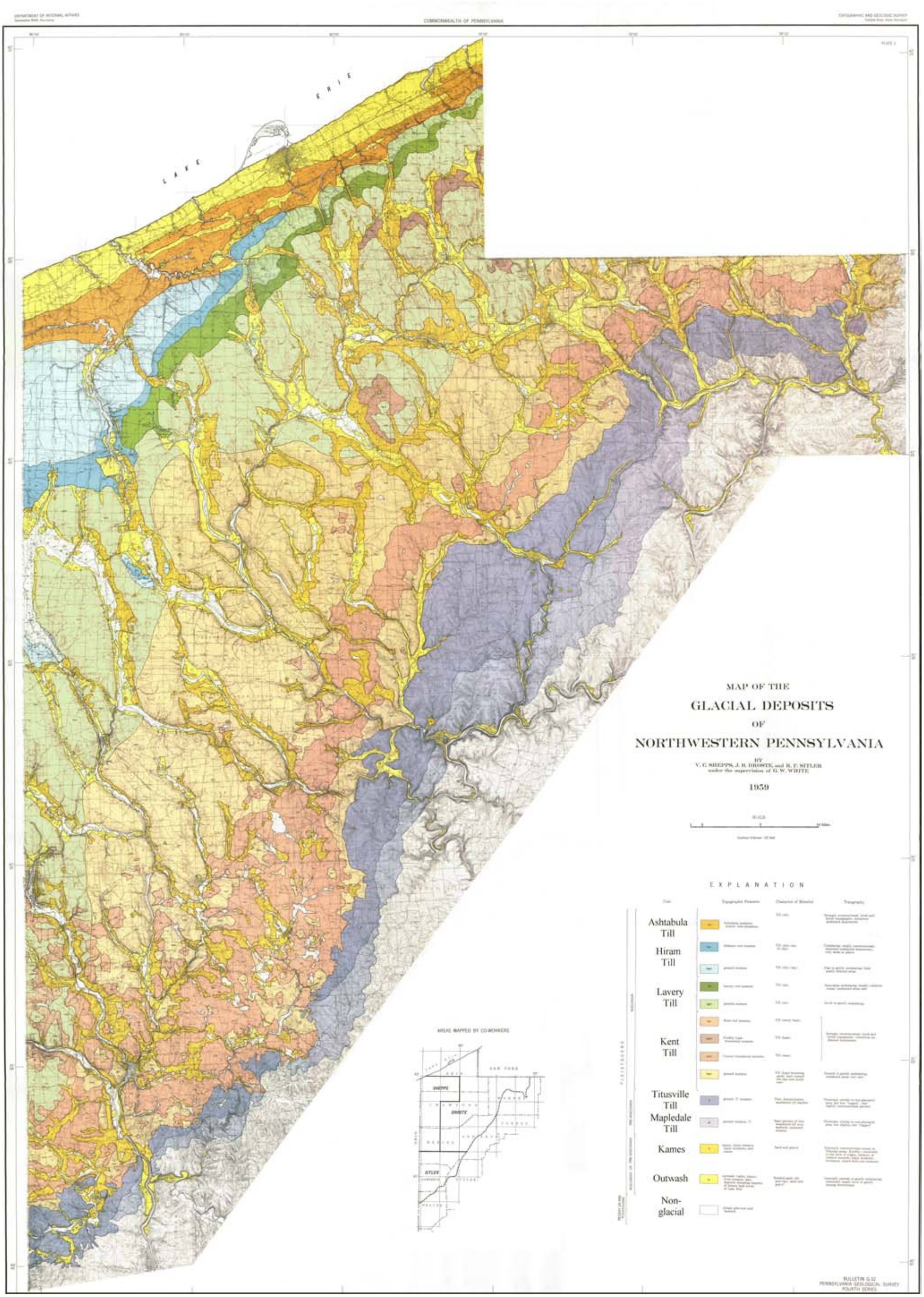
Type Sections and Stereotype Sections

Glacial and Bedrock Geology

in Beaver, Lawrence, Mercer, and Crawford Counties

70th Field Conference of Pennsylvania Geologists — October 13 – 15, 2005

Host: Pennsylvania Geological Survey — Sharon, Pennsylvania



Map of the glacial deposits of northwestern Pennsylvania. Modified from Shepps and others (1959).

Guidebook for the

70TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

TYPE SECTIONS AND STEREOTYPE SECTIONS:
Glacial and Bedrock Geology in Beaver, Lawrence, Mercer, and Crawford Counties

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IN REMEMBRANCE

WILLIAM J. MARKS, GEOLOGIST

(1951–2004)

The Pennsylvania geologic community lost a good friend and valued colleague with the untimely death of William (Bill) J. Marks on June 15, 2004, due to cancer. He was 53 years old. Bill was involved in some of the early planning for this year's Field Conference and had expected to be one of its trip leaders, focusing on the geology of the Vanport marine limestone that he knew so well from his experiences and upbringing in Lawrence County, Pennsylvania. Bill also recognized the significance of the "CVS fold" at STOP 8 of this year's conference and first brought it to the attention of the staff of the Pennsylvania Geological Survey.

Bill was a Licensed Professional Geologist with the Bureau of Abandoned Mine Reclamation, Cambria District Office (Ebensburg), Pennsylvania Department of Environmental Protection (PaDEP), and a Registered Professional Geologist in Pennsylvania. He began his professional career in geology full time in 1984 when he accepted a position with the former Pennsylvania Department of Environmental Resources. Bill was responsible for the design and implementation of drilling projects (both diamond core and air rotary) to identify and document subsidence caused by former underground mining operations (principally coal), or to determine the areal extent and effects of underground mine fires. Along with professional engineers and others, Bill also made recommendations on how best to remediate these environmental hazards. During the Quecreek Mine accident, Somerset County, in July 2002, Bill provided geologic expertise on site to PaDEP Secretary David E. Hess and to Governor Mark S. Schweiker, and contributed information to *The New York Times*.

Early in his career, Bill contacted the Pennsylvania Geological Survey for information and guidance, and from that time forward, maintained a close personal and professional relationship with several Survey staff members. On a number of occasions, he deepened core holes and sampled coals and fossils (for subsequent analysis) on behalf of the Survey to further understanding of the regional stratigraphy and mining history. He also maintained and made available to the Survey open boreholes for geophysical logging prior to their plugging. Moreover, Bill often released rock cores to the Pennsylvania Geological Survey for examination and preservation, once they were no longer needed by the PaDEP, and he often assisted in the arrangement of transportation of the cores to the Survey warehouse.

Bill generally followed Survey methods and procedures to describe cores and cuttings and routinely sent the results of his project work to the Survey for its use. He had a strong interest in the identification and collection of fossil fauna and flora from the coal-bearing strata and older rock units of western Pennsylvania. He surrounded himself with fossils of all kinds, even building a wall and attached fireplace in his home from sandstone that contained numerous casts of fossilized tree trunks, logs, and branches. He was particularly knowledgeable about the Vanport limestone in the lower Allegheny Formation. Among his publications, he was senior author of a paper in *Pennsylvania Geology* (1998, v. 29, no. 2/3, p. 2–6) entitled "Problematic Tracks in the Casselman Formation of Cambria County," which suggested that a fossil trackway Bill identified probably represented walking traces of a giant myriapod (an arthropod having an elongate, annelid-like body and many similar pairs of appendages). Myriapods include such modern-day jointed-leg invertebrates as millipedes and centipedes. He also compiled a handy, representative columnar section of the geology of the Main Bituminous coalfield of western Pennsylvania.

Bill was born on May 16, 1951, in New Castle, Pennsylvania, and graduated from New Castle High School in 1969. He then worked on fishing boats in the Great Lakes. Thereafter, he joined the U.S. Marine Corps as a Combat Engineer and served a tour of duty in South Vietnam during the

Vietnam War. Honorably discharged from the military, Bill later attended Slippery Rock University, paying for his education by working as a truck mechanic. He graduated in 1981 with a bachelor's degree in geology. He then took a job as a mud-logger on offshore drilling platforms in the Gulf of Mexico before joining the Pennsylvania Department of Environmental Resources. Bill was an avid, self-taught musician, playing both the banjo and guitar. He loved to travel, sojourning in the Easter Islands, Australia, western United States, and elsewhere. He had a special interest in the history of the Easter Islands and the ecologic damage by natives that occurred there prior to the area's discovery by Europeans. Bill loved motorcycles and was a wealth of information about them. He owned two Harley-Davidsons—both a 1950s classic and a late-model one for general riding.

Bill was passionate about his profession and compassionate about people. He loved to educate and share his knowledge. Likewise, he loved to learn. Honesty and integrity were fundamentally important to him. He had a gusto for life and a marvelous sense of humor. Bill is survived by his parents, three sisters, and a daughter. He is greatly missed.

Clifford H. Dodge, P.G.

Senior Geologist

Pennsylvania Geological Survey

Bill Marks (left) and Cliff Dodge sorting through boxes of drill core, March 6, 2002. (Photograph by James R. Shaulis, Pennsylvania Geological Survey.)

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Introduction

Welcome to Sharon, Pennsylvania and the 70th annual Field Conference of Pennsylvania Geologists. The headquarters hotel is actually at West Middlesex, birthplace of Alf Landon, who lost the 1936 presidential election to Franklin Delano Roosevelt.

Sharon was until the early 1980s an important industrial center. It has today earned recognition and a small amount of tourist dollars through the somewhat dubious promotion of a number of "world's largest"s, including the "world's largest" shoe store, candy store, bar specializing in chicken wings, off-price fashion store, and American Civil War style plantation not located in the Deep South. Much of this is the brainchild of local entrepreneur James E. Winner Jr., who also made Sharon famous through his invention of The Club, a very popular auto-theft prevention device.

Sharon is also the birthplace of Chilly Billy Cardille, the news reporter in George Romero's *Night of the Living Dead* (1968), and long-time host of *Chiller Theater"* in Pittsburgh (see the name of the leader of STOP 7, where a sequel to *Night of the Living Dead* , starring Chilly Billy's daughter, Lori, was filmed).

Sharon is the home of the Vocal Group Hall of Fame and a campus of Pennsylvania State University.

(The above modified from http://en.wikipedia.org/wiki/Sharon,_Pennsylvania)

The 2005 Field Conference is only the sixth Field Conference headquartered in northwestern Pennsylvania- two in Titusville (1959 and 1976), two in Erie (1987 and 1998), and Warren (1992)- so this area has been sorely underrepresented in the Field Conference. Three other Field Conferences, headquartered in Pittsburgh (1934, 1950, and 1965), ventured into the southern edge of northwestern Pennsylvania.

Two of this year's stops were visited by previous Field Conferences. STOP 1 was visited by the 1965 Field Conference and STOP 4B in 1959.

We will look at both glacial geology and bedrock geology in this year's Field Conference. Day 1 will take us north from Sharon to stops in Mercer and Crawford Counties. Day 2 will take us south into Beaver and Lawrence Counties.

One of the glacial stops is a surprisingly complex outcrop of glaciolacustrine sediments. A lake bluff section at Pymatuning Reservoir, in Pymatuning State Park, contributes to the understanding of the glacial history of northwestern Pennsylvania, as well as the mode of deposition of widespread, homogeneous till sheets, and problems of lakeshore erosion. The third glacial stop addresses the problem of how to identify tills deposited by separate glaciations, versus multiple thin till sheets deposited by a single glacial event.

The Homewood and Connoquenessing Formations have come to be associated with thick sandstone sequences. However, as we will see, there is great lateral variability within the Pottsville Group, and the association with sandstones is a stereotype. As frequently as not, there is little or no sandstone at these horizons. As a result, their type sections could reasonably be called stereotype sections.

The bedrock stops include two type sections: the Mercer, described in the 1800s by H. B. Rogers of the First Pennsylvania Geological Survey and later by I.C. White of the Second Survey; and the Homewood, described by I. C. White. They will serve to illustrate the challenges that these early workers faced in working with the meager exposures of the day. Stratigraphic interpretation of these highly variable rocks was very difficult because of the lack of good data. Other bedrock stops will look at newer large exposures of these same units that will provide a more accurate representation of the key beds in this part of the section. We will also visit an outcrop of the best stratigraphic marker bed in the area, the extensively mined Vanport Limestone.

An additional stop was included because of its rarity in this part of the state. An asymmetric anticline, with multiple thrust faults, is unexpected this far west onto the Appalachian Plateau. Were we to encounter this structure in the Ridge and Valley, we would not be so surprised. Its presence in New Castle warrants a Field Conference stop.

Acknowledgements

Although this year's Field Conference is being run by a relatively small number of people (compared to some recent Field Conferences), many have contributed to its (hoped for) success.

Duane Braun, Jon Inners, Sarah Principato, W.D. Sevon, and John Szabo reviewed the glacial article and stop descriptions. Their suggestions and comments greatly improved the content of those articles.

Jon Inners and Chris Kochanov assisted with the road log.

Bill Bragonier, Tim Miller, and Mike Shultz, of East Fairfield Coal Company, provided stimulating discussions with us in the field while we were developing our ideas for these stops. Bill, in particular, has not forgotten us little people still here at the Pennsylvania Geological Survey (Bill worked here a looong time ago). He has been extremely helpful to us in allowing us access to East Fairfield properties and frequently accompanying us in the field.

Emily Bragonier provided tickets to Pittsburgh Pirate baseball games in order for us to relax in the evenings after long, grueling days in the field preparing for this Field Conference. Those Primanti sandwiches hit the spot!

John Harper of the Pennsylvania Geological Survey played devil's advocate in a number of field discussions, especially at STOP 8.

John Barnes of the Pennsylvania Geological Survey provided X-ray analysis of samples from STOPS 7 and 10.

Casey Koenig, Quarry Manager for Essroc, was very accommodating in allowing us access to the Essroc quarries in the area, in order to look at the glacial sediments, in addition to the Vanport Limestone, as part of our preparations for this Field Conference. He was more than willing to allow us to bring the Field Conference to one or more of his quarries, but logistics (ours, not his) precluded our inclusion of them.

All of the stop landowners have been very cooperative- Harold Wise, Jr. (STOP 2), Doug Shannon (STOP 4A), Bruce Davis (STOP 5), Deborah Sudano of Meritex (STOP 7), and Patsy Armondo, CVS manager, and Linton Construction, the landlord at CVS (STOP 8). All other stops were on public land or road rights-of-way. The Pennsylvania State Police accommodated our parking needs at STOPs 10, 11, and 12.

The Cochranton Community Church and the Homewood Methodist Church permitted us to park the buses in their parking lots while we are at STOPS 2 and 6, respectively.

Pete Houghton and Dennis Mihoci, present, past, and past (don't ask) Managers of Pymatuning State Park generously agreed, weather permitting, to lower the level of Pymatuning Reservoir early this year for the benefit of the Field Conference. STOP 4B might have been quite uncomfortable otherwise. They also waived the reservation fee for the picnic pavilion for Friday's lunch, helping to keep registrations costs down.

Linda Armstrong, Environmental Education Specialist at Pymatuning State Park, ensured that STOP 4 would be free of litter, and that the picnic pavilion for our lunch at STOP 3 on Friday would be stocked with firewood for our use.

Tina Miles, Stuart Reese, and Tom Whitfield, of the Pennsylvania Geological Survey, provided GIS assistance.

Regina Rihn of Butler Motor Coach worked with us in resolving bus parking problems at STOP 1.

Denise Bell, Sales Manager at the Radisson Hotel of Sharon was very helpful in arranging lodging and the evening activities for the Field Conference.

The Mercer County Historical Society made their files available to us for researching the history and origin of the name Hell's Hollow (STOP 1).

Ahhlliizzaabbuutthh Lyon worked diligently to ensure that we would have our high-powered laser pointer in time for use at the Field Conference.

Thanks to the Pennsylvania State Police for not hauling Skema's butt off to jail when they were called to investigate the suicidal jumper on the US 422 roadcut (STOP 10), and to PennDOT for not hauling away all of the blocks full of geological features that fell from the STOP 10 roadcut during the winter.

The Pittsburgh Geological Society, Snyder Brothers Coal Company, and Michael Baker and Associates were very generous with financial contributions to help keep registration costs as low as possible.

SUMMARY OF THE GLACIAL GEOLOGY OF NORTHWESTERN PENNSYLVANIA

by
Gary M Fleeger
Pennsylvania Geological Survey

This year's Field Conference is in the heart of the Northwestern Glaciated Plateau Section of Pennsylvania. Glaciations in this area range in age from greater that 780,000 years to about 15,000 years. Only the Ashtabula, and maybe Keefus Tills do not extend as far south as the Field Conference area. We will have the opportunity to observe the Hiram, Lavery, Kent, and Titusville Tills. Our discussions will focus on problems of the identification of the various tills, the mode of till deposition, the aerial extent of some of the tills, and weathering patterns. All of the glacial stops will be within the border of the Late Wisconsin Episode.

Previous Studies

The First Pennsylvania Geological Survey disclaimed the existence of glaciation and attributed glacial deposits to great floods (Rodgers, 1858, page 775; Lesley, 1876, pages 24, 86, and 172).

J.P. Lesley, director of the Second Survey became a believer in glaciation in the 1850s, after learning of Louis Agassiz' (1840) work (Lesley, 1876). All of the Second Survey corps adhered to the glaciation concept. The county and regional reports of that Survey included descriptions of the drift. H.C. Lewis' report on the terminal moraine in Pennsylvania and western New York (1884) is probably the first report solely about glaciation in northwestern Pennsylvania. Early glacial studies in Pennsylvania also included those of Wright (1890) and Leverett (1902, 1934).

In the early 1930s, George W. White began a 50-year study of the glacial deposits of the Appalachian Plateau. He started in Ohio and moved into northwestern Pennsylvania from 1952 to 1969. The studies by White, his students at the University of Illinois at Urbana-Champaign, and associates resulted in the first detailed mapping of the distribution of glacial deposits in northwestern Pennsylvania (Shepps and others, 1959). Formal lithostratigraphic names of formation rank were applied to most of the tills. A detailed stratigraphic study (White and others, 1969) formally named the remaining tills known at that time, and more thoroughly characterized the texture, composition, stratigraphic position, and morphology of the various tills. White's report on the glacial geology of northeastern Ohio (1982) named the last known till in the Grand River lobe and summarized his 50 years of work on the Appalachian Plateau.

Since White and others' (1969) work, there have been few publications on the glacial geology of northwestern Pennsylvania. Most have involved local studies of drainage diversion and pro-glacial lake systems (Preston, 1977), or remapping small areas of northwestern Pennsylvania (Ward and others, 1979; Sevon, 1995). Students from several colleges and universities, mostly in northwestern Pennsylvania have mapped or studied small areas. Allegheny College and Mercyhurst College probably have been most active with such projects.

Currently, two three-dimensional (3-D) mapping projects are underway in the Bessemer (near New Castle) and Meadville 7½' quadrangles. These projects will build on previous mapping that show the glacial materials at the surface by mapping all of the surficial sediments from the ground surface to the bedrock surface. Drift thickness, bedrock topography, and geologic maps will result from these mapping efforts. 3-D mapping has been underway for a number of years in several Midwestern states, but this is the first attempt in Pennsylvania.

Fleeger, G.M., 2005, Summary of the glacial geology of northwestern Pennsylvania, *in*, Fleeger, G.M. and J.A. Harper, eds., Type sections and stereotype sections: glacial and bedrock geology in Beaver, Lawrence, Mercer, and Crawford Counties, Guidebook, 70th Annual Field Conference of Pennsylvania Geologists, Sharon, PA, pp. 1 - 11.

Temporal Classification

Temporal classification of glacial events has evolved over the years, starting with Chamberlain (1894). Stratigraphic codes in the United States attempted to include classification of glacial deposits (Ashley and others, 1933; ACSN, 1961; NACSN, 1983). Johnson and others (1997) provide a complete background analysis of the evolution of the classification of glacial deposits.

One of the common practices has been to assign tills and other glacial sediments to geochronologic units with time-parallel boundaries. However, the boundaries of glacial deposits are diachronous, or time-transgressive, and may cross over the boundaries of geochronologic units (Figure 1). For example, the Titusville glaciation started earlier and ended later in Erie than in Titusville. Weathering on the Titusville Till that resulted in the Sangamon paleosol started immediately upon retreat of the glacier from a location. Therefore, it began earlier in Titusville than in Erie.

In 1997, Johnson and others proposed a new classification and nomenclature, retaining, as much as possible, names that are well established. This classification uses diachronic units, as defined in the 1983 North American Stratigraphic Code. Since the adjective form of names has been used for many years when referring to geochronologic and chronostratigraphic units, the noun form is applied to the new diachronic units to distinguish those units from the chronostratigraphic and geochronologic units.

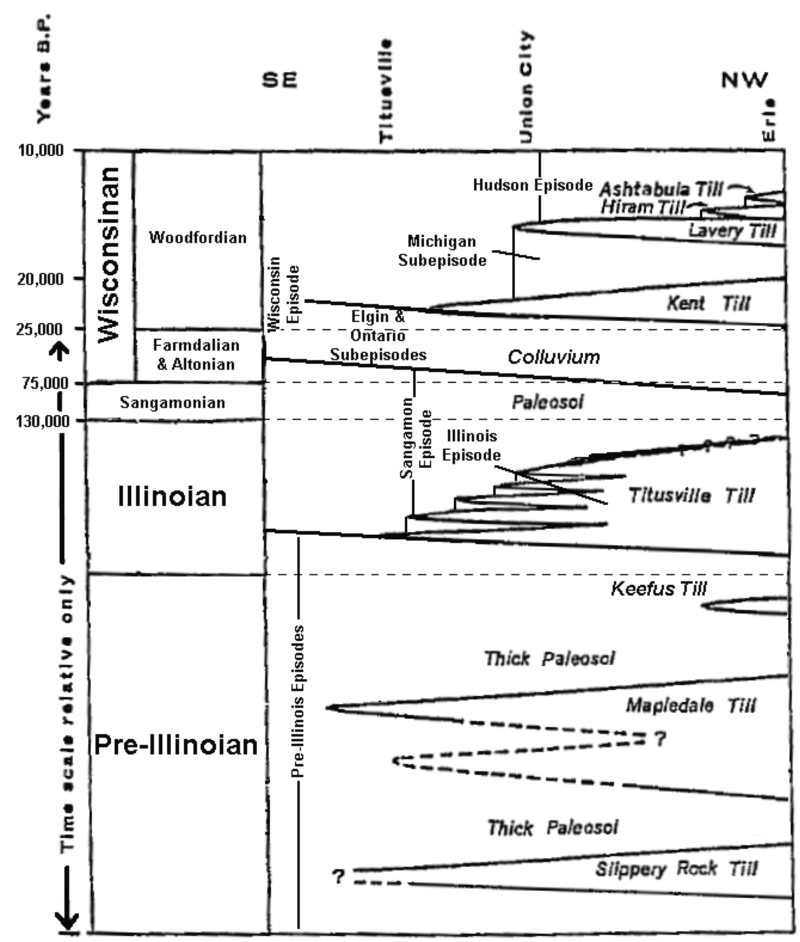

Figure 1- Time-distance diagram showing the stratigraphic classification of the glacial deposits of northwestern Pennsylvania. The adjectival names are geochronologic and chronostratigraphic names (ages/stages and subages/substages). The noun names are diachronic units (episodes and subepisodes). The Keefus Till is shown, even though it has never been seen in place in Pennsylvania. Modified from White and others (1969).

In northwestern Pennsylvania (Figure 1), the major diachronic units are the Hudson Episode, Wisconsin Episode, Sangamon Episode, and Illinois Episode (Johnson and others, 1997). In the northern and eastern Great Lakes area, the Wisconsin Episode is subdivided into the Michigan, Elgin, and Ontario Subepisodes. Because of the lack of a more complete sequence in northwestern Pennsylvania, further subdivision is not possible. Also, because of the lack of age assignments for units older than the Illinois Episode, there are no names for episodes prior to the Illinois Episode (Johnson and others, 1997). They are referred to informally as pre-Illinois episodes.

Glacial Lobes

Northwestern Pennsylvania was glaciated by the Erie lobe of the Laurentide ice sheet and one of its sublobes, the Grand River lobe. The Grand River lobe advanced and spread out from the lowland of the Grand River valley in Ohio. The entire lobe advanced within the Appalachian Plateau, most of it in Ohio. The Kent, Lavery, and Hiram Till borders show the control of the Grand River lobe on its deposition (Figure 2). The Kent and especially the Defiance Moraines outline the lobe very well. The

Titusville border does not show control by the Grand River lobe in Ohio, and the distribution of the Slippery Rock Till is inadequately known to determine lobe control. The Ashtabula and maybe the Keefus glaciers were restricted to the Erie lobe, not having advanced far enough to enter the Grand River valley.

In northwestern Pennsylvania, the glacial margin of the eastern quarter of the Grand River lobe extends from the Ohio state line into Beaver County, and to the Venango – Crawford County border. From there, the glacial border turns more northeasterly, more closely paralleling the Lake Erie shore, and is considered as part of the Erie lobe.

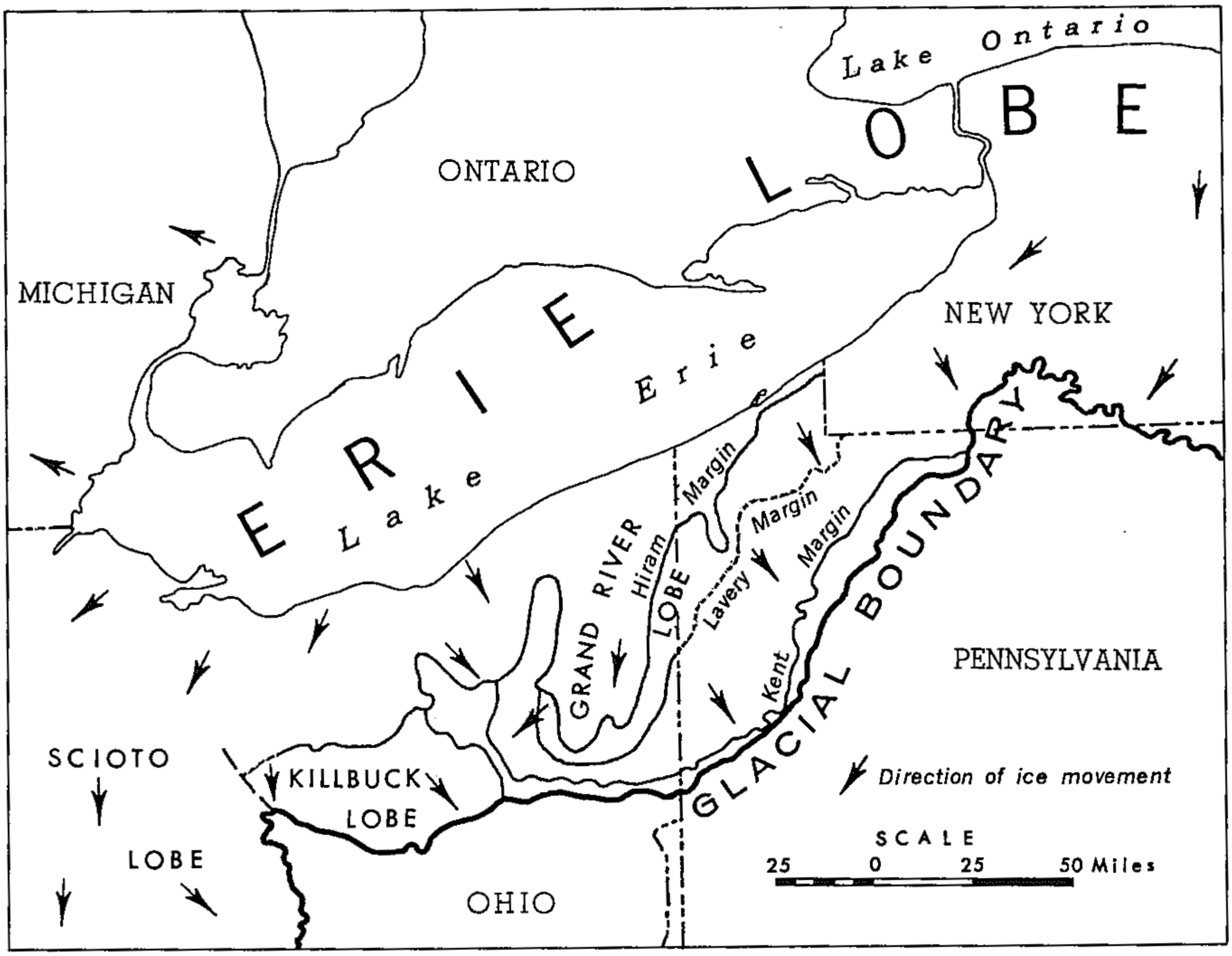

Figure 2. Distribution of ice lobes in northwestern Pennsylvania and adjacent areas and the till margins that define the lobes (from White and others, 1969). Note the tongue projecting to the southeast from the Hiram margin in northwestern Pennsylvania. This is the lobe mapped by Shepps and others (1959) around Conneaut Lake. There is no lobe shown in the Hiram margin that corresponds with Shepps and others (1959) lobe mapped around the southern end of Pymatuning Reservoir, on the Pennsylvania – Ohio border. Contrast that with Figure 3, also from White and others (1969).

Distribution of Glacial Sediments

The distribution of tills on the Allegheny Plateau (Figure 3 and inside front cover) is compressed compared to the till plains of the Midwest. The outcrop areas are narrower. In northwestern Pennsylvania and northeastern Ohio, the glacial border is within 75 miles of Lake Erie, whereas in the till plains of central Ohio and west, the glacial border is over 200 miles from the Great Lake shores. The end moraines on the Plateau are less prominent and closer together, because the topography has greater relief and is more bedrock controlled than in the till plains. Ground moraine areas generally contain thin till.

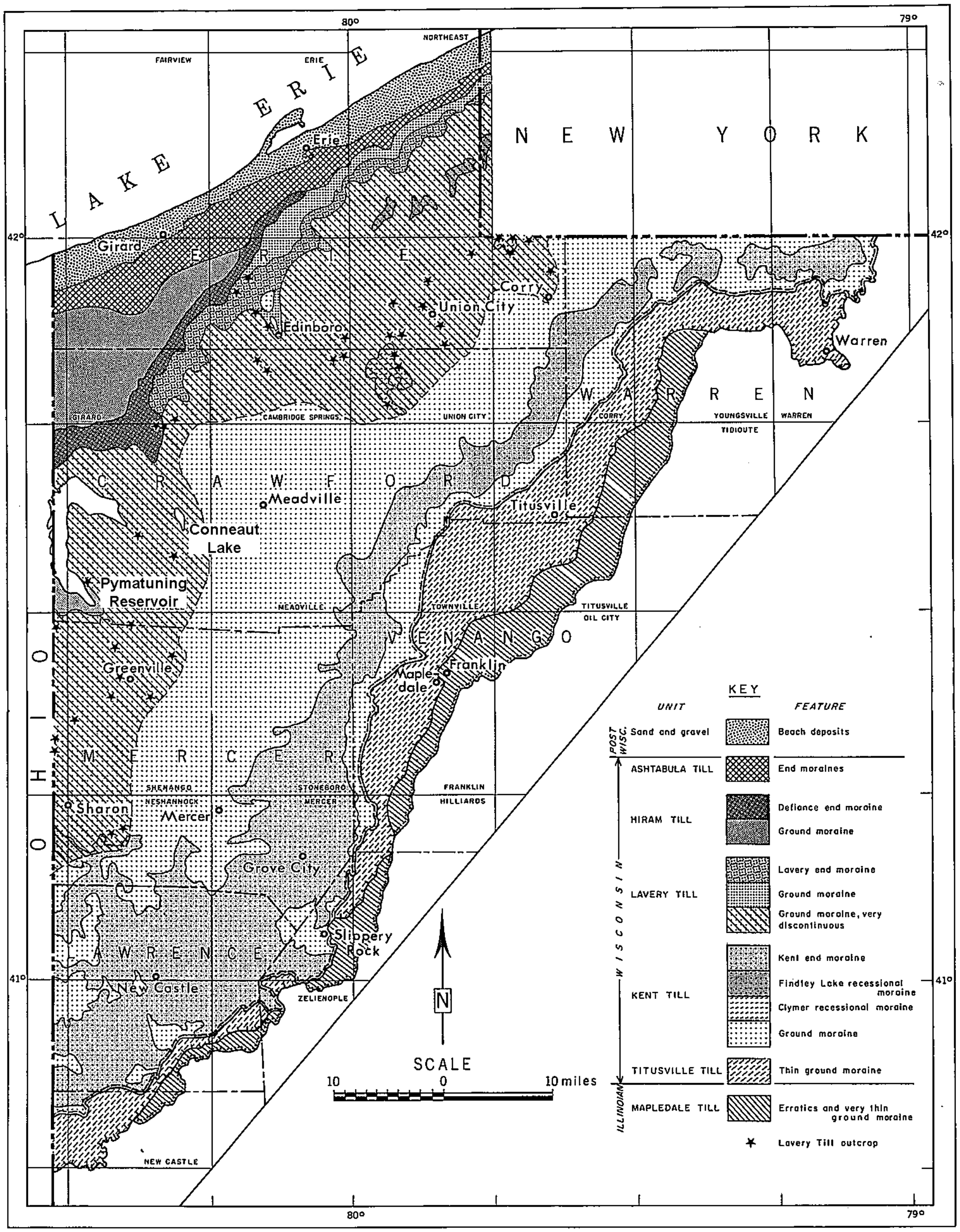

Figure 3- Distribution of the tills of northwestern Pennsylvania (from White and others, 1969). Note the lobe of Hiram Till beyond the Defiance Moraine at Pymatuning Reservoir, and that there is no lobe of Hiram Till mapped around Conneaut Lake.

Most valleys contain extensive kame terraces along the valley walls (Figure 4). STOP 2 is in a kame terrace. The topographic expression of a kame terrace can easily be seen along Toll 60 (see road log for Day 2, mile 7.1). They usually are a series of knolls on the lower valley wall, and were deposited between an ice-remnant in the valley and the valley wall. The deposits are usually rather chaotic, and consist of coarse, poorly sorted sands and gravels, till, and well sorted, sands, gravels, silts, and clays. Sediment was deposited by streams flowing between the ice and valley wall, slumped from the ice surface, and/or in lakes formed in depressions.

Many of the valleys parallel to the general direction of ice flow contain outwash. Some valleys are completely buried. Most are partially buried with depths to bedrock exceeding 300 feet (see road log for Day 1, mile 59.3)

Figure 4. Typical topographic expression of a kame terrace in northwestern Pennsylvania. This one is along the Mahoning River near New Castle.

Lithostratigraphy

The tills of northwestern Pennsylvania have been assigned formal lithostratigraphic names of formational rank (Shepps and others, 1959; White and others, 1969). No non-till units have been given such designations. Most tills, except maybe for the Titusville Till, are usually thin, generally not more than 20 feet thick. The median thickness of individual Wisconsin Episode tills in northeastern Ohio is 5 feet (White, 1982). The uppermost till in most places is so thin that it is often weathered completely through into the next lower till, creating a single weathering sequence through both tills.

Until, 1959, all of the tills in the Grand River lobe were designated by their age (Illinoian till, early Cary till, etc.). Shepps and others (1959) were the first to apply formal lithostratigraphic nomenclature. The benefit of using lithostratigraphic names for tills, rather than age designations, will be seen in the discussion of the Titusville Till.

All of the tills have had type areas defined. Some of the tills have designated type sections. Ideally, type sections of tills should show a typical exposure of the till, with oxidized and unoxidized till, if not a complete weathering sequence, as well as showing the stratigraphic relationships to overlying and underlying units. None of the type sections meet all of those criteria. Sections containing all of those criteria are rare. In addition, the unconsolidated nature of glacial sediments makes it difficult to find a section that will remain adequately exposed for a very long time, so future study of a type section is unlikely. This is the case for all of the tills discussed here. It might be useful to drill and core near type sections, and retain the cores for future reference.

Figure 4. Slippery Rock Till type section. Photo from George W. White's collection. Taken June 13, 1966. Dr. George W. White (left) and Dr. Stan Totten.

Slippery Rock Till- The oldest known till is the Slippery Rock Till, named from the borough of Slippery Rock in northern Butler County, Pennsylvania. The type section (Figure 4) is a highwall in a Vanport Limestone quarry, off of Glacial Till Road (Figure 5), Liberty Township, Mercer County (White and others, 1969). As with most glacial type sections, the Slippery Rock Till type section is no longer

Figure 5. Redundantly-named Glacial Till Road.

accessible in the now flooded quarry. No unoxidized or unleached Slippery Rock Till has ever been found. As a result, the type section does not provide a characteristic description of the till, but does place it beneath the Mapledale Till. The Slippery Rock Till was deposited during a pre-Illinois episode, but no correlation to the marine oxygen isotope record is currently possible.

The Slippery Rock Till has not been found at the surface, but is everywhere buried beneath younger glacial deposits. At places in northwestern Pennsylvania, erratic boulders have been found beyond the mapped limit of tills. These boulders may or may not be related to the Slippery Rock Till.

We will not see the Slippery Rock Till on this field trip.

Mapledale Till- The Mapledale Till is named for the village of Mapledale, near Franklin, in Venango County, Pennsylvania. It was called the Franklin till in White's field notes, but was changed to Mapledale Till because the name Franklin had been applied to so many things (S.M. Totten, personal communication, 2005). The type section at Mapledale, a suburb of Franklin, is in a hillside excavation for a building. It is still accessible with difficulty (behind a chain-link fence), but no longer exposed, being covered with trees. The type section (Figure 6) was Stop 7 of the 1976 Field Conference of Pennsylvania Geologists (Ward and others, 1976). At that time, the section was still exposed, but was difficult to work on due to a problem of sewage effluent emanating from the outcrop, originating from the homes across the street at the top of the section. The type section exposed typical Mapledale Till, but does not expose overlying or underlying units, and does not define its stratigraphic position.

Figure 6- Mapledale Till type section. Dr. Stan Totten for scale. Photo by George W. White, June 24, 1964.

The Mapledale Till can be identified in the field by its coarse matrix, pebbly and cobbly nature, predominance of sandstone clasts, yellow-brown oxidized color, and carbonate content (White, 1969). The latter, especially, serves to distinguish unleached samples from the Titusville and Kent Tills, because the carbonate content of only the Mapledale Till is usually too low to react visibly with hydrochloric acid.

The Mapledale Till (originally called "Outer Illinoian" by Shepps and others, 1959) is the surface till in a fringe beyond the Kent margin in some places (Figure 3). Recent work (D'Urso, 2000) has questioned the identification of Mapledale Till in some places in the fringe, and believes that the deposits at the surface to the glacial margin have Wisconsin Episode weathering characteristics.

The Mapledale deposits are thought to have been deposited during a pre-Illinois episode.

We will not see positively identified Mapledale Till on this field trip.

Keefus Till- The Keefus Till is named for Keefus Road in Conneaut Township, Ashtabula County, Ohio (White, 1982) Its type section (Figure 7) is a stream bank on Conneaut Creek, just east of the Keefus Road bridge over Conneaut Creek (White and Totten, 1979). The type section both exposes

Figure 7. Keefus Till type section. The very hard Keefus is eroded, presumably because of the leaching of the carbonates from the outcrop, leaving the overhanging Titusville Till.

typical Keefus Till and places it stratigraphically below the Titusville Till.

The Keefus Till is a very hard, compact, coarse-grained, dusky red till. It is higher in matrix carbonate than any other pre-Wisconsin episode till in the Grand River lobe, averaging about 9% at its type section (Bruno, 1988). The red color and high carbonate content, which make this till very distinctive, come from the Queenston and Grimsby shales in the Lake Ontario basin (Szabo and Totten, 1995, John Szabo, personal communication, March 14, 2005). The Keefus has only been found in water wells and outcrops within 20 miles of Lake Erie, and does not extend nearly as far onto the Plateau as other Grand River lobe tills. It is found only in the subsurface. It has not been identified in place anywhere in Pennsylvania.

Before the discovery of the Keefus, such a till was predicted, because masses of a pink, high-carbonate till were sometimes found within Titusville Till (White and others, 1969). It was usually described as a purple-pink or maroon till, and as being exceedingly calcareous (G.W. White field notes). However, one interesting section illustrated in White and others (1969; their Figure 17) shows 2 feet of an extremely calcareous, purple-pink till appearing to lie in place on *top* of the Titusville Till.

Because the Keefus Till is older than the Titusville Till, it was apparently deposited during a pre-Illinois episode.

We will not see positively identified Keefus Till on this field trip.

Titusville Till- The Titusville Till is named for Titusville, Crawford County. The type section is a road cut on PA 8 south of Titusville, in Venango County (White and others, 1969). Droste and Tharin (1958) first described this section in one of their pioneering clay mineralogy studies of tills. Again, this type section exposes typical Titusville Till, but, because no other units are exposed there, it does not define the till's stratigraphic position. The section is still accessible, but the sediments are no longer exposed on the vegetated section. A borrow pit adjacent to the type section was substituted for the type section as Stop 5 of the 1976 Field Conference (Ward and others, 1976). The type section was no longer adequately exposed by 1976. The borrow pit also no longer exists.

The Titusville Till is a very hard sandy, cobbly till. It is olive-gray, and oxidizes to olive-brown. The color, texture, and hard compact nature of the till aid in its field identification.

Titusville sediments make up the bulk of the drift in much of northwestern Pennsylvania (White and others, 1969). The thickness sometimes exceeds 100 feet. White and others (1969) believe that the bulk of the Kent Moraine is composed of pre-Kent sediments, mostly Titusville, and that the Kent is simply draped over the moraine, making it a palimpsest moraine.

White and others (1969) have also determined that the Titusville Till is often divided into up to five separate till sheets, separated by sand and gravel layers of varying thickness. They speculate that the Kent Moraine is composed of these multiple till sheets. They interpreted the separate sheets as resulting from minor retreats and readvances of a fluctuating ice margin, and that each readvance extended less far than the previous one. STOP 5 will look at a rare exposure of all five till sheets, well behind the Kent Moraine, and well back from the Titusville margin.

The Titusville Till (called "Inner Illinoian" in Shepps and others, 1959) is the surface material in part of the fringe beyond the Kent Margin (Figure 3). Again, in part of the Slippery Rock basin, D'Urso (2000) determined that the material in part of the fringe has weathering characteristics of deposits of the Wisconsin Episode, and would therefore, be Kent deposits.

The interpreted age of the Titusville Till has undergone changes several times. Shepps and others (1959) originally considered the Titusville Till to be Illinoian, based mainly on its weathered, thin, discontinuous character in its outcrop area. Later (White and Totten, 1965), peat in a gravel pit (Stop 3 of the 1976 Field Conference, Ward and others, 1976) near the type section was radiocarbon dated at about 40,000 years, placing it in the early Wisconsinan, or Altonian substage. The peat was thought to be stratigraphically below the Titusville Till, making the 40,000 years a maximum age for the till. However, there was a large covered section between the till and the peat, and the stratigraphic correlation was uncertain. Later, Totten and Szabo (1987) thermoluminescence dated the loess overlying the Titusville-correlative Millbrook Till in Ohio at about 140,000 years. So Shepps and others (1959) may have been correct that the Titusville Till was deposited during the Illinois Episode.

This illustrates the benefit of assigning names to lithostratigraphic units. As the age interpretation is revised multiple times, the lithostratigraphic name remains the same, preventing confusion when referring to the unit in reports at different times.

In addition to STOP 5, we will also see Titusville Till at STOP 4A.

Kent Till- The Kent Till is named for Kent, Ohio. There is no designated type section, but the Kent area is designated the type locality (Shepps and others, 1959). Shepps and others (1959) were the first to apply the name Kent to these deposits. Prior to that, it was known as "early Cary till" (Shepps, 1955).

The Kent Till is a friable (relative to the Titusville Till), sandy, pebbly gray till that oxidized to a yellow-brown. It can be distinguished from the Titusville Till by its color and friable nature, and from the younger tills by its sandy, pebbly matrix. Younger tills have a much finer-grained matrix and are more sparingly pebbly.

Originally (Shepps and others, 1959), the Kent Till was thought to comprise the bulk of the drift in northwestern Pennsylvania, and to be responsible for the constructional topography of the Kent Moraine, which roughly marks the Kent Till boundary (hence the same name). White and others' (1969) stratigraphic study, made possible by the expansion of interstate highway construction and expanded strip mining in the 1960s, revealed that much of what was thought to be Kent Till, was actually Titusville Till. The Kent was usually a thin drape over the Titusville sediments. Even the Kent Moraine is probably a Titusville-age feature (White and other, 1969). The Kent Till is thin enough in most places that the modern weathering sequence extends completely through the Kent Till into the underlying material.

Kent Till is shown on the map of Shepps and others (1959) to be the surface unit over a large portion of northwestern Pennsylvania. White and others (1969) showed that the Lavery actually extends over much of the Kent outcrop area of Shepps and others (1959), extending well beyond the Lavery Moraine (which is also probably a Titusville feature) (Figure 3 and inside front cover). However, all of the units younger than the Titusville are commonly fairly thin and discontinuous and none form a complete blanket over their mapped outcrop area.

Based on the radiocarbon dating of wood in what was interpreted to be pro-Kent lacustrine sediments near Cleveland, Ohio, the Kent Till is thought to be about 23,000 years old (White, 1968). The Kent Till was deposited during the Michigan Subepisode of the Wisconsin Episode.

We will see the Kent Till at STOP 5.

Lavery Till- The Lavery Till was named by Shepps (Shepps and others, 1959) for Lavery, near Edinboro, in Erie County. Actually, the rumor is that it was named for the Lavery Saloon (Figure 8), where Shepps was partaking of some late afternoon libations at the end of a long day in the field. This rumor has not been substantiated, and its origin is unknown. Prior to the formal lithostratigraphic name, the Lavery Till was referred to as the "middle Cary till" (Shepps, 1955).

Figure 8- Is this the origin of the name of the Lavery Till?

The type area is in the Lavery Moraine, in several roadcuts along the road north from Lavery. Matt Weinrich, a graduate student from the University of Akron, and his advisor, John Szabo, are beginning a study of the deposits in the Lavery type area (Szabo, personal communication, July, 2005). They are drilling a number of holes within areas mapped as Kent, Lavery, and Hiram in the area, and describing and sampling available outcrops.

The Lavery Till is a light gray, compact, silty, pebbly till that oxidizes to a yellow brown color. It has a few cobbles and boulders. It can easily be distinguished in the field from older tills by its fine-grained matrix, and fewer pebbles and cobbles. As we will see at STOP 4B, it can difficult to distinguish from the younger Hiram Till in the field.

The Lavery Moraine is a palimpsest moraine and does not mark the limit of the Lavery Till, as shown on the map by Shepps and others (1959). White and others (1969) extended the Lavery limit to cover the area shown on Figure 3. This map is in error, however, because the Lavery actually extends farther than shown on Figure 3. White's field maps show additional outcrops of Lavery Till farther south, and the glacial map of northeastern Ohio (White, 1982) shows the Lavery border more closely matching the outcrops on White's Pennsylvania field maps. The Lavery border actually extends, at the state line, to southern Lawrence County, as shown on the map inside the front cover, rather than southern Mercer County, as shown on Figure 3.

A radiocarbon date of a marl preserved below peat in a bog at Corry, Erie County (Droste and others, 1960), is within the extended Lavery border, and provides a minimum age of 14,000 years for the Lavery Till. White (1982) indicates that it might be about 19,000 years old. It was deposited during the Michigan Subepisode of the Wisconsin Episode.

We will see Lavery Till at STOP 4B and probably at STOP 5.

Hiram Till- The Hiram Till is named for Hiram, Ohio (Shepps and others, 1959). It was previously referred to as the "late Cary till" (Shepps, 1955). The type section is a roadcut 1½ miles north of Hiram, Ohio (White, 1960). I have not visited this section, and do not know of its current condition. The section contains 6' 7" of Hiram Till over 1' 6" of Kent Till, separated by 3 inches of clay. It contains no unoxidized till, and does not contain the immediately underlying or overlying units to establish its stratigraphic position.

