the section starts immediately above the highest quarry exposures of limestone which are in the basal coarse crinoidal and cherty beds of the Rodman Member. The section descends stratigraphically southeastward to the basal oölite beds of the Snyder Limestone. Beds strike N30°E, dip 20°NW.

	Thickness (feet) Bed	Total
TRENTON GROUP		
NEALMONT LIMESTONE		
Rodman Member		
Concealed; upper coarse crinoidal limestone; probable thickness.	25	26
Limestone, 6-inch irregular bedded, medium-gray (N 5), coarse crinoidal limestone; nodular black chert.	1	1
Probable thickness of Rodman Member.		26
Centre Hall Member		
Limestone, 2-inch to 1-foot irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite; mostly float.	23	44
Bentonite; shaly yellow clay (N_3).		
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite.	5½	21
Limestone, 2-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	2	15½
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite.	6	13½
Limestone, 2-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	3	7½
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite; numerous shaly to clayey partings.	3	4½
Limestone, 1½-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	1	1½
Shaly parting?		
Thickness of Centre Hall Member.		44
UNCONFORMITY. Basal Nealmont and Upper Stover absent.		
HUNTER GROUP		
LINDEN HALL LIMESTONE		
Stover Member		
Limestone, 3-foot bedded, medium-dark-gray (N 4), coarse calcilutite to calcisiltite; numerous silty (probably dolomitic) part-		

SECTION 37—ALLENSVILLE

Section is on the Allensville, Pennsylvania, map (scale 1/62,500), 9,000 feet south of 40°35′ latitude and 8,500 feet east of 77°50′ longitude. The exposures are in an abandoned roadside quarry at the first right-angle bend in the road approximately 2,500 feet north of the intersection with Route 76. Allensville is 9,000 feet further southwest from the intersection but along Route 76. The measured part of the section starts immediately above the highest quarry exposures of limestone which are in the basal coarse crinoidal and cherty beds of the Rodman Member. The section descends stratigraphically southeastward to the basal oölite beds of the Snyder Limestone. Beds strike N30°E, dip 20°NW.

	Thickness (feet) Bed	*Total*
TRENTON GROUP		
NEALMONT LIMESTONE		
Rodman Member		
Concealed; upper coarse crinoidal limestone; probable thickness.	25	26
Limestone, 6-inch irregular bedded, medium-gray (N 5), coarse crinoidal limestone; nodular black chert.	1	1
Probable thickness of Rodman Member.		26
Centre Hall Member		
Limestone, 2-inch to 1-foot irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite; mostly float.	23	44
Bentonite; shaly yellow clay (N_3).		
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite.	5½	21
Limestone, 2-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	2	15½
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite.	6	13½
Limestone, 2-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	3	7½
Limestone, 2-inch irregular bedded, medium-dark-gray (N 4), fossiliferous coarse calcilutite; numerous shaly to clayey partings.	3	4½
Limestone, 1½-foot bedded, medium-dark-gray (N 4), coarse calcilutite.	1	1½
Shaly parting?		
Thickness of Centre Hall Member.		44

UNCONFORMITY. Basal Nealmont and Upper Stover absent.

HUNTER GROUP

LINDEN HALL LIMESTONE

Stover Member

Limestone, 3-foot bedded, medium-dark-gray (N 4), coarse calcilutite to calcisiltite; numerous silty (probably dolomitic) part-

	Thickness (feet) Bed	Total
ings; 7-inch lensing coarse calcarenite bands occur throughout unit as follows: 11½, 15, 17, 19 and 26 feet from top of unit.	30	30
Thickness of Stover Member.		30
SNYDER LIMESTONE		
Upper bioclastic beds (H)		
Limestone, 2-foot bedded, medium-dark-gray (N 4-5), coarse bioclastic calcarenite.	2	14½
Limestone, 1-foot bedded, medium-dark-gray (N 5), fine calcarenite, predominantly "mud-pellet" to oölitic.	2¼	12½
Limestone, 1-foot bedded, medium-gray (N 6), white-weathering fine calcilutite; numerous stylolitic partings; scattered bioclastics.	3¼	10¼
Limestone, 6-inch bedded, medium-dark-gray (N 4-5), fine to medium calcilutite.	½	7
Limestone, 1-foot bedded, medium-gray (N 6), fine calcilutite to fine calcarenite with some scattered to mottled irregular streaks; numerous white-weathering pebbles of fine calcilutite in a "mud-pellet" groundmass.	2½	6½
Concealed; scattered exposures of bioclastic calcarenite.	4	4
Thickness of (H) beds.		14½
Mud-cracked beds (G)		
Limestone, 1-foot bedded, medium-gray (N 6), bioclastic calcarenite with scattered white-weathering pebbles of fine calcilutite; tendency for separation into 2-inch beds along ¼-inch clayey mud-cracked bands.	3	10
Limestone, 2-inch bedded, medium-gray (N 4-6), bioclastic calcarenite with numerous white-weathering pebbles of fine calcilutite; beds appear to be mud-cracked with separation along clayey ¼-inch bands.	7	7
Total thickness of (G) beds.		10
Upper "dolomitic" beds (F) and chemical lime beds (E-D)		
Limestone, 1-foot bedded, medium-gray (N 6), white-weathering fine calcilutite.	1	23
Concealed.	4	22
Limestone, 1-foot bedded, medium-gray (N 5), laminated slightly dolomitic medium calcilutite; dolomitization appears along clay laminae.	7	18
Limestone, 2-foot bedded, medium-gray (N 6), white-weathering fine calcilutite.	3	11
Limestone, 2-foot bedded, medium-gray (N 5), laminated somewhat dolomitic fine to medium calcilutite.	4	8

	Thickness (feet) Bed	Total
Limestone, 2-foot bedded, medium-gray (N 6), white-weathering calcilutite.	4	4
Thickness of (F, E, D) beds (beds become predominantly (D) chemical limestone type).		23
Lower bioclastic beds (C) and oölitic beds (A)		
Limestone, 2-foot bedded, medium-dark-gray (N 5), bioclastic calcarenitic—base concealed.	2	24
Concealed.	20	22
Limestone, 1-foot bedded, medium-dark-gray (N 4), fine grained calcarenite, predominantly oölitic.	2	2
Thickness of (C-A) beds.		24