The Hiram till appears very similar to the Lavery Till, and distinguishing them in the field can be difficult. White (1982) reports that the Hiram is the most clay-rich till in the northeastern Ohio. It is a bluish-gray, clay to silty-clay, sparingly pebbly till (White and others, 1969). Its oxidized color is described as drab brown (Shepps, 1955). Pebbles are rare enough that it sometimes appears to be a lacustrine deposit (White, 1982). The oxidized color difference between the Hiram and Lavery is subtle (White, 1982)

The limit of the Hiram advance is generally marked by the Defiance Moraine. The Defiance Moraine, named for Defiance, in northwestern Ohio, emerges from beneath the younger Ashtabula Morainic System south of Erie, and extends westward across Ohio, extending southward into a number of other sublobes in central and western Ohio, wraps around the end of Lake Erie, and trends north to its terminus near Pontiac, Michigan. The Defiance Moraine reappears from beneath the Ashtabula Morainic System at the New York State line (Shepps and others, 1959). In the Grand River lobe, the Defiance Moraine, like other moraines, is probably a palimpsest moraine created by earlier glaciations. The Hiram glacier apparently had insufficient energy to completely override the moraine, which controlled the extent of the Hiram glacier advance.

Hiram Till was mapped by Shepps and others (1959) with a couple of lobes of Hiram Till extending beyond the Defiance Moraine at Conneaut Lake and the western arm of Pymatuning Reservoir. Later, White and others (1969) showed two maps, one of which showed a Hiram lobe only at Conneaut Lake (Figure 2), and another that showed a Hiram lobe only at Pymatuning Reservoir (Figure 3). STOP 4B will further address this confusion and attempt to resolve to question of whether or not the Hiram glacier advanced down the Shenango River, now the western arm of Pymatuning Reservoir.

White (1982) estimates the age of the Hiram Till to be about 17,000 years. The only date associated with it is of wood preserved in peat in a kettle hole in Medina County, Ohio (Totten, 1976). Its date of 14,050 years provides only a minimum date for the withdrawal of the Hiram glacier, when peat could begin to accumulate in the kettle. It was deposited during the Michigan Subepisode of the Wisconsin Episode.

We may see the Hiram Till at STOP 4B.

Ashtabula Till- The youngest till in northwestern Pennsylvania is named for its type area near Ashtabula, OH. Its type section is a road cut three miles east-southeast of Ashtabula, where 19½ feet of Ashtabula Till is exposed (White, 1960). No other units are exposed. It was previously referred to as the "latest Cary" till (Shepps, 1955). The distribution of the Ashtabula Till in New York, Pennsylvania, and Ohio shows it to be a deposit of the Erie lobe with no indication of a lobe extending into the Grand River lowland.

Figure 9. Outcrop of Ashtabula Till overlain by convoluted sand and silt at Erie Bluffs State Park. Andrew Kozlowski, from Susquehanna University, is at the contact between the till and lacustrine sediments.

Ashtabula Till can also be difficult to distinguish from the Hiram and Lavery, but it appears to be somewhat sandier than the older tills, and has more pebbles. It is also usually has a greater depth of leaching than the two older tills (White, 1982). It is a pebbly, bluish-gray, silt till. Its oxidized color is also similar to the Hiram and Lavery Tills. It outcrops in extensive bluffs along the shore of Lake Erie, where it is usually overlain by lacustrine sands and silts deposited in early, higher levels of Lake Erie (Figure 9).

The Ashtabula is present at the surface only within the Eastern Lake Section. The Ashtabula advance was stopped by the plateau escarpment. A series of moraines, known as the Lake Escarpment Morainic System (Leverett, 1902) or Ashtabula Morainic System (Shepps and others, 1959), was deposited against the escarpment. The morainic system is composed of a series of individually named moraines (Leverett, 1902). Farther east, in New York, the Defiance and Lavery Moraines, merge with the Ashtabula moraines, and become part of the Lake Escarpment Morainic System. I am not aware of any work having been done to evaluate whether the moraines are palimpsest moraines, or were formed by the Ashtabula advance.

There are no radiocarbon dates associated with the Ashtabula Till. White (1982) estimates its age at about 15,000 years. It was deposited during the Michigan Subepisode of the Wisconsin Episode.

We will not see any Ashtabula Till on the Field Conference.

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MERCER COUNTY, PENNSYLVANIA
ABOUT 22,000 YEARS AGO

"Well, so much for global warming!"

STRATIGRAPHY AND PALEONTOLOGY OF THE "MERCER FORMATION" IN WESTERN PENNSYLVANIA AND EASTERN OHIO

by
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Introduction

There are numerous geological problems plaguing western Pennsylvania, both practical and academic. One of these problems is the need for a regional stratigraphic framework of the Pennsylvanian System that doesn't involve coals and fluvial sandstones as key marker beds (Edmunds and others, 1999). Edmunds and others (1999) also cited the basic lack of paleontological and biostratigraphic data on the Pottsville Group (or Formation if that is the term you wish to use), among other formations. The Pottsville is well known for its economic resources – commercial clays, some locally well-developed coals, and salt water, oil, and natural gas that have been produced, historically, from its sandstones. Pottsville sandstone brines provided much of the table salt used in and around the western part of Pennsylvania in the 1800s, and provided Pittsburgh entrepreneur Samuel Kier with the crude oil he used to create the process of oil refining that helped lead Edwin L. Drake to drill his famous well in Titusville (Harper, 1995). But little has been done to understand the stratigraphic relationships and ages of the individual units. Less than a handful of studies has been done on the Pottsville fossils and their stratigraphic relations since the Second Geological Survey of Pennsylvania in the late 1800s (e.g., Williams (1960). This paper is directed at the paleontology of one particular portion of the Pottsville – the "Mercer formation".

I use the name "Mercer formation" here in an informal sense. My Middletown colleagues insist that the Pottsville "Group" deserves only formation rank because the strata vary so widely that it is difficult to segregate discrete mappable units (formations) within it. Thus, they would downgrade all of the classic formations within the Pottsville "Group" to members and beds. Nonetheless, the "Mercer formation" as used in this paper is the same as that used by many geologists during the last 100 years or so.

The "Mercer formation" consists of a series of shales, coals, underclays, marine limestones, bedded and nodular siderites, and sandstones occupying the middle to upper middle portion of the Pottsville. Rogers (1858) first used the name Mercer for a limestone bed found in the vicinity of Mercer, Mercer County, Pennsylvania (see **STOP 1**). White (1879) redefined Rogers' work and extended the name to include all of the rocks found between the "Tionesta shales" (= Homewood shales of modern usage) and the Connoquenessing sandstone(s). Carswell (1965) included the Homewood shales in the "Mercer formation." Because of the nature of marine transgression-regression sequences, I include at least a small portion of the Homewood shales in the "Mercer formation" (see discussion below). It should be noted that in some areas the Homewood and/or Connoquenessing sandstone is missing in the section, resulting in the "Mercer formation" being unrecognizable with any specific degree of certainty until detailed stratigraphic analysis has been done. At other times, much of the "Mercer formation" can be partly or entirely missing where one or both of those sandstones developed beyond their normal limits (DeWolf, 1929). To make matters even more interesting, one or more sandstones can often be found within the Mercer sequence that obscures the typical relationships of the sequence (see **STOPS 10** to **12**). Table 1 indicates the traditionally recognized members of the "Mercer formation" in western Pennsylvania, particularly in Lawrence and Mercer Counties, as well as adjacent strata.

Harper, J. A., 2005, Stratigraphy and paleontology of the "Mercer formation" in western Pennsylvania and eastern Ohio, *in* Fleeger, G.M. and J.A. Harper, eds., Type sections and stereotype sections: glacial and bedrock geology in Beaver, Lawrence, Mercer, and Crawford Counties, Guidebook, 70th Annual Field Conference of Pennsylvania Geologists, Sharon, PA, pp. 13—34.

Table 1. Descriptions and thicknesses of the various strata considered to be part of the traditional Mercer formation (derived from White, 1879, DeWolf, 1928, and personal observation).

<table>
<tr><th>"Formation"</th><th colspan="2">Stratum</th><th>Description</th><th>Thickness (in m)</th><th>Thickness (in ft)</th></tr>
<tr><td rowspan="5">Homewood</td><td colspan="2">Homewood sandstone (Tionesta sandstone of White, 1879)</td><td>Massive, coarse-grained or conglomeratic sandstone, gray to yellow, averages 30 feet</td><td>9 - 15</td><td>30 - 50</td></tr>
<tr><td rowspan="4">Homewood shale</td><td></td><td>Shale</td><td>0 -1.5</td><td>0 - 5</td></tr>
<tr><td>Homewood coal (Tionesta coal of White, 1879)</td><td>Coal, bony, sulfurous, often just bituminous streaks in a thin layer of sandstone, shale, or clay; local</td><td>0 - 1.2</td><td>0 - 4</td></tr>
<tr><td>Homewood clay</td><td>Underclay</td><td>0 - 1.2</td><td>0 - 4</td></tr>
<tr><td></td><td>Shale with siderite nodules and plates (White, 1879, called this Tionesta iron shales); sometimes cut out by Homewood</td><td>3 - 6</td><td>10 - 20</td></tr>
<tr><td rowspan="8">Mercer</td><td colspan="2">Upper Mercer limestone (Mahoning limestone of Rogers, 1858; Upper Wurtemburg limestone of Lesley, 1875)</td><td>Limestone, hard, compact, dense, dark bluish gray to gray black, fossiliferous, which in some localities has been replaced by siderite</td><td>0.3 - 1.2</td><td>1 - 4</td></tr>
<tr><td colspan="2">Upper Mercer coal</td><td>Persistent coal, but shaly and of little value; divided in some places by a limestone</td><td rowspan="2">0.3 - 1.2</td><td rowspan="2">1 - 4</td></tr>
<tr><td colspan="2">Upper Mercer underclay</td><td>Underclay, non-plastic, containing abundant Stigmaria and associated rootlet fossils</td></tr>
<tr><td colspan="2">Upper Mercer shale</td><td>Dark sandy shale, containing siderite nodules and plates, especially concentrated at the base (White, 1880, called this Lower Mercer iron ore)</td><td>0.15 - 0.9</td><td>0.5 - 3</td></tr>
<tr><td colspan="2">Lower Mercer limestone (Mercer limestone of Rogers, 1858; Lower Wurtemburg limestone of Lesley, 1879)</td><td>Tough, dark blue to black, siliceous, fossiliferous limestone, very persistent</td><td>0.6</td><td>2</td></tr>
<tr><td colspan="2">unnamed</td><td>Shale</td><td>0 - 5.5</td><td>0 - 18</td></tr>
<tr><td colspan="2">Lower Mercer coal (Lower Porter coal of Rogers, 1858)</td><td>Shaly and impure, but locally of good quality</td><td>0.15 - 0.9</td><td>0.5 - 3</td></tr>
<tr><td colspan="2">Lower Mercer shale</td><td>Sandy shale, containing siderite nodules and plates; sometimes argillaceous shale with a very rich layer of siderite; a layer of non-plastic underclay can occur at the top</td><td>1.5 - 12</td><td>5 - 40</td></tr>
<tr><td>Connoquenessing (in part)</td><td colspan="2">Upper Connoquenessing sandstone</td><td>Massive, coarse-grained or conglomeratic sandstone, white to yellowish brown.</td><td>1.5 - 25.6</td><td>5 - 84</td></tr>
</table>

The "Mercer formation" in Ohio (Table 2) has been much better understood for a longer time than has the Pennsylvania section, although Slucher and Rice (1994) noted that the Ohio Pottsville section also has many unresolved problems. Note that the section in Table 2 is divided into recognized cyclothems, of which there are several that have not been previously recognized in Pennsylvania (some Ohio geologists use this list, while others don't). These additional cyclothems, and the units within them, indicate either that the section in Pennsylvania has several undiscovered unconformities or that the thick shale sequences between and below the limestones mask some of the cyclothems found in Ohio. As Skema (**STOPS 10** to **12**) shows, most of these Ohio cyclothems can be recognized within the roadcuts along US 422 near New Castle. They were long unrecognized because no one previously had done the detailed stratigraphic measurements and descriptions necessary to recognize the thin coals and fossiliferous siderite beds that Skema has correlated with the Ohio section. Of most importance for correlation are the marine zones – the Lowellville and the "Boggs" – that have not been recognized in Pennsylvania. As it turns out, there are thin zones of siderite nodules less than 10 cm (4 in) thick near the bottom of the sections at **STOPS 11** and **12** that contain very sparse marine fossils. These appear to correlate with the Lowellville marine zone of Ohio. It is also possible that, with more detailed stratigraphic analysis of some of the outcrops around Wampum and Mercer, one could find marine or brackish water zones several centimeters thick within the lower "Mercer formation" shales that would correlate to

Table 2. Descriptions and thicknesses of Ohio cyclothems and stratigraphic units of the middle Pottsville Formation (from Hoare and others, 1979).

Cyclothem	Unit	Description	Thickness (in m)	Thickness (in ft)
Brookville (in part)	Homewood sandstone	Shale and/or sandstone; sandstone locally massive	3	10
Tionesta	Tionesta coal	Coal No. 3B, thin, local	3	1
	Tionesta underclay	Underclay, plastic, persistent	1.5	5
	Tionesta shale	Shale and/or sandstone; sandstones locally massive	7.3	24
Bedford	Upper Mercer limestone	Limestone and/or flint and shale, dark bluish gray to black, fossiliferous, marine	0.5	1.67
	Bedford coal	Coal, patchy	0.3	1
	Bedford underclay	Underclay, siliceous	0.9	3
	Bedford shale	Shale and/or sandstone	3.2	10.5
Upper Mercer	Upper Mercer coal	Coal no. 3A, local	0.3	1
	Upper Mercer underclay	Underclay, siliceous, plastic	0.9	3
	Upper Mercer shale	Shale and/or sandstone	3.4	11
		Shale, siliceous	0.5	1.75
Middle Mercer	Lower Mercer limestone	Limestone and shale; dark-bluish-gray to black limestone and shaly limestone, locally ferruginous or siliceous; similarly colored shale, very fossiliferous, marine, very persistent	0.6	2
	Middle Mercer coal	Coal, thin, persistent	0.15	0.5
	Middle Mercer underclay	Underclay, siliceous, plastic	1	3.5
	Middle Mercer shale	Shale and/or sandstone	1.5	5
Flint Ridge	Flint Ridge coal	Coal, thin, local	0.15	0.5
	Flint Ridge underclay	Underclay, flint and plastic	1.2	4
	Flint Ridge shale	Shale and/or sandstone	1.5	5
Lower Mercer	"Boggs" limestone	Limestone, flint, ironstone, and /or shale, fossiliferous, marine, nonpersistent; in east-central and southern Ohio only	0.15	0.5
		Shale, siliceous	0.3	1
	Lower Mercer coal	Coal No. 3, thin, persistent	0.3	1
	Lower Mercer underclay	Underclay, siliceous	0.9	3
	Lower Mercer shale	Shale and/or sandstone; sandstones locally massive	7	23
Vandusen	Lowellville (or Poverty Run) limestone	Limestone, ironstone, and shale, dar-gray to black; limestone resistant; shale with ironstone nodules locally; fossiliferous, marine; in east-central and northeastern Ohio only	0.3	1
	Vandusen coal	Coal, thin, nonpersistent	0.3	1
	Vandusen underclay	Underclay	0.6	2
	Vandusen shale	Shale and/or sandstone	5.2	17
Bear Run	Bear Run shale	Shale and ironstone; blue-gray shale and red or gray black-band ironstone, fossiliferous, brackish-water (?); in southern Ohio only, local	0.6	2
	Bear Run coal	Coal, local	0.5	1.5
	Bear Run underclay	Underclay siliceous	0.9	3
	Massilon sandstone	Shale and/or sandstone; sandstones locally massive	7.3	24

the "Boggs" marine zone of Ohio.

The "Mercer formation" varies in thickness throughout western Pennsylvania. In Mercer County, a typical section of the formation is about 17.5 m (57.5 ft) thick (White, 1880). Carswell (1965) stated that it reached a maximum of 27 m (90 ft) in the Neshannock quadrangle. However, Carswell included the Homewood shales in the "Mercer formation" whereas White included them in the "Tionesta" portion of the Pottsville (= "Homewood formation" of Table 1). Chance (1879) placed the thickness of the "Mercer Group" at about 12.5 m (41 ft) in the Beaver Valley. Newberry (1878) described 63 m (207 ft) of strata equivalent to the "Mercer formation" in Mahoning County, Ohio, just over the state line from Lawrence County. Skema (**STOPS 10** and **11**) measured about 26.5 m (87 ft) of section in the New Castle area. Some of this variability probably stems from differences of opinion about what constitutes the "Mercer formation," whereas the differences in compactibility of sandstone and limestone versus shale and siltstone could greatly affect measurements from outcrop to outcrop.

Pennsylvanian Cyclothems

It has been well known for at least 75 years that the Pennsylvanian System (and Upper Carboniferous of the rest of the world) shows a cyclical pattern of sedimentation, a consistent repetition of two or more kinds of rock, more or less alternating throughout the sequence, called "cyclothems" (Figure 1). One cycle can be very different from another, especially in bed thickness, fossil content, coloration, and other physical and chemical characteristics. However, the repeated alternation of the various layers is unmistakable. Geologists have debated the origins of these cycles endlessly, with proponents of episodic tectonism, local and regional variations in sedimentation, changes in ocean basin geometry, and climatically controlled eustasy filling journals and monographs around the world. The current consensus is that the cyclothems were caused by eustasy triggered by a long-term Ice Age in the southern higher latitudes (Veevers and Powell, 1987; Klein and Willard, 1989). As global temperatures

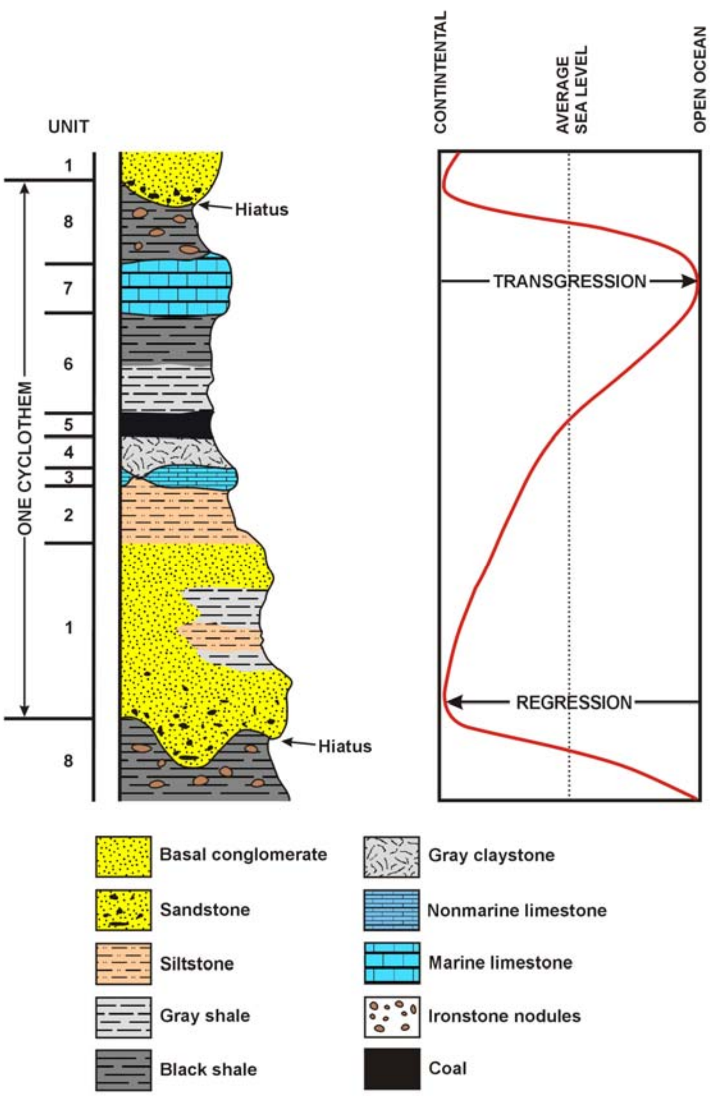


Figure 1. Ideal cyclothem (left) and accompanying sea level curve. The channel sandstone at the base of the cyclothem (unit 1) represents maximum regression and the marine limestone near the top (unit 7) represents maximum transgression.

cooled, ice sheets formed in the south polar and temperate zones of Gondwanaland, resulting in regression as the sea retreated from the land. This in turn caused increased erosion by exposing more land and by lowering base level, requiring streams to cut down into the now relatively higher landscape. Erosion created hiatuses in some areas, and the eroded rock was redeposited in other areas, often out onto the now exposed lowland where the sea used to be. Increasing global temperatures had the opposite effect. Glaciers melted, sea level rose, and a transgression occurred as the sea crossed the lowlands. Because the effects were global, the cycles are recorded in the rock record all over the world at the same time.

Figure 1 shows the relationship of a typical cyclothem to sea level rise and fall. The amazing thing is how long this Late Carboniferous-Permian Ice Age lasted. It is well documented that it spanned the Namurian through Sakmarian epochs (Veevers and Powell,1987). Based on the currently accepted time scale, that amounts to 60 million years of episodic glaciation/deglaciation!

How many cycles were there? Heckel (1986) counted 55 just in the mid-Desmoinesian to mid-Virgillian (middle to upper) portion of the Pennsylvanian section in Kansas. Hoare and others (1979) list only 18 from the Appalachians of Ohio for that same time interval. Either one of these authors miscounted or, as is more likely, many of the cycles recognized in the marine-dominated midcontinent have been masked in the Appalachians by erosion/non-deposition or by thick sequences of shale, sandstone, or paleosols (the Pittsburgh red beds of the Conemaugh Group being a prime example of the latter). Numerous geologists have linked the Pennsylvanian climatic cycles to Milankovitch cycles, although there is still some debate as to the amount of time the cycles lasted. Analyses by Busch and Rollins (1984) in the Appalachians and by Heckel (1986) in the midcontinent established that the cycles, which can be divided into a hierarchical classification of transgressive-regressive units, do seem to fit Milankovitch patterns. Busch and Rollins' 5^{th}-order units, which are essentially equivalent to Heckel's "major cycles," appear to have lasted 400-450 Ka whereas their 6^{th}-order units, which are equivalent to Heckel's "minor cycles," seem to have lasted 100-225 Ka. Both of these intervals fall within established Milankovitch cycles.

It should be pointed out, however, that based on European work cited by Klein (1990), the Upper Carboniferous lasted only 19 Ma, not the 30 to 40 Ma currently considered a reasonable estimate. Should the European time scale prove to be correct, the calculations of cycle length of both Busch and Rollins (1984) and Heckel (1986) probably would no longer fit Milankovitch orbital parameters, casting that relationship in serious doubt.

As Klein and Willard (1989) noted, the nature of any particular cyclothem depends on where the sedimentation took place. Figure 1 could easily be from the "type" area of the Illinois basin, where continental and marine influences alternated within the cycle. Cyclothems from the area of the epeiric sea of the mid-continent (such as in Kansas) typically contain marine-dominated cycles with rare or no continental influence. Appalachian cyclothems, on the other hand, typically are dominated by continental sedimentation and may contain few if any marine units. Not every unit is present in every cyclothem. Episodic thrust loading and associated flexural subsidence of the continental margin from collisions of Laurentia with a series of microcontinents influenced Appalachian-type cylothems (Klein and Willard, 1989). Fluvial sandstones and paleosols dominate the cycles. Local changes in sedimentation obscure or eradicate many of the units that might otherwise be present. For example, the limestones and shales that constitute a marine zone (unit 7 and portions of units 6 and 8 in Figure 1) might be completely eroded by a stream that deposits the overlying sandstone (unit 1). We will see a good example of this at **STOPS 10** to **12**. However, enough of the units recur throughout the Pennsylvanian section in the Appalachian basin to make the cycles apparent, if not totally clear.

"Mercer Formation" Marine Zones

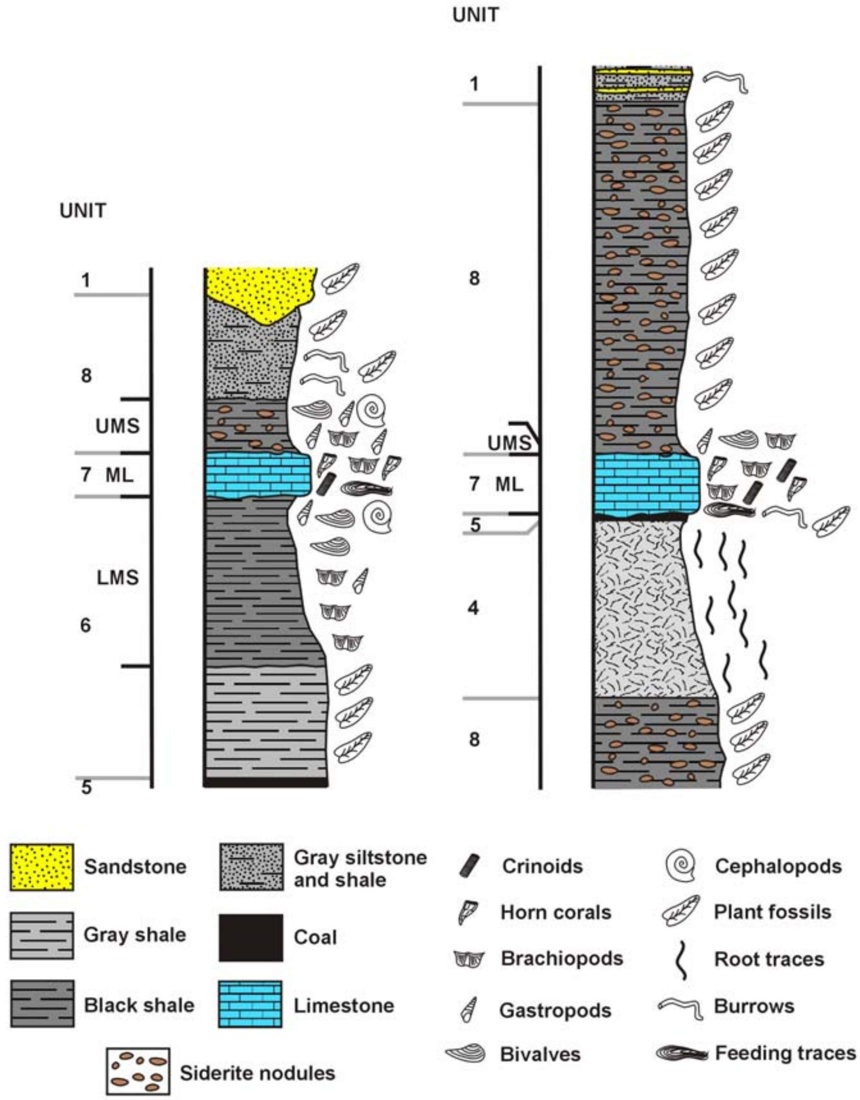


Figure 2. Diagrams of Pennsylvanian marine zones in western Pennsylvania. Left, a typical marine zone from the Upper Pennsylvanian Conemaugh Group in the Pittsburgh area. Right, the Upper Mercer marine zone from Hells Hollow (based on Skema, **STOP 1**). The unit numbers on the left correspond with those on Figure 1.

Pennsylvanian marine zones in the Appalachian basin have been studied for over 90 years, both historically as a source of information on fossils and their potential for stratigraphic correlation (e.g., Raymond, 1911) and, more recently, for their paleoecological importance (e.g., Rollins and others, 1979). Unfortunately, study of the Conemaugh Group marine zones has dominated, followed by prominent Allegheny Formation marine zones such as the Vanport Limestone or the Columbiana marine shale. The Pottsville marine zones have been given short shrift – a few student theses (e.g., Anderson, 1986) and the work of Ohio paleontologists (e.g., Morningstar, 1922; Sturgeon and Hoare, 1968) provide most of our knowledge of the Pottsville marine zones (Williams, 1960, and Edmunds, 1992, being notable exceptions). It is difficult to say how many marine zones exist within the Pottsville. To date, only the Upper and Lower Mercer marine zones have been recognized in western Pennsylvania, although Skema (**STOPS 11** and **12**) is suggesting the presence of at least one more. Ohio paleontologists recognize nine Pottsville marine zones, of which five are beds of nodular siderite containing a very sparse marine fauna. The Ohio section also contains at least four brackish-water units in the lower Pottsville (below the "Mercer formation") that probably represent equivalents of marine units farther west (Kentucky, Illinois, and Kansas) (Brezinski and others, 1989, tab. 1). In addition, Edmunds (1992) documented an early Pottsville marine zone in the Broad Top synclinorium of central Pennsylvania that appears to predate every known marine incursion in the Appalachians of western Pennsylvania, eastern Ohio, and northern West Virginia.

Brezinski (1983) pointed out that the major seaway connecting the Appalachian basin with the epeiric sea in the midcontinent during the Pennsylvanian was located to the southwest, with the axis of deposition trending northeastward. The Cincinnati arch restricted access to the west, whereas to the east the basin was bounded by land prograding from the Appalachian highlands. The eastern coastline was dominated by lobate deltas and their associated marine, transitional, and continental environments. During any particular cycle of deposition, large interdistributary bays (marine) gave way to: 1) fluvial-deltaic, fluvial, paludal, and/or lacustrine (all marginal to nonmarine) deposition during regressions, tectonic pulses, and/or episodes of wetter climatic conditions (all of which would have resulted in increased erosion in the eastern highlands); and 2) open marine conditions during transgressions.

Figure 2 represents a typical Appalachian Pennsylvanian marine zone and associated rocks (essentially units 6 to 8 in Figure 1). Such marine zones commonly consist of a tripartite stratigraphic section that includes: 1) a lower transgressive shale, typically dominated by nearshore molluscan faunas (bivalves and gastropods mostly, with some scaphopods and brachiopods, and cephalopods becoming common toward the top of the unit (LMS in Figure 2); 2) a marine limestone representing stillstand conditions that can be dominantly open marine, dominantly nearshore, or a combination of the two (ML). Such limestones typically contain a fauna consisting mostly of crinoids, brachiopods, and horn corals, although molluscs do occur; and 3) an upper regressive shale containing siderite nodules and a rich molluscan/brachiopod fauna near the lower surface (UMS). All three of these units contain marine fossils in varying quantities and diversities, although the shales might be barren within a short vertical distance of the limestone. Donahue and others (1972) indicated that the units aren't always evenly distributed or of consistent composition. Variations in lithology and depositional setting existed throughout the Pennsylvanian. The limestones range from pure or relatively pure carbonates where deposition was dominated by open marine conditions (e.g., the Vanport Limestone) to very clastic-rich carbonates or carbonate-rich mudstones in nearshore conditions (e.g., any of the Conemaugh marine limestones). The shales might be normal gray, argillaceous marine shales, but they often contain a high percentage of preserved organic matter that induces strange effects on marine fossils – for example, many of the mollusc shells found in the organic-rich shales of the Brush Creek marine zone (lower Conemaugh) have the original aragonitic shell structure preserved, a very unusual phenomenon for 300 Ma-old shell material (Brand, 1989). The thicknesses of the units also vary widely. The transgressive and regressive shales range from a few millimeters to over a meter thick. The limestones range from 0 to 1 m – in many outcrops the limestone is non-existent, or represented only by an increase in carbonate content within the shales.

Below are descriptions of the four marine zones that occur in the "Mercer formation" of eastern Ohio and, possibly, western Pennsylvania. Only the Lower and Upper Mercer marine zones have been documented previously. Based on very sparsely fossiliferous siderite nodules, the Lowellville marine zone questionably occurs at **STOPS 11** and **12**, whereas the "Boggs" marine zone does not appear to be represented in this portion of Pennsylvania.

Lowellville Marine Zone

Lamb (1910) named the Lowellville Limestone for the lowest limestone exposed in the creek valleys on the south side of the Mahoning River at Lowellville, Mahoning County, Ohio. The Lowellville occurs only in this area in Ohio (Lamborn, 1951). However, Morningstar (1922) correlated it to the Poverty Run Limestone, which is known in a small area near its type locality along Poverty Run, Muskingum County, Ohio. As a result, you will find many authors refer to this portion of the section as the Lowellville (Poverty Run) limestone (e.g., Morningstar, 1922) or Lowellville-Poverty Run marine zone (e.g., Anderson, 1986).

Lowellville has priority (Stout, 1918, did not coin the name Poverty Run limestone until eight years after Lamb named the Lowellville), but in all likelihood the two are completely separate deposits of the same marine incursion. The Lowellville limestone consists of a dark colored, compact, fossiliferous, and impure limestone only 0.3 m or less in thickness. Morningstar (1922) also included the overlying dark-colored shales, which are about 0.6 m thick, and contain an abundance of well-preserved fossils. No one, as far as I know, has included a lower shale in this marine zone. In fact, Lamborn (1951) places the limestone at the very bottom of the type section along Grindstone Run in Lowellville. Although the type locality of the Lowellville contains 0.3 to 0.6 m (1 to 2 ft) of limestone, a fossiliferous, sometimes calcareous black shale typically represents the marine zone throughout northeastern Ohio (Slucher and Rice, 1994).

It is uncertain whether or not the Lowellville marine zone occurs in western Pennsylvania. A bed of nodular siderite near the base of the section at **STOPS 11** and **12** might represent the Lowellville in this area. A nodule at **STOP 11** yielded a brachiopod that appears to be a fairly large specimen of *Derbyia*, or perhaps *Orthotetes*, and two nodules at **STOP 12** contained specimens of the brachiopod *Hustedia miseri* Mather and a horn coral. However, as both of these latter nodules were loose, rather than found in place, it is as likely they washed out of the Lower Mercer marine zone above the outcrop. The presence of a marine fossil in the siderite nodule at **STOP 11** is significant; the nodule zone occurs about 7.6 m (25 ft) below a coal Skema has identified as the Flint Ridge coal (Table 2).

According to classical geology, the Lowellville marine zone lies at the base of the "Mercer formation" and stratigraphically above the Upper and Lower Connoquenessing sandstones (= Massilon sandstone of Ohio). Based on measured sections at outcrops and in cores, however, Slucher and Rice (1994) suggested that the stratigraphic position of the Lowellville is lower than the Quakertown coal, which lies within or below the Upper Connoquenessing sandstone at its type locality on Quakertown Run in Lawrence County, Pennsylvania (White, 1879). Although this is possible, it is more likely that Slucher and Rice (1994) relied too heavily on ephemeral coals and fluvial sandstones for correlating the problem section. As Skema shows at **STOPS 10** to **12**, the "Mercer formation" contains a thick sequence of fluvial sandstone between the Mercer marine zones that it would be too easy to call Upper Connoquenessing sandstone simply because of its position below the Upper Mercer limestone. The Upper Mercer is better developed and more prominent than the Lower Mercer in the New Castle area. It could easily be confused with the Lower Mercer. If such were the case, it would be very tempting to call the middle Mercer sandstone "Upper Connoquenessing.

Rice and others (1979) correlated the Lowellville-Poverty Run marine zone with the Kendrick Shale, part of the Breathitt Formation of Kentucky. Based on marine invertebrate fossils, Chestnut and Slucher (1990) proposed that the Kendrick is late Morrowan in age. Henry (1998, p. 28) indicated that the Kendrick correlates to the Trace Creek Shale Member, which is the basal member of the Atoka Formation in Arkansas. Merrill (1970-71; also 1974) placed the Lowellville marine zone in the *Gnathodus noduliferus* (now *Declinognathodus noduliferus*) conodont zone, which typically is considered to be Morrowan in age (its first appearance is at the Mississippian-Pennsylvanian boundary as defined by Lane and others, 1999). No fusulinid foraminiferans are known from the Lowellville. In addition, in Pennsylvania, there is not enough known about the Lowellville fauna, if it exists, to adequately determine its age. Based on the conodonts, however, it appears that the Lowellville is late Morrowan in age.

"Boggs" Marine Zone

Orton (1884, p. 421-422) named the Boggs Iron Ore for a bedded siderite deposit "occurring in sheets or 'flags' like sandstone or shale" found on the Boggs farm in Scioto County in southeastern Ohio. Orton correlated this valuable iron ore northward with a sequence of limestones, flint beds, and fossiliferous shales associated with siderite in east-central, and for over 100 years Ohio geologists accepted this correlation. Because the northern limestone-shale-siderite zone contained marine fossils, the name has been altered over the years from Boggs Iron Ore to Boggs Member or Boggs marine zone. Slucher and Rice (1994) questioned the stratigraphic equivalence of the Boggs Iron Ore to the same-named marine zone. More recently, Hoare and others (1999) stated that the Boggs marine zone in northeastern Ohio is actually a younger unit than the type Boggs of southeastern Ohio, but, other than citing a personal communication with Michael Hansen of the Ohio Geological Survey, did not explain their reasoning. The Boggs of east-central Ohio, therefore, is currently an unnamed unit. Slucher and Rice (1994) noted that a marine to brackish water gray shale, which they termed Unit B, occurs at about the same stratigraphic position as the "Boggs marine zone," although they hesitated to say the two were equivalent. For this study, I'm following the lead of Hoare and others (1999) in using the term "Boggs" for the marine zone in this interval that occurs in east-central Ohio and, questionably, in northeastern Ohio as well.

The "Boggs" marine zone is best developed in Muskingum and Licking Counties, Ohio, and questionably extends at least as far as Mahoning and Trumbull Counties, Ohio (Stout, 1944). In Muskingum County, it varies from a hard, dark blue, very fossiliferous limestone associated with fossiliferous shale to shale, flinty limestone, and siderite (Morningstar, 1922). In some places it has been replaced by sandstone. It typically attains a thickness of about 0.6 m (2 ft) in that area. In Mahoning County, when it can be found at all, it typically occurs as a limestone, sideritic flint, or fossiliferous shale (Stout, 1944, who reported that "Boggs" ore might have been mined in the Mahoning River valley for some eastern Ohio furnaces). There are no reported lists of fossils from Mahoning County or anywhere else in northeastern Ohio, although Morningstar (1922) reported a very diverse fauna of bryozoans, brachiopods, bivalves, gastropods, cephalopods, crinoids, and fish teeth and plates, as well as a few plant fossils, from Muskingum County. More recently, Hoare (1999) described *Arcochiton concisus*, a new species of polyplacophoran (chiton), from the "Boggs," but once again it was a central Ohio occurrence.

Skema (see **STOP 11**) describes a zone of siderite nodules between what he is calling Flint Ridge Coal and Lowellville marine zone. This could be the Boggs Iron Ore of southeastern Ohio. It definitely wouldn't be the "Boggs" marine zone.

Rice and others (1979) correlated the "Boggs" with the Lost Creek marine zone of the Breathitt Formation in Kentucky. Based on the marine fauna found in east-central Ohio, the "Boggs" marine zone is lower Atokan in age. Merrill (1970-1971) placed the "Boggs" marine zone in the *Neognathodus symmetricus* conodont zone, which is considered to be lower or middle Morrowan in age (Lane and others, 1970-1971). However, Merrill (1970-1971) had not found any conodonts in the "Boggs" at the time of his publications. The marine zone contains the fusulinid foraminiferans *Profusulinella ohioensis* Douglass, *Fusulinella imprima* Douglas, and *Fusulinella stouti* Thompson, all of which point to an early Atokan age for the unit (Douglass, 1987).

Lower Mercer Marine Zone

In naming the Lower Mercer limestone, White (1879) replaced the name "Lower Wirtemburg [sic] limestone" of Lesquereux (1865) and Lesley (1875), which those authors used for the lower of two limestones cropping out along Slippery Rock Creek in the vicinity of Wurtemburg, southeastern Lawrence County. The Lower Mercer limestone consists of dark blue to black, hard and dense, often siliceous and/or iron-rich limestone, typically very fossiliferous (White, 1879; Stout and Lamborn, 1924; Lamborn, 1951). Morningstar (1922), DeWolf (1929), Lamborn (1951), and Slucher and Rice (1994) considered it the most persistent stratum within the entire Pottsville because it extends from Kentucky northward across Ohio and into Pennsylvania with essentially no change of character other than thickness. Ironically, at both the type locality near Mercer and in the New Castle area roadcuts, it is the less well developed of the two Mercer limestones. In Pennsylvania, the Lower Mercer limestone ranges from about 0.3 to about 0.8 m (1 to 2.5 ft), whereas in Ohio it can be thicker than 3 m (10 ft) (Lamborn, 1951). It typically averages about 0.6 m (2 ft).

The tripartite division of the Lower Mercer marine zone is not very well developed. The limestone itself is thick and tends to be very fossiliferous, which should make fossil hunters very happy. Unfortunately, the limestone also tends to be extremely hard, promoting the use of hefty sledge hammers and chisels and a great deal of elbow grease. Since the upper and lower marine shales tend to be quite thin to non-existent, they don't increase one's ability to collect anything useful. The limestone often sits directly on the Lower Mercer coal so that the lower marine shale is missing entirely, or is incorporated into the coal. Where the limestone and coal are separated, however, the shale can be quite fossiliferous. For example, in Mahoning County, Ohio, just across the state border, Lamb (1910) and Morningstar (1922) found an extremely fossiliferous black shale between 10 and 15 cm (4-6 in) thick beneath the limestone. The marine portion of the overlying shale is likewise very thin, and is often replaced with iron ore (siderite or limonite) and/or cone-in-cone structure.

Merrill (1970-1971; also 1974) placed the Lower Mercer marine zone in the *Gnathodus bassleri bassleri* (now *Neognathodus bassleri bassleri*) conodont zone, which Lane and others (1970-1971) indicated as being middle Morrowan in age. Merrill (1974) indicated a middle Atokan age for this zone. Dunn (1976) noted that a nearly identical form to *N. bassleri bassleri* (Harris & Hollingsworth) called *Neognathodus colombiensis* (Stibane) occurs in the Atokan, and I have to wonder if Merrill didn't confuse these two. Based on the occurrence of the fusulinid foraminiferans *Fusulinella iowensis* Thompson and *Fusulinella stouti* Thompson, the Lower Mercer is definitely late Atokan in age (Douglass, 1987). Brezinski and others (1989) reported the presence of the trilobite *Sevillia sevillensis* Weller in the Lower Mercer, the only known occurrence of this fossil in the Appalachian basin. The trilobite occurs only in Atokan rocks in the midcontinent, but occurs in both the upper Morrowan and Atokan in the Cordilleran region (Brezinski and others, 1989). In addition, the brachiopod *Antiquatonia coloradoensis* (Girty) (= *Antiquatonia portlockiana* var. *inflatia* of Sturgeon and Hoare, 1968), a common form found in the Lower Mercer in Ohio and at New Castle, also indicates a late Morrowan or Atokan age (Henry, 1998). So far in my own collecting, *A. coloradoensis* (Girty) is the only respectible index fossils I've been able to identify from the Lower Mercer in western Pennsylvania. Most of the other species I've encountered are very long ranging and of essentially no biostratigraphic value.

Figure 3. Photograph of the surface of a goethite layer on the top of the Upper Mercer marine zone showing cone-in-cone structures developed in the iron ore. The largest diameter cone is about the size of a quarter.

Upper Mercer Marine Zone

White (1879) coined the name Upper Mercer limestone to replace both Rogers' (1858) name "Mahoning Limestone" and Lesquereux's (1865) and Lesley's (1875) name "Upper Wirtemburg [sic] limestone." White felt that Rogers' name, which was based on the limestone's presence along the Mahoning River, might cause undue confusion with the well-known Mahoning section (Mahoning sandstone, coal, and shales) at the base of the Conemaugh Group. The Upper Mercer limestone is often seen as a twin of the Lower Mercer. Like the latter, it is very hard, compact, dark blue to black, fossiliferous limestone up to 1.2 m (4 ft) thick in Mercer and Lawrence Counties (White, 1879). However, it is not quite as persistent as the Lower Mercer, even in Ohio where it is fairly well developed (Morningstar, 1922; Lamborn, 1951). Ironically, it is the better developed of the two limestones at the New Castle localities (**STOPS 10** to **12**). It is also typically darker in color than the Lower Mercer (which, in Ohio, was often called the Blue limestone by farmers and iron mongers in the 19th century).

Like the Lower Mercer, the Upper Mercer marine zone consists of three distinct parts – a lower transgressive shale, a middle still-stand limestone, and an upper regressive shale, but once again the development of the tripartite division depends on where the marine zone is encountered. Like the Lower Mercer, the Upper Mercer limestone at New Castle tends to sit directly on the underlying coal so that the lower marine shale is greatly reduced or completely missing. The upper marine shale also is greatly reduced, usually only one or two cm (0.4-0.8 in) in thickness and often replaced with siderite or goethite containing cone-in-cone structure (Figure 3). White (1879 and 1880) noted that the Upper Mercer limestone was very fossiliferous wherever he found it, but he seemed to have concentrated exclusively on the limestone and ignored any associated marine shales. This is not surprising since the limestone sits directly on the Upper Mercer coal in most places in Pennsylvania. As such, most of the species described or documented from the Upper Mercer came from Ohio.

Merrill (1974) placed the Upper Mercer marine zone in the *Neognathodus bothrops* conodont zone, and assigned it a late Atokan age. The Upper Mercer also contains the fusulinid foraminiferans *Fusulinella iowensis* Thompson and *Fusulinella stouti* Thompson, indicating a late Atokan age (Douglass, 1987). In addition, it contains the brachiopod *Antiquatonia coloradoensis* (Girty), which also indicates an Atokan age (Henry, 1998). Of these, only *A. coloradoensis* (Girty) has been documented from the Upper Mercer marine zone in western Pennsylvania.

"Mercer Formation" Fossils

The "Mercer formation" in eastern and central Ohio, in particular, and in western Pennsylvania contains a large array of fossil forms, especially macroinvertebrates. There are large quantities of microinvertebrates as well (Anderson, 1986), although there was not enough time in this study to look for anything smaller than a few millimeters in diameter. However, not all of the "Mercer formation" consists of marine limestones, shales, and siderites, nor do the fossils that can be found consist only of marine invertebrates. The nonmarine shales, claystones, and sandstones contain plant fossils, and the marine limestones contain many interesting trace fossils.

Invertebrate Fossils

Invertebrate fossils constitute the most abundant of all described species from the "Mercer formation", mostly from eastern and central Ohio. Illustrations of the more common ones, particularly those listed below, can be found in Figure 4. Appendix 1 is a list of the invertebrate fossils that have been documented from the "Mercer formation" marine zones. The vast majority of these fossils have been found thus far only in Ohio, with some subsidiary faunas known from western Pennsylvania, and northern West Virginia, and northeastern Kentucky. The majority of the species listed in Appendix 1 are rare to abundant in both the Upper and Lower Mercer marine zones, but many also occur in the Lowellville and "Boggs" marine zones as well. Few of them are restricted to only one marine zone. In fact, many of these listed species range throughout the Pennsylvanian marine zones of the Appalachians, from Pottsville to Conemaugh, demonstrating their lack of utility for biostratigraphic zonation.

Lowellville marine zone. Morningstar (1922) identified the following species at the Lowellville type locality in Mahoning County, Ohio (taxonomy has been updated as much as possible):

Orbiculoidea missouriensis (Shumard)
Derbyia crassa (Meek & Hayden)
Rugosochonetes delicatus Sturgeon & Hoare
Kozlowskia haydenensis (Girty)
Kozlowskia splendens (Norwood & Pratten)
Desmoinesia muricatina missouriensis (Girty)
Juresania nebraskensis inflatia Sturgeon & Hoare
Linoproductus planiventralis Hoare
Composita subtilita (Hall)
Antracospirifer rockymontanus (Marcou)
Punctospirifer kentuckyensis (Shumard)
Parallelodon sangamonensis (Worthen)
Pseudorthoceras knoxense (McChesney)
Crinoid columnals

This list does not include *Antiquatonia coloradoensis* (Girty), although Sturgeon and Hoare (1968) listed the Lowellville as one of the marine zones where it could be found. *A. coloradoensis* is an index fossil of the late Morrowan and Atokan in the midcontinent and Cordilleran regions.

"***Boggs" marine zone.*** Although there is a substantial quantity of marine invertebrates in the "Boggs" marine zone in the area around Muskingum County, Ohio, Morningstar (1922) found nothing in Mahoning County. The lack of any recognizable marine or brackish water faunas from the New Castle area suggests the "Boggs" does not extend that far east in the Appalachian basin.

Lower Mercer marine zone. White (1879 and 1880) and Morningstar (1922) found the following species in the Lower Mercer in Lawrence and Mercer Counties, and at Lowellville, Mahoning County, Ohio, respectively (taxonomy has been updated as much as possible):

Unnamed bryozoans
Derbyia crassa (Meek & Hayden)
Mesolobus mesolobus (Norwood & Pratten)
Koslowskia splendens (Norwood & Pratten)
Juresania nebrascensis inflatia Sturgeon & Hoare
Antiquatonia coloradoensis Girty
Linoproductus planiventralis Hoare
Composita subtilita (Hall)
Anthracospirifer rockymontanus (Marcou)
Anthracospirifer occiduus (Sadlick)
Neospirifer cameratus (Morton)
Phricodothyris perplexa (McChesney)
Astartella concentrica (Conrad)
?*Edmondia* sp. (reported as *Cardiamorpha subglobosa*, a Mississippian species)
Unnamed nautiloid cephalopod
Unnamed crinoids

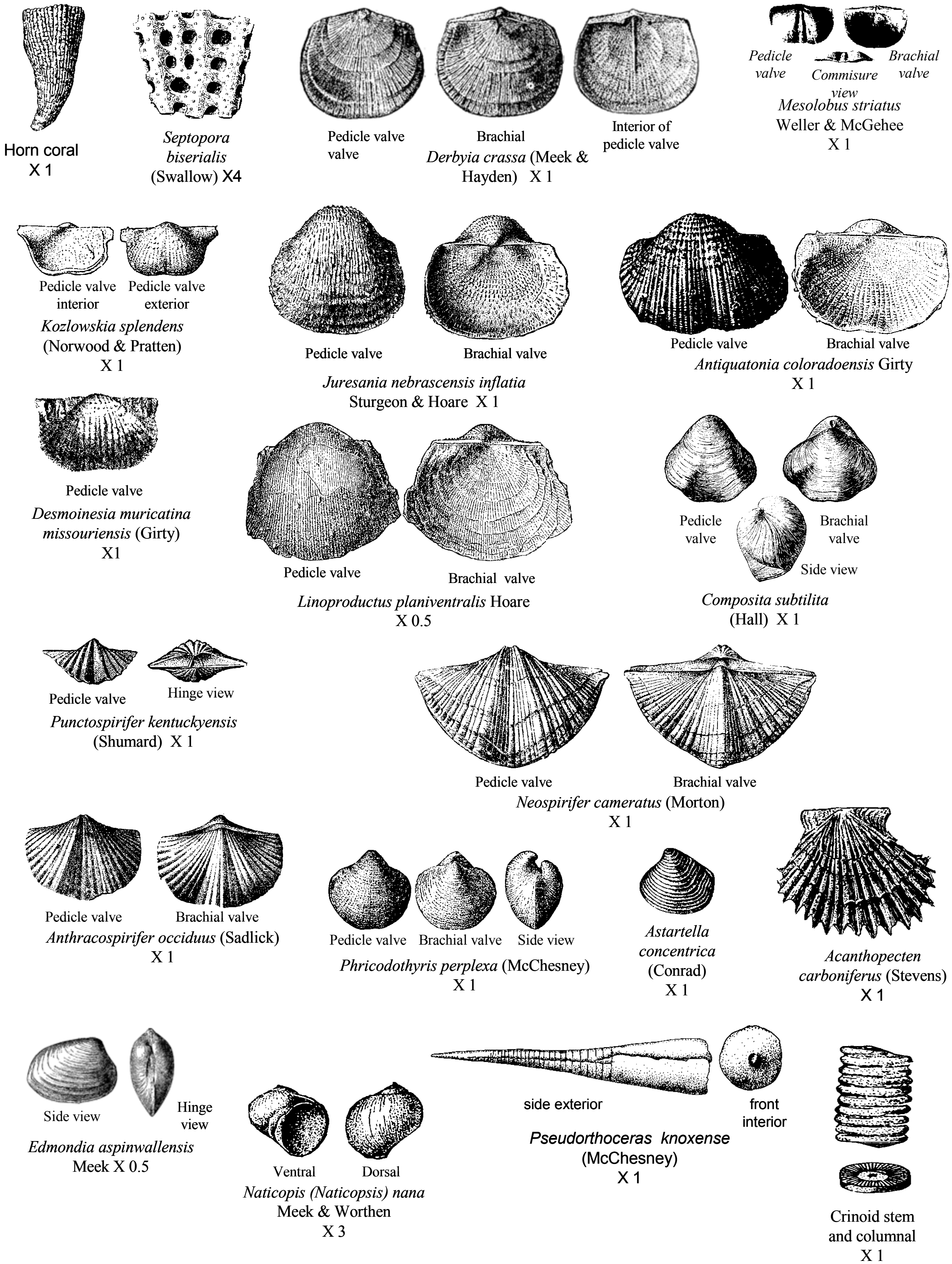


Figure 4. Illustrations of the more common invertebrate fossils found in the "Mercer formation" (modified from Lesley, 1889-1890; Sturgeon and Hoare, 1968; and Hoskins and others, 1983).

Based on my own collecting, I can add the coral *Stereostylus*(?) sp. to the above list. Notice that this list contains *Antiquatonia coloradoensis* (Girty).

Upper Mercer marine zone. White (1879 and 1880) and Morningstar (1922) listed the following species from outcrops of the Upper Mercer limestone of Lawrence and Mercer Counties,

Septopora biserialis (Swallow)	*Neospirifer cameratus* (Morton)
Mesolobus striatus Weller & McGehee	*Punctospirifer kentuckyensis* (Shumard)
Kozlowskia haydenensis (Girty)	*Phricodothyris perplexa* (McChesney)
Kozlowskia splendens (Norwood & Pratten)	*Acanthopecten carboniferous* (Stevens
Desmoinesia muricatina missouriensis (Girty	*Naticopsis (Naticopsis) nana* Meek & Worthen
Antiquatonia coloradoensis (Girty)	Crinoid columnals
Composita sp.	

and in eastern Mahoning County, Ohio, respectively (taxonomy has been updated):
Based on my own collecting, I can add the coral *Stereostylus*(?) sp. and the cephalopod *Pseudorthoceras knoxense* (McChesney) to the above list. Once again, *Antiquatonia coloradoensis* (Girty) occurs in this marine zone as well as the lower ones, suggesting the entire "Mercer formation" is Atokan in age.

White (1880) also noted that fragments of Upper Mercer limestone could be found in old mine-dump heaps at the Stranahan iron mine near Hells Hollow (**STOP 1**), and that the fragments commonly contained mollusc shells (he probably meant brachiopods) and crinoid columnals.

Vertebrate Fossils

Vertebrate fossils are rare in the Pottsville. Although my literature search thus far cannot be considered exhaustive, I haven't found a single named species within any of the Pottsville strata in western Pennsylvania or eastern Ohio. Morningstar (1922) noted the existence of rare isolated teeth and plates from the Lowellville marine unit in Muskingum and Mahoning Counties, Ohio and from the "Boggs" marine unit in Vinton County, Ohio (also in two marine units below the "Mercer formation"), but neglected to describe or illustrate any of them.

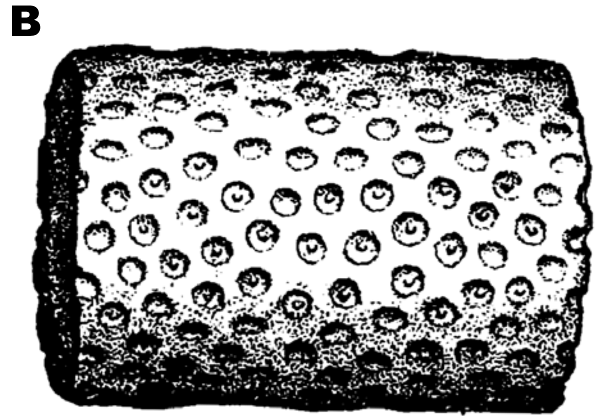
Plant Fossils

A significant number of plant forms have been described and/or documented from the Pottsville throughout the Appalachian basin (Appendix 2), most of which come from the Sharon or Homewood sections of the Pottsville. However, Darrah (1969) listed several of them from the "Mercer formation" itself.

The lycopod rhizophore ("root"), *Stigmaria ficoides* (Sternberg) (Figure 5), is the most noticeable and recognizable plant fossil to be seen at the "Mercer formation" stops. Sandstone or siltstone molds and casts of the rhizophore (Figure 5A) are particularly abundant (relatively speaking) in the shales between the two marine limestones at **STOPS 10** and **11**, and can be seen within the sandstone developed between the Mercer limestones at **STOP 12** (as well as above the Mercer formation at **STOP 1**). It typically is well developed in the underclays and clayey sandstones beneath the coals, often accompanied by the traces of the roots. In many of the strata beneath the coals, the roots are the most prominent feature of the strata (Figure 5C). Other plant fossils occur, primarily in the fluvial sandstones, as log impressions of *Sigillaria* and *Lepidodendron*, arborescent lycopods (Figure 6).

Trace Fossils

Trace fossils, the tracks, trails, burrows, etc. of animals, are quite common in the "Mercer



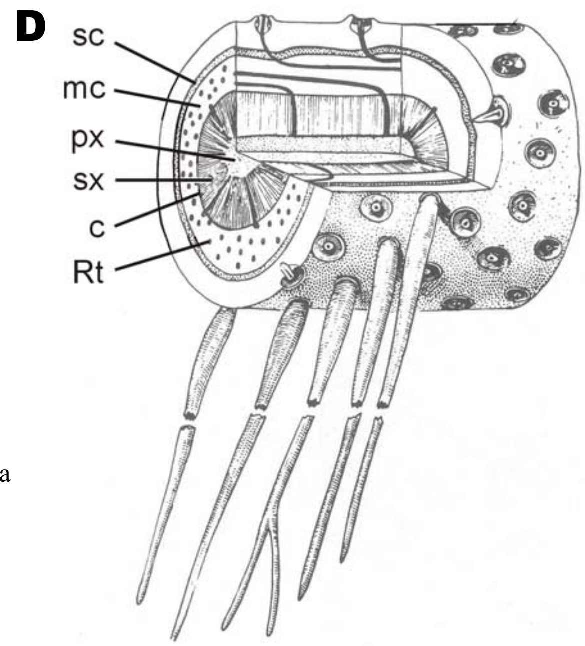


Figure 5. *Stigmaria*, the most recognizable plant fossil in the "Mercer formation". A. Photograph of a cast of the surface of a rhizophore in siltstone from **STOP 10**. B. Illustration of a typical *Stigmaria* cast for clarity. C. Photograph of *Stigmaria* rootlets in the sandstone below the Upper Mercer coal at Wurtemburg. D. Illustration of *Stigmaria ficoides* showing the probably makeup of the root system (modified from Stewart, 1983). c – cambium; mc – middle cortex; px – protoxylem; rt – root trace; sc – secondary cortex; sx – secondary xylem.

formation" at the outcrops along US 422, and probably at other Mercer locations as well. Several ichnogenera are present. Some ichnologists and sedimentologists consider root traces as trace fossils. For the sake of simplicity, root traces are discussed above under "plant fossils" and the term "trace fossil" will be herein restricted to invertebrate animal traces.

The correct designation of any trace

Figure 6. Photograph of fossil tree logs from the "Mercer formation" sandstone developed at **STOP 12**. These probably are *Sigillaria elongata* Brongniart.

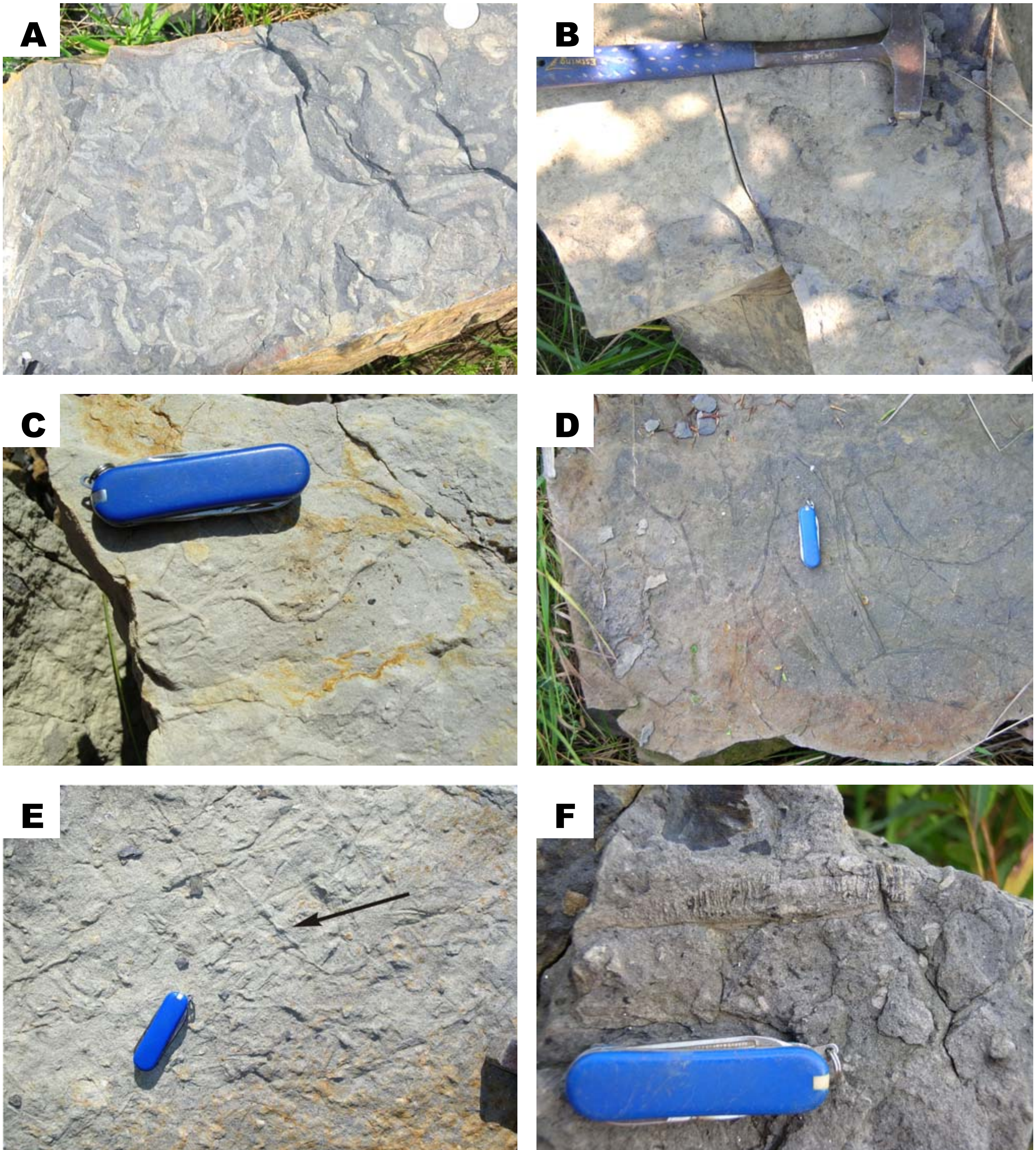


Figure 7. Photographs of some representative trace fossils from the "Mercer formation" at **STOPS 10** to **12**. A. *Thalassinoides*; B. *Rhizocorallium*(?); C. *Planolites*; D. *Palaeophycus*; E. *Rhabdoglyphus* (at arrow); F. *Arthrophycus*.

fossil is suspect because there are so many varieties of them and few have undergone the sort of monographic treatment that is necessary to "separate the wheat from the chaff," as it were. Pemberton and Frey (1982), for example, pointed out the enormous problems paleontologists and

Figure 8. Photograph of *Zoophycos marginifera* (Lesquereux) from the Lower Mercer limestone at **STOP 11**. Lesquereux (1865) first described this trace fossil from the Lower Mercer limestone at Wurtemburg, Lawrence County, Pennsylvania.

sedimentologists create for themselves by inadequately diagnosing and describing the trace fossils they are studying. Many of the names I use here are simply fill-in-the-blank designations; I invite anyone on this field trip, or who might be independently examining the Mercer rocks at these localities, to provide their own alternative names and interpretations for the burrows and trails that can be found.

Ichnologists traditionally have placed less emphasis on the trace fossils found in carbonates than in most other types of sedimentary rocks (Kennedy, 1975). However, many trace fossils and their associations can be quite recognizable despite the great differences in the ages of the deposits in which the traces are found. For example, *Thalassinoides,* a common trace fossil found in shallow water carbonates of all ages, including in the Recent, is very common in the Mercer limestones. It can be seen as lighter colored "stains" on the dark bedding planes (Figure 7A). *Rhizocorallium* (Figure 7B) also occurs in the Upper Mercer limestone, and probably in the Lower Mercer as well. *Planolites* occurs in the limestones, but appears to be more common in the "Mercer formation" sandstones than the limestones (Figure 7C). Other trace fossils in the sandstones include *Palaeophycus* (Figure 7D), *Rhabdoglyphus* (Figure 7E), and *Arthrophycus* (Figure 7F). Their presence in the sandstones suggests a brackish water association.

Perhaps the most notable trace fossil in the "Mercer formation" is *Zoophycos marginatus* (Lesquereux) (Figure 8), originally described from the Lower Mercer limestone along Slippery Rock Creek at Wurtemburg. It can be found in both Mercer limestone beds. In describing *Zoophycos marginatus*, Lesquereux (1865) believed, as did most paleontologists of the early and middle 19th century, that trace fossils were remains of marine algae called "fucoides." It only became clear in the latter part of the 1800s that many fucoides were, in fact, the burrows or trails of worms, snails, trilobites, and other creatures crawling around in the mud of the sea floor. Lesquereux found a strong resemblance between his "*Caulerpites marginatus*" and the well-known *Spirophyton caudi-galli* (Vanuxem), or "rooster tail fucoid," from the Devonian of New York. Based on what he perceived were aspects of its plant structure, he placed it near a living group of green-seed seaweeds called *Caulerpae* – thus the derivation of Lesquereux's original generic name. We now know that *Zoophycos* was produced by an as yet unknown host animal, an infaunal feeder, and that the trace was produced by the excretion of ingested sediment beneath the sediment-water interface (Kotake, 1989). Interestingly, even as late as the 1970s some *Zoophycos* and *Spirophyton* fossils were considered to be plants (e.g., Loring and Wang, 1971).

Although most trace ichnologists and sedimentologist think *Zoophycos* is especially widepread in deep water carbonate facies, it is actually a well-known trace fossil in carbonate substrates of all depths, ranging from subtidal to basinal environments, throughout geologic history (Senglaub and Yacobucci, 2004). It typically occurs in an assemblage that includes *Thalassinoides*, *Planolites*, and *Chondrites* (however, I have not recognized this latter ichnogenus in the Mercer limestones). The lithology normally associated with this assemblage is chalk (Ekdale and others, 1984), with *Planolites* common in soupy sediments, *Thalassinoides* and *Zoophycos* common in softground sediments, and *Zoophycos* and *Chondrites* common in firmgrounds. Ekdale and others

(1984) also noted that the preservational style of the trace fossils confirms the consistency of the substrate. *Planolites* burrows tend to be poorly preserved with indistinct walls and a high degree of compaction as a result of "soupy" sediments. Firmground specimens of *Zoophycos* tend to have very sharp, crisp walls. *Thalassinoides*, which occupys the softground between these two extremes, tends to have intermediate features, with sharp walls but indications of compactional distortion. The *Zoophycos* found in the Mercer limestones, have somewhat indistinct walls and other features (such as the spreiten within the trace). This, coupled with the apparent lack of *Chondrites* and the relatively low abundance of *Planolites* in the Mercer limestones points to these rocks having been softground sediments at the time of bioturbation.

Wrap-Up

The "Mercer formation" of western Pennsylvania and eastern Ohio may never receive formal designation as a mappable unit. There is just too much variability in the section, especially where the overlying Homewood sandstone and the underlying Connoquenessing sandstone(s) are either over- or underdeveloped. There is also still a great deal of confusion regarding precisely what defines the upper and lower contacts of the sequence. Do we include the Homewood shales in the "Mercer formation" as Carswell (1965) did, or exclude them? If the latter, should we include the few centimeters of marine shale above the Upper Mercer limestone as part of the "Mercer formation" or part of the "Homewood formation?" Does the Lowellville limestone actually lie within the Connoquenessing sequence as Slucher and Rice (1994) suggest, or have they miscorrelated a mid-Mercer sandstone, such as that found at **STOPS 10** to **12**, with the Upper Connoquenessing and, therefore, made much of their work suspect? These and many other questions remain to be answered.

Those of us who have studied and used the Pennsylvanian stratigraphic section laid out by the geologists of the 19^{th} and 20^{th} centuries realize the need to find something more reliable to hang our correlations on than thin coals representing ephemeral swamps and fluvial sandstones having shoestring, rather than blanket, geometries. Ash beds would be ideal, but they appear to be few and far between, or simply have not yet been recognized in the section. Index fossils, both plant and animal, also are useful, but too few geologists in this day and age are being trained in paleontology and biostratigraphy (many university geology departments are dropping their paleontology courses as "nonessential"). Many fossil species, when recognizable at all, are long ranging and of no use biostratigraphically. And, from a personal standpoint, it is not enough to say that the "XYZ marine unit" in Ohio is Atokan in age, so it must also be Atokan in age in Pennsylvania because our scientific ancestors recognized these rocks as being identical across the state boundaries. There are such things as onlap and differences in times of deposition in different areas. It is LIKELY that the "Mercer formation" marine zones represent at least three separate marine transgressions and regressions during the Atokan age, but all good scientific hypotheses need to be tested. Some day some bright-eyed and bushy-tailed young upstart might discover that the Lower Mercer in western Pennsylvania is younger than the Lower Mercer in Kentucky. Now, wouldn't that open some eyes?

Appendix 1
Fossil species documented from the Mercer marine zones, mostly in eastern Ohio with some representation in western Pennsylvania

Foraminifera

Hyperammina bulbosa Cushman & Waters
Ammodiscus semiconstrictus regularis Waters
Glomospira simplex Harlton
Tolypamminia confusa Galloway & Harlton
Ammovertella inversa (Shellwien)
Ammovertella latimerensis Galloway & Harlton
Reophax asper Cushman & Waters
Palaeotextularia sp.
Climacammina copiacellula Maloney, Hoare & Sturgeon
Climacammina cushmani (Harlton)
Climacammina cylindrica Cushman & Waters
Climacammina lucilleae (Harlton)
Tetrataxis concava Galloway & Rynicker
Tetrataxis lata Spandel
Endothyra excentralis Cooper
Endothyra kennethi St. Jean
Endothyra ovata Waters
Endothyra rothrocki Harlton
Endothyranella inflata Hoare & Sturgeon
Endothyranella kentuckyensis Hoare & Sturgeon
Endothyranella minuta Waters
Endothyranella sobrina (Plummer)
Endothyranella sp.
Quasiendothyra ovata (Waters)
Quasiendothyra whitesidei (Galloway & Ryniker)
Ozawainella ciscoensis (Harlton)
Ozawainella radiata (Brady)
Millerella extensa Marshall
Millerella marblensis Thompson
Millerella sp.
Paramillerella mutabilis Rauzer-Chernousova
Paramillerella rjasanensis Rauzer-Chernousova
Eoschubertella diminutiva (Thompson)
Eoschubertella gallowayi (Skinner)
Profusulinella ohioensis Douglass
Fusulinella imprima Douglass
Fusulinella iowensis Thompson
Fusulinella stouti Thompson
Pseudostaffella atokensis (Thompson)
Pseudostaffella douglassi Hoare & Sturgeon
Spirillina? *concavaconvexa* Galloway & Rynicker

Sponges

Heliospongia ramose Girty

Conularids

Conularia crustula White
Conularia newberryi Winchell

Corals

Lophophyllidium proliferum (McChesney)
Stereostylus sp.

Bryozoans

Bascomella gigantea Morningstar
Tabulipora ohioensis (Foerste)
Chainodictyon laxum Foerste
Fenestella limbata Foerste
Fenestella remota Foerste
Fenestella shumardi Prout
Fenestella sp.
Polypora fastuosa Foerste
Polypora sp.
Penniretepora whitii Foerste
Rhombopora lepidodendroides Meek
Rhombopora multipora Foerste
Streblotrypa merceri Morningstar

Bryozoans (Continued)

Stictopora biserialis (Swallow)
Stictopora biserialis gracilis (Meek)
Stictopora carbonaria (Meek)
Stictopora serata (Meek)

Brachiopods

Lingula carbonaria Shumard
Lingula kanawhensis Price
Trigonoglossa nebrascensis (Meek)
Orbiculoidea capuliformis (McChesney)
Orbiculoidea meekana (Whitfield)
Orbiculoidea missouriensis (Shumard)
Lindstroemella patula (Girty)
Crania modesta White & St. John
Schizophoria resupinoides (Cox)
Rhipidomella carbonaria (Swallow)
Derbyia crassa (Meek & Hayden)
Derbyia sp.
Rugosochonetes lamellosus Sturgeon & Hoare
Mesolobus striatus Weller & McGehee
Plicochonetes dotus Sturgeon & Hoare
Krotovia paucispina Sturgeon & Hoare
Kozlowskia haydenensis (Girty)
Kozlowskia splendens (Norwood & Pratten)
Desmoinesia muricatina (Dunbar & Condra)
Desmoinesia muricatina missouriensis Girty
Echinaria semipunctata Knighti (Dunbar & Condra)
Juresania nebrascensis inflatia Sturgeon & Hoare
Antiquatonia coloradoensis (Girty)
Antiquatonia costellata Sturgeon & Hoare
Linoproductus echinatus Hoare
Linoproductus planiventralis Hoare
Cancrinella boonensis (Swallow)
Hustedia miseri Mather
Cleiothyridina orbicularis (McChesney)
Cleiothyridina orbicularis crassalamellosa Sturgeon & Hoare
Composita ovata Mather
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Anthracospirifer occiduus (Sadlick)
Anthracospirifer opimus (Hall)
Anthracospirifer rockymontanus (Marcou)
Neospirifer cameratus (Morton)
Neospirifer goreii (Mather)
Punctospirifer kentuckyensis (Shumard)
Phricodothyris perplexa (McChesney)
Beecheria bovidens (Morton)

Ostracodes

Kirkbyella gutkei Chroneis & Gale
Hollinella (Hollinella) bassleri Knight
Hollinella (Hollinella) dentata Coryell
Kirkbya bendensis Harlton
Kirkbya clarocarinata Knight
Kirkbya fuldaensis Shaver & Smith
Aurikirkbya triseriata Shaver
Amphissites (Amphissites) centronotus (Ulrich & Bassler)
Amphissites (Amphissites) congruens Cooper
Amphissites (Amphissites) rugosus Girty
Amphissites (Amphikegelites) henryi Sohn
Amphissites (Amphikegelites) sohni Christopher, Hoare & Sturgeon
Kegelites harltoni (Cooper)
Kellettina prolata Hoare, Hansen & Merrill
Shleesa rothi (Bradfield)

Ostracodes (continued)
- *Shleesa sullivanensis* (Payne)
- *Moorites erugatus* Hoare
- *Moorites knighti* (Wilson)
- *Moorites minutus* (Warthin)
- *Moorites ornatus* Hoare
- *Moorites sturgeoni* Hoare
- *Sansabella stewartae* Marple
- *Pseudoparaparchites elongatus* Cooper
- *Bairdia altifrons* Knight
- *Bairdia bradfieldi* Payne
- *Bairdia cuspidis* Hoare, Svitko & Sturgeon
- *Bairdia grahamensis* Harlton
- *Bairdia hartoni* Cooper
- *Bairdia pennata* Coryell & Sample
- *Bairdia peracuta* Warthin
- *Bairdia pompilioides* Harlton
- *Orthobairdia dornickhillensis* (Harlton)
- *Orthobairdia texana* (Harlton)
- *Cryptobairdia coryelli* (Roth & Skinner)
- *Rectobairdia apiculata* Hoare, Svitko & Sturgeon
- *Rectobairdia sohni* Hoare, Svitko & Sturgeon
- *Bairdiacypris haydenbranchensis* (Payne)
- *Bairdiacypris minuta* (Cooper)
- *Bairdiacypris regularis* (Cooper)
- *Bairdiacypris tenuis* (Cooper)
- *Bairdiacypris trojana* (Wilson)
- *Bairdiacypris warthini* (Bradfield)
- *Entmena distenta* Hoare, Svitko & Sturgeon
- *Bythocypris pediformis* Knight
- *Bythocypris pediformis* parallela Knight
- *Monoceratina bradfieldi* Cooper
- *Monoceratina macoupena* Scott & Borger
- *Healdia elegans* Warthin
- *Healdia fabalis* Cooper
- *Healdia glennensis* Harlton
- *Healdia longula* Cooper
- *Healdia* sp.
- *Cavellinella casei* Bradforld
- *Sulcella sulcata* Coryell & Sample
- *Microcheilinella minuta* Cooper
- *Jonesina biformis* Bradfield

Trilobites
- *Sevillia sevillensis* Weller
- *Sevillia trinucleata* (Herrick)
- *Ameura missouriensis* (Shumard)
- *Ditomopyge scitula* (Meek & Worthen)

Polyplacophorans
- *Helminthochiton simplex* (Raymond)
- *Pterochiton carbonarius* (Stevens)
- *Acutichiton pyrmidalus* Hoare, Sturgeon & Hoare
- *Arcochiton concisus* Hoare
- *Arcochiton raymondi* Hoare & Sturgeon

Gastropods
- *Euphemites enodis* Sturgeon
- *Euphemites multiliratus* Sturgeon
- *Euphemites nodocarinatus* (Hall)
- *Euphemites vittatus* (McChesney)
- *Bellerophon (Bellerophon) crassus* Meek & Worthen
- *Bellerophon (Bellerophon) wabaunseensis* Tasch
- *Pharkidonotus labioreflexus* (Sturgeon)
- *Pharkidonotus percarinatus* (Conrad)
- *Retispira fasireticulatus* Hoare, Sturgeon & Anderson
- *Retispira tenuilineata* (Gurley)
- *Knightites (Cymatospira) montfortianus discordis* Hoare, Sturgeon & Anderson
- *Patellilabia tentoriolum* Knight
- *Straparollus (Euomphalus) plummeri* Knight
- *Amphiscapha catilloides* (Conrad)

Gastropods (continued)
- *Trepospira (Trepospira) illinoiensis* (Worthen)
- *Callistadia spirallia* Hoare & Sturgeon
- *Euconospira equisita* Hoare, Sturgeon & Anderson
- *Euconospira turbiniformis* (Meek & Worthen)
- *Spiroscala decorate* Hoare, Sturgeon & Anderson
- *Spiroscala pagoda* Knight
- *Spiroscala rockymontana* Girty
- *Glabrocingulum (Glabrocingulum) grayvillense* (Norwood & Pratten)
- *Glabrocingulum (Glabrocingulum) wannese* (Newell)
- *Neilsonia invisitata* Hoare, Sturgeon & Anderson
- *Shansiella beckwithana* (McChesney)
- *Shansiella carbonaria* (Norwood & Pratten)
- *Porcellia gillianus* (White & St. John)
- *Paragoniozona nodolirata* Nelson
- *Phymatopleura nodosa* (Girty)
- *Abylea insolitus* Hoare, Sturgeon & Anderson
- *Abylea minuta* Sturgeon
- *Abylea ornatiformis* (Morningstar)
- *Abylea paradoxus* Hoare, Sturgeon & Anderson
- *Stegocoelia (Taosia) copei* (White)
- *Goniasma lasallensis* (Worthen)
- *Eucochlis perminuta* Knight
- *Naticopsis (Naticopsis) nana* Meek & Worthen
- *Naticopsis (Naticopsis) scintilla* Girty
- *Naticopsis (Jedria) ventrica* (Norwood & Pratten)
- *Naticopsis (Marmolatella) pulchella* Morningstar
- *Trachydomia nodosa* (Meek & Worthen)
- *Trachydomia ortoni* (Whitfield)
- *Palaeozygopleura* sp.
- *Microptychia expetendus* Hoare & Sturgeon
- *Spiromphalus pervius* Hoare
- *Plocezyga (Plocezyga) conica* (Hoare & Sturgeon)
- *Plocezyga (Plocezyga) delicata* (Hoare & Sturgeon)
- *Plocezyga (Plocezyga) lirata* (Hoare & Sturgeon)
- *Plocezyga (Plocezyga) subnodosa* (Hoare & Sturgeon)
- *Plocezyga (Gamizyga) attenuata* (Hoare & Sturgeon)
- *Plocezyga (Gamizyga) morningstarae* (Hoare & Sturgeon)
- *Plocezyga (Hyphantozyga) fusiforma* (Hoare & Sturgeon)
- *Plocezyga (Hyphantozyga) perattenuata* (Hoare & Sturgeon)
- *Cyclozyga attenuata* Hoare & Sturgeon
- *Palaeostylus (Pseudozygopleura) acuminatus* Knight
- *Palaeostylus (Pseudozygopleura) balteus* Hoare & Sturgeon
- *Palaeostylus (Pseudozygopleura) contractus* Hoare & Sturgeon
- *Palaeostylus (Pseudozygopleura) deloi* Knight
- *Palaeostylus (Pseudozygopleura) inornatus* Knight
- *Palaeostylus (Pseudozygopleura) kellettae* Knight
- *Palaeostylus (Pseudozygopleura) lanceolatus* Hoare & Sturgeon
- *Palaeostylus (Pseudozygopleura) macrus* Knight
- *Palaeostylus (Pseudozygopleura) pagodus* Knight
- *Palaeostylus (Pseudozygopleura) peoriense* (Worthen)
- *Palaeostylus (Pseudozygopleura) pinquicula* Hoare & Sturgeon
- *Palaeostylus (Pseudozygopleura) pluricostata* Knight
- *Palaeostylus (Pseudozygopleura) schucherti* Knight
- *Palaeostylus (Pseudozygopleura) sinuosior* Knight
- *Palaeostylus (Pseudozygopleura) tenuivirga* Knight
- *Orthonema ascensus* Anderson, Hoare & Sturgeon
- *Orthonema chorda* Anderson, Hoare & Sturgeon
- *Orthonema conicum* Meek & Worthen
- *Orthonema nebrascense* (Geinitz)
- *Orthonema subtaeniatum* (Geinitz)
- *Callispira quinquicostata* Nelson
- *Bulimorpha turnerensis* Sayre
- *Soleniscus typicus* (Meek & Worthen)
- *Strobeus brevis* (White)
- *Strobeus intercalaris* (Meek & Worthen)
- *Strobeus klipperti* (Meek)
- *Strobeus paludinaeformis* (Hall) X

Gastropods (Continued)
Strobeus primogenius (Conrad)
Strobeus regularis (Cox)
Meekospira peracuta (Meek & Worthen)
Girtyspira minuta (Stevens)
Donaldina quadroliratus Anderson, Hoare & Sturgeon
Donaldina robusta (Stevens)
Donaldina stevensana (Meek & Worthen)
Donaldina swallowiana (Geinitz)
Streptacis meeki Knight

Cephalopods
Brachycycloceras sp.
Pseudorthoceras knoxense (McChesney)
Mooreoceras normale Miller, Dunbar & Condra
Metacoceras perelegans Girty
Metacoceras sp.
Endolobus forbesianus (McChesney)
Endolobus ortoni (Whitfield)
Latitemnocheilus johnsoni (Miller, Dunbar & Condra)
Latitemnocheilus sp.

Cephalopods (continued)
Domatoceras williamsi Miller & Owen
Mahoningoceras pottsvillense (Morningstar)
Mahoningoceras subquadrangulare (Whitfield)
Solenochilus peculiare Miller & Owen
Ctenobactrites isogramma (Meek)
Ephippioceras ferratum (Cox)
Phaneroceras compressum (Hyatt)
Dimorphoceratoides campbellae Furnish & Knapp
Gastrioceras sp.
Paralegoceras sp.
Mangeroceras canfieldense Sturgeon, Windle, Mapes & Hoare

Rostroconchs
Pseudoconocardium parrishi (Worthen)
Pseudobigalea crita Hoare, Mapes & Brown

Bivalves
Nuculopsis anodontoides (Meek)
Nuculopsis croneisi Schenck
Nuculopsis girtyi Schenck
Paleyoldia stevensoni (Meek)
Phestia attenuata (Meek)
Phestia bellistriata (Stevens)
Phestia bellistriata prolongata (Morningstar)
Solemya (Janeia) radiate Meek & Worthen
Parallelodon carbonarius (Cox)
Parallelodon obsoletus (Meek)
Parallelodon sangamonensis (Worthen)
Parallelodon tenuistriatus (Meek & Worthen)
Modiolus (Modiolus) radiatus Hoare, Sturgeon & Kindt
Promytilus pottsvillensis Hoare, Sturgeon & Kindt
Pteronites americana (Meek)
Septimyalina perattenuata (Meek & Hayden)
Septimyalina sinuosa (Morningstar)
Monopteria subalata Beede & Rogers
Placopterina ohioensis Hoare, Sturgeon & Kindt
Leptodesma (Leptodesma) ohioense (Herrick)
Dunbarella knighti Newell
Dunbarella rectalaterarea (Cox)
Dunbarella striata (Stevens)
Aviculopecten appalachianus Hoare, Sturgeon & Kindt

Bivalves (continued)
Aviculopecten coxanus Meek & Worthen
Aviculopecten germanus Miller & Faber
Aviculopecten halensis Mather
Aviculopecten occidentalis (Shumard)
Aviculopecten sorer Herrick
Acanthopecten carboniferous (Stevens)
Fasciculiconcha knighti Newell
Fasciculiconcha providencensis (Cox)
Fasciculiconcha scalaris (Herrick)
Streblochondria hertzeri (Meek)
Streblochondria tenuilineata (Meek & Worthen)
Euchondria levicula Newell
Pseudomonotis carbonaria (Meek & Worthen)
Pseudomonotis precursor Mather
Pseudomonotis sp.
Posidonia fracta (Meek)
Pernopecten attenuatus (Herrick)
Pernopecten ohioensis Newell
Palaeolima retifera (Shumard)
Schizodus acuminatus Hoare, Sturgeon & Kindt
Schizodus affinis Herrick
Schizodus amplus Meek & Worthen
Schizodus cuneatus Meek
Schizodus wheeleri (Swallow) X
Permophorus costatiformis (Meek & Worthen)
Permophorus immaturus (Herrick)
Permophorus oblongus (Meek)
Permophorus spinulosus (Morningstar)
Permophorus tropidophorus (Meek)
Pleurophorella sesquiplicata Price
Astartella compacta Girty
Astartella concentrica (Conrad)
Astartella newberryi Meek
Astartella varica McChesney
Cypricardinia carbonaria Meek
Edmondia anodontoides (Meek)
Edmondia aspinwallensis Meek
Edmondia gibbosa (M'Coy)
Edmondia meekiana (Herrick)
Edmondia ovata Meek & Worthen
Edmondia reflexa Meek
Prothyris (Prothyris) elegans Meek
Unklesbayella geinitzi (Meek)
Exochorhynchus altirostratus (Meek & Hayden)
Wilkingia terminale (Hall)

Scaphopods
Plagioglypta meekana (Geinitz)
Plagioglypta prosseri Morningstar

Crinoids
Miscellaneous columnals and stems

Echinoids
Archaeocidaris spines

Conodonts
Ozarkodina minutus (Ellison)
Ozarkodina orphanus Merrill
Diplognathodus coloradensis (Murray & Chronic)
Neognathodus bassleri bassleri (Harris & Hollingsworth)
Neognathodus bothrops Merrill

Appendix 2
Plant fossil species documented from the Pottsville Formation, mostly in eastern Ohio with some representation in western Pennsylvania and northern West Virginia.

Arborescent lycopods
- Stems
  - *Sigillaria schlotheimiana* Brongniart
  - *Asolanus camptotaenia* Wood
  - *Lepidodendron aculeatum* Sternberg
  - *Lepidodendron lanceolatum* Lesquereux
  - *Lepidodendron obovatum* Sternberg
  - *Lepidodendron ornatus* Brongniart
  - *Lepidophloios larcinus* Sternberg
  - *Bothrodendron minutifolium* (Boulay)
  - *Ulodendron majus* Lindley & Hutton
- Roots
  - *Stigmaria ficoides* (Sternberg)
- Leaves
  - *Lepidophylloides longifolium* Brongniart
- Cones
  - *Sigillariostrobus* sp.
  - *Lepidocarpon* sp.
  - *Polysporia mirabilis* Newberry
- Spores
  - *Carpolithes fragarioides* Newberry

Herbaceous lycopods
- Stems
  - *Lycopodites* sp.

Sphenophytes (herbaceous scrambling rushes)
- Leaves
  - *Sphenophyllum cuneifolium* (Sternberg)
  - *Sphenophyllum emarginatum* (Brongniart)
  - *Sphenophyllum majus* (Bronn)
- Cones
  - *Bowmanites* sp.

Equisetids (horsetails and scouring rushes)
- Stems
  - *Calamites carinatus* Sternberg
  - *Calamites undulatus* Sternberg
- Leaves
  - *Annularia asteris* Bell
  - *Annularia galioides* Lindley & Hutton
  - *Annularia radiata* (Brongniart)
  - *Annularia sphenophylloides* (Zenker)
  - *Annularia stellata* (Schlotheim)
  - *Asterophyllites charaeformis* Sternberg
  - *Asterophyllites equisetiformis* (Schlotheim)
  - *Asterophyllites grandis* (Sternberg)
  - *Asterophyllites longifolius* (Sternberg)
- Cones
  - *Calamostachys* germanica Weiss
  - *Palaeostachya* sp.

Zygopterids (primitive ferns)
- Leaves
  - *Alloiopteris coralloides* (Gutbier)

Marattialids (fern trees)
- Leaves
  - *Pecopteris miltoni* (Artis)
  - *Pecopteris oreopteridia* (Schlotheim)
  - *Pecopteris plumosa* Artis
  - *Pecopteris pseudovestita* White

Spermatopsids (seed ferns – primitive gymnosperms)
- Leaves
  - *Sphenopteris amoena* Stur
  - *Sphenopteris chaerophylloides* (Brongniart)
  - *Sphenopteris coemansii* Andrae
  - *Sphenopteris gracilis* White

Spermatopsids (continued)
- Leaves (continued)
  - *Sphenopteris neuropteroides* (Boulay)
  - *Sphenopteris obtusiloba* Brongniart
  - *Sphenopteris schatzlarensis* Stur
  - *Mariopteris latifolia* (Brongniart)
  - *Mariopteris minima* Andrews
  - *Mariopteris nervosa* (Brongniart)
  - *Mariopteris occidentalis* White
  - *Alethopteris ambigua* Lesquereux
  - *Alethopteris decurrens* (Artis)
  - *Alethopteris friedelii* Bertrand
  - *Alethopteris grandifolia* Newberry
  - *Alethopteris lonchitica* (Schlotheim)
  - *Alethopteris serlii* (Brongniart)
  - *Linopteris obliqua* (Bunbury)
  - *Megalopteris dawsonii* (Hartt)
  - *Megalopteris ovata* Andrews
  - *Neuropteris gigantea* Sternberg
  - *Neuropteris heterophylla* Brongniart
  - *Neuropteris laceolata* Newberry
  - *Neuropteris ovata typica* Hoffman
  - *Neuropteris rarinervis* Bunbury
  - *Neuropteris scheuchzeri* Hoffman
  - *Neuropteris schlehani* Stur
  - *Neuropteris tenuifolia* (Schlotheim)
  - *Odontopteris gracillima* Newberry
  - *Odontopteris macrophylla* Newberry
  - *Odontopteris neuropteroides* Newberry
  - *Orthogoniopteris clara* Andrews
  - *Palmetopteris furcata* (Brongniart)
  - *Paripteris gigantea* (Sternberg)
  - *Protoblechnum holdenii* (Andrews)
  - *Rhacopteris elegans* (Ettingshausen)
- Pollen-bearing organs
  - *Aulacotheca campbelli (White)*
  - *Whittleseya elegans Newberry*
- Seeds
  - *Trigonocarpus multicarinatum* Newberry
  - *Trigonocarpus ornatum* Newberry
  - *Trigonocarpus* sp.
  - *Trigonocarpus tricuspidatum* Newberry
  - *Trigonocarpus triloculare* Hildreth
  - *Holcospermum maizeretense* Stockmans & Williere

Cordaitids (primitive conifers)
- Leaves
  - *Cordaites principalis* (Germar)
  - *Cordaites* sp.
  - *Rhabdocarpus acuminatus* Newberry
  - *Rhabdocarpus apiculatus* Newberry
  - *Rhabdocarpus carinatus* Newberry
  - *Rhabdocarpus costatus* Newberry
  - *Rhabdocarpus laevis* Newberry
- Seeds
  - *Cardiocarpon annulatum* Newberry
  - *Cardiocarpon bicuspidatum* (Sternberg)
  - *Cardiocarpon elongatum* Newberry
  - *Cardiocarpon latum* Newberry
  - *Cardiocarpon minus* Newberry
  - *Cardiocarpon orbiculare* Newberry
  - *Cardiocarpon retusum* (Sternberg)
  - *Cardiocarpon samaraeforme* Newberry

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SOME FINDINGS RELEVANT TO THE REGIONAL DISTRIBUTION OF THE VANPORT LIMESTONE

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The Middle Pennsylvanian (Desmoinesian) Vanport limestone occurs in the lower Allegheny Group, approximately midway between the overlying Lower Kittanning coal and the underlying Clarion coal, and has been a significant factor in the industrial development of western Pennsylvania and eastern Ohio. The Vanport contains abundant marine fossils and represents the primary facies of the most significant marine transgression within the Allegheny Group. It obtains a maximum thickness of slightly over 40 feet (O'Neill,1964). Thickness variations range from very gradual to quite abrupt. Bergenback (1964) and Williams and Ferm (1965) were the first to study the lateral thickness variations within the Vanport and relate them to facies changes, and subsequently developed a depositional model. They suggested the primary control on Vanport thickness was the underlying paleotopography.

The areas of thicker Vanport accumulation (+ 20 ft.) are confined to southern Clarion, Butler, Beaver and Lawrence Counties in Pennsylvania, and Columbiana and Mahoning Counties in Ohio. In Pennsylvania, thinner Vanport occurs in northern Allegheny and northern Westmoreland counties, and over various portions of Armstrong, Indiana, Jefferson, Clearfield, and Elk Counties. Vanport-equivalent marine facies extend further into the perimeter counties.

Figure 1 was constructed with the aid of over 1100 drill holes. Unlike previous Vanport isopach maps (O'Neill, 1964, Williams and Ferm, 1965), Figure 1 differentiates between syndepositional and post-depositional determinates of Vanport thickness variation.

The most dramatic influence on Vanport thickness is the result of post-depositional scour by the Kittanning sandstone. In most areas, the channel limit is equivalent to (or very closely parallels) the zero-isopach of the Vanport. Aside from its geometry, the Kittanning sandstone exhibits all of the characteristics of a fluvial sandstone, including high-angle cross-bedding, fining-upward profiles, scour surfaces, lag deposits (characterized by rounded siderite pebbles, rip-up clasts and coalified plant materials), and soft-sediment slumping of the underlying and adjacent rocks. However, in southeastern Indiana County and adjacent areas of northern Westmoreland County, drill hole descriptions of the sandstone are repeatedly characterized by the use of adjectives such as "quartz-rich," "quartzose," "hard," "crystalline," and "clean." These descriptions are suggestive of the possibility of a beach/barrier bar system that represents a near-shore coeval environment of the Vanport.

While this situation requires more investigation, an easily observable example of synchronous deposition exists in northern and central Indiana County. The limestone facies of the Vanport thins from eight feet to nothing where it gradually grades into a calcareous shale with marine fossils. To the south and east, this facies grades into a shale without marine fossils. The geometry of these facies is strongly suggestive of a prodeltaic depocenter which effectively shut down the local Vanport "carbonate factory."

To the north and west, the Vanport gradually thickens, achieving a maximum thickness of slightly over twenty feet in eastern Butler County. Beyond the limits of Figure 1, the Vanport thickens to over twenty-five feet in portions of Lawrence and Beaver Counties and in Mahoning and Columbiana Counties in Ohio. Figure 2 illustrates the internal stratigraphy of the Vanport near the Pennsylvania-Ohio state line in the vicinity of Petersburg, Ohio. The thinner shaly units at Petersburg are not universal, but the more prominent units can be recognized in most areas of thicker Vanport, including the Wampum section at STOP 7.

Bragonier, W.A. (2005) Some findings relevant to the regional distribution of the Vanport Limestone, *in*, Fleeger, G.M. and J.A. Harper, eds., Type sections and stereotype sections: glacial and bedrock geology in Beaver, Lawrence, Mercer, and Crawford Counties, Guidebook, 70th Annual Field Conference of Pennsylvania Geologists, Sharon, PA, pp. 35 - 43.

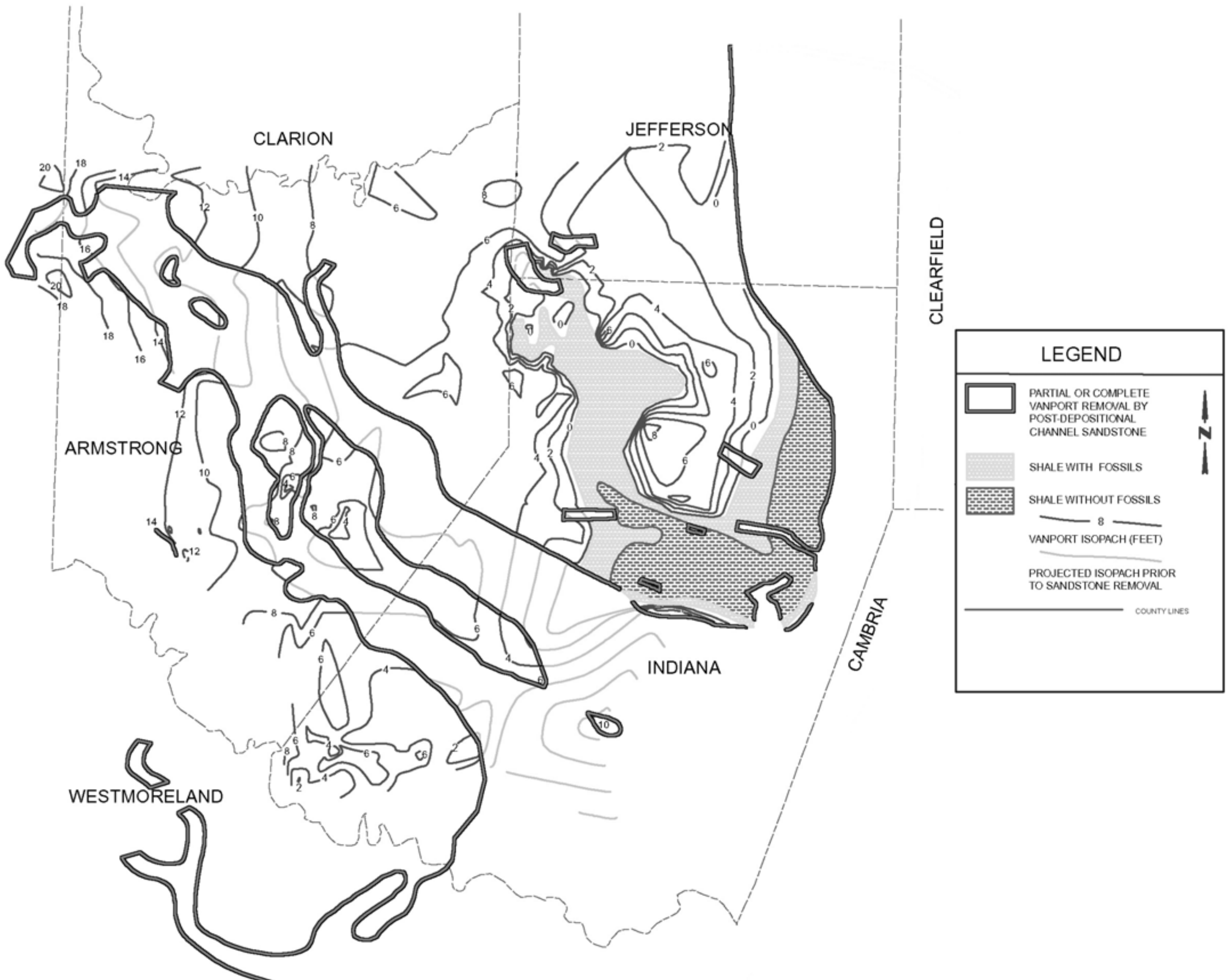


FIGURE 1. VANPORT LIMESTONE DEPOSITIONAL GEOLOGY IN CENTRAL WESTERN PA.

As an aside, it is worth pointing out that the characteristic Buhrstone ore, which exists throughout most of Pennsylvania, is not present in the Petersburg area. The Buhrstone ore is a siliceous sideritic ore that caps the Vanport limestone and obtains a maximum thickness of about 20 inches. It was mined as iron ore in the nineteenth century. A summary of the possible origins of the Buhrstone ore is discussed in Coyle (2003). At Petersburg, however, there is a peculiar solutioning feature first described by Shultz (2000). In several areas, the top of the Vanport is dissolved or "pitted." Cavities that vary in depth from several inches to over 5 feet exist in a linear to curvilinear area in eastern Ohio that roughly corresponds to a minor paleotopographic high. These features, humorously dubbed "giant turtle nests" or simply "turtle nests," are shown in Figures 3A and 3B. It is understandable that a moderate to extreme amount of secondary mineralization usually accompanies these features. The predominant secondary minerals are siderite and dolomite, but limonite and chert also occur. As evidenced in Figure 3B, overlying strata are draped over the "turtle nests," indicating the solutioning existed prior to post-Vanport deposition. The "turtle nest" features represent more than interesting curiosities when planning an underground mine,

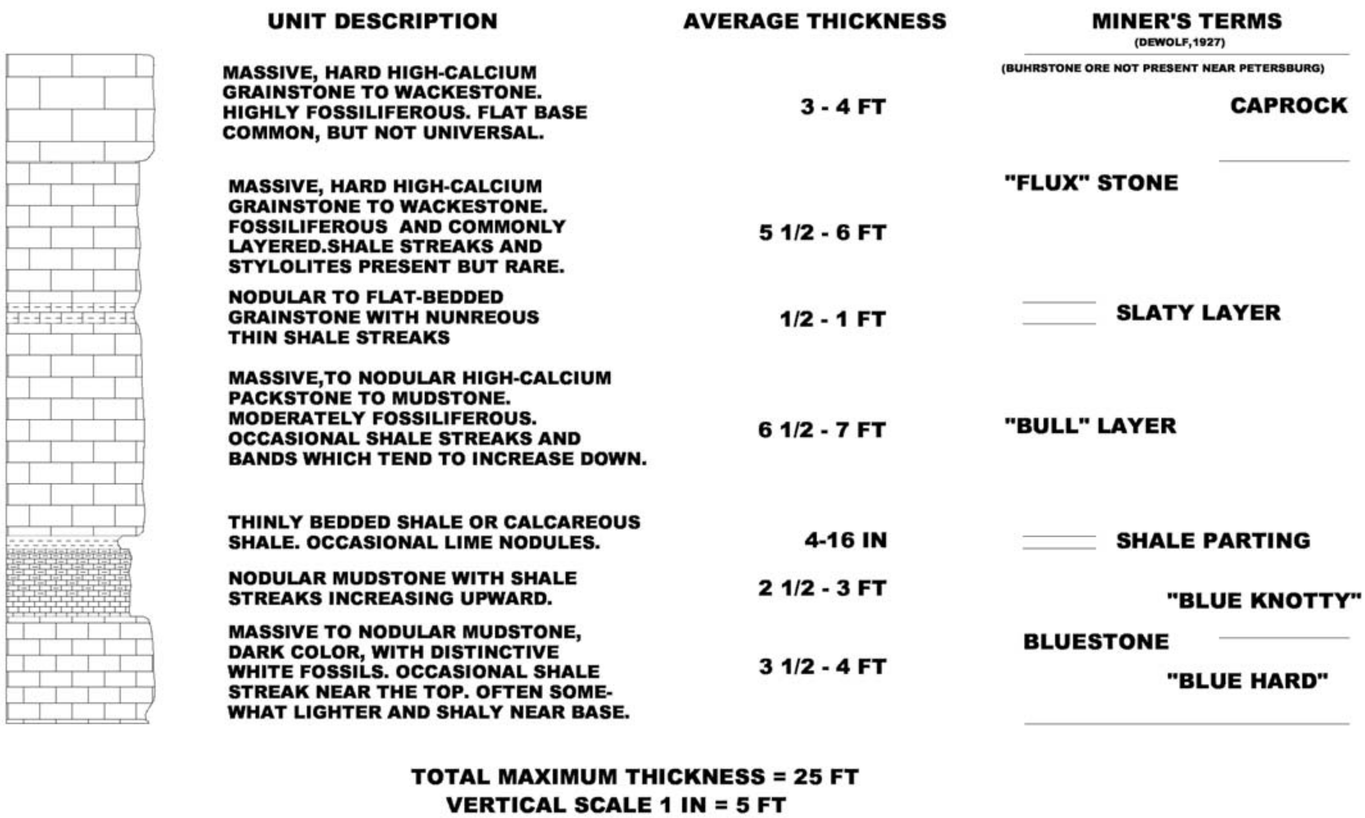


FIGURE 2. TYPICAL VANPORT STRATIGRAPHIC COLUMN NEAR PETERSBURG, OHIO

which typically employs the caprock as the immediate roof, especially if they are undetectable from the base of the caprock.

Returning to Figure 1, it may be seen that in Indiana and Armstrong Counties, the Vanport appears to thicken gradually to the west. However, in areas of thicker (20 ft. +) Vanport, it is curiously prone to more drastic thickness variations. This is illustrated in Figure 4, which is a cross-section constructed near the Pennsylvania state line. Several aspects of this cross-section are noteworthy, not the least of which are the scales and distances between the drill holes. In terms of stratigraphic relationships, the following are emphasized:

- In Drill Holes 1 through 4, the total Vanport thickness is approximately 23 feet. Between Drill Holes 4 and 6, there is a modest, gradual thinning to approximately 20 feet. In Drill Hole 7, what can be recognized as Vanport limestone equivalent is exactly 6.15 feet thick. But the real story unfolds between Drill Holes 4 through 7 when the Vanport is subdivided into its three most basic components which are defined by the shale parting.
- The“bluestone” or rock beneath the parting is limestone that averages slightly over six feet in thickness west of Drill Hole 4. In Drill Holes 5 through 7, the bluestone thins gradually to slightly under four feet, and becomes increasingly less calcareous to the east. Nevertheless, in Drill Hole 7 the fossiliferous calcareous shale maintains characteristics that may be recognized as bluestone.

Figure 3A. Solutioning feature or "giant turtle nest" on top of the Vanport limestone in a quarry near Petersburg, OH.

Figure 3B. Solutioning features or "giant turtle nest" on top of the Vanport limestone in a quarry near Petersburg, OH. Note bending of overlying strata into the depressions, indicating the solutioning occurred prior to deposition of overlying units.

- The shale parting thickens from several inches in the westernmost holes to over several feet in Drill Holes 6 and 7. It also becomes calcareous and contains numerous sub-parallel, sub-horizontal, knife-edge calcite streaks. These are clearly discernable in Drill Hole 7 and provide an excellent marker.
- The most dramatic change occurs above the shale parting. With the exception of a shale band approximately 7 inches thick and a few scattered shale streaks in the lower half, the 14.63 feet of rock above the main shale parting in Drill Hole 5 is high-calcium limestone. In Drill Hole 6, the amount of shale above the main parting has increased slightly and the overall thickness has decreased to 13.70 feet, but the unit, especially the upper half, can still be characterized as high-calcium limestone. In Drill Hole 7, 836 feet away, it does not exist. The rock above the shale parting is a dark, non-fossiliferous clay shale with numerous siderite streaks. It is the basal unit of a coarsening upward clastic sequence of rock that culminates in a sandstone which underlies the Lower Kittanning fireclay.
- In Drill Holes 1 through 4, there is no coal immediately underlying the Vanport limestone. In Drill Holes 5, 6 and 7, the Scrubgrass coal is 1 ¼ inches, 8 ½ inches and 14 inches, respectively.
- The interval between the Lower Kittanning coal and the base of the Vanport limestone thickens from 62 feet in Drill Hole 1 to 81 feet in Drill Hole 7 with most of the increase occurring between Drill Holes 5, 6 and 7.
- Drill Holes 2 and 7 were drilled through the Upper Mercer marine zone. The Clarion coal was encountered in both holes and is interpreted to be split in Drill Hole 2. The 35 foot interval between the top of the upper Clarion split and the base of the Vanport in Drill Hole 2 is occupied predominantly by sandstone, while the same interval in Drill Hole 7 is only 20 feet thick and is occupied by fireclay and clay shale.
- The interval between the base of the Lower Kittanning coal and the top of the Upper Mercer marine limestone is 140 feet in Drill Hole 2 and 134 feet in Drill Hole 7.

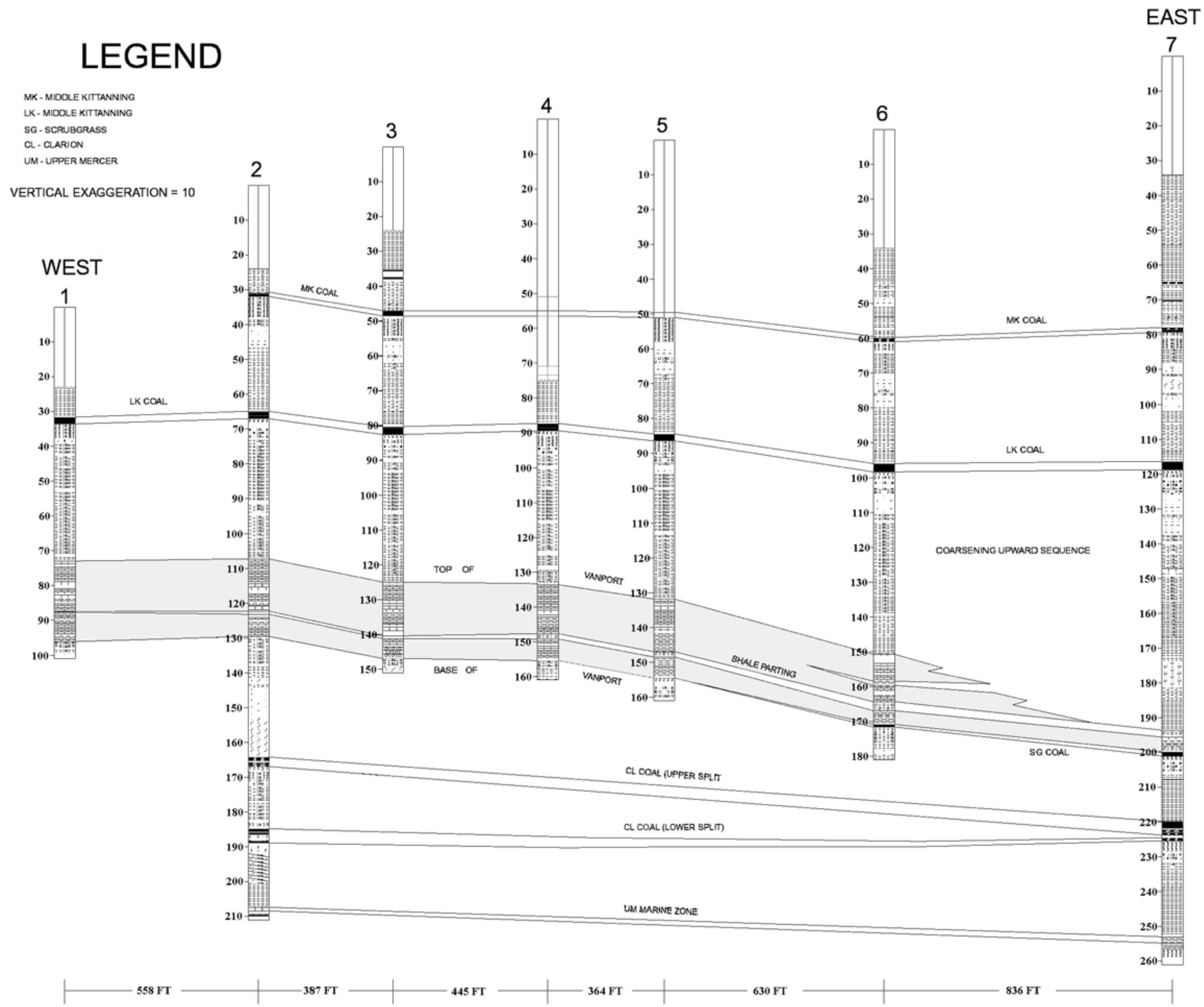


FIGURE 4. CLOSELY SPACED DRILL HOLES ILLUSTRATING THE DISAPPEARANCE OF THE VANPORT OVER A SHORT LATERAL DISTANCE NEAR THE PA-OH STATE LINE.

With consideration of the above observations, it is possible to construct a likely geologic history of the Vanport thinning at this location. The triggering, or forcing, mechanism that led to the Vanport thinning is differential compaction of the sediments between the Clarion coal and the base of the Vanport limestone. The geometry of the lithologies in this interval is, in turn, a function of events that affected the distribution of the Clarion coal, but the details of these events are not discernable from two drill holes. What is known is that the sandstone in Drill Hole 2 is fine-grained, with either horizontal or low-angle cross-bedding indicative of a bar-type deposit, which probably grades laterally into fine-grained shales. From this and other drilling in the immediate area, it has been determined that the distribution of this sandstone body is approximately equivalent to areas of thick Vanport limestone. That is, the sandstone acted as a platform over which the Vanport developed, which is consistent with the findings of Bergenbach (1964) and Williams and Ferm (1965). The distribution of the Vanport limestone in extreme western Pennsylvania and eastern Ohio is controlled by the paleotopography over which it developed, and it occurs as discrete, isolated "mounds." The compatible intervals between the Lower Kittanning coal and the Upper Mercer marine limestone in Drill Holes 2 and 7 (noted above) rules out structural influence.

The differential compaction associated with the lithologic variations overlying the Clarion coal, once established, were most likely accentuated by erosion. The existence of an underclay beneath the Scrubgrass coal suggests this surface was sub-aerially exposed. But prior to the advent of the Vanport limestone, the low areas became the site of Scrubgrass peat accumulation, as illustrated in Figure 5A-1.

The Vanport marine event began with the deposition of the "bluestone" over a relatively flat surface, but sediment accumulation over the Scrubgrass peat caused the peat to compact almost immediately (Figure 5A-2), subsequently affecting the lithologic properties of the "bluestone" over the peat-filled areas. Early interruption of the limestone-forming environment occurred with the incursion of the shale parting (Figure 5A-3). The marked eastward thickening of the parting indicates the peat continued to compact with the weight of the additional sediment, increasing the overall relief. The calcareous nature of the parting in the low suggests that some carbonate was being removed from paleotopographic highs and carried by currents in the drainageways.

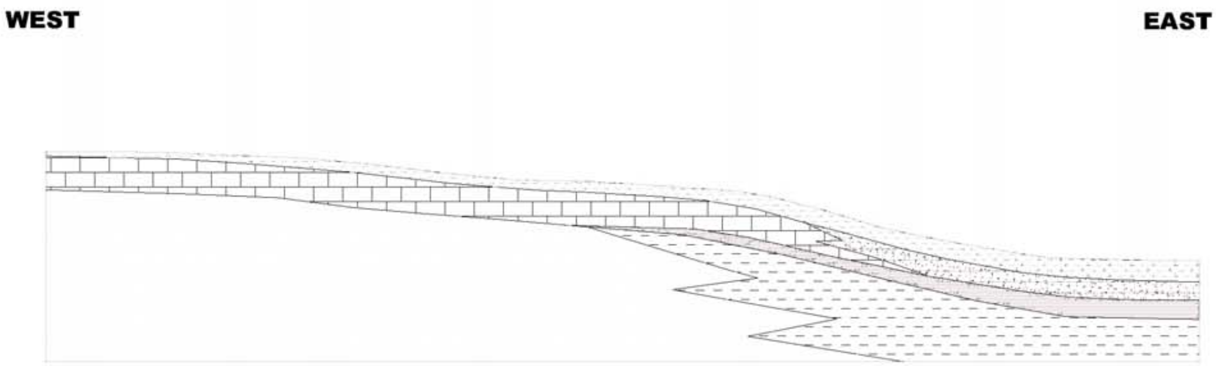
Deciphering the remainder of the Vanport thinning is somewhat more challenging. In an outcrop near Shippingport, PA, the Vanport may be observed grading laterally into shale. At this locale, the Vanport occurs as a nodular facies with thin shale streaks between some of the nodular layers. The directional loss of limestone occurs as the shale streaks increase in size and number. The nodular, undulating bed form is maintained as the outcrop becomes a shale with numerous limestone nodules.

The shale above the Vanport-equivalent rocks in Drill Hole 7 contains no calcite and is void of marine fossils. It is dark gray, flat-bedded, and contains numerous streaks of siderite, quite unlike the shale at Shippingport. As noted above, the shale in Drill Hole 7 is the basal unit of a gradually coarsening upward sequence. The existence of marine fossils at the Vanport horizon in a black, fissile carbonaceous shale at the northern end of the massive road cut immediately south of East Liverpool, OH certainly demonstrates that coeval environments could have existed during the Vanport transgression. However, the complete lack of fossils in the Drill Hole 7 shale and the short distances involved suggest otherwise. The argument can be proposed that the Vanport above the shale parting gradually thinned and "shaled out" into the Drill Hole 7 paleotopographic low. Nevertheless, the low is the likely area for subaqueous (and possibly subaerial) syndepositional and post-depositional paleocurrents. It is therefore suggested that the upper Vanport equivalents in the paleotopographic lows were removed from the depositional system prior to development of the progradational sediments in Drill Hole 7. (Figures 5B-1 and 5B-2)

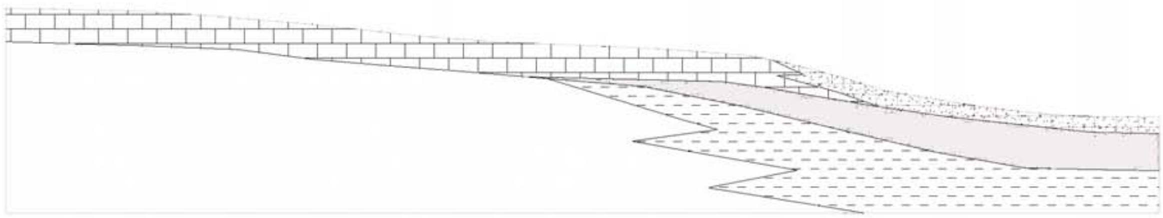
Finally, two questions arise relative to the stratigraphy in Figure 4.

1. If the Vanport can laterally thin over relatively short distances when it's well over 20 feet thick, does it act the same way when it is thin. In other words, should Figure 1 be re-interpreted? Two arguments tend to support the existing interpretation:
    a. Considering the amount of data used to construct Figure 1, if areas of no Vanport existed, one would expect some of the drilling to intercept these areas.
    b. Because the underlying paleotopography is critical to the development of the thick Vanport "mounds," it may follow that if the paleotopography is lacking, thick Vanport won't develop.
2. There is a limestone in Ohio known as the Putnam Hill. It is typically an immature marine limestone that overlies the Clarion coal. Could this limestone, at least in some instances, be the Vanport equivalent in paleotopographic lows?

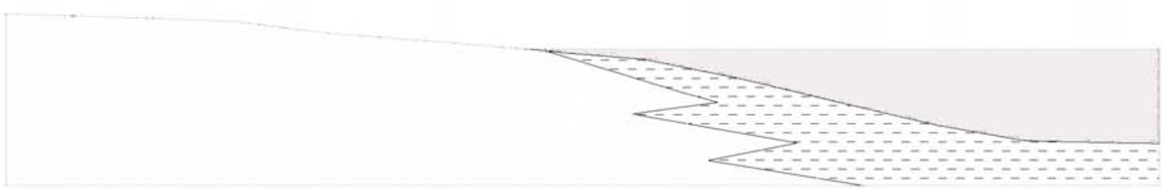
Figure 6. Crinoid stem on a bedding plane of the "caprock" in a quarry near Bessemer PA.



3 INTERRUPTION IN LIME DEVELOPMENT WITH INTRODUCTION OF DETRITUS WHICH BECOMES THE SHALE "PARTING". THE "PARTING" THICKENS MARKEDLY AND BECOMES CALCAREOUS IN THE LOW. THE SCRUBGRASS PEAT COMPACTS FURTHER ADDING ADDITIONAL RELIEF.



2 ACCUMULATION OF "BLUESTONE" LIME WHICH CAUSES COMPACTION OF THE SCRUBGRASS PEAT. THE LIME IN THE LOW CONTAINS A HIGH INORGANIC FRACTION BUT IS RECOGNIZABLE AS "BLUESTONE".



1 DEVELOPMENT OF A PALEOTOPOGRAPHIC SURFACE DUE TO DIFFERENTIAL COMPACTION AND PROBABLE MINOR EROSION FOLLOWED BY ACCUMULATION OF SCRUBGRASS PEAT IN THE LOW.

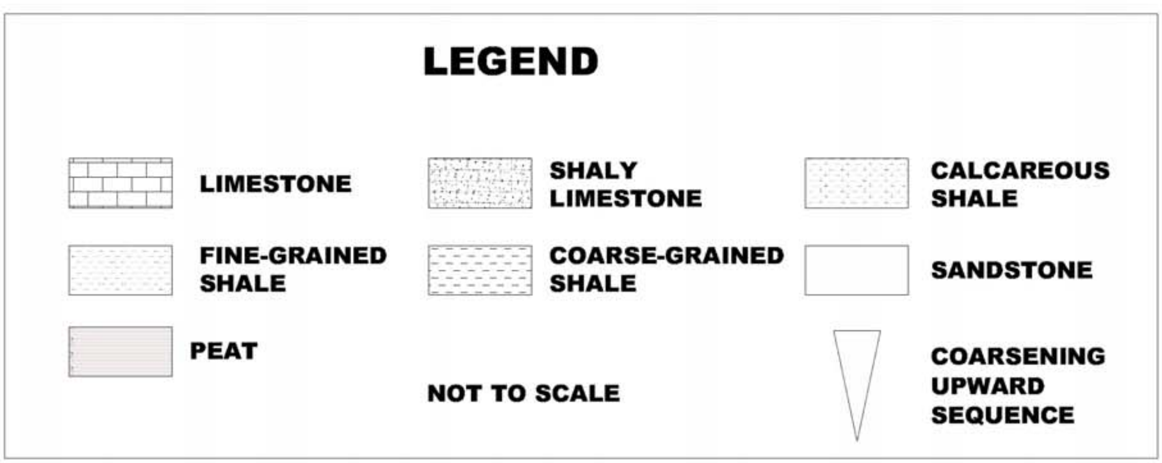
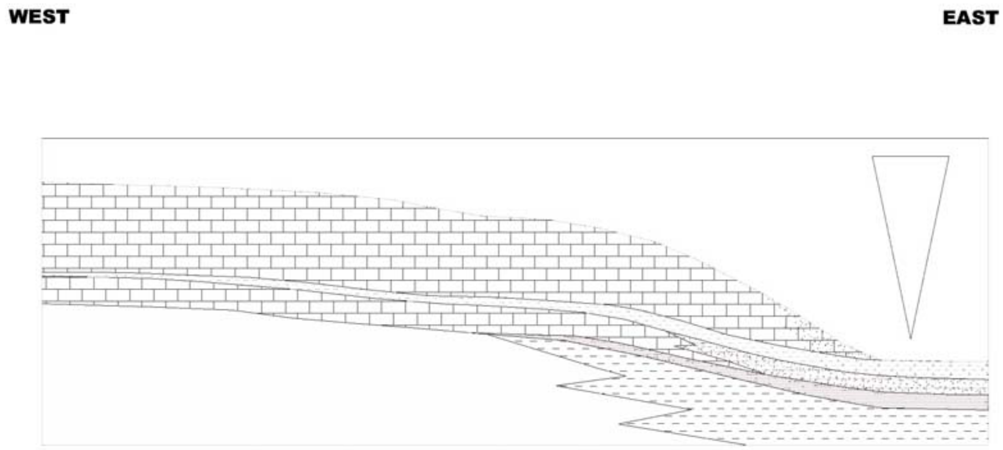
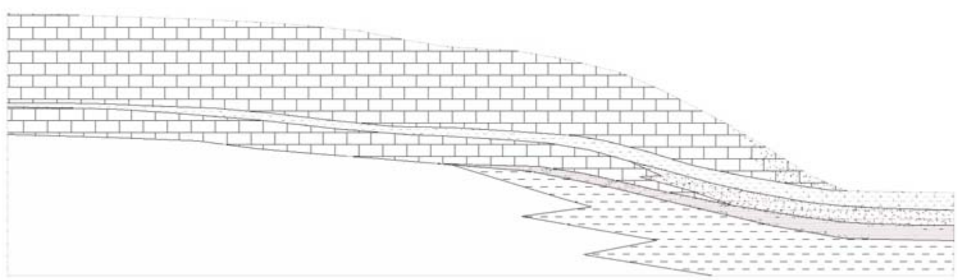


FIGURE 5A. CARTOON OF THE DEVELOPMENT OF THE VANPORT LIMESTONE AND SURROUNDING ROCKS NEAR THE PENNSYLVANIA-OHIO STATE LINE.



2 CHANGE TO A REDUCING ENVIRONMENT AND DEVELOPMENT OF A PROGRADATIONAL COARSENING UPWARD SEQUENCE. THE LACK OF FOSSILS, DARK COLOR AND NUMEROUS SIDERITE BANDS IN THE NON-CALCAREOUS SHALE IN THE LOW SUGGESTS IT WAS POST-VANPORT AND NOT LATERALLY EQUIVALENT TO THE CARBONATE. THIS SUGGESTS PROBABLE CURRENTS IN THE LOW DURING CARBONATE DEPOSITION AND REMOVAL OF CARBONATE ON THE FLANKS OF THE TROUGH.



1 ACCUMULATION OF THE MAIN VANPORT CARBONATE BODY ON THE PALEOTOPOGRAPHIC HIGH. THIS HIGH-CALCIUM LIME CONTAINS A FEW THIN SHALE STREAKS AND BANDS IN THE LOWER TWO THIRDS OF THE UNIT, BUT THEY ARE RARE TO NON-EXISTENT IN THE "CAPROCK".

FIGURE 5B. CARTOON OF THE DEVELOPMENT OF THE VANPORT LIMESTONE AND SURROUNDING ROCKS NEAR THE PENNSYLVANIA-OHIO STATE LINE.

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OIL AND GAS GEOLOGY OF LAWRENCE AND MERCER COUNTIES, PENNSYLVANIA

by
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INTRODUCTION

The purpose of this paper is to present a concise summary of the subsurface geology in Lawrence and Mercer Counties, Pennsylvania, particularly as it relates to our current knowledge of oil and gas exploration and development. Several oil and gas fields have been established here, with a majority of the fields located in Mercer County (Figure 1). Figure 2 presents the subsurface stratigraphic units that occur in the study area. Oil and gas are produced from several of these units, from the Late Devonian-age Berea Sandstone down to the Early Silurian-age Medina Group (Figure 2). The Pennsylvania Geological Survey uses the Devonian-age Tully Limestone as an arbitrary, stratigraphic cutoff for designating "shallow" and "deep" petroleum production. Accordingly, "shallow" fields produce from formations younger than the Tully (e.g., Venango Group), and "deep" fields produce from formations older than this unit (e.g., Medina Group; Figure 2).

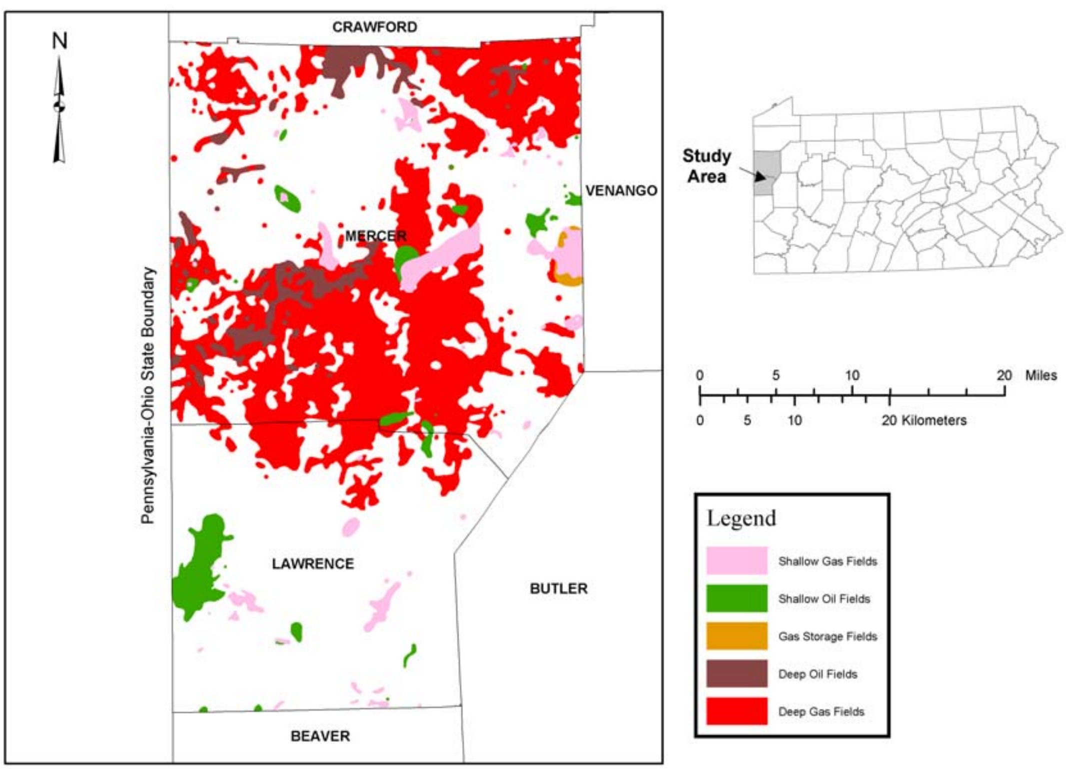

Figure 1. Map of the study area illustrating the locations of oil and gas fields in Mercer and Lawrence Counties, Pennsylvania (adapted from the Pennsylvania Geological Survey's digital oil and gas fields map using data available as of May 2005; see Tables 1 and 2).

Carter, K.M., 2005, Oil and Gas Geology of Lawrence and Mercer Counties, Pennsylvania, *in* Fleeger, G.M. and J.A. Harper, eds., Type sections and stereotype sections, glacial and bedrock geology in Beaver, Lawrence, Mercer, and Crawford Counties, Guidebook, 70th Annual Field Conference of Pennsylvania Geologists, Sharon, PA, pp. 44 - 58.

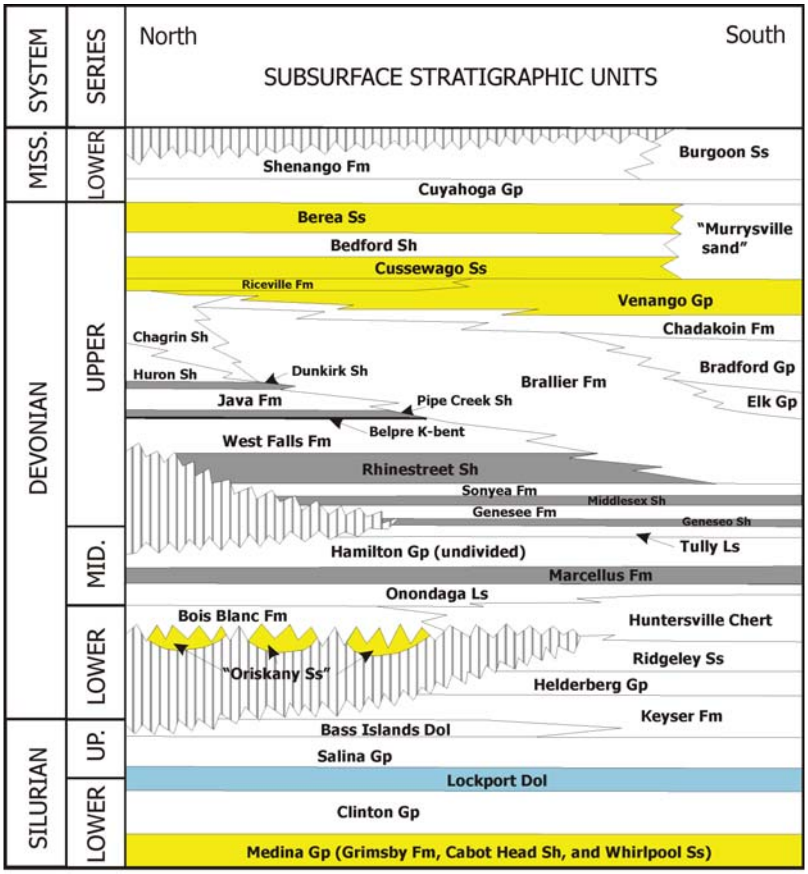

Figure 2. Stratigraphic correlation chart of subsurface geologic units in the study area (modified from Berg and others, 1983). Oil and gas-bearing sandstones discussed in this paper are highlighted in yellow, gas-bearing shales are shown in gray, and gas-bearing dolomite is shown in blue.

Drilling for petroleum in the northern portion of the Appalachian basin dates back to 1821, when a natural gas well was completed in the Devonian-age Dunkirk Shale in Fredonia, New York (Boswell, 1996). Another first occurred in Titusville, Pennsylvania, in 1859, when Edwin L. Drake used salt-well drilling techniques to drill a shallow well for the express purpose of extracting oil from the subsurface (Carter, 2003). In the study area, petroleum exploration was first attempted in the 1870's, when shallow oil and gas wells were completed in the Berea Sandstone and Venango Group (Table 1). Exploration of these and deeper units continued over time, with the most recent discovery being an Oriskany Sandstone gas pool in 2004 (Tables 1 and 2). Current exploration activities in the study area target not only the units with proven production, but also some deeper strata, as discussed at the end of this paper.

HISTORY OF EXPLORATION AND PRODUCTION

Oil and gas production in northwestern Pennsylvania has been associated with numerous reservoir rocks, from shallow Devonian units to deep Cambrian strata. In Mercer and Lawrence Counties, oil and gas has been produced from the Upper Devonian Berea Sandstone, Cussewago Sandstone, and Venango Group sandstones; Devonian gas shales; Lower Devonian Oriskany Sandstone; and Silurian Lockport Dolomite and Medina Group sandstones (Figure 2). While some of these plays are better developed than others, each provides an interesting view into the subsurface geology and depositional history of the basin in the study area. The remainder of this section provides a summary of exploration and production for each unit, and in the case of the Medina Group, the lithology, reservoir characteristics, and production details are discussed as well.

Upper Devonian Berea Sandstone and Cussewago Sandstone

Both the Upper Devonian Berea and Cussewago Sandstones are considered part of the Berea natural gas play. Newberry (1870) named the Berea Sandstone for its type locality in Berea, Ohio, calling it the "Berea grit" based on outcrop observations he made at this location (Tomastik, 1996). Throughout the study area, the Berea Sandstone is overlain by the Cuyahoga Group and underlain by the Bedford Shale (Tomastik, 1996). White (1881) named the Upper Devonian Cussewago Sandstone

Table 1. Selected oil and gas field data, Lawrence and Mercer Counties, Pennsylvania(1)

Producing Formation	Field Name	Pool Name	Shallow/Deep Designation	Product(s)	Year Discovered
Berea Ss	BESSEMER	UNNAMED	shallow	oil & gas	1906
Berea Ss	BIG MEADOWS	PRINCETON	shallow	gas	1895
Berea Ss	BIG MEADOWS	UNNAMED	shallow	gas	1895
Berea Ss	ELLWOOD CITY	SQUAW RUN	shallow	gas	1902
Berea Ss	ELLWOOD CITY	UNNAMED	shallow	oil & gas	1902
Berea Ss	ENON VALLEY	UNNAMED	shallow	oil	1904
Berea Ss	HONEY CREEK	UNNAMED	shallow	gas	1895
Berea Ss	LILLYVILLE	UNNAMED	shallow	gas	1910
Berea Ss	MORAVIA	UNNAMED	shallow	oil & gas	1891
Berea Ss	MOUNT JACKSON	UNNAMED	shallow	gas	1904
Berea Ss	NEW CASTLE	UNNAMED	shallow	gas	1900
Berea Ss	NEW GALILEE	UNNAMED	shallow	oil & gas	1885
Cussewago Ss	SANDY LAKE	UREY	shallow	gas	1996
Berea Ss	SHARON	UNNAMED	shallow	oil & gas	1900
Berea Ss	SLIPPERY ROCK	UNNAMED	shallow	oil	1864
Berea Ss	VALCOURT	UNNAMED	shallow	gas	1911
Berea Ss	VOLANT	AMSTERDAM	shallow	gas	1995
Venango Gp	BIG BEND	UNNAMED	shallow	gas	1873
Venango Gp	COOLSPRING	MERCER	shallow	oil	1912
Venango Gp	COOLSPRING	UNNAMED	shallow	gas	1912
Venango Gp	ELLWOOD CITY	WURTEMBERG	shallow	gas	1902
Venango Gp	HADLEY	UNNAMED	shallow	oil & gas	1944
Venango Gp	HARMONY-ZELIENOPLE	SCHOLARS RUN	shallow	oil	1900
Venango Gp	HARMONY-ZELIENOPLE	UNNAMED	shallow	gas	1889
Venango Gp	KANTZ CORNERS	MILLEDGEVILLE	shallow	oil	1900
Venango Gp	NEW HAMBURG	UNNAMED	shallow	oil & gas	1954
Venango Gp	RAYMILTON	UNNAMED	shallow	oil & gas	1870
Venango Gp	SANDY LAKE	UNNAMED	shallow	oil & gas	1920
Venango Gp	VOLANT	UNNAMED	shallow	oil & gas	1876
Venango Gp	WESLEY	UNNAMED	shallow	gas	1910
Venango Gp	WOLF CREEK	ARAB	shallow	oil	1912
Venango Gp	WOLF CREEK	HENDERSON STORAGE	shallow	--- (2)	
Venango Gp	WOLF CREEK	UNNAMED	shallow	gas	1892
Devonian Sh	VOLANT	NESHANNOCK CREEK	deep	gas	1980
Oriskany Ss	HADLEY	DERBER	deep	gas	1981
Oriskany Ss	MAYSVILLE	STULLS	deep	gas	1982
Oriskany Ss	SHEAKLEYVILLE	CEMETERY	deep	gas	2004
Lockport Dol	SHARON	PYMATUNING	deep	gas	1991
Lockport Dol	WOLF CREEK	KILGORE	deep	gas	1966

(1) - Based on data compiled in May 2005 for the Pennsylvania Geological Survey's digital oil & gas fields Geographic Information System.

(2) - The Henderson Storage pool is used to store natural gas, and produces neither gas nor oil.

for outcrop exposures along the valley of Cussewago Creek in Crawford County, Pennsylvania. deWitt (1946) subsequently defined this unit as a friable, green to brown, quartz sandstone. The Cussewago Sandstone is overlain by the Bedford Shale, and underlain by the Riceville Formation and the Venango Group (north to south) (Tomastik, 1996). In the southern portion of the study area, the Murrysville Sandstone is laterally equivalent to the Berea Sandstone, Bedford Shale, and Cussewago Sandstone (Figure 2).

Natural gas was first discovered in the Berea Sandstone in East Liverpool, Ohio, circa 1860 (Tomastik, 1996). Much like other natural gas discoveries throughout the Appalachian basin, the one in East Liverpool occurred by happenstance because drillers were really looking to strike oil or brine. Natural gas from this and subsequent wells was used to heat and light the town of East Liverpool. Spurred by this discovery, shallow wildcat wells were drilled throughout Ohio and Pennsylvania in the early 1860’s (Tomastik, 1996). A total of 17 Berea pools

Table 2. Summary of data for oil and gas fields producing from the Medina Group in Lawrence and Mercer Counties, Pennsylvania[1]

Field Name	Pool Name	Product(s)	Year Discovered	Reservoir Characteristics							Average Initial Production (per day) [2]	Cumulative Production [3]	
				Average Producing Depth (feet BGS)	Net Thickness (feet)	Temp-erature (degrees F)	Pres-sure (psi)	Porosity (%)	Water Satura-tion (%)	Salinity (ppm)		Oil (Bbl)	Gas (Mcf)
BARKEYVILLE	DUNCAN	gas	1973	6,650	76	128	1,600	5		251,370	1,684 Mcf Af		3,946,263
BIG BEND	DELAWARE	gas	1983	5,350	51	116	1,350	7	27	187,250	498 Mcf Af		
BIG BEND	LACKAWANNOCK	oil & gas	1990	5,600	65	76	1,350	7	27	196,000	969 Mcf Af		
CARBON	UNNAMED	gas	1997	5,800	94	121	1,525	8	18	203,000	663 Mcf Af		
COCHRANTON	DECKARD	gas	1980	5,100	69	101	1,300	5	14	192,780	98 Mcf Af		3,149,872
COOLSPRING	FILER CORNERS	gas	1983	5,700	50	124	1,200	7	30	199,500	40 Mcf Nat; 896 Mcf Af		11,356,541
GENEVA	GREENWOOD	gas	1973	4,900	155	102	1,297	8	25	185,220			2,177,247
GENEVA	ROCK CREEK	gas	1977	4,950	60	103	1,100	8	25	187,110			1,875,910
GREENFIELD	UNNAMED	oil & gas	1984	5,500	100	124	1,500	6	28	192,500	38 Mcf Nat; 870 Mcf Af	9,845	27,255,470
GREENVILLE	THIEL	oil & gas	1981	4,700	139	93	1,235	6	28	164,500	223 Mcf Af	5,805	312,464
HADLEY	PERRY SCHOOL	oil & gas	1981	5,200	44	112	1,390	6	12	182,000	740 Mcf Af		373,715
HALFMOON	UNNAMED	gas	1991	5,650	150	121	1,415	6	28	197,750	487 Mcf Af		812,879
JAMESTOWN	UNNAMED	oil & gas	1979	4,450	96	108	1,500	5	26	155,750	5 Mcf Nat; 350 Mcf Af	5,736	756,020
KANTZ CORNERS	EAST FAIRFIELD	gas	1980	5,000	61	109	1,250	5	14	189,000			2,242,379
KANTZ CORNERS	UNNAMED	oil & gas	1977	5,300	60	117	1,420	8	23	185,500	783 Mcf Af	4,156	21,818,194

(1) - Based on data compiled in May 2005 for the Pennsylvania Geological Survey's digital oil & gas fields Geographic Information System.

(2) - Based on available initial production data available in the Pennsylvania Geological Survey's Wells Information System (WIS) database as of June 2005, and averaged for each pool.

(3) - Based on annual production data available in the WIS database as of 2003, and summed for each pool.

BGS - below ground surface; degrees F - degrees Fahrenheit; % - percent; Bbl - Barrels oil; Nat - natural open flow

psi - pounds per square inch; ppm - parts per million; Mcf - Thousand cubic feet gas; Af - after treatment open flow

Table 2. Summary of data for oil and gas fields producing from the Medina Group in Lawrence and Mercer Counties, Pennsylvania (continued)[1]

Field Name	Pool Name	Product(s)	Year Discovered	Reservoir Characteristics							Average Initial Production (per day) [2]	Cumulative Production [3]	
				Average Producing Depth (feet BGS)	Net Thickness (feet)	Temperature (degrees F)	Pressure (psi)	Porosity (%)	Water Saturation (%)	Salinity (ppm)		Oil (Bbl)	Gas (Mcf)
MAYSVILLE	UNNAMED	oil & gas	1981	4,850	74	110	1,300	6	28	169,750	3 Bbl Af; 404 Mcf Af	13,875	783,700
MAYSVILLE	WEST SALEM	oil & gas	1977	4,850	56	108	1,365	6	28	169,750	968 Mcf Af	2,317	348,522
NEW CASTLE	EASTBROOK	gas	1999	6,150	65	139	1,370	8	15	232,470	574 Mcf Af		279,148
NEW HAMBURG	GOODHOPE	oil & gas	1979	4,800	71	109	1,425	6	28	181,440	1,047 Mcf Af	3,370	348,988
SANDY LAKE	CARPENTER CORNERS	gas	1982	5,450	52	110	1,450			206,010	727 Mcf Af		1,498,363
SANDY LAKE	NEW LEBANON	gas	1983	5,600	64		1,420			211,680	569 Mcf Af		2,109,760
SHARON	SHARON DEEP	oil & gas	1978	4,750	90	105	1,275	3	77	179,550	161 Mcf Nat; 864 Mcf Af	66,995	14,838,781
SHEAKLEYVILLE	OSBORN	oil & gas	1981	4,950	133		1,330			187,110	612 Mcf Af	14,864	2,981,639
SHEAKLEYVILLE	UNNAMED	gas	1975	5,050	60		1,320			190,890	693 Mcf Af		749,204
STONEBORO	LAKE	gas	1983	5,500	104	110	1,455	9	28	207,900	620 Mcf Af		1,342,392
UTICA	FRENCH CREEK	gas	1981	5,350	74	120	1,080	7	30	202,230	720 Mcf Af		2,771,100
VALCOURT	CARMONA	gas	1994	6,300	137	142	1,510	8	15	238,140	530 Mcf Af		194,806
VOLANT	LIGO	gas	1982	5,900		115	1,600			223,020	46 Mcf Nat; 688 Mcf Af		13,564,799
VOLANT	PARDOE	gas	1981	6,050			1,025			228,690	41 Mcf Nat; 1,053 Mcf Af		29,627,219
WESLEY	IRWIN	gas	1972	6,400	124		1,630			241,920	134 Mcf Af		628,901
WHEATLAND	UNNAMED	oil & gas	1963	5,200	100	99	1,225	8	65	196,560	1 Bbl Af; 127 Mcf Nat; 531 Mcf Af	59,167	3,977,314
WOLF CREEK	BLACK RUN	gas	1981	5,950	67		1,380			224,910	19 Mcf Nat; 36 Mcf Af		12,169

(1) - Based on data compiled in May 2005 for the Pennsylvania Geological Survey's digital oil & gas fields Geographic Information System.

(2) - Based on available initial production data available in the Pennsylvania Geological Survey's WIS database as of June 2005, and averaged for each pool.

(3) - Based on annual production data available in the WIS database as of 2003, and summed for each pool.

BGS - below ground surface; degrees F - degrees Fahrenheit; % - percent; Bbl - Barrels oil; Nat - natural open flow

psi - pounds per square inch; ppm - parts per million; Mcf - Thousand cubic feet gas; Af - after treatment open flow produce oil and gas in the study area, the earliest of which (the unnamed pool of Slippery Rock field) was discovered in 1864. [Slippery Rock Creek was named after a rock that was slippery due to being coated by an oil seep that initiated drilling and discovery of the field (Lytle and Lytle, 1974).]

Although most Berea pools in the study area were established around the turn of the 20th century, two recent discoveries (Amsterdam and Urey pools) occurred in the mid 1990's (Table 1).

Upper Devonian Venango Group

The Upper Devonian Venango Group is named for the oil fields that were so prolific in Venango County, Pennsylvania, after Drake's oil discovery in 1859. In the late 1870's, John Carll and Charles Ashburner, both of the Second Geological Survey of Pennsylvania, surveyed the geology of these oil fields, and referred to the productive zones as the "Venango oil-sands group" of the Catskill Formation in their reports (Boswell and others, 1996). Throughout the study area, the Venango Group is overlain by the Upper Devonian Riceville Formation, Cussewago Sandstone, and Murrysville Sandstone (north to south), and is underlain by the Upper Devonian Chadakoin Formation (Figure 2).

Oil was first discovered in this play in August 1859, when "Colonel" Edwin L. Drake drilled a shallow well (69.5 feet deep to be exact) to the top of the Riceville Formation (adjacent and laterally equivalent to the Venango Group; Figure 2) and struck oil (Boswell and others, 1996; Harper and Ward, 1999). On the heels this discovery, some 5,500 wells were drilled over the next ten years in what was called the "Venango District" in north-central Venango County, but only about 1,200 of them actually produced oil (Boswell and others, 1996). Initial production (IP) data for these wells were on the order of 1,000 barrels of oil per day (Bopd) (Boswell and others, 1996). During the course of drilling, natural gas was found by happenstance. When it was, the gas was either wasted by venting to the atmosphere or used onsite to support drilling operations. As the 1800's came to a close, exploration for oil and gas in the Venango Group sands moved to the south and west, away from the Venango District. Fifteen pools produce oil and gas from the Venango Group in the study area, the first of which was the unnamed pool of Raymilton field, established in 1870. All but one of the remaining Venango Group pools were discovered by 1920, the exception being an unnamed pool in New Hamburg field, which first produced oil and gas in 1954 (Table 1). Most of these old, shallow pools are probably all but depleted.

Devonian Gas Shales

The term "Devonian gas shales" refers to all organic-rich, marine shales deposited in Middle to Late Devonian time as part of the Acadian clastic wedge (deWitt, 1986; Boswell, 1996). Thanks to the efforts of the Eastern Gas Shales Project (EGSP) in the late 1970's, the stratigraphy of this package was interpreted and formally presented in a coherent stratigraphic framework that heretofore was lacking (Roen and Kepferle, 1993). Based on the work of the EGSP, three major black shale facies (Dunkirk, Rhinestreet, and Marcellus) and three minor shale facies (Pipe Creek, Middlesex, and Geneseo) were identified (Harper and Piotrowski, 1979; Piotrowski and Harper, 1979). These shales are overlain by the Huron and Chagrin Shales in the northern part of the study area and Brallier Formation toward the southern part of the study area. The Marcellus Formation, which represents the base of the Devonian gas shales, is underlain by the Onondaga Limestone throughout the study area (Figure 2).

The first well to produce natural gas from the Devonian gas shales was drilled in Fredonia, New York, in 1821 (Piotrowski and Harper, 1979; deWitt, 1986; Boswell, 1996). The well was completed 27 feet into the Dunkirk Shale (Boswell, 1996) and produced approximately 3 million cubic feet (Mmcf) of gas annually, which was used to light local street lamps (Piotrowski and Harper, 1979; deWitt, 1986). By the time the Fredonia well was plugged in 1885, it had produced a total of 195

Mmcf (deWitt, 1986). Subsequent Devonian shale wells were drilled along the shores of Lake Erie in New York, Pennsylvania, and Ohio, but the quick dropoff in production associated with these shallow wells, as well as the prolific production of Venango Group sandstones in the region, caused interest in Devonian gas shales in the northern part of the Appalachian basin to wane after the early 1900's (Piotrowski and Harper, 1979; deWitt, 1986; Boswell, 1996). Even though the "Big Sandy" area of eastern Kentucky and southwestern West Virginia produced significant quantities of natural gas in the 1920's, it wasn't until the energy crisis of the 1970's and 1980's that exploration of existing Devonian gas shale fields was renewed in the northern part of the basin (Piotrowski and Harper, 1979; deWitt, 1986; Boswell, 1996). Within the study area, only the Neshannock Creek pool of Volant field, discovered in 1980, has reported gas production in this play (Table 1).

Lower Devonian Oriskany Sandstone

Vanuxem (1939) named the Oriskany Sandstone for its type locality in Oriskany Falls, Oneida County, New York. Throughout the study area, this unit is unconformably overlain by the Lower Devonian Bois Blanc Formation and unconformably underlain by the Lower Devonian Helderberg Group (Figure 2; Opritza, 1996; Patchen and Harper, 1996). Reference to the "Oriskany Sandstone" in the study area (and the northern half of the Appalachian basin for that matter) is based on drillers' terminology used for all Middle and/or Lower Devonian quartzose sandstones deposited in the stratigraphic position of the "true" Oriskany Sandstone of New York and northwestern Pennsylvania (Patchen and Harper, 1996). An updip sandstone pinch-out against the "Oriskany No-Sand Area" of northwestern Pennsylvania separates typical Oriskany Sandstone from the age-equivalent Ridgeley Sandstone of western and southcentral Pennsylvania. The "Oriskany No-Sand Area" constitutes an area of either nondeposition of sand or uplift and erosion, whereby any sand that was deposited subsequently was removed (Patchen and Harper, 1996). The use of "Oriskany" nomenclature has been adopted herein to be consistent with this driller's convention.

The first well to produce natural gas from the Oriskany Sandstone in the Appalachian basin was drilled in Austinburg Township, Ashtabula County, Ohio in 1900 (Opritza, 1996). Subsequent discovery wells in the Oriskany were completed in the 1920's and 1930's in the northern half of the basin, spanning northward from West Virginia and Ohio to Pennsylvania and New York (Abel and Heyman, 1981; Flaherty, 1996; Harper and Patchen, 1996; Opritza, 1996; Patchen and Harper, 1996). The first field to be discovered near the study area was the Blackhawk field in Beaver County, Pennsylvania, in 1935. This field encompassed 580 acres and produced 3,000,000 thousand cubic feet (Mcf) of gas during the period of 1935-1960 (Patchen and Harper, 1996). A total of three Oriskany pools exist in the study area, the earliest of which (the Derber pool of Hadley field) was discovered in 1981 (Table 1).

Upper Silurian Lockport Dolomite

Hall (1839) named the Lockport Dolomite for its type locality in Lockport, New York. Throughout the study area, this unit is overlain by the Salina Group and underlain by the Clinton Group (Figure 2).

The first well to produce natural gas from the Lockport Dolomite was drilled in Ontario, Canada, in 1889. This spawned exploration activities throughout the Appalachian basin in the United States, where the first Lockport production occurred in Mansfield, Ohio, in 1906 (Noger and others, 1996). It wasn't until 1966, however, that Lockport production was reported in the study area (Table 1). At this time, the Kilgore pool of Wolf Creek field was discovered in southeastern Mercer County on part of a geologic structure known as the Henderson Dome. This structure has a circular surface expression and diameter of roughly five miles (Fettke, 1954). At the Lockport Dolomite horizon, the dome is more elliptical in shape and contains an estimated 15 billion cubic feet (Bcf) of natural gas (Kuminecz and

Gorham, 1993). The Kilgore pool has the distinction of being the deepest known Lockport-producing field in the basin (Noger and others, 1996). The only other Lockport pool in the study area is the Pymatuning pool of Sharon field, which was discovered in 1991 (Table 1).

Lower Silurian Medina Group

Vanuxem (1840) named the Medina Group for its type locality in Medina, Orleans County, New York. The basal unit of this sequence, the Whirlpool Sandstone, was named by Grabau (1909) for its type locality along the Canadian side of the whirlpool in the Niagara River Gorge, and the uppermost unit of this sequence, the Grimsby Sandstone, was named by Williams (1914). Reference to the productive zones in this sequence as "Clinton" originated in Fairfield County, Ohio, where drillers erroneously thought that limestone in the overlying Clinton Group was the source of gas in the Medina discovery well (McCormac and others, 1996). By the time it was established that the Medina Group sands were actually the producing units in these early wells, the "Clinton" misnomer had become engrained in basin operator terminology, and still is today.

The Lower Silurian Medina Group was first discovered as a natural gas producer in February 1887. In Fairfield County, Ohio, wildcatters targeting the Middle Ordovician Trenton Group struck gas at a much shallower depth than their target horizon. This Medina discovery well, and other local wells completed shortly thereafter, were used to light the nearby city of Lancaster, Ohio. During the same time frame, natural gas wells were drilled to produce from the upper sands of the Medina Group in Erie and Chautauqua Counties, New York (McCormac and others, 1996). A total of 32 Medina Group pools produce oil and gas in the study area, the earliest of which (an unnamed pool in the Wheatland field) was discovered in 1963 (Table 2).

McCormac and others (1996) identified three stages of development of the Medina Group play. These include: (1) the late 1800's – early 1900's; (2) the 1940's; and (3) the 1970's – early 1980's. Around the turn of the 20th century, development of the Medina Group was limited only by the availability (or unavailability) of drilling and treatment technologies and equipment. This meant that if a well was a marginal, natural producer of Medina Group gas, it remained a marginal producer or was abandoned. In the 1940's, the availability of rotary drilling, electrical logging, and hydraulic fracturing techniques changed the development landscape, allowing producers to drill deeper, characterize subsurface formations better, and enhance the productivity of pay zones. By the early 1980's, the national energy crisis provided impetus for the Medina Group and other selected horizons to be designated as "tight" sands, which gave the oil and gas industry higher prices and tax credits for investigating and developing these units that otherwise may have been left unexplored. All but one of the Medina pools in the study area were established during or after this third stage of development, with the most recent pool being discovered in 1999 (Eastbrook pool of New Castle field; Table 2).

Early studies of the Medina Group and equivalent units were performed in the 1960's through early 1980's (Cate, 1961; Yeakel, 1962; Cate, 1965; Kelley and McGlade, 1969; Knight, 1969; Martini, 1971; Piotrowski, 1981; Cotter, 1982 and 1983). A summary of these and related works was provided in *The Atlas of Major Appalachian Gas Plays* (Roen and Walker, 1996). By the 1990's, sequence stratigraphy was emerging as an important tool for the interpretation of reservoir rocks. Perhaps the most prominent, recently published studies relative to the Medina and equivalent units are those of Castle (1998), Hettinger (2001), and Ryder (2004). Each of these researchers used sequence stratigraphy, rather than lithostratigraphy, to correlate Early Silurian-age units in the northern Appalachian basin.

Lithology and Reservoir Characteristics: The Medina Group consists of interbedded sandstones, siltstones, and shales with some carbonates, all of Early Silurian age (Laughrey, 1984; Laughrey and

Harper, 1986; McCormac and others, 1996). In the study area, the Medina Group is comprised of three major stratigraphic units: 1) the Grimsby Formation; 2) the Cabot Head Shale; and 3) the Whirlpool Sandstone. Outside the study area, the Medina Group includes a fourth unit known as the Manitoulin Dolomite (equivalent to the basal Whirlpool Sandstone), which occurs near the shores of Lake Erie, eastern Ohio, and southern Ontario (Laughrey, 1984; McCormac and others, 1996; Castle, 1998). To the south and east of the study area, the Medina Group nomenclature is lost, and these units grade into the laterally equivalent Tuscarora Sandstone (Piotrowski, 1981; Avary, 1996).

The sandstones of the Grimsby Formation are very fine- to medium-grained, monocrystalline, quartzose rocks, with subangular to subrounded grains, variable sorting, and thin, discontinuous, silty shale interbeds. These sandstones vary in color, from white to gray to red; hence, the reference to these units by drillers as "Red Clinton" and "White Clinton", particularly in eastern Ohio. Cementing materials include secondary silica, evaporites, hematite, and carbonates (Piotrowski, 1981; McCormac and others, 1996). The Cabot Head Shale is a dark green to black, marine shale with thin, quartzose, siltstone and sandstone laminations that increase in number toward the top of the unit (Piotrowski, 1981; Laughrey, 1984). The Whirlpool Sandstone forms the basal unit of this sequence, and in the greater part of the Appalachian basin, is composed of a white to light gray to red, fine- to very fine-grained quartzose sandstone that is moderately well sorted and has subangular to subrounded grains (Piotrowski, 1981; Brett and others 1995; McCormac and others, 1996). This basal unit becomes dolomitic in localized areas within the northwestern part of the basin (i.e., the Manitoulin Dolomite) (Laughrey, 1984; McCormac and others, 1996; Castle, 1998).

The nature of the contacts of the Medina Group with overlying and underlying units varies depending upon which stratigraphic approach is applied. The traditional, lithostratigraphic view of Early Silurian-age rocks in the Appalachian basin is consistent with a conformable upper contact between the Medina Group and Middle Silurian Clinton Group (Figure 2), and a combination of conformable and unconformable lower contacts between this sequence and Upper Ordovician shales and sandstones. In the northern portion of the basin, the Medina Group is interpreted as unconformably underlain by the Queenston Formation (Piotrowski, 1981; Laughrey, 1984; Laughrey and Harper, 1986; Brett and others, 1995; McCormac and others, 1996). The origin of this unconformity is associated with a drop in sea level (i.e., regression) during Late Ordovician time. As the Medina grades into the Tuscarora Sandstone in centralwestern and central Pennsylvania (i.e., outside the study area), traditional lithostratigraphy interprets a gradational contact with the Queenston Formation's equivalent, the Juniata Formation (Heyman, 1977; Piotrowski, 1981; Avary, 1996; McCormac and others, 1996).

In recent years, the oil and gas industry has begun to use sequence stratigraphy to interpret reservoir rock relationships. Using this framework as a guide, the Medina and equivalent units are seen as unconformably underlain by the Queenston and Juniata Formations basin-wide (Castle, 1998; Hettinger, 2001). Here, Hettinger (2001) identifies the Cherokee discontinuity as the sequence boundary between the Medina Group and underlying Queenston Shale, with this boundary interpreted as inferred between the Tuscarora and Juniata Formations in the eastern portion of the basin. At the top of the Medina Group, a marine flooding surface separates the Grimsby Sandstone from the overlying Clinton Group (Castle, 1998).

The depositional history of the Medina Group dates back to the latter part of the Taconic orogeny in early Silurian time. During this period, clastic material was eroded from both foreland fold-belt highlands adjacent to the eastern edge of the Appalachian basin and the plutonic igneous rocks of the arc orogen (Laughrey, 1984; Laughrey and Harper, 1986; Brett and others, 1995). The directions of sediment transport from these highlands were both parallel (i.e., northeast-southwest) and perpendicular (i.e., toward the northwest) to the shoreline (Laughrey and Harper, 1986), which ran across the study area from northern Beaver County to central Warren County (Piotrowski, 1981). The Medina depositional system is that of a shelf/longshore bar/tidal flat/delta complex. The Whirlpool

Sandstone is the basal transgressive unit of this system and is overlain by shelf muds and transitional silty sands of the Cabot Head Shale. These sediments were overlain by shoreface and nearshore sands of the lower Grimsby Sandstone, which grade into argillaceous sands at the top of this unit (Laughrey, 1984; Laughrey and Harper, 1986; Brett and others, 1995). Laughrey (1984) divided the Medina Group's depositional system into five facies: (1) tidal flat, tidal creek, and lagoonal sediments; (2) braided fluvial channel sediments; (3) littoral deposits; (4) offshore bars; and (5) sublittoral sheet sands. Facies 1, 2, and 3 sediments comprise the Grimsby Sandstone, which was deposited in a complex deltaic to shallow marine environment. The deeper, offshore mud and sand bar deposits of Facies 4 were reworked by both storm and tidal currents to become the Cabot Head Shale. The Whirlpool Sandstone is included in Facies 5, which was formed in nearshore marine and fluvial, braided river environments in existence during the beginning of a marine transgression (Piotrowski, 1981; Laughrey, 1984; McCormac and others, 1996). This depositional history influenced the lithology, thickness, porosity, and other reservoir characteristics of the Medina Group, as discussed below.

The Medina Group crops out at its type locality in New York, and in central Pennsylvania, outcrops of the equivalent Tuscarora Sandstone are present. In the remainder of the Appalachian basin, however, the Medina and equivalent units remain in the subsurface. The depth to this reservoir ranges from less than 1,000 feet to 6,700 feet, with wells located offshore in central Lake Erie reporting depths of over 2,200 feet (McCormac and others, 1996).

Venteris and others (2005) have recently evaluated the structure and thickness of the Medina Group throughout the Appalachian basin. Figures 3 and 4 illustrate these Medina Group features for the study area. The structure on top of the Medina Group strikes northeast-southwest and dips toward the southeast at a rate of approximately 50 to 70 feet per mile, with more shallowly dipping strata north and west of the study area (Figure 3). An isopach map of this sequence shows net thicknesses ranging from less than 50 to 350 feet (Figure 4), with averages of 85 feet in the study area (Table 2). These thicknesses are generally consistent with those previously published by Laughrey and Harper (1986) and McCormac and others (1996). The actual pay zones of the Medina Group (i.e., where reservoir porosity and permeability are favorable) comprise only a portion of these thicknesses, however, ranging from 3 to 50 feet and averaging 23 feet (McCormac and others, 1996).

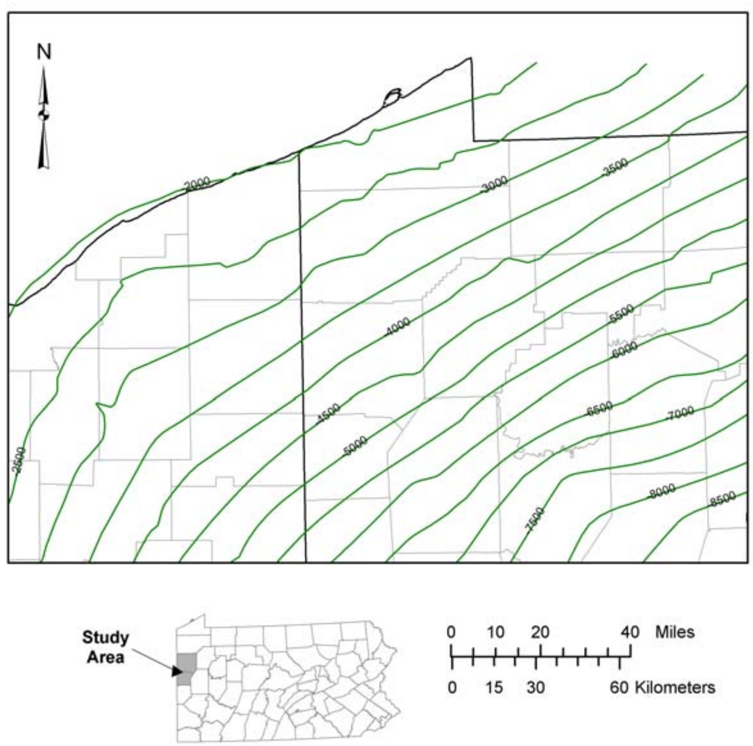

Figure 3. Structure contour map of the Medina Group in the study area (modified from Venteris and others, 2005). The subsea elevation of the top of this unit is illustrated at a contour interval of 500 feet. In the study area, subsea elevations range from about –3,500 feet to –5,500 feet.

Figures 5 and 6 illustrate typical geophysical logs (gamma ray and porosity curves) for the Medina Group in the northern and southern portions of the study area, respectively. The gamma ray

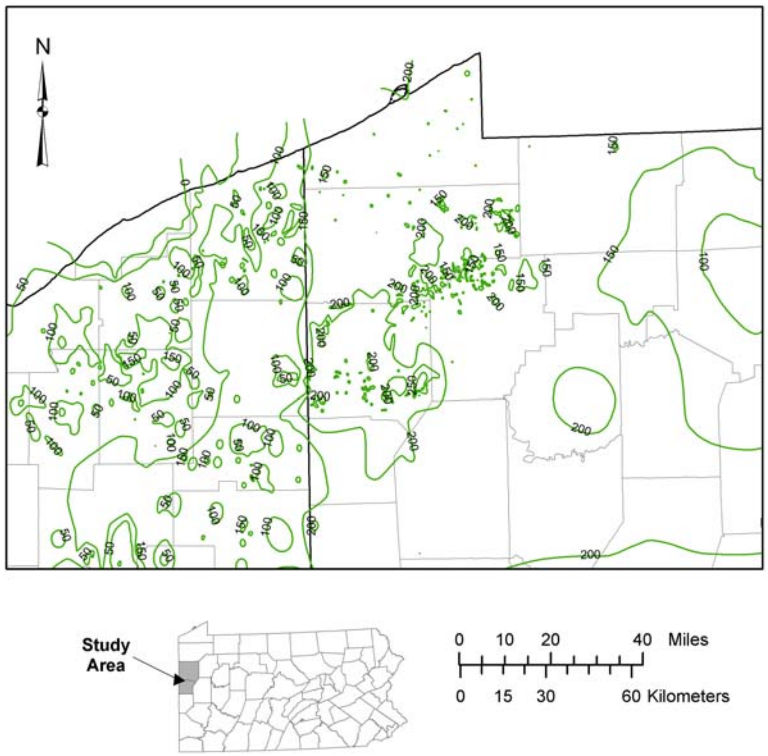

Figure 4. Isopach map of the Medina Group in the study area (modified from Venteris and others, 2005). The thickness of this unit is shown at a contour interval of 50 feet. In the study area, the average net thickness is 85 feet.

signatures for both type logs demonstrate the thick, sandy nature of the Grimsby, the increasing-upward siltstone laminations within the Cabot Head Shale, and the abrupt, sandy signature of the Whirlpool Sandstone as it overlies the Queenston Formation, all of which have been collectively referred to as a "broken sandstone" gamma ray signature (Laughrey, 1984). Even though the lithologic characteristics of these two logs are similar, the porosity logs tell a different story. To the north, where Medina Group production has been more prolific (Figure 1), the porosity logs illustrate many more porous zones throughout the Grimsby Sandstone, the siltstone laminations of the Cabot Head Shale, and the Whirlpool Sandstone (Figure 5). In contrast, to the south, neutron and density logs indicate less porosity (Figure 6). Porosity values for fields in the study area range from 3 to 9 percent, and average 7 percent (Table 2). Most Medina Group porosity is attributed to secondary porosity created by diagenetic processes, where silica and carbonate have cemented primary intergranular porosity of the sandy zones. In northwestern Pennsylvania, the highest porosity zones are influenced by both depositional environment and diagenetic phenomena (Laughrey, 1984; McCormac and others, 1996).

In addition to porosity and net thickness, Table 2 summarizes other Medina reservoir characteristics. Producing depths vary from 4,450 to 6,650 feet. Reservoir temperatures and pressures range from 76 to 142 degrees Fahrenheit (ºF) and 1,025 to 1,630 pounds per square inch (psi), respectively. Water saturations range from 12 to 77 percent, and reported salinities are in excess of 155,000 parts per million (ppm).

Throughout the Appalachian basin, stratigraphic traps have been shown to control the occurrence of gas in the Medina Group, although in localized areas, gas production may be enhanced by geologic structure (Piotrowski, 1981; Laughrey and Harper, 1986; McCormac and others, 1996). The overall heterogeneity of this reservoir is evidenced by the variety of mechanisms forming the traps, which include sandstone pinch-outs, porosity changes, gas-water contacts, and diagenesis (Laughrey and Harper, 1986). According to Laughrey (1984), the best Medina reservoirs are found in braided fluvial channel deposits of the Grimsby Sandstone. The littoral and sublittoral sandstones of the Grimsby, Cabot Head Shale, and Whirlpool Sandstone are fair to poor reservoir rocks. Drozd and Cole (1994) used organic geochemistry to establish the Ordovician-age Point Pleasant Formation as the petroleum source for the Medina Group reservoir.

Oil Fields: Of the 32 Medina Group pools in the study area, twelve of them produce oil (Table 2).

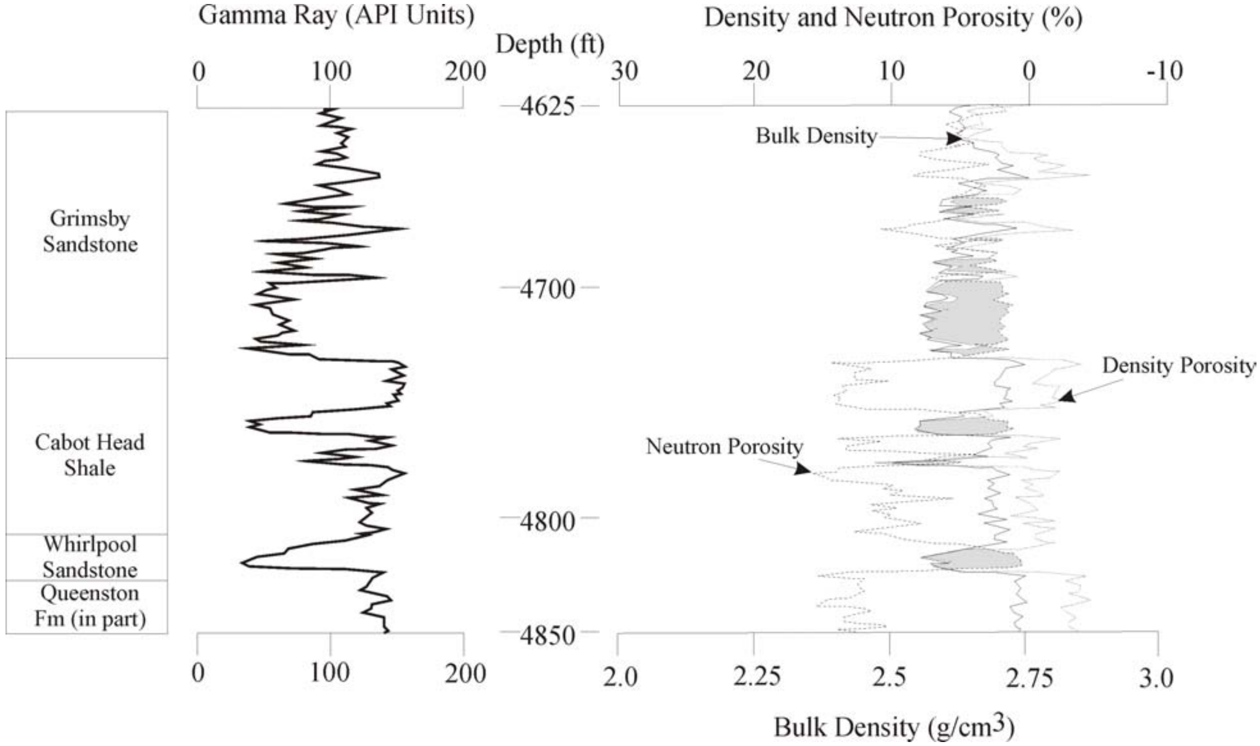

Figure 5. Gamma ray and porosity geophysical log curves for the Madura #1 (085-20801), which produces from the Medina Group. The gamma ray response (left) is higher for shales since they have a greater natural radioactivity. The crossover between density porosity and neutron porosity curves (right) is shown with light gray shading and indicates a gas effect in the porous zones of the Grimsby Sandstone, the transitional, silty sands of the Cabot Head Shale, and the Whirlpool Sandstone.

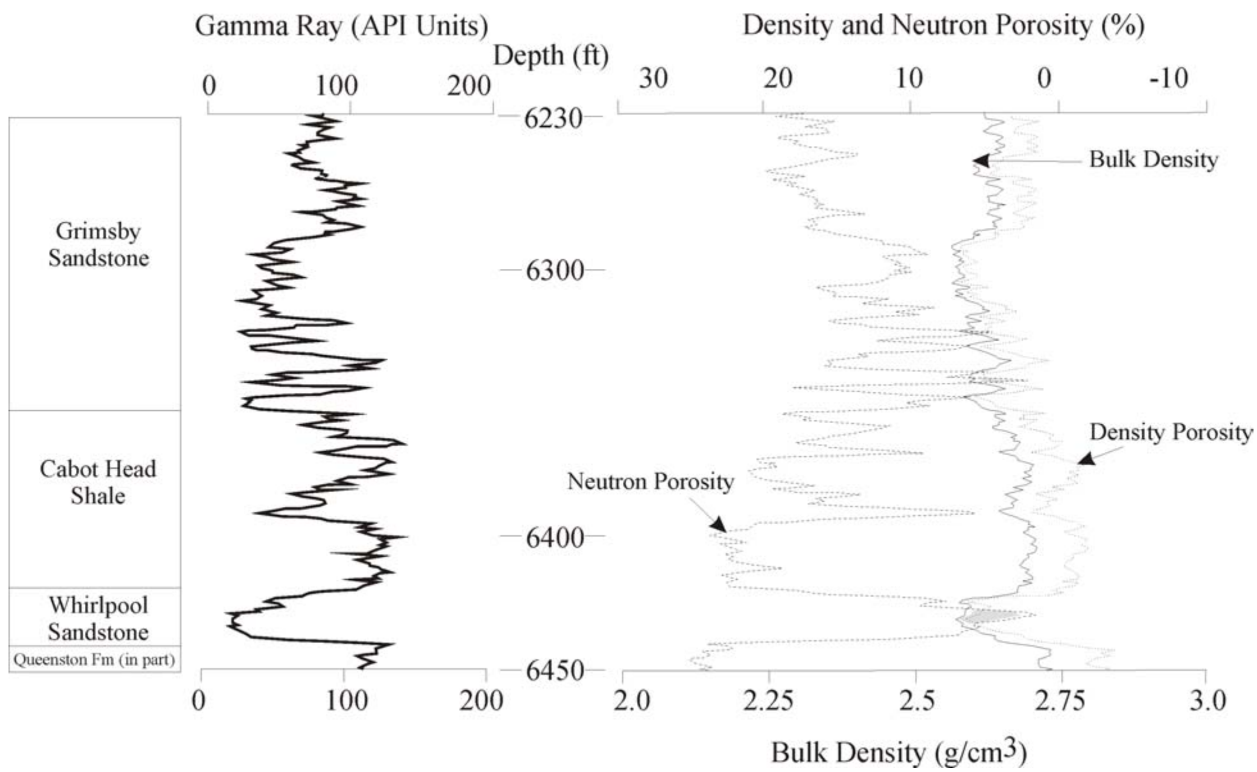

Figure 6. Gamma ray and porosity geophysical log curves for the Sankey #1 (073-20110), a Medina Group-producing well. Although the gamma ray signature (left) looks comparable to Figure 5, neutron-density crossover (due to the presence of natural gas in pore spaces) only occurs in the Whirlpool Sandstone (right).

The unnamed pool in the Wheatland field was the first to be discovered (1963), reporting an IP of 1 Bopd after treatment. Most of the remaining fields were discovered during the energy crisis boom of the late 1970's – early 1980's, from the unnamed pool of the Maysville field in 1977 (3 Bopd after treatment) to the unnamed pool of the Greenfield field in 1984. The most recent Medina Group discovery was the Lackawannock pool of Big Bend field, which occurred in 1990. Cumulative oil production figures for these pools range from 2,317 to 66,995 barrels (Bbl).

Gas Fields: Thirty-two pools produce natural gas from the Medina Group in the study area (Table 2). The unnamed pool in the Wheatland field was the earliest to produce gas from the Medina. The most recent Medina Group discovery occurred in 1999 in the Eastbrook pool of the New Castle field. Average IP's vary from 5 to 161 Mcf per day (natural) to 36 to 1,684 Mcf per day (after treatment). Cumulative gas production ranges from 12,169 to 29,627,219 Mcf.

FUTURE PROSPECTS

Future prospects for oil and gas in Mercer and Lawrence Counties are many, since abundant source rocks, reservoir rocks, and trapping mechanisms all exist in this area. Because oil and gas exploration in northwestern Pennsylvania has been particularly successful in the Medina Group sands, however, it's safe to say that some existing reservoirs and other potential reservoirs have not been explored to their fullest extent.

For example, the reservoir rocks of the Lockport Dolomite could be further studied beyond the areas of known production (i.e., Pymatuning and Kilgore pools; Table 1). As pointed out by Laughrey (1987), some Medina Group wells in this part of the state could potentially be redeveloped for Lockport gas production, in those locations where good geophysical log data are available. Reevaluation of these data might identify producing zones originally overlooked during drilling to the underlying Medina Group.

In addition, further evaluation of the Henderson Dome in southeastern Mercer County using geophysical and seismic methods could identify the potential for gas-bearing units other than the Lockport. This research could target the Venango Group on the dome, as discussed by Kuminecz and Gorham (1993), as well as the unusually thick Medina Group section along the flanks of the dome, as reported by Piotrowski (1981).

Finally, as carbonate rocks in the Trenton-Black River play have become increasingly popular drilling targets in the Appalachian basin over the past few years, deep drilling in and beyond the study area could help to "connect the dots" between the Trenton-Black River successes reported in New York, Ohio, and West Virginia. Due to the complex nature of the Trenton-Black River play, and in particular, the basement faulting associated with the migration of hydrocarbons, both seismic and geophysical surveying techniques will be key to characterizing these potential reservoirs in the study area.

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FIELD TRIP STOP DESCRIPTIONS- DAY 1

STOP 1- HELLS HOLLOW. "MERCER LIMESTONE" TYPE SECTION.

Leader- Viktoras Skema

Introduction

There are several local legends related to the origin of the name for Hell's Hollow (Bower, 1973). All involve ghosts. The most prevalent one describes the murder of an Indian by one of the early settlers. This tale has several versions, the essence of which is that in the early settlement days a rather nasty, Indian-hating white resident of Mercer, had an ugly confrontation with a fearsome, obnoxiously drunken local Indian because of the Indian's perceived menacing treatment of a neighbor's boy. The next day the resident followed the Indian out of town and murdered him in this dark hollow about a mile and a half west of Mercer. The Indian's angry spirit is said to have returned to haunt the hollow, frightening the occasional lone traveler with eerie lamenting cries and murmurs, especially on dark, stormy nights.

However, one can't help but think that the name may in part also be attributable to the hellish smoky atmosphere that must have been present in the hollow in the middle of the nineteenth century. The charcoal-fired Oregon Iron Furnace was situated to the west near the mouth of the hollow on the Lackawannock Creek (Figure 1-1) and operated during the 1840s and 1850s (Washlaski and Washlaski, 2001 and White, 1880, p. 137). The First Geological Survey Report on The Geology of Pennsylvania, based on field work done in the late 1830s and early 1840s, does not mention the hollow by name (Rogers, 1858). The Second Geological Survey Report of the Geology of Mercer County, refers to the hollow as Devils Hollow (White, 1880).

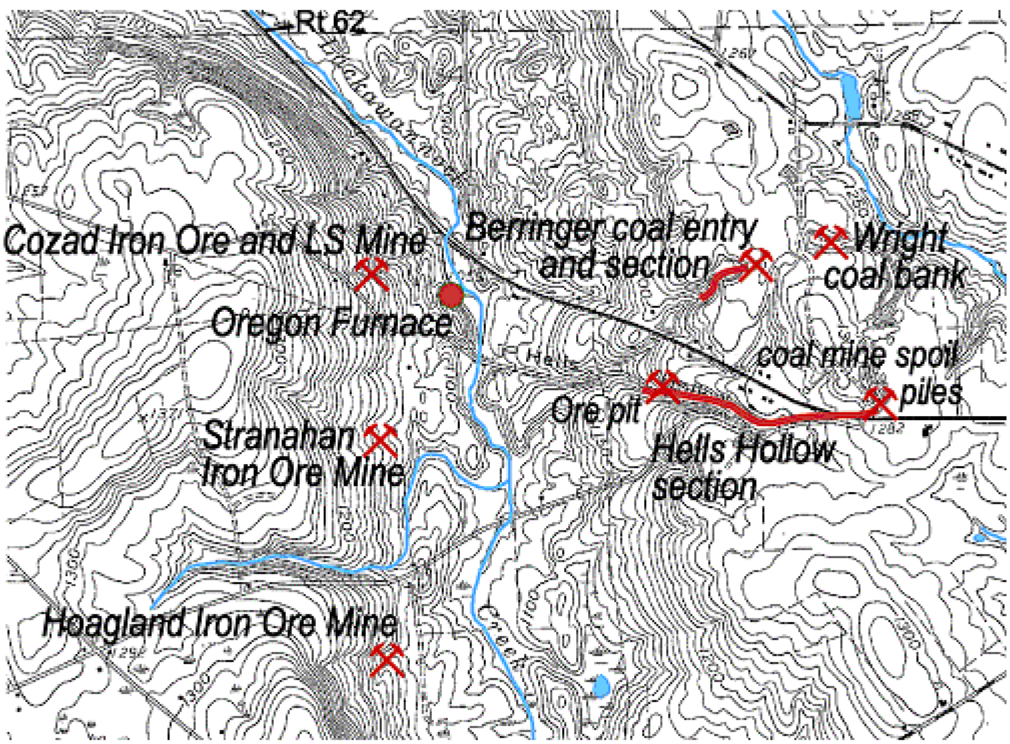

Figure 1-1. STOP 1 is at Hells Hollow 1 1/2 miles west of Mercer. Most of the locations of measured sections, mines, and the iron furnace are approximations made from written descriptions in 2nd Geological Survey Report QQQ on Geology of Mercer County.

The appearance of Hells Hollow has probably changed very little since a geologist first visited it nearly 170 years ago. The rock exposure at Hells Hollow was one of the best available in this region in the nineteenth century and was significant in the early geologic work in the Main Bituminous Coal Field of western Pennsylvania. Examining the history of the first attempts at conceptualizing the stratigraphy of these rocks is revealing. It gives us a better understanding of how our present stratigraphic nomenclature for the upper Pottsville Group and lower Allegheny Group was developed. The paucity of good rock exposures made it difficult to unravel the stratigraphic complexity of this part of the geologic section, and was the main cause of some of the analytical mistakes made and the disparate stratigraphic interpretations arrived at by the early workers. Remarkably, despite this limitation, these geologists were able to develop a basic framework that for the most part is used to this day.

First Geological Survey Description and Interpretation

James T. Hodge was probably the first to examine the rocks exposed in Hells Hollow. He assisted Henry D. Rogers in his effort to conduct the First Geological Survey of Pennsylvania (Lesley, 1876, p 69). Hodge spent that field season examining mines and other rock exposures in the northwestern district, and he most likely was responsible for the first published description of the rocks of this hollow (Rogers, 1858, p 564).

This was historically an important site because it provided Rogers with probably his first detailed, nearly complete look at the rocks of the upper Pottsville Group directly above the Connoquenessing Sandstone (his Seral sandstone and conglomerate) west of the Allegheny River. The section here at Hells Hollow is over 100 feet thick and contains mostly shale with a few thin sandstones, four coals and a limestone. Since he did not find the massive Homewood Sandstone (his "great" Tionesta sandstone), he assumed that it had been eroded here and that the entire section was stratigraphically beneath the Homewood. This assumption was based on the underlying stereotypical concept, so prevalent among stratigraphers for many years, that the major sandstone beds such as the Homewood and Connoquenessing were widespread and virtually continuous throughout all of the western and north-central Pennsylvania Bituminous Coal Fields. He designated this sequence of rocks the Tionesta Group and remarked that it had changed greatly in appearance and thickened considerably from the stratigraphically equivalent section east of the Allegheny River (Rogers, 1858, p 489). The thick coal near the top of the section he identified as the Tionesta coal, a coal encountered earlier in his work to the northwest in Forest County, where it was situated directly under the "Tionesta Sandstone". Here, near Mercer, it is five to six feet thick and was being mined at several separate locations at the time the section was measured. Rogers reported that the coal mine on top of the hill east of the hollow, "Wright's Coal-bank", was the chief supplier of fuel to the town of Mercer. He noted that 17 feet of black shale containing fossil shells overlie the coal at this mine (Rogers, 1858, p 564).

The significance of the road cut at Hells Hollow is that it contained a rare good exposure of a stratigraphically key marine limestone (Figure 1-2). The exposed section was long enough that an accurate measurement could be made of the spatial relationship of the limestone to the thick "Tionesta" coal being mined at the top of the hill. This limestone was found elsewhere in the immediate vicinity of Mercer but was generally poorly exposed or seen only as float. Rogers named the limestone exposed here in the hollow the Mercer Limestone because of its close proximity to the town of Mercer (Rogers, 1858, p 489 and White, 1880, p 136). Good exposures of the limestone were eventually found at other sites in Mercer and Lawrence County. Farther south in the New Castle area and specifically in the runs flowing down the steep valley walls of the Mahoning River Rogers reported finding a pair of marine limestones in this part of the section about 30 feet apart. He correlated the Mercer Limestone with the lower limestone of this pair and named the upper one the Mahoning Limestone (Rogers, 1858, p 489). He made this determination even though he reported finding a

Figure 1-2. Upper Mercer Limestone exposed along Old Sharon Road in Hells Hollow. According to I. C. White of the 2nd Geological Survey, this was H. D. Rogers's type section of the "Mercer Limestone"

stratigraphically lower “unknown” limestone near Hells Hollow on the Porter Farm (Rogers, 1858, p 565), which would imply that the Mercer limestone was more likely equivalent to the upper of the pair of limestones.

I. C. White’s Description and Interpretation

The outcrops in Hells Hollow were also important in the more detailed Second Geological Survey mapping of the area. I. C. White, a prominent Survey geologist who later became director of the West Virginia Geological Survey, spent the summer of 1878 collecting data in Mercer County for his Report of Progress of the Geology of Mercer County. The report includes two measured sections of the rocks in the hollow (he referred to it as Devils Hollow) and several other sections from nearby sites (White, 1880, p 36, 134-138). He had more data available than Rogers because of the increase of mining activity in the area since the time of the First Geological Survey, particularly iron ore mining. The “Tionesta” coal mines reported by Rogers on the hilltop east of the hollow were still active. Additionally, iron ore for the Oregon Furnace had been strip-mined in a small excavation half way down the hollow. The ore pit can still be found today (Figure 1-1). White also reported that the two-foot-thick coal, prominently exposed in the hollow atop a rootworked sandstone, was strip-mined along the side of the road in the hollow prior to his visit (Figures 1-3 and 1-4). He described other mines located close to the hollow that extracted iron ore and limestone. Two of these mines contained a pair of limestones and associated iron ore beds. These mines were on the Stranahan property approximately one-half mile to the southwest of Hells Hollow and another mine to the northwest in the vicinity of the Oregon Furnace on the Cozad property (Figure 1-1).

I. C. White was finishing the writing of his previous Lawrence County Geology Report at the time he was doing his field work in Mercer County. After examining Rogers’s type locale of the Mercer Limestone in the area of Hells Hollow west of Mercer and the relationship of the pair of limestones seen nearby, he concluded that the pair was the same as those found near the Mahoning River in Lawrence County. Since he was able to follow the pair of limestones over a large area in Lawrence County, he proposed the revision in his discussion of the limestones in the Lawrence County Report (White, 1879, p 57-58). However, he retained Rogers’s Mercer type locality and used it for both limestones. He changed the name of the Mercer Limestone to the Lower Mercer Limestone. He did this because he believed that in Lawrence County the lower of the pair of limestones was the more persistent. With some reservation, he assumed that this tendency carried over into Mercer County and that the limestone typically seen alone throughout most of the county, as in Hells Hollow, was the lower limestone as well. He renamed the upper limestone the Upper Mercer Limestone. He abandoned the Mahoning River type locale previously designated for it, moving it to the same Mercer locale as the lower limestone even though it was rarely seen in Mercer County. He felt justified in doing this because of its presence at Stranahan’s iron ore pit and anecdotal evidence he had received from the operators of the defunct Oregon Furnace that both limestones were present there also (White, 1880, p 137). His main objection to Rogers’s nomenclature was that the name Mahoning was already being used for a sandstone positioned much higher in the section that had good exposures along Mahoning Creek in Indiana and Jefferson Counties (Lesley, 1856 and Rogers, 1858, pp 477, 493).

White recognized that there was not much evidence available to definitely determine which of the pair of Mercer limestones was the more persistently present in Mercer County. He expressed this uncertainty in several places in the report (White, 1880, p 37, 40-41). He acknowledged that some of the recorded exposures of the Lower Mercer Limestone might instead actually be the Upper Mercer Limestone. Considering the exposure in Hells Hollow to be the type section of the Lower Mercer Limestone (Rogers’s Mercer Limestone) (White, 1880, p 136), he went to great lengths to find the position of the upper limestone horizon there. He compared the Hells Hollow section with another nearby section he had measured that contained limestone float. This section was a quarter mile to the north along the tributary to Hells Hollow below the Berringer coal entry (Figure1-1). He compared the interval (vertical distance) from limestone found in each section to the thick mined coal at the top of both sections. For Hells Hollow he compared

Figure 1-3 I. C. White's "Upper Mercer" coal in Hells Hollow lying directly on rootworked sandstone paleosol. The coal was mined in the hollow during the mid-nineteenth century.

Figure 1-4. Sub-vertical, carbonaceous root remains are common throughout the sandstone paleosol beneath I. C. White's "Upper Mercer" coal in Hells Hollow.

a section he had measured to the identical section "carefully leveled" by F. H. Oliphant, Jr., operator of the Pardoe mines east of Mercer, just to be certain of the accuracy of the measurement between the mined coal and limestone (White, 1880, p 136). His measurement in Hells Hollow was 76 feet (Oliphant had 77 feet), whereas in his Berringer section he measured only 56 feet between limestone and coal. Based on the different intervals, he concluded that the limestone in the Berringer section had to be the Upper Mercer Limestone and that the limestone in Hells Hollow was the Lower Mercer. He correlated the coal directly under the limestone in the Berringer section with the two foot coal sitting on the rootworked sandstone in Hells Hollow, which placed the horizon of the missing Upper Mercer Limestone directly above this coal. He based this decision strictly on interval and ignored the possible presence of any other unique beds common to both sections that could be used for correlation.

White did not agree with Rogers's identification of the mined "Tionesta" coal at the top of the Hells Hollow section (White, 1880, p30). He thought it was instead the Brookville coal and that the usually present, underlying Homewood Sandstone (Rogers's Tionesta Sandstone) had not been deposited at this site. His identification of this thick mined coal in the Mercer area appears to be based on its position relative to the Homewood Sandstone. He reported that the Homewood was present throughout the rest of the county as massive and often conglomeratic sandstone (White, 1880, p 34). He described the position of the Brookville coal as being almost directly above the Homewood Sandstone over much of the county and at the most separated from the sandstone by no more than 15 feet of fireclay and sandy shales. He stated that he had never seen a trace of coal in this interval. He did, however, report that Mr. F. H. Oliphant, Jr. "thinks he has seen a thin coal 10' to 12' below the Pardoe coal," [White's Brookville] "and calls it the Brookville bed, and the Pardoe coal the Clarion." He also wrote that at the Berringer coal mine near Hells Hollow, "Mr. Berringer states that in draining his mine he cut an 18" coal, lying 15' below his bed" [White's Brookville] (White, 1880, p 31). Elsewhere in the report White makes the comment regarding this 18" coal, "but that I am inclined to look with suspicion on its alleged presence." (White, 1880, p 134). He does not report that both Oliphant and Rogers also report a thin coal in their Hells Hollow sections at about the same horizon between what White calls the Upper Mercer coal and the mined Brookville coal.

I. C. White had an interesting relationship with his boss, J. P. Lesley, the director of the Second Geological Survey of Pennsylvania. They had their share of disagreements over the stratigraphy of the Pennsylvanian section in western Pennsylvania. Despite his disagreements, Lesley would usually relent and allow White to publish his views; however he almost always would include a lengthy argument expressing his opinions on the subject in a preface to White's published reports. In Mercer County, Lesley did not agree with Whites identification of the mined coal at the top of the Hells Hollow section. He believed that it was not the Brookville coal, but the Clarion instead. He published his usual argument in the preface to the Mercer County Report (Lesley, preface to White, 1880, p xii-xiv), and also inserted an editor's disclaimer in brackets at the end of White's section describing the Brookville coal (White, 1880, p 32). His rationale for this conclusion was elaborate and based mainly on the work of H. M. Chance in Butler, Clarion, and Venango Counties. He argued that there the Clarion, identifiable because of its position in relation to the also present Vanport Limestone, was locally found close above the Homewood Sandstone with no trace of the Brookville apparent between the Clarion coal and the sandstone beneath it. He surmised that the Brookville was not deposited in these local areas because the thick sandstone formed a gentle local anticlinal structure, "or least a swell in the water-floor."(Lesley, preface to White, 1880, p xiii)

Present Description and Interpretation

Previous stratigraphic identification of the coals in the Hells Hollow Section was based mainly on their vertical position in relation to several key beds thought to be present over most of Mercer County and the region. The beds commonly used were the thick, mined coal at the top of the section, the marine limestone near the bottom of the section and indirectly the massive "Homewood Sandstone". The sandstone was thought to be persistently present throughout western Pennsylvania and was used extensively as a stratigraphic guide. However, it is not present at Hells Hollow. Rogers, who named the sandstone the Tionesta, took its near universal presence for granted, and since he did not find it in the Hells Hollow section, he assumed that all of the coals there had to be situated below the sandstone in his Tionesta Group. I. C. White recognized that even though the massive sandstone was absent, its horizon was contained in the section, and he relied on the thick coal to anchor his stratigraphic interpretation of the section. Even though there was a difference of opinion as to the stratigraphic identity of the coal, there was general agreement that this coal could be traced through the entire county as the main mined coal. Again, the Homewood Sandstone was the basis for this correlation of the mined coal. In most of Mercer County, with Hells Hollow being the only exception, this coal and its underclay were positioned a short distance above thick sandstone. White, Lesley and others assumed that this sandstone was the Homewood. There was also general recognition of the widespread occurrence of the limestone and its utility as a stratigraphic marker bed, and attention was given to understanding the spotty geographic distribution of the other stratigraphically nearby limestone. However, no thought was given to identifying other invertebrate fossil-bearing lithologies or their potential use as reliable stratigraphic marker beds.

Three such beds are present in the Hells Hollow section and are important in establishing the stratigraphic identification of the coals and other rocks in the hollow and in the region. The first of these, a 0.3-foot thick siderite bed is near the bottom of the Hells Hollow section. It lies directly on a thin coal and is presently exposed in the ditch on the north side of the road (Figure 1-5). On careful examination, this bed was found to contain small broken shell fossil fragments visible on its weathered bottom surface. Its position about 20 feet below the marine limestone is close to the interval that Rogers reported between the pair of limestones seen in Lawrence County near the Beaver River and the distance that White observed between the pair of limestones at the nearby Stranahan iron ore mine. The occurrence of siderite with these limestones is a common association, and White reported that a local miner had in some cases seen the siderite completely replace the limestone. It is reasonable to assume that the siderite bed is equivalent to the Lower Mercer Limestone and that the limestone in Hells Hollow that commonly appears alone throughout the area is the Upper Mercer Limestone. A piece of burned limestone float was found in an abandoned ore pit a short distance to the west of the fossiliferous siderite in the ditch (Figure 1-1). This old excavation is situated in the hillside above the road at about the same elevation as the siderite. It is the strip-mined iron

Figure 1-5. Thin siderite bed exposed in roadside ditch at Hells Hollow at the Lower Mercer Limestone horizon. It contains fossil shell fragments.

ore pit reported by White (White, 1880, p 46) and the burned limestone float may indicate that both siderite and limestone are present at the Lower Mercer horizon here in the pit.

The two foot-thick coal that White identified as the Upper Mercer on top of the rootworked sandstone is most likely the Mount Jackson coal that was present over a large area in Lawrence County. This coal has been given many names in previous reports, including the "Tionesta" and "Homewood" to name a few. Curiously, in Lawrence County it is often also associated with a rootworked sandstone paleosol. Here at Hells Hollow it is overlain by carbonaceous shale containing a few fish scales and plants, mostly coaly compressions of Calamites.

The second of these non-limestone fossil beds is the dark shale at the top of the section described by Rogers. Old coal mine spoil piles can still be found at the top of the hill east of the hollow on the old Wright property where the thick coal was mined in the middle of the nineteenth century (Figure 1-1). These piles contain a large amount of discarded bone coal and carbonaceous shale roof rock, along with a few scattered siderite nodules and apparent fragments of siderite beds. The siderite contains an assortment of marine invertebrate fossils. A cursory examination revealed an intact short segment of a crinoid column, a *Mesolobus* brachiopod shell (Figure 1-6), possibly a *Composita* brachiopod shell, and other unidentified fossil shells and fragments. Considering its vertical position in relation to the Upper Mercer Limestone and the Lower Mercer Limestone horizon, this fossiliferous, siderite-bearing, dark shale definitely represents a facies of the Vanport Limestone, and the fossiliferous bed-like siderite fragments may represent the thin, sideritized, Vanport Limestone bed itself. This time it has to be said that irrespective of his reasoning, the boss, J. P. Lesley, was right. At Hells Hollow the upper-most mined coal has to be the Clarion or the Scrubgrass coal, or a combination of the two.

Figure 1-6. Siderite nodule from Vanport marine zone at top of Hells Hollow section containing *Mesolobus* brachiopod fossil and other shell fragments. This nodule was found in the spoil pile of an old Clarion coal mine.

Interestingly, in his Hells Hollow section, Rogers also reported the presence of a thin fireclay between the Clarion coal and the fossiliferous dark shale above it. These fireclays, sometimes also called underclays, are massive, clay rich beds that usually, but not necessarily, are directly under coals and can be traced over great distances. They are ancient soils or "paleosols". The better developed ones contain obvious soil-like features such as: remains and traces of plant roots; a massive, hackly structure containing many small, randomly oriented, slickensided surfaces; and horizontal zonation into layers of different composition, color, or texture. These paleosols always have a sharp upper contact and a gradational lower contact, and gradational contacts between internal layers or "soil horizons". Lower horizons often contain nodules or concretions (Retallack, 1988). A well-developed fireclay is usually found under the Scrubgrass coal. The reported presence of one above the mined thick coal at Hells Hollow suggests that the coal is the Clarion coal and that the Scrubgrass coal, often found directly beneath the Vanport Limestone, was not deposited, but that its horizon can be placed above the upper-most fireclay.

One of the main criteria that I. C. White used in determining that the limestone in the hollow was the Lower Mercer and not Upper Mercer was the stratigraphic interval between the limestone and the mined coal at the top of the hill that he assumed was the Brookville. He had established this interval in Lawrence County where both Mercer Limestones and the Vanport Limestone were present enabling accurate identification of the Brookville coal. He believed that there was typically an interval of 70 or 75 feet between the Lower Mercer Limestone and the Brookville coal, and 40 to 50 feet between the Upper Mercer and the coal. Since his identification of the mined coal was incorrect at Hells Hollow, and the coal at the top of the section is the stratigraphically higher Clarion coal, the measured vertical distance between it and the limestone adds further support to the identification of the limestone as the Upper Mercer Limestone.

The third subtle fossiliferous bed in the Hells Hollow section is positioned eleven feet above the prominently exposed Mount Jackson (Tionesta) coal. It is a 0.3 foot-thick, well-indurated, slate-like, grayish black, carbonaceous clay shale containing *Lingula* brachiopods and rare, small fish scales. It is more resistant to weathering than the shale above and below it, weathers a brownish-yellow color, and displays a pronounced bone-coal-like joint fracturing pattern (Figure 1-7). Two feet below this fossiliferous bed there is a thin coaly shale underlain by a thin underclay. Both Rogers and Oliphant also reported a thin coal at about this horizon in their Hells Hollow sections. This coal horizon is probably equivalent to the 18 inches of good coal reported in the nearby Berringer section. The vertical distance between this coal horizon and the Upper Mercer Limestone is about the same in all of the measured sections. However, the 15 foot interval between the coal in the Berringer section and the mined Clarion coal above is considerably less than the 32 feet reported at Hells Hollow. This discrepancy in interval and the difference in thickness and quality of the coal itself may be due to a change in depositional environment. The rocks between this coal and the Clarion coal above are reported as fireclay and shales in the Berringer section, whereas at Hells Hollow there is also sandstone. The difference in compactibility between sand and shale at Hells Hollow and the predominantly clayey beds in the Berringer section could account for the difference in interval between the two sites. Also, the ten-foot thick sandstone above the thin coaly shale in the Hells Hollow section is severely tilted. This

Figure 1-7 Coaly shale is at Brookville coal horizon in Hells Hollow. It is overlain by thin, slate-like, carbonaceous clay shale containing *Lingula* brachiopod fossils at the Putnam Hill marine zone horizon.

may be the result of slumping into a paleo-channel. The difference in coal thickness and quality between the sites and the relative thickening and coarsening of the overlying clastic sediment would all be consistent with the existence of a fluvial channel at or near Hells Hollow.

This coaly shale in Hells Hollow is at the Brookville coal horizon. The determination is based on its stratigraphic position relative to the Clarion coal, the Vanport marine zone, and the Upper Mercer Limestone. The fossiliferous, carbonaceous shale above it is equivalent to the Putnam Hill Limestone, first reported near Putnam Hill, Muskingum County, Ohio (Andrews, 1870). A fossiliferous dark shale facies of the Putnam Hill marine zone is not uncommon in Pennsylvania. An identical thin, *Lingula*-bearing, carbonaceous shale bed in about the same part of the section was seen directly above a coal near Homewood, Beaver County along the westbound lanes of the Pennsylvania Turnpike west of the Beaver River. *Lingula*, along with other brackish-water fossils such as *Orbiculoidea* brachiopods and *Dunbarella* bivalves, has also been found in dark shale above the Brookville coal at other sites in western Pennsylvania.

Summary

Hells Hollow was an important site in the early development of the stratigraphic nomenclature of the upper Pottsville Group. A recent reexamination of the rocks here has led to the discovery of two additional marine/brackish-water fossil horizons, and a better understanding of a third fossil horizon at the top of the section described by H. D. Rogers. This has led to a new evaluation of the stratigraphy in the geologic section for this famous site (Figure 1-8). The following is a summary of the significant features observed by the various geologists that have visited this hollow and the evolving stratigraphic interpretation of these findings.

- Henry Darwin Rogers, Director of the First Geological Survey of Pennsylvania, found a marine limestone exposed in Hells Hollow and named it the "Mercer Limestone" for the nearest town. The limestone proved to be an important correlation tool in Mercer and Lawrence Counties. He believed that the entire section was below his "Tionesta Sandstone" (Homewood), and he considered it to be a complete, representative example of his "Tionesta Group" for this region. He reported shell fossils in the dark shale above the thick, mined coal at the top of the section, but did not recognize any stratigraphic value to their presence.
- White examined the rocks in Hells Hollow in 1878 and recognized that the section spanned the Pottsville and Allegheny Groups. He understood that the section contained the Homewood Sandstone horizon, but that the sandstone was not present because it was not deposited in this area. This placed the mined coal at the top of the section in the Allegheny Group, and White identified it as the Brookville.
- White found two limestones at a nearby site. He correlated the lower of the two with the limestone exposed in the hollow and renamed it the Lower Mercer, and named the upper of the pair the Upper Mercer. He could find no trace of the Upper Mercer Limestone in the hollow, but placed its horizon above a prominent coal in the hollow that sits on a rootworked sandstone. He based the correlation of the Lower Mercer Limestone in the hollow on the vertical distance between the limestone and the stratigraphically higher Brookville coal. He had previously established a typical interval between the two in Lawrence County.
- Siderite nodules containing marine fossils were found in the old mine dumps just above the hollow to the east. These were old mines in the thick coal at the top of the section, and the siderite was part of the fossiliferous shale reported by Rogers. In this part of the geologic section in the lower Allegheny Group these could only come from the Vanport Limestone horizon, making the underlying coal ether the Scrubgrass, the Clarion, or a combination of the two. The reported presence of a thin fireclay separating the coal and overlying fossiliferous shale implies that the Scrubgrass coal horizon, which typically is underlain by fireclay, is at the base of the shale, and that the mined coal is most likely the Clarion.

- A siderite bed found 18 feet below the limestone in the hollow contains fossil shell fragments, and is likely equivalent to the Lower Mercer Limestone. The interval between it and the limestone above is similar to the distance between the pair of limestones seen at the site nearby. This means that the limestone in the hollow should be correlated with the upper of the pair of limestones at the other site and that it is the Upper Mercer. The vertical distance between the limestone and what turns out to be the Clarion coal (not the Brookville as misidentified by White) also confirms this identification of the limestone as the Upper Mercer.
- A thin carbonaceous clay shale containing Lingula brachiopods and positioned about two feet above a thin coaly shale and underclay was found between the mined Clarion coal and the coal sitting on the rootworked sandstone. At this stratigraphic position these are the Brookville coal horizon overlain by the Putnam Hill marine zone, and the coal below these that is sitting on rootworked sandstone is the Mount Jackson (Tionesta) coal. If the sandstone above this Lingula zone in Hells Hollow is equivalent to the massive sandstone found below the mined Clarion coal throughout the county, then the prominent sandstone in this part of the section in this region is not the Homewood, but the Clarion Sandstone.

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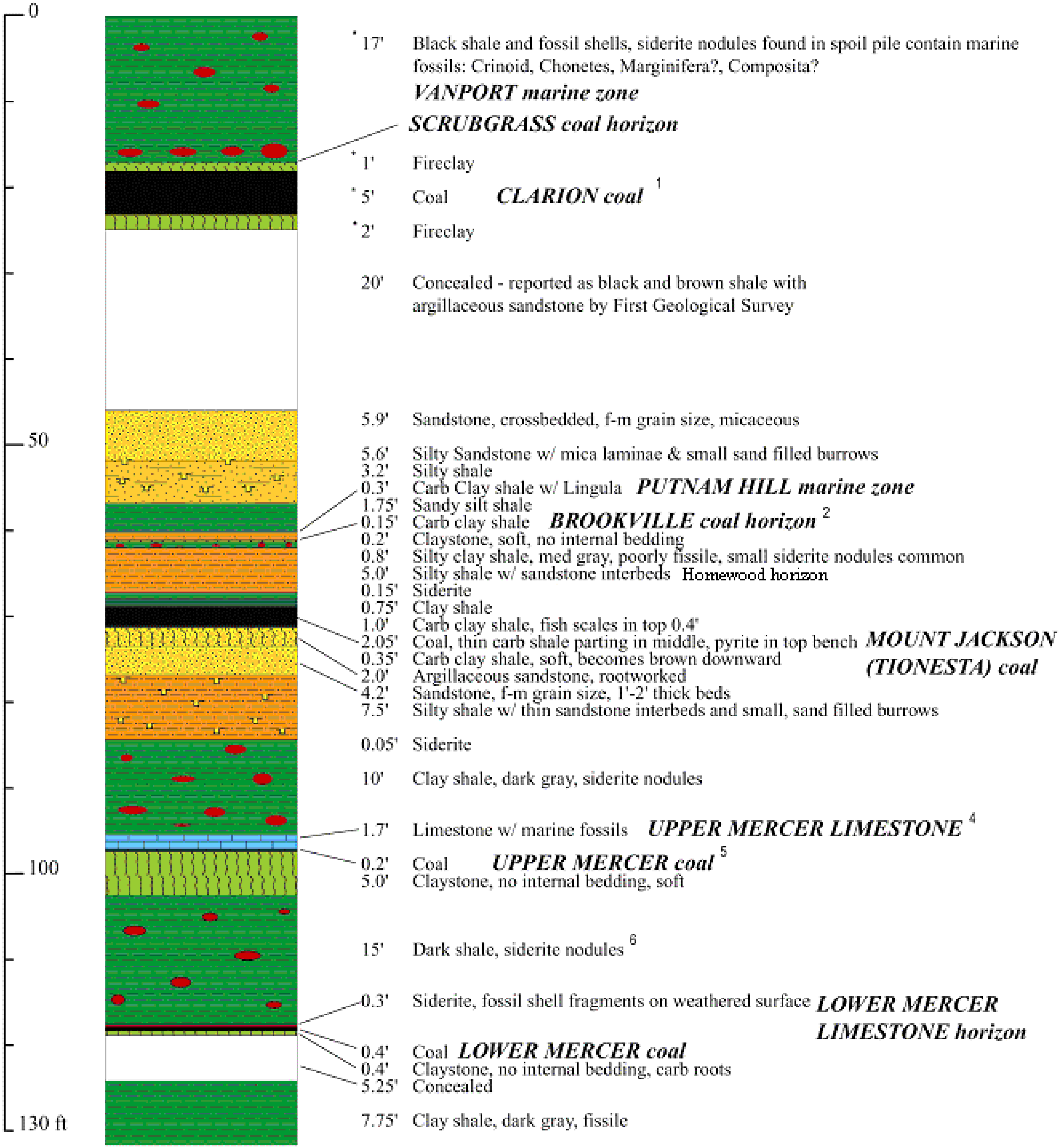
Hells Hollow Geologic Section



* Description and measurements as presented in H. D. Rogers First Geological Survey 1858 Report on the Geology of Pennsylvania, pg 564
1 H. D. Rogers' Tionesta coal and I. C. White's Brookville coal and J. P. Lesley's Clarion coal
2 H. D. Rogers' Upper Porter coal
3 H.D. Rogers' Middle Porter coal and I. C. White's Upper Mercer coal
4 H.D. Rogers' Mercer Limestone and I.C. White's Lower Mercer Limestone
5 H.D. Rogers' Lower Porter coal and I.C. White's Lower Mercer coal
6 Most of this unit is now concealed. Description and measurement as presented in I. C. White's "Devils Hollow " Section

Figure 1-8. Geologic Section of Hells Hollow, Mercer County.

STOP 2- COCHRANTON GLACIOLACUSTRINE SEDIMENTS.

Leader- Gary M Fleeger

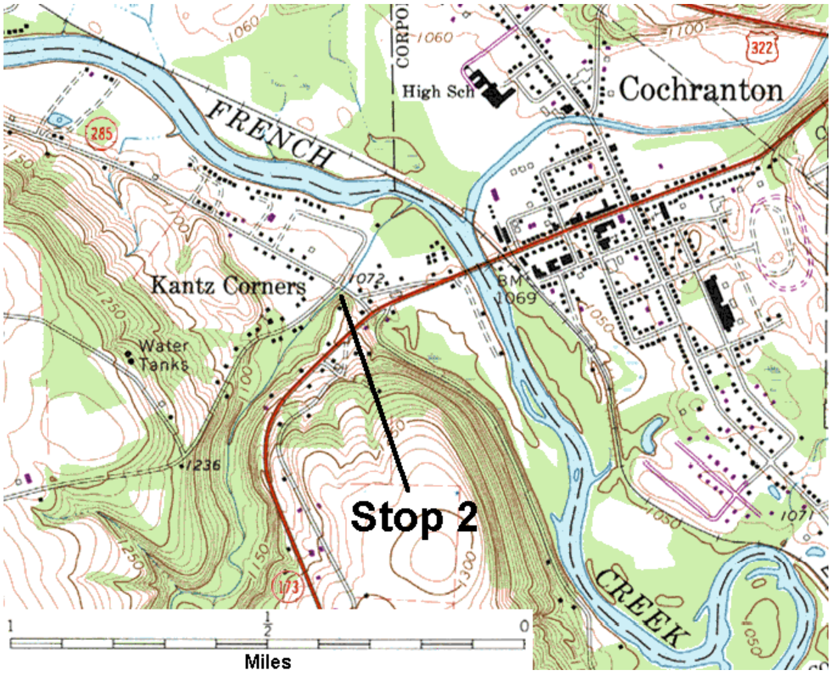


Figure 2-1. Location map for STOP 2.

This stream bank exposes glaciolacustrine sediments displaying a plethora of primary sedimentary structures. It became exposed during a flash flood in July, 2003. One of the residents of Steen Hill Road, paralleling the stream, Molly Eccles, is a former student of Dr. Charles Shultz at Slippery Rock University. She alerted Dr. Shultz to its existence. After examining the section, he notified me. Timing is everything.

This stream, known locally as Wymans Run, is a tributary to French Creek, which is about 360 meters downstream (Figure 2-1). Wymans Run has flooded a number of times in the last 15 years. The July, 2003 storm apparently increased the discharge sufficiently that the bridge on PA 285 could not handle the flow, and the road effectively acted as a dam. Most of the homes across Steen Hill Road were flooded. Limestone blocks up to a foot in diameter have moved as much as 60 meters downstream since it was emplaced here, presumably during storms associated with Hurricanes Ivan and Frances.

The owners, Marjorie and Harold Wise, Jr., live on top of the hill into which the stream has cut. They have graciously permitted the Field Conference to visit this exceptional exposure. Because continued erosion of the bank could eventually threaten their house, please do not dig into this outcrop. Generally, the sedimentary structures and other features are best seen on a slightly weathered surface. The surface of this section was scraped about a month ago, and allowed to weather.

To help prevent further erosion into the bank, PennDOT has placed the riprap that you see at the base of the cut, thereby reducing the exposure available to us by about half. Ms. Eccles, via Dr. Shultz, has provided us with some photos of the section prior to being PennDOTted (Figure 2-2). The pre-PennDOT photos were especially helpful in interpreting the events of the lower half of the bank as it is presently exposed.

General Geologic Setting

This exposure is within the French Creek valley. French Creek flows through the pre-glacial Middle Allegheny River valley. There were three pre-glacial Allegheny Rivers (Figure 2-3). Two of these three rivers (middle and upper) were dammed by advancing glaciers, forming lakes in their valleys. Glacial lake overflow eroded the divides between the separate basins, diverting the flow and connecting them together to form today's Allegheny River.

The Kent Moraine crosses the French Creek valley (Figure 2-4) about 10 kilometers to the southeast (Shepps and others, 1959). The Kent Moraine is thought to be a palimpsest moraine, created by the Titusville glaciation (Illinois Episode), and the Kent (Wisconsin Episode) sediments are simply draped over it (White and others, 1969). Indeed, there is a band of Kent Till mapped beyond the Kent Moraine in the

Figure 2-2. Southern end of the section prior to the emplacement of rip-rap. Four packages of in-phase (darker) over in-drift (lighter) climbing ripples below the unconformity are indicated. Currently, only packages 4, 3, and half of 2 are exposed. Photo courtesy of Molly Eccles

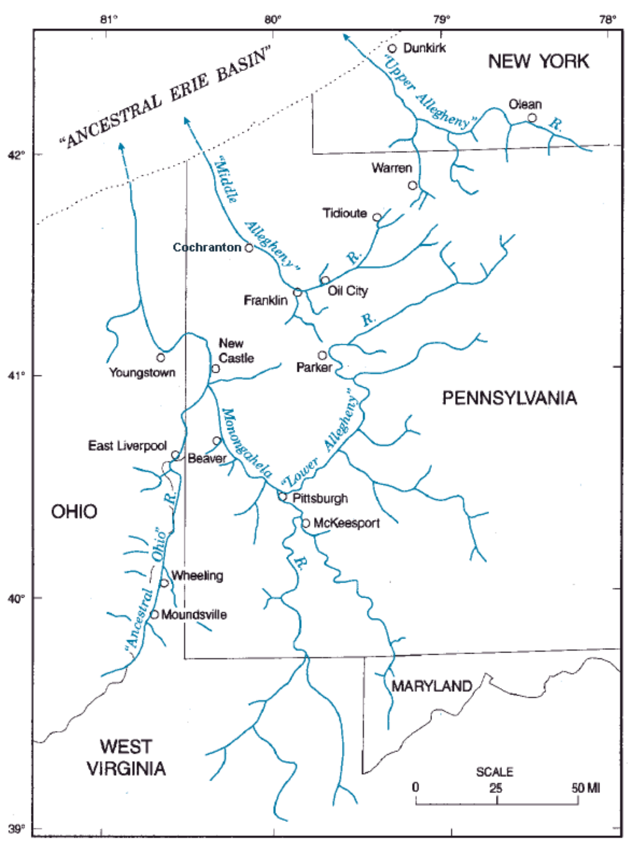


Figure 2-3. Pre-glacial drainage of western Pennsylvania, as determined from geologic mapping over the past 120 years. Notice that the Monongahela was the major stream in western Pennsylvania, there were three Allegheny rivers, and all of the streams drained northward toward Canada. Modified from Leverett (1934) and Wagner and others (1970).

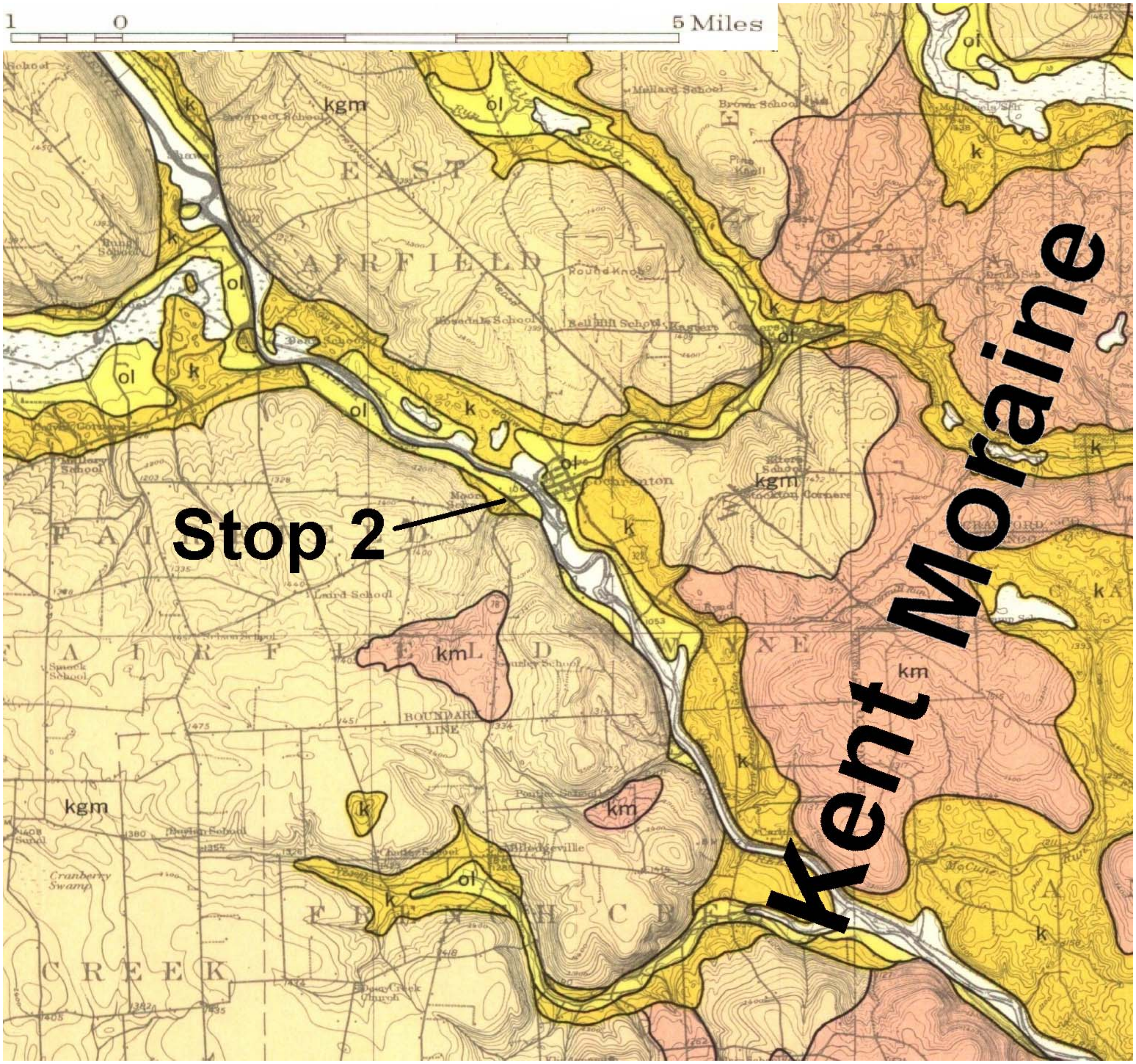
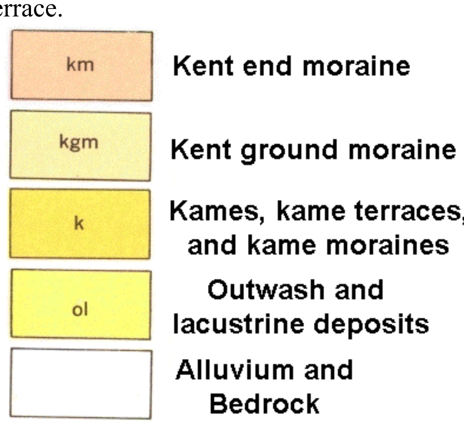


Figure 2-4. A portion of Plate 1 from Shepps and others (1959) showing the location of STOP 2 relative to the Kent Moraine. The location of STOP 2 is mapped as a kame terrace.



French Creek valley (Figure 2-4), and most of northwestern Pennsylvania (Shepps and others, 1959). STOP 2 is located in a kame terrace, as mapped by John Droste (Shepps and others 1959).

The term kame terrace, as used by Shepps and others (1959), includes almost all non-till sediments deposited along valley walls in northwestern Pennsylvania, and they do not necessarily have a terrace form. However, here at Cochranton, there is a terrace form on the southwest side of the creek. There are much more extensive kame terraces mapped on the northeast side of the French Creek valley, and there are a number of gravel pits opened in them. I have not had the opportunity to visit any of these gravel pits before the Field Conference.

Description

The section contains a variety of sedimentary structures. The initial impression is that these sediments are varves. Indeed, there is rhythmic sedimentation here, but varves require that the couplets be annual. This cannot be demonstrated here, and it probably can be demonstrated that at least some of the sedimentation is not annual, but resulted from discreet flow events in a relatively short period of time.

There are 2 sets of sediments, separated by an unconformity. Much of the section below the unconformity is now covered by PennDOT-emplaced rip-rap and slump material.

Lower set

Sediments below the unconformity are best exposed in the southern half of the exposure. One of the most common sedimentary structures here is climbing ripples, or ripple-drift lamination. Climbing ripples form by deposition from flowing water with a very high sediment content (McKee, 1965). Because of the high sediment content, there is much sediment deposition, and little, if any, erosion by the successive passage of ripples.

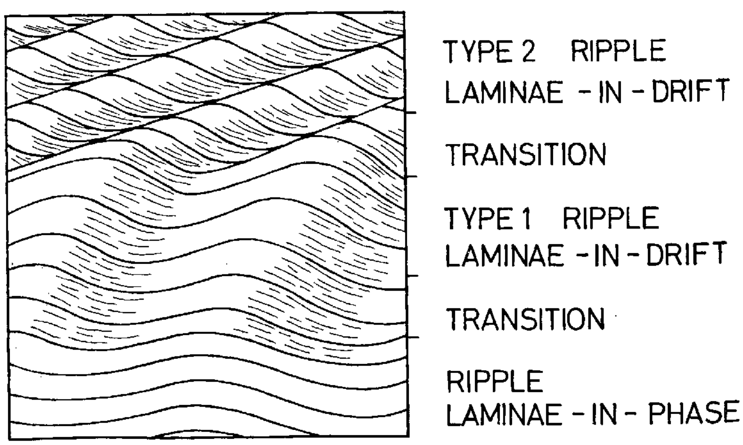


Figure 2-5. Sketch of the various types of climbing ripples. The variation is mainly in the preservation of stoss-side sediment, and results from changes in the suspended/bedload ratio (decreasing upward in the sketch). Modified from Jopling and Walker (1968) by Reineck and Singh (1980)

Climbing ripples form a continuum, with in-phase climbing ripples at one end and in-drift climbing ripples at the other end of the continuum. The laminations in in-phase climbing ripples form a sinusoidal wave, where the crest of each succeeding ripple is directly above the crest of the previous ripple. These are deposited under conditions of maximum sedimentation, including a very high component of suspended sediment. In the transition to in-drift climbing ripples, the crests of succeeding ripples are offset in the direction of flow relative to the crest of the previous ripple. In-drift climbing ripples form with a higher bedload component relative to in-phase climbing ripples. These ripples show stoss-side erosion and lee side deposition. The erosion on the stoss side of the preceding ripple might be partial (type 1 in Figure 2-5), or, at the end of the continuum, the stoss side might be completely eroded (type 2).

All types of climbing ripples are present in the lower set of sediments here. They alternate between in-phase ripples or parallel laminae, and in-drift climbing ripples. Currently, three sets of in-drift ripples alternate with three sets of in-phase ripples (Figures 2-6 and 2-7). Photographs of the section prior to the emplacement of the rip-rap (Figure 2-2) indicate that there are one more set of each, with a combined thickness similar to the six sets currently exposed. The thickness of the sets decreases upward.

A particularly fine set of in-drift climbing ripples, overlain by a set of in-phase ripples is exposed under the overhang separating the northern and southern halves of the section (Figure 2-8). The in-drift ripples indicate flow to the north (right to left). There is significant, but not complete stoss-side erosion.

The flow direction indicated by the ripples in the lower set is almost always to the north. One exception is the topmost set of in-drift climbing ripples. That set of ripples indicates flow in different directions in different places, but usually also to the north. I cannot determine from the pre-rip-rap photos the flow direction indicated by the in-drift ripples that are no longer exposed.

In the northern half of the section, there are a few beds of gravel just below the "peak" of the unconformity, with the maximum pebble size approximately 1 cm in diameter. None of the gravel beds extends laterally very far, either pinching out or being truncated by the unconformity. They are generally about 2 cm thick. No other gravel beds were noted. Adjacent to the gravel beds are some pebbles (up to 3 cm in diameter) "floating" in the silt and sand.

The uppermost beds, immediately beneath the unconformity contain clay beds across the entire length of the section. These clay beds are much finer grained than the fine-grained lamina elsewhere in the section. There are three continuous clay beds that thicken under the "peak" of the unconformity.

In contrast to the sediments above the unconformity, the lower set does not seem to contain any dropstones or convolute bedding. It also contains few faults. The largest fault in the section, a down-to-the-north normal fault, offsets beds in both sets of sediments, but no other faults were observed in the sediments below the unconformity.

The sediments below the unconformity most likely resulted from deposition in a lake. Given its location in the French Creek valley, and its relation to the upper set, it is most likely a glaciolacustrine deposit. However, flow into the lake appears to have been mostly from the landward shore into the lake. It is also not as clear as it is in the upper set as to whether the lake was an ice-contact lake, because there are no dropstones and no faults formed by the removal of supporting ice walls. It may have been ice-dammed from a distant glacier, moraine-dammed after the glacier retreated, or a slackwater lake caused by Wymans Run being dammed by outwash aggradation in the French Creek valley.

The alternating sets of in-phase and in-drift ripple laminae suggest alternating periods of relatively high and low flow. The in-drift ripples represent the high-flow periods when there was a greater amount of bedload, and the in-phase ripples (or parallel laminae) formed during the relatively low-flow periods of sedimentation, which probably had a greater component of suspended flow. I speculate that these paired sets of in-phase over in-drift ripples may be annual pairs. The uppermost in-phase ripples are overlain by clay beds at the unconformity, indicating waning sedimentation during the final phase of the lake's existence.

Other than the few, laterally non-continuous gravel beds just below the clay, there are no coarse-grained sediments below the unconformity. The gravel beds are poorly sorted and show no bedding or flow structures. Based on these criteria, I suspect that they were deposited by release from floating ice, similar to dropstones in the upper set, or as small mudflows into the lake. This would imply a rather shallow lake at this point to allow mixed sediment to be dropped in the lake and undergo only a small amount of sorting during its descent through the water.

Figure 2-6. Complete current exposure of the lower set of sediments. The unconformity is at the top of the dark clay beds at the top. Climbing ripple packages 4, 3, and part of 2 (from Figure 2-2), from the top, down, are exposed. Scale in cm (top of scale) and inches.

Figure 2-7. Details of the in-drift climbing ripples near the base of the southern part of the exposure. The photo shows the in-phase climbing ripples of package 2 (from Figure 2-2) overlain by in-drift ripples of package 3, and the base of the in-phase climbing ripples of package 3. Scale in cm (top of scale) and inches. Flow is right to left (south to north)

Figure 2-8. In-drift climbing ripples overlain by in-phase climbing ripples. This is the upper part of package 2 and lower part of package 3 of Figure 2-2. Scale is in cm.

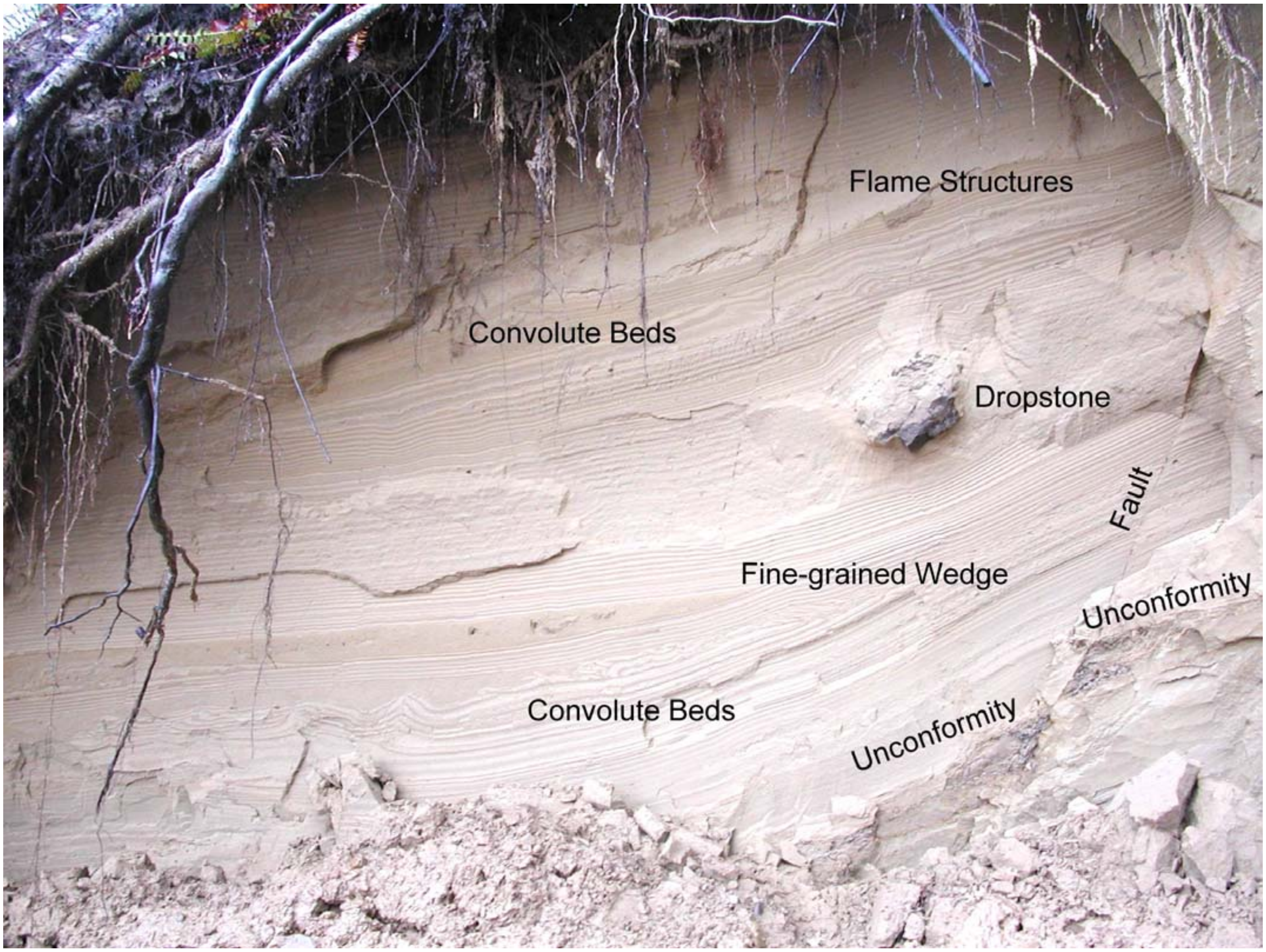


Figure 2-9. Photograph of the northern end of the section, with features discussed in the text labeled. Photo taken January 12, 2005. A failure and collapse of part of this face on March 30, 2005 removed the dropstone. The dropstone is 25 centimeters in diameter.

Upper set

In contrast to the fairly straightforward interpretation of the lower set, the upper set is quite complicated, and contains many more sedimentary structures, not all of which I understand.

Like we see in the lower set, there are repeating packages of in-phase over in-drift ripples, but the packages are more subtle. In addition to the various type of climbing ripples, you'll find flaser bedding, lenticular bedding (Figure 2-12), convolute bedding, and flame structures. In addition, some of the laminae in the upper set are more likely to be varves, although the annual nature of the couplets cannot be demonstrated. Most of the features of the upper set can be best observed in the northern half of the section (Figure 2-9).

Four packages of in-phase over in-drift climbing ripples are most apparent directly above the "peak" of the unconformity. They appear as packages of darker (in-phase) over lighter (in-drift) sediments. However, these packages have considerably more variation laterally than the packages of the lower set. The in-drift ripples change laterally to flaser beds locally, or become in-phase laterally.

Upward from the "peak" in the unconformity, we pass through a sequence of fine sands draped over the unconformity. Above that are rippled fine sand eroded into the underlying draped sands, flaser beds (within the in-drift sediments of package 2), in-phase climbing ripples (of package 2), and in-drift climbing ripples of package 3 (Figure 2-13). The section above that is somewhat inaccessible. Flow direction is mostly to the south, from the center of the valley toward the margin- opposite that of the lower set. The flaser beds appear to result from increased erosion on the stoss side and tops of the ripples, leaving the fine-grained sediment in the trough.

Laterally from the "peak" of the unconformity, the sedimentary structures die out, and north from the large fault, the sediments appear as though they could be varves. The sequences of various types of ripple laminations do not appear here, but the four sediment packages still retain their identity by alternating zones with many dark laminae with zones with few dark laminae. Some light and dark couplets, except where disrupted by penecontemporaneous deformation (convolute bedding and flame structures), have sharp bases and grade upward into finer grained material. Other couplets have sharp upper and lower boundaries to both fine and coarse layers. There are no directional flow structures, and they appear to result from deposition of suspended sediment.

The laminae are not, however, without complication. They are interrupted by several convolute beds, and by several wedge-shaped beds of finer-grained sediment that pinch out to the south.

One of the wedge-shaped beds is relatively undeformed by soft-sediment deformation. It does not show any evidence of erosion (channel fill). The thin laminae immediately above and below the wedge bed continue to the south beyond the feather-edge pinchout of the finer-grained bed (Figure 2-14). Toward the north, the light and dark lamina immediately beneath the wedge bed, thicken, apparently by becoming convolute, and are incorporated into the wedge bed (Figure 2-15). The bed appears to have been rapidly deposited, but with no erosion of the substrate.

Two other thick, originally wedge-shaped beds, one near the base of the section, and one near the top, are deformed by penecontemporaneous deformation, as are a number of other beds. The lower bed is convolute, with folds and brecciation/faulting suggesting downslope movement to the north (Figure 2-15). The upper wedge-shaped bed contains flame structures (Figure 2-16), suggesting that the overlying sand/silt bed foundered into the saturated silt/clay bed during deposition, forcing the water upward, dragging the silt/clay along with it. Flame structures are thought to be formed by turbidite flows, where the sand is deposited while still moving. The sand founders into the underlying mud, and because it is still moving, causes a drag effect on the underlying mud, distorting the mud that moves upwards between the load casts (Conybeare and Crook, 1968).

The most obvious features to be seen at a glance are a down-to-the-north normal fault that offsets sediments both above and below the unconformity, and large dropstones (Figure 2-9).

The fault is a high-angle normal fault. The timing is after deposition of the sediments above the unconformity, but also affects the sediments below it. The apparent offset is about 17 centimeters (Figure 2-9).

There are numerous other faults, all except two (see next paragraph) of which are also down-to-the-north normal faults. Some are single discreet fault planes, while others have fault zones (Figure 2-10). Most have apparent offsets of less than a centimeter.

The exposed portion of a textbook-quality dropstone (Figure 2-11) was about 25 centimeters in diameter. This stone fell from the outcrop as part of a failure on March 30, 2005. During deposition of the dropstone, the laminae beneath it were deformed from the weight of the stone as it was dropped to the bottom of the lake. The impact also formed two small down-to-the-south normal faults beneath two protrusions at the bottom of the stone. Sediment deposited subsequent to the emplacement of the dropstone was draped over it. Other dropstones, exposed as a result of the March 30 collapse of the face, display some similar features. All of the large dropstones are within the in-drift portion of package 3. The dropstones were transported in icebergs calved from the glacier, and dropped into the lake when the icebergs melted sufficiently.

The sediments above the unconformity also were likely deposited in a glaciolacustrine environment. However, the presence of the down-to-the-north faults in this set suggest that they were deposited in contact with ice. When the supporting ice in the center of the French Creek valley melted, the subsequent slumping created the faults. The presence of dropstones also suggests proximity to ice, as does the predominant flow direction indicators of flow from the French Creek valley center. The lake in which this set of sediments was deposited may have been formed by the glacier damming French Creek, or a mass of dead ice that remained in the center of the French Creek valley blocking Wymans Run. It was probably not a moraine-dammed lake, because the evidence suggests close proximity to ice.

The mode of deposition of both sets appears to be mainly by numerous small density flows into the lakes. The flows had high sediment contents that created the climbing ripples. Where the sediments appear to be varves, there is still evidence of flow in flame structures and lateral change to climbing ripples.

Questions

1. Does the unconformity represent an period of subaerial erosion?
2. What is the origin of the gravel beds/lenses in the lower set of sediments?
3. In what type of lakes (ice contact, moraine dammed, etc.) were these sediments deposited?
4. What is the periodicity of the light and dark couplets if not annual, which they appear to not be where there are climbing ripples?
5. How does this sequence fit in the glacial history of the area? What other evidence do we need to find to make that determination?

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Figure 2-10. Fault zone offsetting sediments above the unconformity about a centimeter. End of pocket knife for scale.

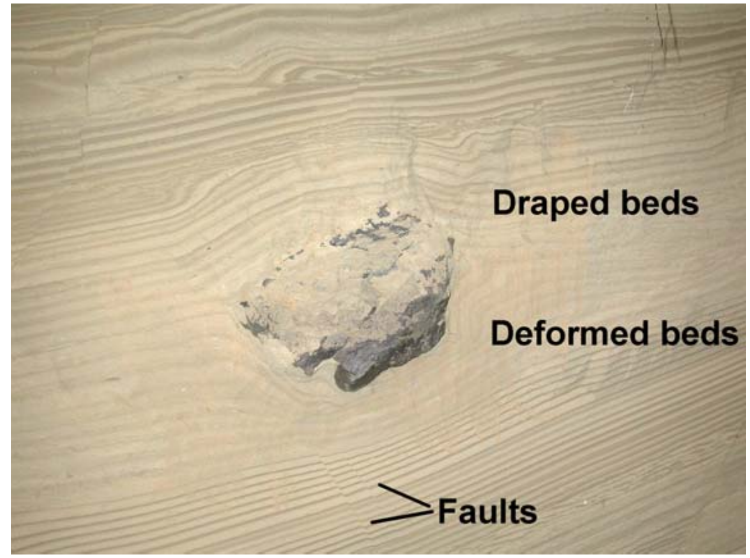

Figure 2-11. Dropstone with deformed sub-stone sediments, faults, and draped sediments over the stone. Dropstone is about 25 cm in diameter.

Figure 2-12. Lenticular bed (just above knife) extends across the southern half of the section, suggesting erosion of most of a sand bed before subsequent deposition.

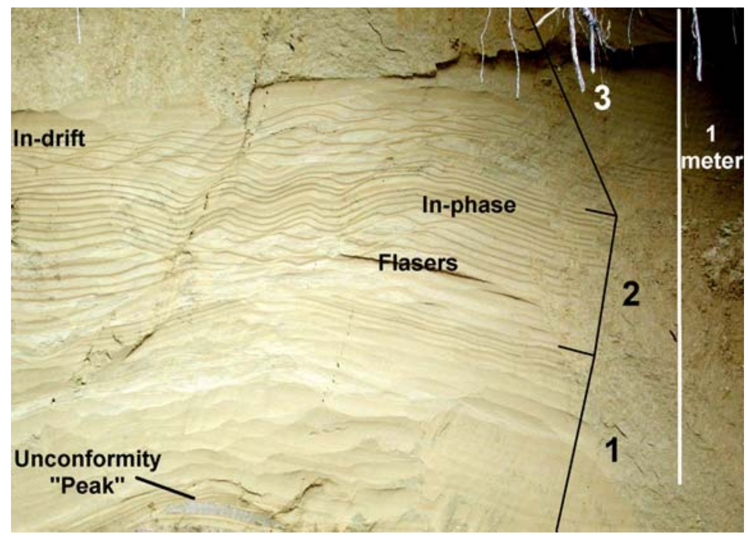

Figure 2-13. Sequence of fine sands draped over the unconformity. Above that are rippled fine sand eroded into the underlying draped sands, flaser beds, in-phase climbing ripples, and in-drift climbing ripples. Three of the four packages of in-phase over in-drift climbing ripples are labeled.

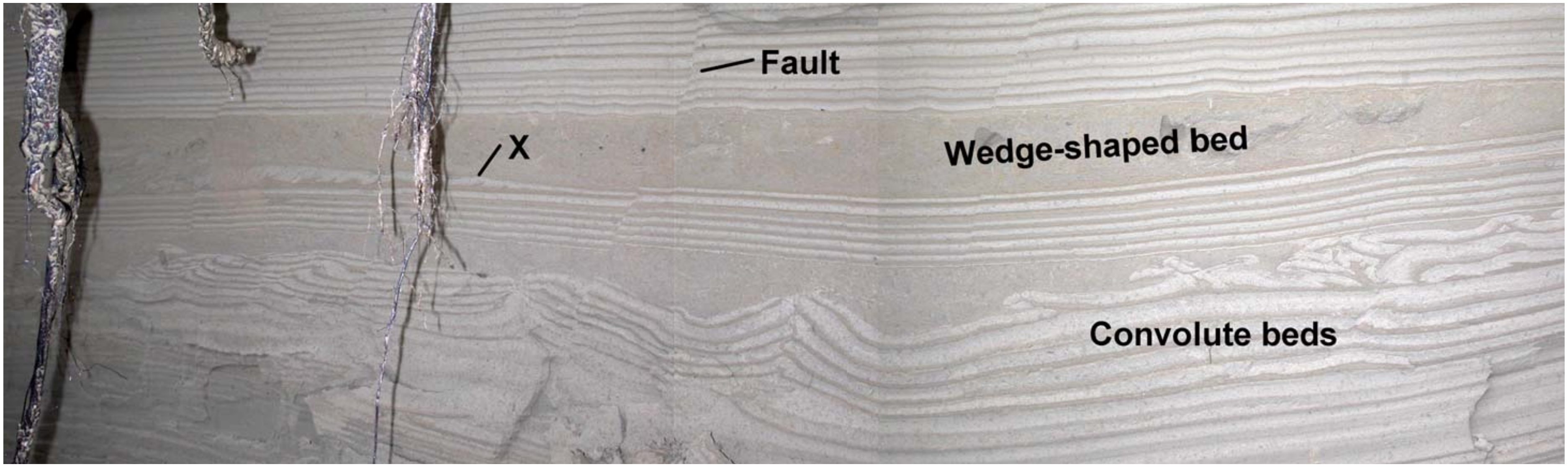

Figure 2-15. Composite photograph of some of the convolute beds, and one of the wedge-shaped, fine-grained beds. Light and dark lamina immediately beneath the wedge bed, thicken, apparently by becoming convolute (at "X"), and are incorporated into the wedge bed to the left side of the photo. Convolute beds show folds suggesting slumping downslope from right to left., distorting the lower wedge-shaped bed (just above convolute beds- not labeled).

Figure 2-14. Pinchout of wedge-shaped, fine-grained bed. The light lamina beneath the bed, and the extremely thin light lamina above the bed continue without disruption beyond the end of the wedge. Couplets are each about 1 cm thick.

Figure 2-16. Flame structure. The overlying fine sand bed was still moving as it foundered into the underlying mud bed, causing the water to be expelled and deforming the mud bed. Pocket knife for scale.

STOP 3. PYMATUNING RESERVOIR AND STATE PARK

Leader- Linda Armstrong

The Pymatuning area was the home to a number of Indian tribes beginning with the Monongohela, Eriez and the Lenni Lenape (Delaware). All these tribes used the swamp for hunting purposes. Early pioneers began filtering into the area in 1796 after the Treaty of Greenville (Ohio) with the Indians. The word Pymatuning is derived from the Delaware and means Crooked-mouthed Man's Dwelling Place referring to the facial disfigurement of one of the Delaware chiefs.

Settlers at the north end of the swamp attempted to drain the soil to create agriculturally productive land. It was found that the black muck was great for growing onions. By 1915, half of Pennsylvania's onions came from Linesville.

Ten severe floods between 1806 and 1904 in the Shenango Valley south of the reservoir and several years of severe drought intensified campaigns to promote the construction of a dam. It was a series of starts and stops over the next 20 years before the actual construction of the reservoir began.

Ground was broken on October 6, 1931 and 7,000 men were employed to clear the 16,000 acres of swamp that are now covered by water. There were three main construction projects – the dam itself, the Espyville-Andover Highway and the Linesville railroad and highway project. This last project separated the upper reservoir from the lower reservoir. The spillway dam impounds the water of the 2,500-acre upper reservoir or wildlife refuge to an average depth of five feet.

The dam structure is a rolled earth embankment 2,400 feet long and has a maximum height of 50 feet. The core of the dam is made of fine-grained clay, in the center of which is a row of interlocking steel piling. The upstream side is paved with sandstone varying in thickness from eighteen to thirty-six inches.

The project was completed in 1933 at a cost of $3,717,739.00. Pymatuning was dedicated as a park in 1937 and was managed by the Water and Power Resources Board until 1971, when the Department of Forests and Waters was reorganized into the Department of Environmental Resources. At that time, Pymatuning was placed under the Bureau of State Parks, becoming the largest state park in Pennsylvania.

The reservoir has a capacity of 64,275,000,000 gallons of water. The lake is 17,088 acres in size and 17 miles long. Its average width is 1.6 miles with 70 miles of shoreline. The maximum depth is 35 feet. The total park acreage in Pennsylvania and Ohio is 31,122.0 acres.

During WWII, Westinghouse Corporation in Sharon was asked to develop a wake less, or electric torpedo which was tested (minus the warhead) at the Westinghouse Bay on the west side of the Reservoir.

As recently as the 1970s, there was only one known eagle nest in Pennsylvania, here at Pymatuning. During 2002, the Pennsylvania Game Commission reported 63 nesting pairs of eagles in the state, an increase of more than 150 percent in five years. Today, Pymatuning supports the largest concentrations of nesting bald eagles in the state

If you have any questions concerning the park and it's history, please contact the park office at 724/932-3142. We will be happy to answer any inquires. If you are in the area, please stop to see us at the park office, which is open Monday through Friday 8 am to 4 pm.

STOP 4- PYMATUNING LAKE BLUFF AND STREAM CUT

Leader- Gary M. Fleeger

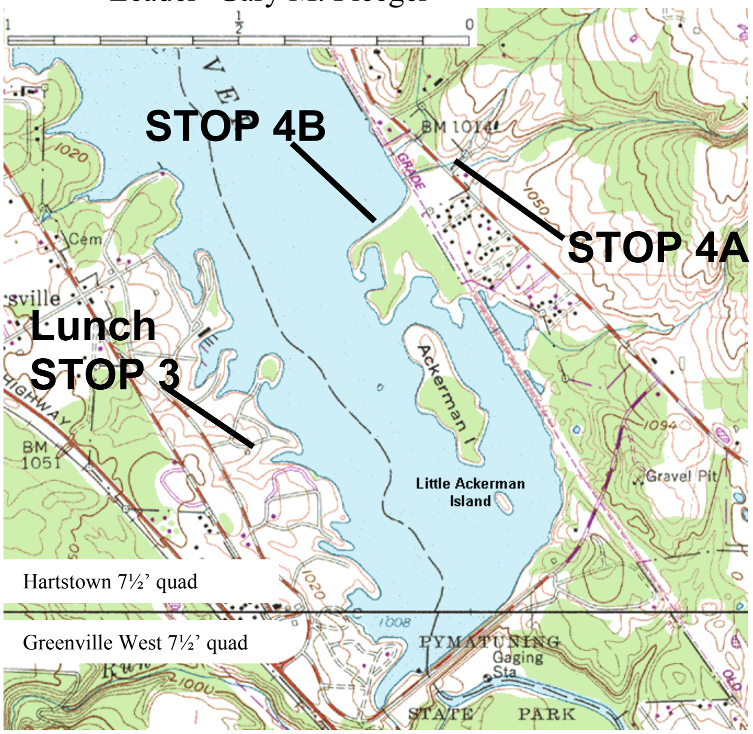

Figure 4-1. Location of STOPS 4A and 4B, Ackerman Island, and lunch stop. From the Hartstown and Greenville West 7½' topographic maps.

STOP 4A will be a brief stop to look at an exposure Titusville Till, and to illustrate the concept of depth of oxidation. STOP 4B will occupy most of our time here.

STOP 4A (Figure 4-1) is an eroded streambank. When I first visited this location about 15 years ago, the bank was quite clean and the sediments well exposed. Over the years, slumping of material covered the sediments, and by 1998, nothing was visible. In the fall of 2004, while working at STOP 4B, I decided to re-examine this stream cut, thinking that the late-summer storms associated with Hurricanes Ivan and Frances might have re-eroded the bank. Indeed the streambank is again clear for examination by the Field Conference. Again, timing is everything!

The till in this stream cut is interpreted as Titusville Till overlain by colluvium. The Titusville Till is identified based on its oxidized (olive brown) and unoxidized (olive gray) color, sandy matrix, and compactness. There may be Kent Till in the upper part of the section, but it is difficult to determine. The Kent Till is typically much less compact than the Titusville Till, but distinguishing Kent Till from Titusville Till is difficult where weathering extends through thin Kent Till into the Titusville Till.

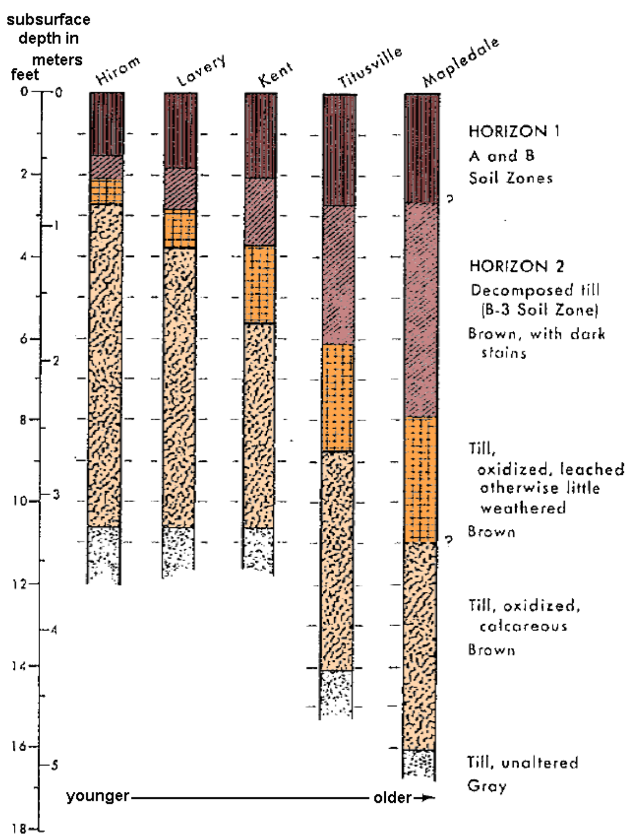

Figure 4-2. Average depths of various weathering horizons developed on till in the Grand River lobe (modified from White, 1969).

The original color of till in northwestern Pennsylvania is usually a shade of gray, a reflection of the bedrock over which the glaciers flowed. After deposition, weathering of the unaltered material begins. Oxidation of iron minerals within the till cause its color to change from the original gray to a yellow, brown, or red. During oxidation, clay minerals are altered. Near-surface, carbonate minerals are leached from the matrix by percolating water. Each till unit has a characteristic range of depths of oxidation and depths of leaching, which are summarized in Figure 4-2.

In this stream cut, the depth of oxidation is clearly seen at a depth of about 13½ feet, within the Titusville Till (Figure 4-3). This is fairly close to the average for the Titusville Till in the Grand River lobe. The important point to be illustrated here is that the typical depth of oxidation, even for Illinois Episode tills in this area, generally does not exceed 15 feet. This will be contrasted with the depth of oxidation we will see at

Figure 4-3. Change in till color in stream cut at STOP 4A indicating the depth of oxidation. The section is about 16 feet high.

STOP 4B, in Wisconsin Episode tills. Also note the coarseness of the till here compared to what we will see at STOP 4B.

STOP 4B (Figure 4-1 and 4-4) is an excellent exposure of glacial sediments that is kept relatively clean by wave erosion undercutting the bluff. The Field Conference is a little later than usual this year simply because there was less chance of the water level being lowered sufficiently earlier in the month. The park manager agreed to lower the lake level earlier than usual this year, if possible, for the convenience of the Field Conference.

Pymatuning Reservoir was created in 1934 by damming the Shenango River, but the first mention that I have seen of the existence of this bluff is in November, 1959. Vincent C. Shepps' 1955 thesis and 1952 field notes do not mention this bluff, even though he does describe a nearby road cut. His 1959 GSA field trip stop is the same road cut he described in 1952, but his hand-written marginal notes in his personal copy of the guidebook indicate that they visited this bluff, rather than the road cut. He may have also visited this bluff in May, 1959 with the Field Conference.

Figure 4-4. Photo of the lake bluff- STOP 4B. Note the gravel channel fill (darker) near the base of the section.

The drift filling the Shenango River valley is about 200 feet thick here (Schiner and Kimmel, 1976). The oldest glacial material that I have seen along the margins of the valley is the Titusville Till (Illinois Episode), exposed in the streamcut at STOP 4A. The orientation of two segments of the Shenango River (now the eastern and western arms of Pymatuning Reservoir) suggests that pre-glacial drainage was to the northwest. However, the deep partially-buried valley of the Shenango River does not continue to the northwest, but follows only the current valley (Schiner and Gallaher, 1979). This suggests that any diversion of the Shenango River from the northwest to its present course was probably due to erosion during early to middle Pleistocene glaciations or pre-glacial.

Previous Interpretations

The history of stratigraphic interpretation here starts with Shepps' Ph.D. thesis work in the early 1950s. There is considerable confusion in conflicting reports, changing interpretations, etc. of Shepps' (1955) interpretation that a lobe of Hiram ice had extended down the valley of the Shenango River at Pymatuning Reservoir. Remapping of the area by White and others (1969) and of adjacent northeastern Ohio by White (1982), and the reinterpretation of the extent of the Lavery Till by White and others (1969) greatly confused the interpretation of the glacial history of the Pymatuning Reservoir area.

Figure 4-5. Shepps and others' (1959) interpretation of lobes of Hiram Till around Pymatuning Reservoir and Conneaut Lake in Pennsylvania. Modified from Shepps and others (1959)
Key to Figures 4-5 and 4-6:
Kent Till. Lavery Till, **Lavery end moraine**, Hiram ground moraine, Defiance (Hiram) end Moraine.

The original work done by Shepps in the early 1950's resulted in the interpretation of a Hiram ice lobe extending down both the Shenango River (Pymatuning Reservoir) valley and Conneaut Creek valley to Conneaut Lake (Shepps and others, 1959). In addition, Shepps thought that there might be some Hiram deposits in the Pymatuning Creek valley in Mercer County (now Shenango River Reservoir), and also down the valley now containing the eastern arm of Pymatuning Reservoir. He did not determine whether the deposits were due to other Hiram lobes in those valleys or part of a more widespread glaciation, but speculated on both possibilities (Shepps, 1955). In all of these areas, Shepps mapped Kent Till as the surface till except where covered by Hiram or Lavery Tills in the valleys. In summary of Shepps' early work, he interpreted that the deposits around the western arm of Pymatuning Reservoir and Conneaut Lake (Figure 4-5), and possibly the eastern arm of Pymatuning Reservoir and the Pymatuning Creek valley were most likely all the result of lobes of Hiram ice extending ahead of the main glacier down the valleys.

Detailed work on the stratigraphy of northwestern Pennsylvania by White, Totten, and Gross (1969) resulted in a generalized remapping of northwestern Pennsylvania. The remapping was not intended to be part of the project to define the Pleistocene stratigraphy, but was forced upon the authors by the recognition of new stratigraphic units and new interpretations of known units. As a result, the 1969 map may not be completely accurate (Totten, personal communication, 1986). The new interpretation of the Lavery Till was that an area of thin, discontinuous till extended up to 10 miles beyond the Lavery Till border mapped by Shepps. This extension included the areas interpreted by Shepps as lobes of Hiram Till around both arms of Pymatuning Reservoir and Conneaut Lake, and the area interpreted as possible Hiram Till by Shepps in the Pymatuning Creek (now Shenango River Reservoir) valley. White, Totten, and Gross (1969) specifically interpreted the fine-grained till near Shenango River Reservoir as part of the extended Lavery deposits. Their text did not address whether or not the Pymatuning Reservoir and Conneaut Lake deposits are considered to be Hiram lobe deposits or re-interpreted as part of the extended Lavery deposits. However, the new

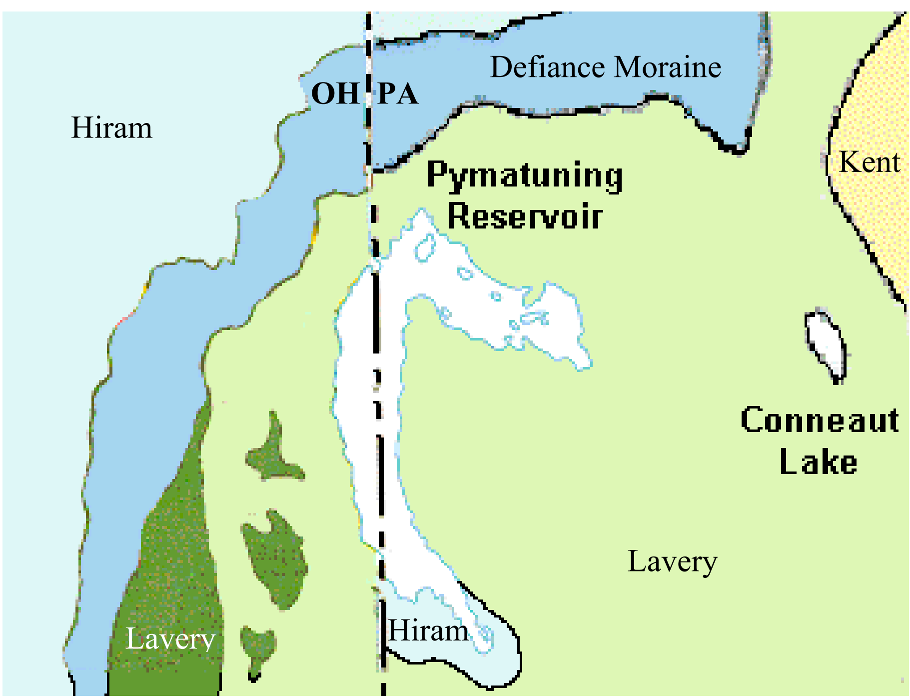

Figure 4-6. One of White and others' (1969) [in PA] and White's (1982) [in OH] interpretations of Hiram Till around Pymatuning Reservoir in Pennsylvania, but not in Ohio, creating a border fault at the state line. The lobe around Conneaut Lake had also been removed. Note that the Lavery Till extends beyond the Lavery end moraine. Modified from White and others (1969) and Pavey and others, 1999.

generalized map (their Figure 2, Figure 3, page 4, this guidebook) still showed the Hiram Till around the western arm of Pymatuning Reservoir, but no longer showed it around Conneaut Lake. This area was now shown on the map as thin, discontinuous Lavery Till. To further confuse things, White, Totten, and Gross' (1969) Figure 1, a general map of the southern part of the Erie Lobe (Figure 2, page 3, this guidebook), shows a Hiram Till lobe around Conneaut Lake, but not Pymatuning. In summary of the 1969 study, it appears that the interpretation may have changed to be deposits of a Hiram lobe around Pymatuning Reservoir, and thin, discontinuous, extended Lavery Till around Conneaut Lake and Shenango River Reservoir (Figure 4-6).

In 1982, White published a comprehensive report on his 50 years of investigation of the glacial deposits of northeastern Ohio. In that report and map, he gave no indication that a lobe of Hiram ice extended from Ohio into Pennsylvania around Pymatuning Reservoir (Figure 4-6), contradicting one of his earlier works (White and others, 1969), and agreeing with another (White, 1969), as well as contradicting Shepps' (1952) earlier work. A border "fault" was created with the publication of this map- Hiram Till on the Pennsylvania side of the border, and Lavery Till on the Ohio side. Totten (personal communication, 1986) indicated that no evidence of Hiram Till was seen in the valley in Ohio, but also stated that such Hiram lobes are common in other valleys in Ohio and Pennsylvania. The Ohio and Pennsylvania reports are in agreement around Shenango River Reservoir. No Hiram Till is mapped. It is interpreted to be Lavery Till at the surface in both states.

The topics to discuss at this stop are:

1. The glacial stratigraphy and geomorphology
2. The method of deposition of the sediment
3. The bluff erosion problem

<u>Stratigraphy</u>

The till exposed in this section is obviously very different from that exposed in the stream cut (STOP 4A). The Kent and/or Titusville Till have a much sandier matrix, and considerably more cobbles and pebbles than the till here in the lake bluff. The difference is sufficient that the tills can easily be distinguished in the field.

The bluff is over 20 feet high, which approaches the maximum thickness ever reported for either the Hiram or Lavery Till, which both have a median thickness of 4 feet (White, 1971). Almost never is a Woodfordian till sheet greater than 15 feet thick (White, 1971). The entire 20± feet of till in this bluff is oxidized. This is an excessive amount of oxidation for any of the tills in this area (Figure 4-2). Visits to the bluff at various times over the last 15 years resulted in the observation of different characteristics because of changes that occur as erosion proceeds. In 1998, with the lake at its low winter level, I was able to more easily examine the exposure near the base. A distinct, apparent contact between massive till above, and sorted sediment below was made more obvious by the discharge of groundwater below the contact. However, as I examined the exposure, it became obvious that the apparent contact was not a contact between the deposits of two separate glacial advances because the sorted sediment was in discontinuous masses, and the same till occurred above and below, connected between separate masses of sorted sediment (see Figure 4-11). This will be further discussed under "Deposition" of the glacial sediment.

Laboratory analysis, by John Szabo of the University of Akron, of samples that I collected in 1999 is summarized in Figure 4-7. I sampled starting just below the depth of leaching (4' 1"- within the measured amounts of leaching for both the Lavery and Hiram Tills in the Grand River lobe [White, 1982]), and proceeded downward every 3 feet. These mineralogical variations are subtle, but suggest a possible break between samples 2 and 3, between 7 and 10 feet below the top of the section. The main suggestion of a break is the change in the matrix carbonate content and the DI (diffraction intensity) ratio.

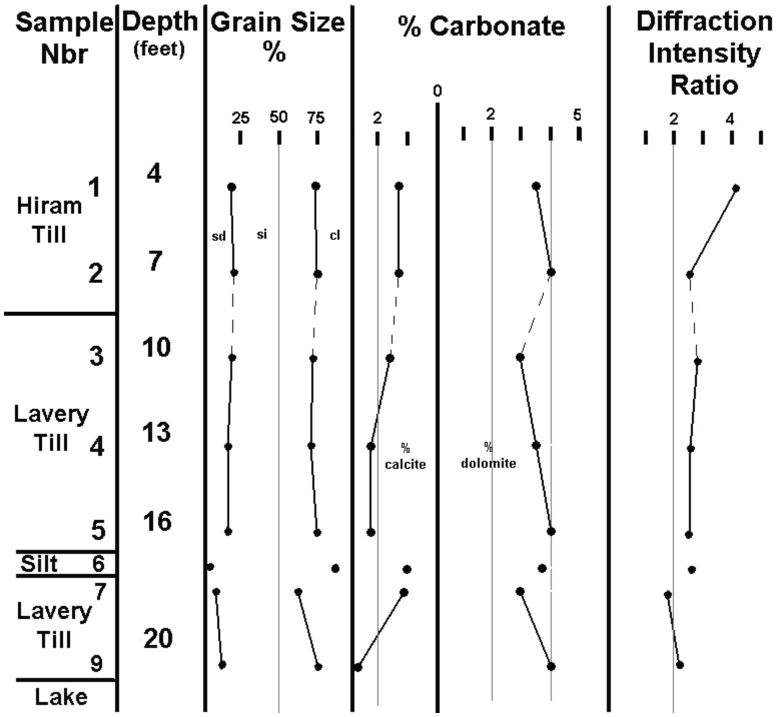

Figure 4-7. Texture and composition of till matrix samples. For grain size, the interval between the left edge of the column and the 1st line is the % sand. The interval between the 2 lines is the % silt. The interval between the line on the right and the right edge of the column is the % clay. The 2 lines in the % Carbonate column represent the % calcite (to the left of the 0% line) and % dolomite (to the right of the 0% line), and the interval between the lines indicates the total % carbonate.

In a weathering sequence of a single till, the carbonate content of the till matrix is expected to decrease upward, as the carbonates in the shallower levels are dissolved by infiltrating water. The carbonate content of the samples increases upward from 4.6% to 5.3% from sample 3 to 2. The reversal of the expected carbonate sequence suggests a period of exposure and weathering at the top of a till (sample 3), prior to being buried by the deposition of another till (sample 2).

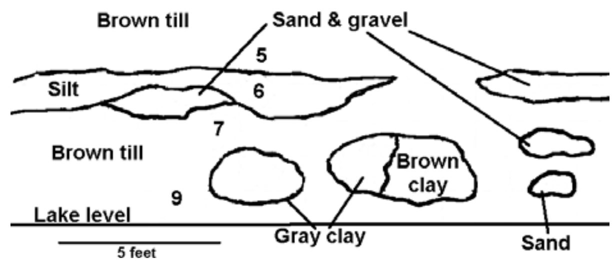

Figure 4-8. Location of samples in Figure 4-7, near the base of the bluff, as exposed on November 20, 1998.

The DI ratio is the ratio of the diffraction intensity (in counts per second) of illite to that of kaolinite plus chlorite, as determined from the X-ray diffraction of the clay minerals in the till matrix (Willman and others, 1966). Weathering of till results in an alteration of chlorite to vermiculite, and ultimately, montmorillonite. This results in an upward increase in the DI ratio (as the amount of chlorite decreases), which reflects an increasing amount of weathering upward in the weathering profile. The data here suggest more weathering in sample 3 (DI = 2.8), than in the overlying sample 2 (DI = 2.5). This upward decrease is the only deviation from the expected pattern of upward increase in DI ratio within the massive till. This further suggests that the lower till may have been exposed to weathering for a short time before the deposition of the overlying till. The carbonate and clay mineral pattern reversals coincide and are well above the apparent contact marked by the top of the sorted sediment.

The till beneath the silt (samples 7 and 9) and the till above the silt (sample 5) are physically connected, between the silt and sand lenses (Figures 4-8 and 4-11). Are samples 7 and 9 a third till or a continuation of the second till (of sample 5)? The texture and mineralogy of sample 7 are different than that of sample 5. Sample 7 is finer grained, but this could be caused by incorporation of underlying lacustrine sediments, masses of which can be seen incorporated into the till near the base of the bluff (Figure 4-8). The carbonate content of sample 7 is less than that of sample 5. Is this indicative of weathering at an exposed surface, or is it partial leaching due to groundwater movement in the adjacent silt? The clay mineralogy of sample 7 does not suggest any increased weathering relative to sample 5, and clay mineralogy is usually the most sensitive indicator of weathering (Willman, Glass, and Frye, 1966).

I have tentatively interpreted the tills in the lake bluff as Hiram Till over Lavery Till, with the contact between the two tills between samples 2 and 3. The physical properties of the two tills are very similar, according to published descriptions (Shepps, 1955; Shepps and others, 1959; White and others, 1969; White, 1982). The Hiram Till is finer grained and lighter in color when oxidized. There is no obvious color difference here, but Shepps' (1955) description of the tills in the immediate area suggests that there is little color difference. In other areas, the Lavery Till is described as being chocolate brown and the Hiram Till yellowish brown (White, 1982). Shepps (1955) described both tills as yellowish brown in this area. Both are described as sparingly pebbly, but the Hiram Till has fewer pebbles. Where superimposed, they can sometimes be distinguished by the amount of pebbles on a weathered surface (White, 1982). The Hiram Till often appears to be a lacustrine deposit until observed in greater detail (White, 1982). There is insufficient evidence to determine that a third till is present at the base of the bluff. Stratigraphically, the next older till would be the Kent Till, which is much sandier than the till at the base of the bluff. I interpret the Lavery Till to continue to the base of the bluff.

Preliminary interpretations based on the analysis of the samples suggests that Shepps (1955) was correct in his interpretation of Hiram Till in the Shenango River valley. It appears that the area was glaciated by the Titusville, Kent (STOP 4B), and Lavery glaciers before the Hiram glacier extended down the valley. Was the Hiram Till deposited by a lobe of glacier ice advancing down the Shenango River valley, as Shepps (1955) interpreted, or was ice more widespread, similar to the Lavery advance? These questions will require a more regional study to resolve.

Geomorphology

On this peninsula, behind the eroding bluff, is an area containing several closed depressions (Figure 4-9) typical of morainic development, one of which forms a large lagoon. In addition, there are two islands (Ackerman Island and Little Ackerman Island) aligned with this peninsula containing the bluff between here and the reservoir dam, about ¾ mile to the southeast (Figure 4-1). Ackerman Island also has closed depressions. Could these be the remnants of a moraine developed along the margin of a glacier lobe extending down the valley? If this is a moraine, is it a Hiram or Lavery moraine. The bulk of the sediment in the bluff is Lavery drift, not Hiram. It would appear that it is a Lavery moraine with thin Hiram Till draped over it.

Figure 4-9. Closed depression on peninsula behind lake bluff.

Sedimentology

In recent years, the theory that homogeneous tills covering large areas were created and deposited by pervasive shear in subglacial sediments, rather than the lodgement and ablation processes to which it has been attributed in the past, has received more credibility. Although the idea can be traced back to the 1960s (MacClintock and Dreimanis. 1964), it has gained favor as a model of till formation and deposition in recent years (Alley, 1991; numerous other references listed in Johnson and Hansel, 1999).

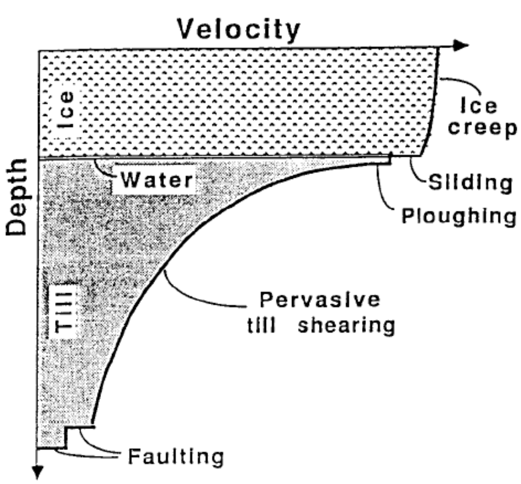

Figure 4-10. Possible mechanisms of ice velocity in a fast-moving, wet-based glacier on unconsolidated sediment. From Alley (1991).

Description of the Deforming Bed Model- In the deforming-bed model, pervasive deformation will occur up to depths of 10 meters under glaciers with high ice velocities and low basal shear stresses, overriding a thawed bed with high, saturated porosity and high basal water pressures. Subglacial deformation is responsible for most of the ice velocity (Figure 4-10). The subglacial water pressure is relatively low near subglacial channels. Near these subglacial channels, sediment transport is by water transport and by sediment creep into the channels (Alley, 1991). Clast-clast, and clast bed abrasion creates the matrix in which the clasts float. Subglacial debris may also be added to the mix. The mixing of the sediment results in a homogeneous deposit. Deposition of deformation till may result from the transport and accumulation of sediment within the deforming layer, or it may downcut into undeformed sediment, increasing the thickness of the deforming layer (Bennett and Glasser, 1996). We will see a possible example of the latter situation at STOP 5.

In the lodgement model, friction between the base of the glacier and the substrate (Bennett and Glasser, 1996) causes deposition by the plastering of sediment, particle-by-particle from the base of the glacier onto the underlying substrate. I find it more difficult to envision the homogeneity found in till sheets being attributed to this process.

Deforming beds have been observed in a variety of small and large glaciers (Alley, personal communication, 2000). From Richard Alley (personal communication, 2000)

> The first demonstration of subglacial deformation was Engelhardt et al, 1978 Journal of Glaciology (although Boulton was arguing for it by 1974 based on inference from glacial deposits). The 1978 work was looking at the Bed of Blue Glacier with a borehole camera lowered down holes melted with hot water. The next one, much more convincing and interesting, was the Boulton work in 1979 in Journal of Glaciology, with clear demonstration of pervasive deformation beneath marginal regions of Breidamerkurjokull. The key thing for Boulton was that the deforming bed, after ice retreat left a subaerial till sheet, was a "lodgment till"--it had all the look of the till sheets of the Lake Erie basin or of Wedron [classic exposure in the Wedron Quarry in northeastern Illinois]. It was really the first demonstration of the origin of a homogeneous "ground moraine" or "lodgment till", and it immediately showed either that such deposits are polygenetic, or that all such deposits are the result of deforming beds! Since then, observations beneath Columbia Glacier, Black Rapids Glacier, Trapridge Glacier, Storglaciaren, Ice Stream B, and Ice Stream D have found deforming tills, and to the best of my knowledge, there are no observations of rigid subglacial tills. The data are still quite sparse, but I believe we can now argue that deforming beds should be the default hypothesis, and the old ideas of "lodgment tills" must be demonstrated or discarded.
>
> Our work moved the deforming tills from small glaciers to big ones (Antarctica). The genius was Blankenship and Rooney, who did the seismic work demonstrating that ice stream B in West Antarctica rests on meters of a water-saturated, poorly consolidated material. I suggested deformation, and then worked out a lot of possible implications that seemed to fit the setting in West Antarctica. Observations since then have shown that we overdid it a little, but got a lot of things correct, and that Blankenship was virtually perfect in the seismic interpretation.

<u>Evidence of Bed Deformation at Pymatuning</u>- Originally, I thought that a zone of sorted sediment marked the contact between the two tills. However, a visit to the bluff in the spring, when the lake level was still at the low winter level, permitted me to more carefully examine the bluff without having to stand knee-deep in the lake. More detailed examination revealed that the zone of sorted sediment was discontinuous masses of sand, silt, or gravel, and that the till below the sorted sediment extended between the masses and is the same till as above (Figure 4-11). Each sorted sediment mass is composed of one size of sediment (silt, or sand, or gravel), and appears to be massive (no layering). Small lenses of till, similar to the enclosing till, are surrounded by sorted sediment near the tops of the sorted masses (Figures 4-12). Thin stringers and boudins of the silt or sand are found near the base of the till above the sorted masses. (Figure 4-12). In other places, the enclosing till "intrudes" into the sorted sediment masses (Figure 4-13).

The tills in this section are interpreted as subglacially deposited by deformation of a water-saturated substrate. The lower part of the section shows clear signs of subglacial shearing. The sorted sediments were deposited in subglacial channels eroded into the till substrate. Movement of the glacier over the channels deformed them. The overlying tills are also interpreted as subglacial deformation till. If there were any additional sorted sediments within the sequence, they have been sheared and deformed so that they have become completely homogenized into the till. The lower part did not undergo complete homogenization, and the deformed channel forms and sorted sediments remain. Early phases of homogenization have occurred as evidenced by the thin stringers of till within sorted sediments and vice

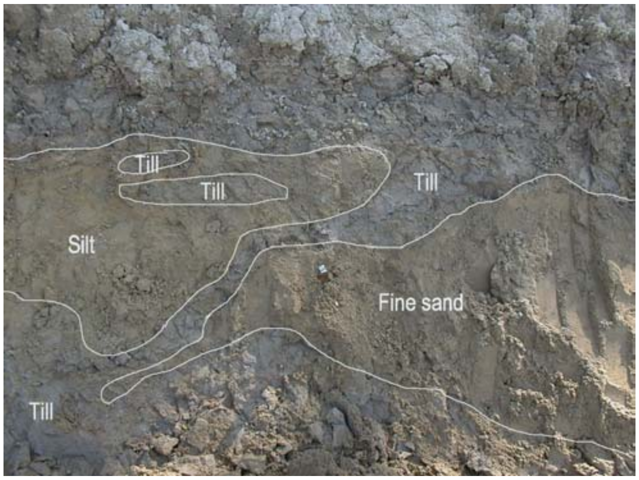

Figure 4-11. Photo of deformed channels and till. Note the isolated inclusions of till within the silt channel, and the till between the two deformed channels connecting the till above and below. Photos taken in April, 1999. Knife for scale.

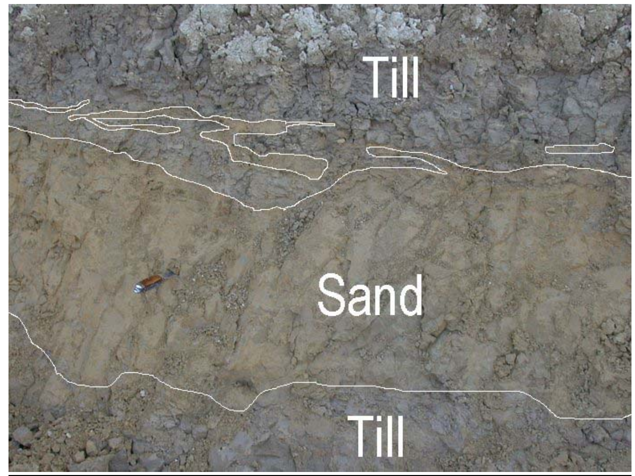

Figure 4-12. Sand stringers occur in the till above the channels. Knife for scale.

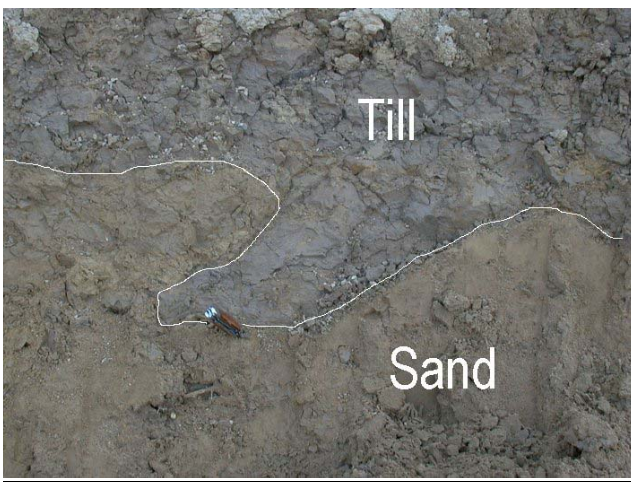

Figure 4-13. Till intrudes into a channel of sand. Knife for scale.

versa. Because homogenization of some of the sediments is not complete, and deformation features (boudins, stringers, intrusions, etc.) still exist, we are left with good evidence of subglacial deformation.

Bluff Erosion

Shoreline erosion of the lake has resulted in bluffs, like this one. This bluff is the largest along the lakeshore. As noted above, it has been eroding for at least 46 years (since first noted by Shepps in 1959) and has been a source of concern for park officials. It is an excellent location for a bluff to develop. The top of the ridge is about 20+ feet above the lake. The peninsula extends well into the lake and the northwest side is very exposed to prevailing westerly winds coming across the lake.

There are three main issues concerning the shoreline erosion for park officials. One is that the erosion will undermine park and private structures built on and near the shore. The bluff at STOP 4B poses no threat to any structures, but other smaller bluffs do pose threats to structures that were built at or near the shoreline. The second concern is largely aesthetic, in that many people (though perhaps not geologists) consider the brown bluffs to be eyesores interrupting the pleasant greenery of most of the shoreline. The third concern is that the fine-grained sediment eroded from the bluffs increases the turbidity of the lake, and can be detrimental to aquatic life, and not aesthetically pleasing to swimmers and boaters.

Several erosion control measures have been tested, and others used in critical areas (where structures are threatened). The park is evaluating its options to control the shoreline erosion, based on the effectiveness and cost of several different measures, mainly different types of rip-rap and vegetation.

From a geologist's point of view, shoreline erosion may not always be a problem. For one, is the shoreline erosion significant when compared to the amount of sediment transported into the lake by streams during storms? Gravel bars built up at the mouths of the streams entering the lake near STOP 4B (including the stream at STOP 4A- Figure 4-14) suggest that sediment eroded by storms and transported by many

Figure 4-14. Gravel bar built up at the mouth of the stream seen at STOP 4A.

streams into the lake contribute significantly more sediment into the lake than does direct bluff erosion. The aesthetic and aquatic concerns of the increased turbidity will likely not be resolved by stopping shoreline erosion. It would likely require stopping all eroded sediment in the watershed from entering the lake- not a practical option. Secondly, geologists welcome the exposures created by the erosion. The bluff we are observing contains a plethora of features that help us to understand the geology and geologic history of northwestern Pennsylvania and northeastern Ohio. Not everyone considers this an eyesore.

Questions for this stop

1. Is the till above and below the sorted sediment masses the same till?
2. Is the till at the surface the same till as at the base of the bluff?
3. What are the depths of oxidation and leaching?
4. Are the subtle difference in till mineralogy significant in interpreting the stratigraphy and weathering history?
5. What is the origin of this hill into which the lake is eroding? Is it related to the islands between here and the dam? Are they morainal features related to a Hiram lobe in the valley?
6. What sediments make up the sorted sediment masses?
7. What is the environment of deposition of these sediments, both the till and the sorted sediments?
8. What are the tills in the stream cut to the northeast (STOP 4A)?
9. How big a problem is the shoreline erosion that created this bluff, and other bluffs along the shore?

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STOP 5- BOOTH RUN SECTION

Leader- Gary M. Fleeger

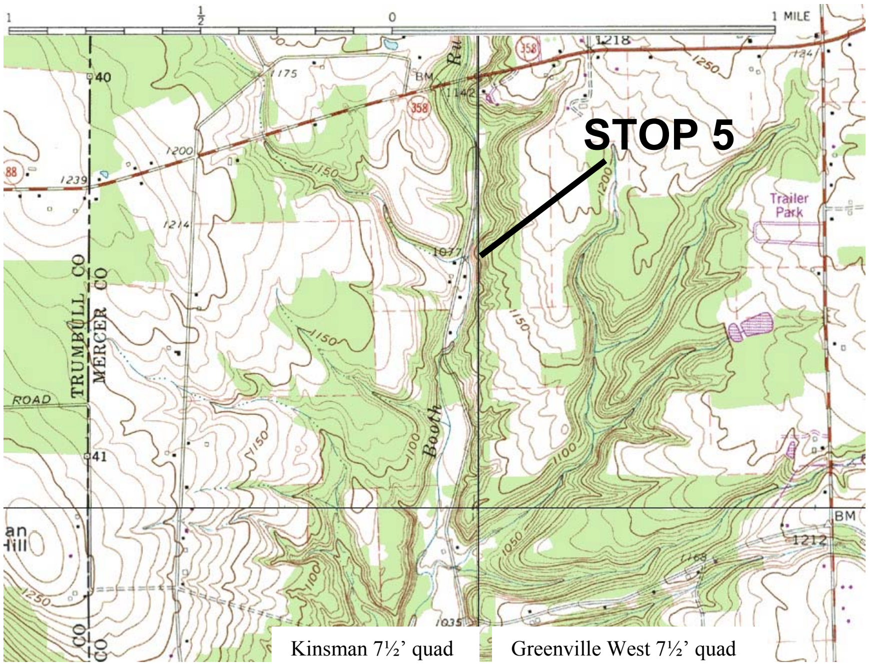

Figure 5-1- Location map of the Booth Run section. From the Kinsman, OH and Greenville West 7½' topographic maps.

At STOP 5 (Figure 5-1), we will see a thick section containing multiple tills (Figure 5-2). White and others (1969) and White (1982) described the Titusville Till in the subsurface as being composed of up to five separate till sheets, separated by sand and gravel layers. We may have all five of White's Titusville sheets present in this section, plus the Lavery and Kent Tills, above. White and others (1969) suggested that multiple Titusville sheets "stacked up" to form the bulk of the Kent Moraine. However, we are many miles behind the Kent Moraine here. We'll speculate on what the five Titusville sheets really are.

The section also illustrates complex weathering patterns associated with jointing in the till and the effects of the sand beds on the adjacent till.

The boulder in the stream bed was embedded in the section until the storm associated with Hurricane Frances last September. Prior to that, there were several other larger boulders in the stream that have been moved from here, presumably by the high flows associated with the storm. The landowner indicates that he did not move them. The storm also cleared the base of the section so that glacially-rotated bedrock can now be seen.

Stratigraphy

Up to 7 tills have been identified here based on field evidence and laboratory data (Table 5-1). Whether each of the 7 tills represents a separate glacial advance is open to speculation.

Similar to STOP 4B, the depth of oxidation at the top of the section is much greater than that normally seen in any single till in northwestern Pennsylvania. This location is within the area mapped as thin, discontinuous Lavery Till by White and others (1969). Most likely, there is Lavery Till present at the top, but it is weathered completely through to the Kent Till, and not able to be positively identified.

Figure 5-2- Photo of the Booth Run section on May 7, 1999. Multiple sand beds separating the tills are obvious in this photo. The line of the measured section is indicated.

Table 5-1: Booth Run Section

Measured December 3, 2004 by Fleeger and Berkheiser

Lavery (?) and Kent	Description	Unit thickness (ft)	Aggregate thickness (ft)
Tills	Silt- clayey, friable, pebbly, yellow-brown (soil zone). 0.1' humus and moss at top	2.9	2.9
	Till- mottled gray-brown, very sandy, friable but more compact than above, pebbly (up to 2" in diameter), non-calcareous	9.3	12.2
	Till- gray-brown, very compact, very pebbly and stony (up to 7" in diameter), slightly calcareous (very weakly reactive). Samples BR-1 and BR-2.	8.3	20.5
	Stone concentration		20.5
Titus-ville ↓	Till- gray-brown, very compact, very pebbly and stony. Same as above, but not visibly calcareous. Sample BR-3	0.4	20.9
Till	Till, as above, with pods of gray till. Gray till pods more plastic and more calcareous than brown till. Some thin sand streaks and layers. Stone concentration at 29.1'. Sample BR-4 in gray till pod.	9.0	29.9
	Stony brown till with gray till pods.	1.4	31.3
	Till- blue-gray, sandy, stony. Dense, but not as compact as above. Oxidized zones along joints.	1.4	32.7
	Sand and gravel bed- brown, continuous across outcrop	1.4	34.1
↓	Till- gray with oxidation along joints. Sample BR-5 (gray till) and BR-6 (oxidized joint).	1.8	35.9
	Till- brown (oxidation shadow from subjacent sand bed?)	0.6	36.5
S	Sand- orange-brown with black streaks, continuous across outcrop	0.3	36.8
Keefus ↓	Till- brown, friable, calcareous, with gray till pods. Sample BR-7 (brown till)	3.0	39.8
(?) Till	Till- gray, calcareous, with sand stringers. Oxidized along joints. Sample BR-8 (gray till).	2.2	42.0
S	Sand- orange-brown, lateral continuity uncertain (poorly exposed)	0.3	42.3
	Till- brown, calcareous (oxidation shadow from superjacent sand bed?)	0.1	42.4
	Till- gray, calcareous. Thin oxidized joints. Sample BR-9	1.8	44.2
↓	Till- gray, calcareous. Samples BR-10 and BR-11	6.5	50.7
	Covered interval- slumped material	1.4	52.1
	Sand and gravel- brown-gray, coarse, poorly sorted, cobbles up to 4" in diameter, lateral continuity uncertain (poorly exposed).	2.5	54.6
	Covered interval- slumped material	10.7	65.3
Maple-dale (?) Till	Till- gray, calcareous, compact, sandy, cobbly. Pieces of angular siltstone and sandstone. Beds of near-vertical sandstone. Sample BR-12	3.0	68.3
	Booth Run		

Down-pointing arrows indicate incomplete weathering sequences progressing from oxidized (brown) till, to oxidized till with unoxidized (gray) pods, to unoxidized till with oxidation only adjacent to joints, to unoxidized till.

S indicates sand beds with an oxidation "shadow" in the sub and /or superjacent till.

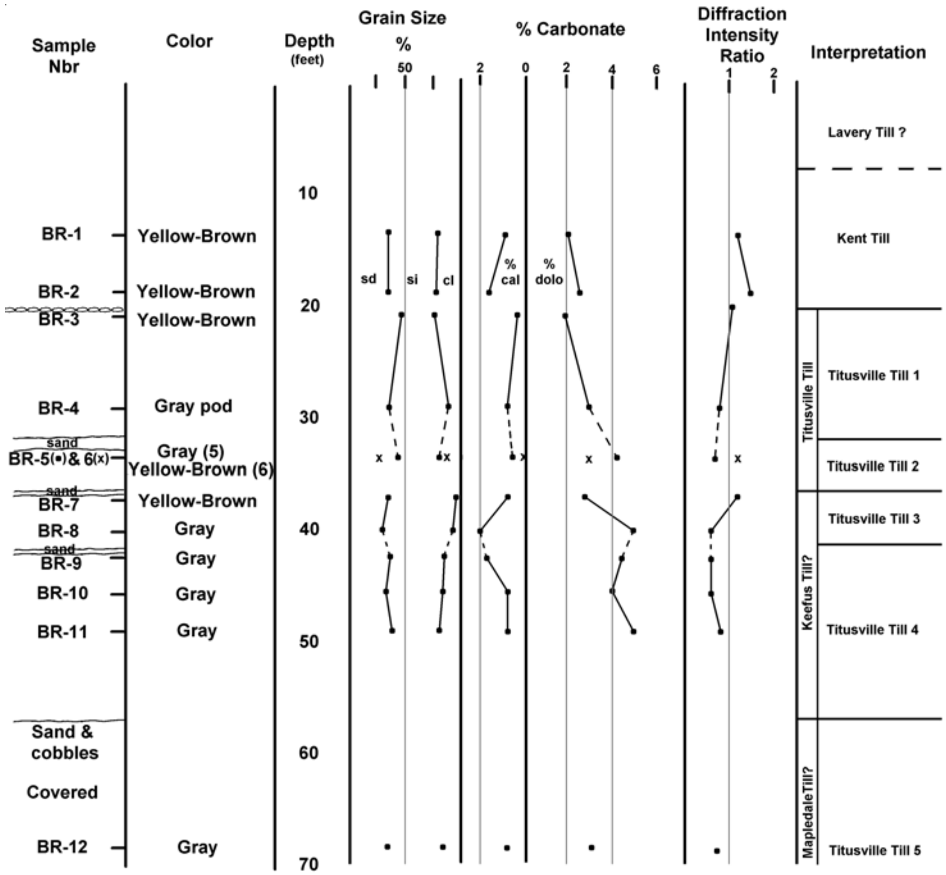

Figure 5-3- Two possible interpretations of the pre-Kent stratigraphy in the Booth Run section based on the mineralogy of the till samples. The Titusville Till 1, 2, 3, 4, and 5 designations, indicate multiple Titusville Till sheets, as described by White and others (1969), separated by multiple sand beds. The Titusville Till, Keefus Till?, and Mapledale Till? designations suggest fewer till sheets, based on weathering sequences, and suggest possible correlations with other Grand River Lobe tills.
See Figure 4-7 for explanation of the format of the diagram.

The till immediately above the stone concentration at 20.5 feet is most likely Kent Till. Below the stone line, there are multiple possible interpretations of the stratigraphy, based on our current knowledge of the glacial stratigraphy of northwestern Pennsylvania and northeastern Ohio.

White and others' (1969) interpretation of five separate Titusville Till sheets, usually separated by sand and gravel beds, could be applied here (Figure 5-3). There are four sand beds separating five tills, all below the Kent Till. However, it is not clear as to how many separate glacial events they represent.

The mineralogy, showing the changes resulting from weathering, suggest that there may be fewer than five tills, and that the sands do not all represent breaks between glacial events. Using till mineralogy and weathering evidence, there are probably only three tills beneath the Kent Till (Figure 5-3). However, that also has problems in that weathering can extend through one till into underlying tills, complicating the interpretation of the stratigraphy, especially if the tills are thin, as they are here.

So how do we distinguish the deposits of separate glacial events? Reinterpretations of glacial sequences in Illinois have resulted in the reduction of the interpreted number of glacial advances, because multiple tills are now thought to result from different phases of a single glaciation (Hansel, Johnson, and Socha, 1987). However, the till of sample BR-7 most likely does represent weathering from subaerial exposure. The oxidized till beneath the sand bed is 3 feet thick, which is too thick to be a weathering shadow (see Weathering section below).

Paleosols are the best evidence of separate glacial events, but we have none here. However, the absence of a soil does not prove that there was no time break. Where White had multiple Titusville sheets over Mapledale Till, there was always part of a soil, or at least a leached zone, preserved on the Mapledale Till, and all tills between the Kent Till and the Mapledale paleosol were identified as the multiple Titusville Till sheets (White and others, 1969). His Titusville sheets are always separated by sand beds, as they are here, but a sand bed does not necessarily require that the tills above and below are from different glacial events. So we have to find a way to identify the deposit, in places where it can be identified by a preserved soil, and apply that method to the places where there is no preserved soil. Here, I have attempted to apply weathering sequences that suggest a time break, even if there is no preserved soil.

Going with the conservative interpretation of three tills below the Kent Till, the next question is "Which tills are they?" White would probably have interpreted them as multiple Titusville Till sheets. The origin of White's multiple Titusville sheets is not well understood. However, if I may speculate a bit here, there are other options. If they are not multiple Titusville sheets, then they must be older tills. The older (Illinoian and older) tills identified in the Grand River Lobe are the Keefus, Mapledale, and Slippery Rock (White, and others, 1969; White, 1982).

The Keefus Till has been identified, mostly in water well logs, only within 20 miles of Lake Erie (White, 1982). It has a distinctive reddish color and is high in matrix carbonate content (9.1% at its type section- Bruno, 1988), relative to the other tills in the lobe. Its existence was predicted earlier by White and others (1969) because it was found as inclusions in the Titusville Till. White (1982) reports that the Titusville Till averages about 3% carbonate. The till of samples BR-7 to BR-11 has the highest matrix carbonate content in the section, including 2 samples (BR-8 and BR-9) with carbonate contents greater than 6%, and there is no known nearby source of carbonate material. It is in the stratigraphic position of the Keefus Till at its type section (White, 1982). Could this be the Keefus Till? The Keefus Till has rarely been seen, and never (I don't think) with any soil development. Maybe the Keefus Till is just one of White's Titusville sheets with local red coloration near Lake Erie. The red color is thought to be from eroded Grimsby Shale in the Niagara region (John Szabo, personal communication, March, 2005). Once the Keefus glacier advanced over the gray bedrock of the plateau, perhaps the till lost its red color, and that may be why it has not been identified further south.

Red tills in the mid-continent retain their distinctive red color for large distances. But the glaciers that deposited them did not flow over the Allegheny Escarpment onto the Allegheny Plateau. Flowing over the escarpment may have caused increased erosion of local bedrock, resulting in compositional changes, and perhaps a color change. Szabo (1987) discussed compositional changes resulting from glacial flow over the Allegheny Escarpment in Ohio. Gross and Moran (1971) determined that, on the Plateau in northwestern Pennsylvania, 50% of the Titusville Till is derived from within 20 miles of the site of deposition.

The till exposed at the base of the section (sample BR-12) also has a carbonate content of 4%. The Mapledale Till generally does not react visibly to dilute HCl in the field (White and others, 1969). White and others (1969) indicates that there is a second Mapledale sheet in places, that has a greater carbonate value. This lowest till may be a lower Mapledale sheet. There is a 10+ foot covered section between the sand and gravel underlying the Keefus (?) Till and the lowest till, which may contain the upper, low-carbonate Mapledale sheet. A Slippery Rock Till possibility is more difficult to determine. To my knowledge, no unweathered Slippery Rock Till has ever been found, so its original mineralogy is unknown.

Figure 5-4 - Upturned bedrock in the till at the base of the section.

The base of the section contains very angular pieces and slabs of the underlying bedrock (which is exposed in place in the stream bed about ¼ mile upstream), some of which are upturned to a vertical orientation (Figure 5-4). The base of the section is probably very near bedrock, which is near-horizontal Meadville Shale. This also suggests that till creation and deposition may be by subglacial deformation of the underlying material, as we discussed at STOP 4. The upturned bedrock was probably at the base of the deforming layer beneath the glacier.

Weathering

This section displays some weathering phenomena that complicate interpretations. Patterns of oxidized sediments overlying unoxidized sediments have traditionally been interpreted as a single sequence of subaerial weathering. However, in this section there are two other factors controlling the patterns of oxidation. One is a weathering "shadow" produced by increased weathering adjacent to sand beds due to groundwater flow through the sand beds. The other is the uneven base of the oxidized zone because of oxidation to greater depths along joints.

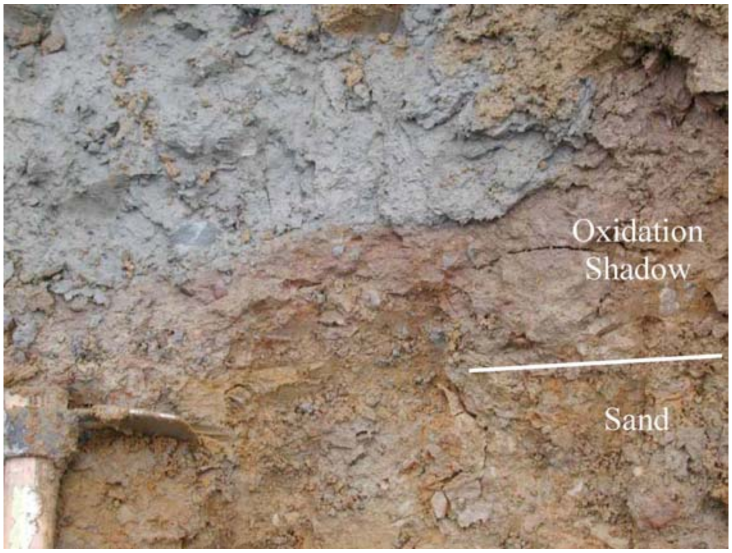

Figure 5-5- Sand bed (at mattock) with a thin oxidation shadow above it.

There are two sand beds in this section that appear to have oxidation shadows in the overlying and/or underlying till. Both are indicated in the measured section (Table 5-1) by the letter **S** to the left of the description. The upper of the two sand beds appears to have a shadow above it. Whether a shadow exists in the subjacent till is difficult to determine. The underlying till has a 3-foot thick oxidized zone. Oxidation shadows generally extend considerably less than a foot into the adjacent till. This till may also have undergone subaerial weathering. The overlying 0.6-foot shadow is more typical (Figure 5-5). The lower sand bed has only a very thin shadow in the underlying till.

The other weathering complication is caused by weathering agents penetrating deeper into tills along joints. The joints in the till are usually discreet linear fractures, which serve a preferred pathways for weathering agents. Oxidation proceeds downward along the joints faster than between joints, and also outward from the joints. This section displays many example of oxidized till adjacent to joints within generally unoxidized till. The oxidation extends outward from some joints only a centimeter or less, but 10 or more centimeters at other joints. Weathering along joints produces the same initial mineralogical changes as subaerial weathering. For example, samples BR-5 and BR-6 were taken beside each other (Figure 5-6). BR-6 is partially leached of carbonates and has had its clay minerals altered from the composition of BR-5 (Figure 5-3).

Figure 5-6- Photo of oxidation along joints within unoxidized till. The oxidized till weathers out in relief due to iron cementation. BR-5 came from the location of the mattock, and BR-6 from the oxidized joint on the right.

This section has sequences that progress downward from oxidized till, to oxidized till containing unoxidized till pods (masses of gray, unoxidized till completely surrounded by oxidized till), to unoxidized till with oxidation only along joints, to completely unoxidized till. The unoxidized pods appear to be remnants of till that have not yet been affected by weathering moving downward along joints or laterally along other preferred paths (Figures 5-6, 5-7, and 5-8).

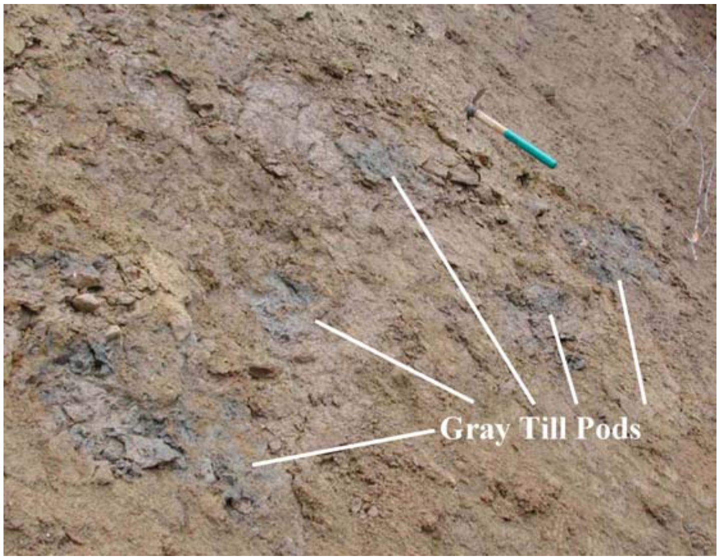

Figure 5-7- Photo of unoxidized till pods within oxidized till, grading down into unoxidized till with oxidized joints.

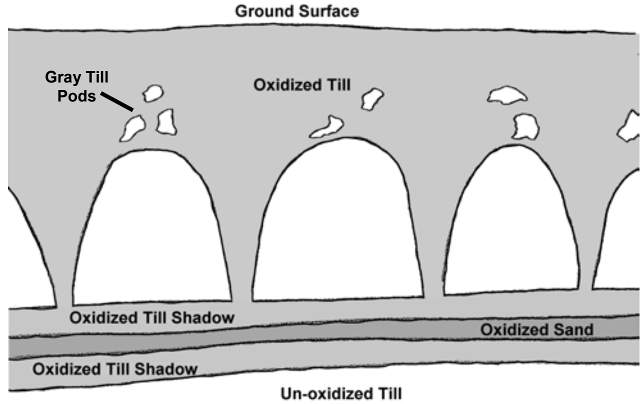

Figure 5-8- Sketch illustrating an idealized weathering sequence from oxidized to fresh till, and oxidation shadows adjacent to sand layers within a till mass. It also shows the complexities created when two sources of oxidation (from surface and sand beds) intersect.

The downward sequences from oxidized to unoxidized till overlap with the oxidation shadows, making it difficult to determine the cause of oxidation in some places, and where stratigraphic breaks may be.

Questions to ponder at this stop

1. What till is at the surface (Lavery, Kent, or Titusville)
2. Which sand beds separate deposits of different glacial advances?
3. Is the Keefus, Mapledale, and/or Slippery Rock Till present here?
4. How are different tills distinguished?
5. What effect do the various weathering features have on stratigraphic and geologic history interpretation.
6. How were the sand beds within tills, and between tills deposited?

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STOP DESCRIPTIONS- DAY 2

STOP 6- HOMEWOOD SANDSTONE (STEREO)TYPE SECTION

Leader: Viktoras Skema

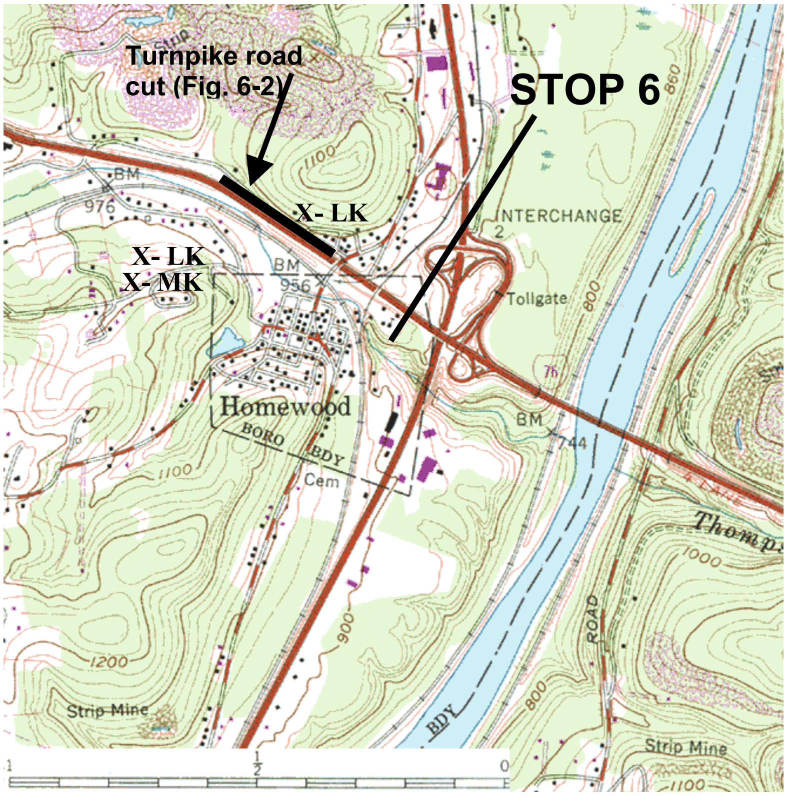

Figure 6-1. Location map for STOP 6, Homewood (stereo)type section. From the Beaver Falls 7½' topographic quadrangle. X marks deep mine openings mapped by DeWolf (1929).

The type section for the Homewood Sandstone is in the valley of Clarks Run (Figure 6-1). The unit (originally called the Upper Homewood Sandstone) was named by I.C. White (1878) for this exposure, although the concept of designating formal type sections did not yet exist. The site is preserved as the Buttermilk Falls Natural Area by Beaver County.

The purpose of this stop is to illustrate what we have termed a stereotype section. The Homewood Sandstone has long been "known" to be a thick, fluvial sandstone that crops out in many places in the Beaver, Mahoning, and Shenango River valleys. But as we have seen at STOP 1, and will see at STOPS 10 – 12, the Homewood horizon does not always contain thick, fluvial sandstones, nor are the thick, fluvial sandstones that have been called Homewood always at the Homewood horizon (STOP 12). Thick sandstone, which may have been erroneously correlated with the Homewood Sandstone, is also sometimes developed in the lower Allegheny Group and within the Mercer sequence (both will be seen at STOP 12).

The Homewood Sandstone is 155 feet thick here. This is the thickest known development of the sandstone, so it is certainly not a typical exposure of the sandstone. In fact, this section has long been "known" to include more than the Homewood. White (1878) concluded that the abnormal thickness here was the result of the Homewood Sandstone thickening upward through the overlying Clarion rocks and Vanport Limestone. DeWolf (1929) considered the abnormal thickness to be the result of the merging of the Homewood and Upper Connoquenessing Sandstones. Carswell and Bennett (1963) and Poth (1963) both concluded, based on their work farther north, that the great thickness of sandstone at Homewood likely resulted from Kittanning fluvial sandstones that were deposited in channels eroded through the Vanport Limestone and Clarion shales into the Homewood Sandstone. It may be none of the above.

Stratigraphy

The detailed stratigraphy of the section was not studied for this Field Conference, so we cannot draw any definite conclusions. However, a reconnaissance review of the mining and drilling data, and of outcrops in the area suggests that the sandstone here may not be at the top of the Pottsville Group. Skema discovered three separate marine zones above the thick Homewood Sandstone exposed in the Pennsylvania Turnpike roadcut just to the northwest of STOP 6 (Figure 6-2). These zones are positioned between the sandstone and the mapped horizon of the Vanport Limestone (DeWolf, 1929, plate IV). A Lower Kittanning coal deep-mine opening at 1025 ft elevation is also shown by DeWolf (1929) 200 feet north, directly up the hill from this roadcut exposure. All three marine zones appear to be in separate depositional cycles. The upper two are underlain by coal and underclay. The upper-most zone is a platy, slate-like, black clay shale containing *Lingula* brachiopods, similar to that found at STOP 1. This *Lingula*-bearing bed and coal are approximately 70 to 80 feet below the deep-mined Lower Kittanning coal. The middle marine zone is approximately 15 feet lower in a dark, thinly bedded shale that contains a variety of fossil shells including the marine brachiopod, *Mesolobus*. The lowest marine zone also is in dark shale and contains marine brachiopods, including *Mesolobus*. There were also nodules in this shale, though they are not obviously sideritic. This zone is 110 feet below the deep mine. The section was not measured in detail and intervals are estimated from the topographic map and elevations stated in DeWolf (1929). However, the initial interpretation of this new data is that the "type Homewood Sandstone" is well down into the Pottsville Formation, and is beneath the Lower Mercer marine zone, Upper Mercer marine zone and coal, and the Brookville coal overlain by the Putnam Hill marine zone. There probably is no good reason to name the fluvially-deposited sandstones in this part of the section. But if this thick sandstone at Homewood had to now be given a formal name for the first time, there would be no need for a new name. The choice would be obvious- "Connoquenessing"!

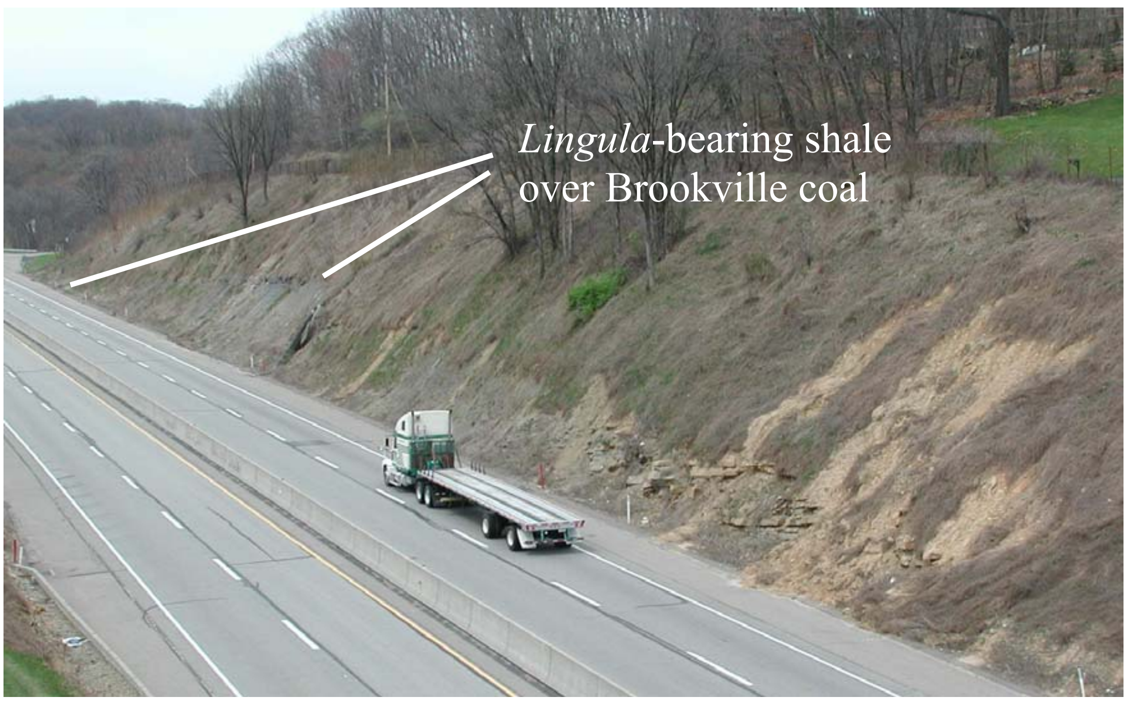

Figure 6-2. Roadcut along the Pennsylvania Turnpike just northwest of the Homewood Sandstone type section.

The Quarry

The trail through the natural area passes through an abandoned sandstone quarry (Figure 6-3). This quarry probably opened in the 1850s, shortly after the Ohio and Pennsylvania Railroad was constructed along the Beaver River. A larger operation here started in the 1880s by the Clydesdale Stone Company. The quarry closed in the late 1940s or early 1950s (Alan DeSanzo, personal communication, August 31, 2005). Dimension stone from this quarry was used for the construction of roads, canal locks, bridge abutments, and buildings. The Western Penitentiary in Pittsburgh was constructed with stone from this quarry.

Figure 6-3. One of the faces from the old abandoned Homewood Sandstone quarry. Photo by Jon D. Inners.

The Falls

This waterfall has been known as both Homewood Falls and Buttermilk Falls (Figures 6-4 and 6-5). A group of Civil War veterans named Buttermilk Falls in 1870. They were on a picnic here with their lady friends, and toasted the occasion using buttermilk. For many years, the name was associated with this falls. Later, it seems to have become more commonly known as Homewood Falls, after the town. The name Buttermilk Falls was resurrected when the park was created in 2000.

Figure 6-4. Stereograph of Homewood Falls. This stereograph part of the Homewood stereotype section was photographed circa 1870 by William T. Purviance, the “official” photographer of the Pennsylvania Railroad Company at that time. This view of the waterfall is as I.C. White would have seen it when he studied the geology of the area in 1876. (From Clifford H. Dodge collection.)

Figure 6-5. Buttermilk (Homewood) Falls today.

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STOP 7. THE VANPORT LIMESTONE AT WAMPUM

Leader: Bill "Chilly Billy" Kochanov and Bill Bragonier

The Vanport Limestone is unique in the Allegheny Group. Its composition, thickness, and widespread geographic distribution throughout western Pennsylvania make it an ideal stratigraphic marker.

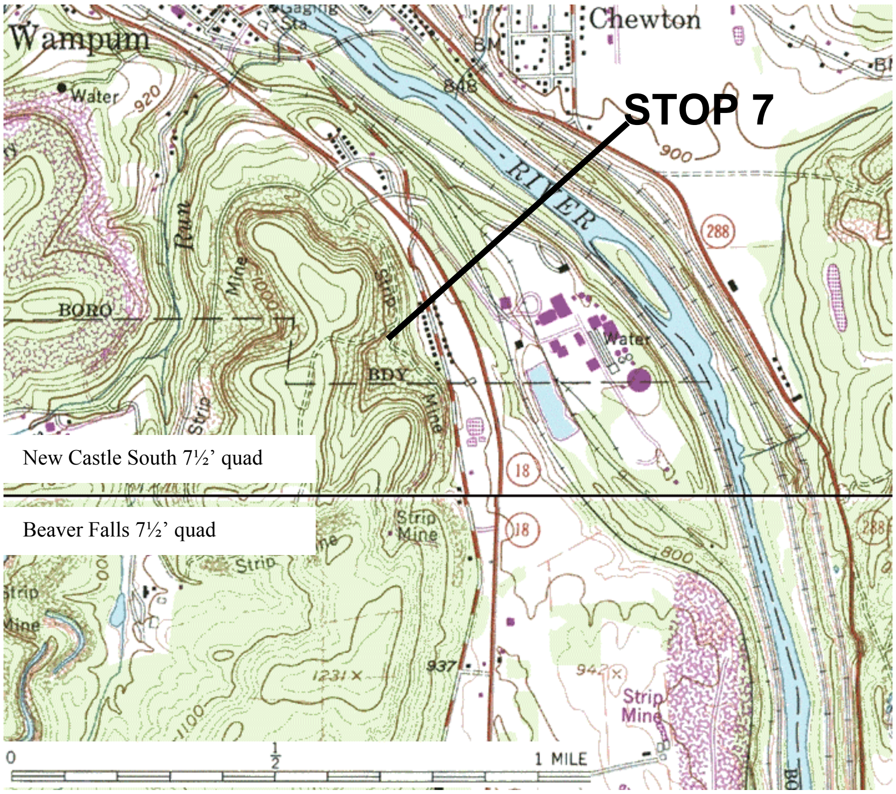


Figure 7-1. Location map for the Gateway Commerce Center.

The Vanport that we will examine is located at the Gateway Commerce Center (Meritex), a subsurface storage facility one mile south of Wampum (Figure 7-1). The underground facility was originally a limestone mine, but now uses the 2.5 million square foot facility primarily for vehicle and record storage. Limestone pillars up to 30 feet in diameter support Gateway's ceiling, and concrete floors are laid over a solid limestone base. For you trivia buffs, the facility was also used as a set in the filming of George Romero's 1985 movie "Day of the Dead," which was the sequel to "Night of the Living Dead" (1968) and "Dawn of the Dead" (1978) (IMBD, 2005).

The stratigraphic section exposed at this site includes the sequence from the Scrubgrass coal up through the Vanport Limestone, and the shales and siltstones of the coal-bearing Lower Kittanning suite (Figure 7- 2).

The site can be divided into two sections. The first section (Section 1 on Figure 7-3) is the outcrop on the south side of the entrance to the underground storage facility, above the retaining wall. This includes the shales and siltstones of the Lower Kittanning, the Buhrstone ore bed, the "cave" opening around the hill to the south, and the upper Vanport Limestone. The second section (Section 2 on Figure 7-3) is on the north side of the roadway entrance to the underground storage facility. This includes the Scrubgrass coal up through the lower Vanport Limestone. Although the primary discussion will revolve around these two sections, there are outlying exposures that are also available for examination on the north side of the entrance road (Figure 7- 3).

The Vanport Limestone can be broken down into distinct beds based upon color and sedimentary structures. In Section 1 the outcrop appears massive, with two distinct partings in the upper third of the outcrop (Figure 7- 4). Closer examination of the limestone shows the wavy nature of the lower beds, and the transition to more planar beds as one goes up section. The contacts between bedding in the upper limestone are not smooth, and are actually rather bumpy, even somewhat crinkly. This wavy to more crinkly transition was also noted by I.C. White (1878) where he describes the weathered limestone

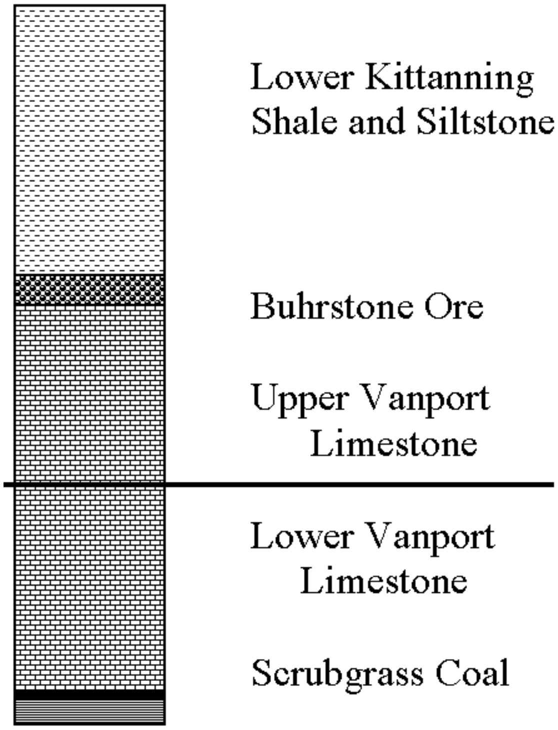


Figure 7-2. Stratigraphic column showing the units cropping out at STOP 7.

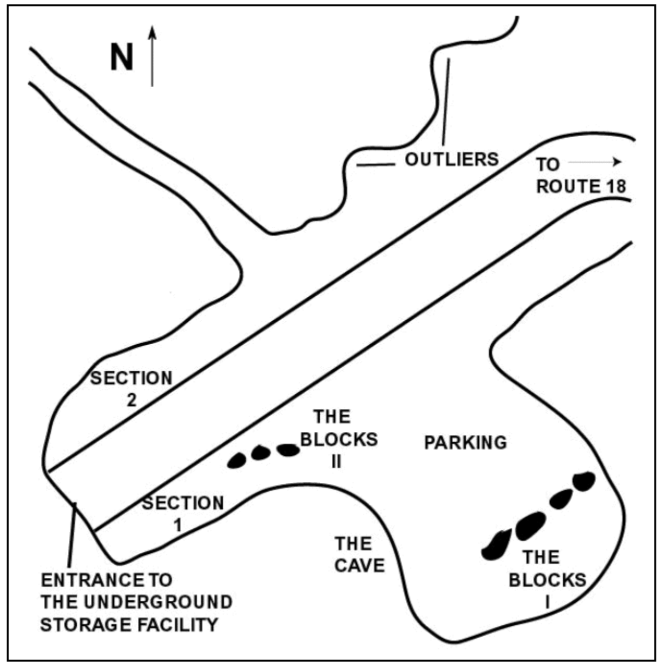


Figure 7-3. Sketch map for STOP 7 at the Meritex subsurface storage facility. Not to scale.

Figure 7-4. Photo of Section 1 showing the upper and part of the lower beds of the Vanport. Note the partings in the upper one third of the exposure.

as being traversed by horizontal furrows that have a wavy margin and give the limestone a shriveled appearance. The transitional nature of the limestone is better observed in the more weathered Section 2 (Figure 7- 5).

At first glance the wavy appearance of the lower limestone may lead one to think that the sequence is a series of stacked rippled beds. The variations in bedding thickness, plus the pinch-and-swell character of individual limestone beds across the face of the outcrop give it the appearance of boudinage structures (Figure 7- 6). Wilson and Jordan (1983) describe sedimentary boudinage as the result of differential compaction between beds of shale and limestone. The differences in composition between shale and the more easily lithified limestone result in a texture of irregular, closely-spaced nodular bedding that is caused by the disruption of layers by solution and compaction, giving the impression of stretching and flowage.

This undulatory bedding is characteristic of a middle carbonate shelf environment where the deposits are continuous, widespread sheets from carbonate sediments produced in shallow-water environments (Wilson and Jordan, 1983).

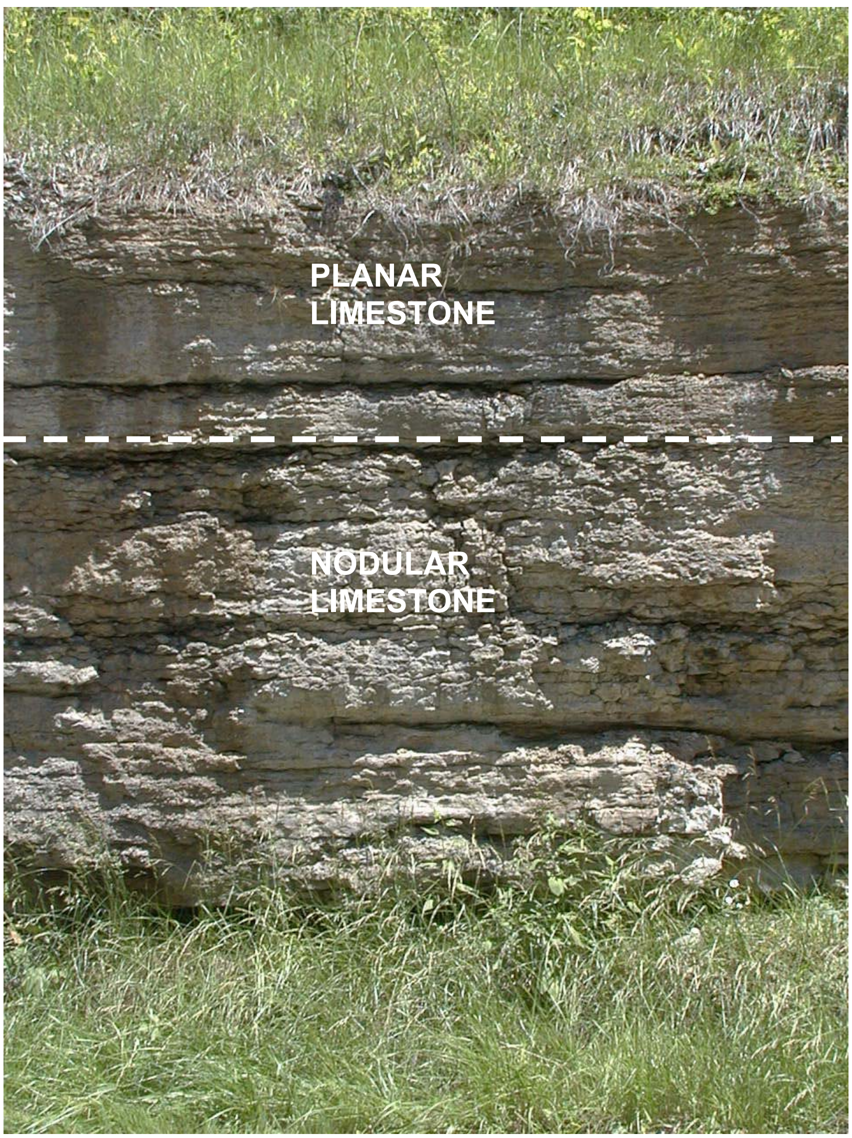


Figure 7-5. View of Section 2 showing more weathered Vanport, and the transition from the lower nodular-bedded limestone to more planar bedded upper limestone.

At the east end of Section 2, exposed bedding surfaces show a rough, irregular texture. This has also been observed at the natural bridge in Hell's Hollow at McConnells Mills State Park (Pre-Conference Field Trip), where there are large slabs of breakdown beneath the "bridge" that exhibit a similar, bumpy, irregular, planar surface. This may be the result of the weathering of various sediment types. Heterogeneity in the original sediment may be attributed to burrowing, shell beds, or local accumulations of pebbles or intraclasts on the sea floor (Wilson and Jordan, 1983). Differential weathering may enhance the relief of the clasts, giving the irregular surface.

The shriveled appearance that has been observed in the upper, more planar beds may be an expression of stylolites that are present at the contacts between clay seams and the carbonate layers. This may indicate that the dissolution of $CaCO_3$ occurred along with compaction. Stylolites are common throughout the Vanport, and are more easily discernable in core borings. It may also be that the clay seams are not due to primary deposition of detrital clay, but are, at least in part, stylolite surfaces along which clay, as well as other impurities, have been concentrated as an insoluble residue (Bathurst, 1975).

The Vanport limestone is generally gray to light brownish–gray in color, with the basal part being dark gray where it is transitional from the underlying Scrubgrass coal. In the older literature, the lower limestone is sometimes referred to as the "blue" limestone, and was deemed inferior as analyses showed it to have more silica, an undesirable in the iron-making process (White, 1879). The Vanport ranges in thickness from 1 to 25 feet, with some as much as 30 feet. Petrographic study of the Vanport shows it to be primarily lithified carbonate ooze (Bergenback, 1964).

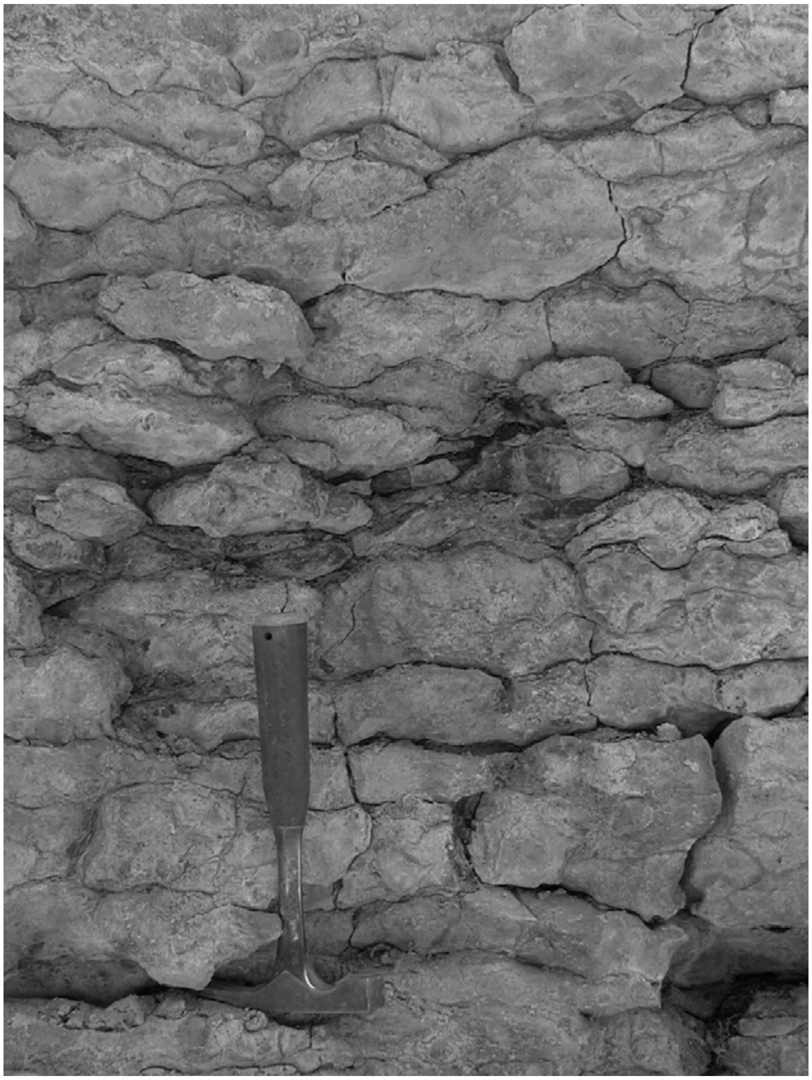


Figure 7-6. Close up view of nodular bedding at Section 2.

Gypsum Occurrence

At Section 2, much of the limestone surface is covered with an encrusting mineral. In places, it can appear as though it is "exuding" out between the beds of the limestone (Figure 7- 7), and quite sparkling at other places (Figure 7- 8). At the west end of Section 2, fractures in the limestone are filled with a white material, giving a dendritic pattern (Figure 7- 9). At first it was thought that this mineral was calcite, and that it was some form of calcareous tufa. Using X-ray diffraction and SEM examination, however, John Barnes (2005, personal communication) identified the crust as gypsum (Figure 7- 10). This brings to the forefront the question of the origin of the gypsum.

To form gypsum (Ca_2SO_4), there needs to be a source of calcium and sulfate ions. In the limestone dissolution process, water interacts with carbon dioxide to form carbonic acid (H_2CO_3). This weak acid is the primary agent in the dissolution of carbonate bedrock, and in the long term, helps to develop the karstic landscape. When the carbonic acid comes in contact with limestone, calcium and the carbonate ions are disassociated, resulting in free calcium and the carbonate ions joining with water to form bicarbonate ions. In general:

$$H_2O + CO_2 \rightarrow H_2CO_3$$

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

There are other steps and combinations in this reaction series, but for purposes of this discussion, these will suffice. For a more detailed discussion, see White (1988).

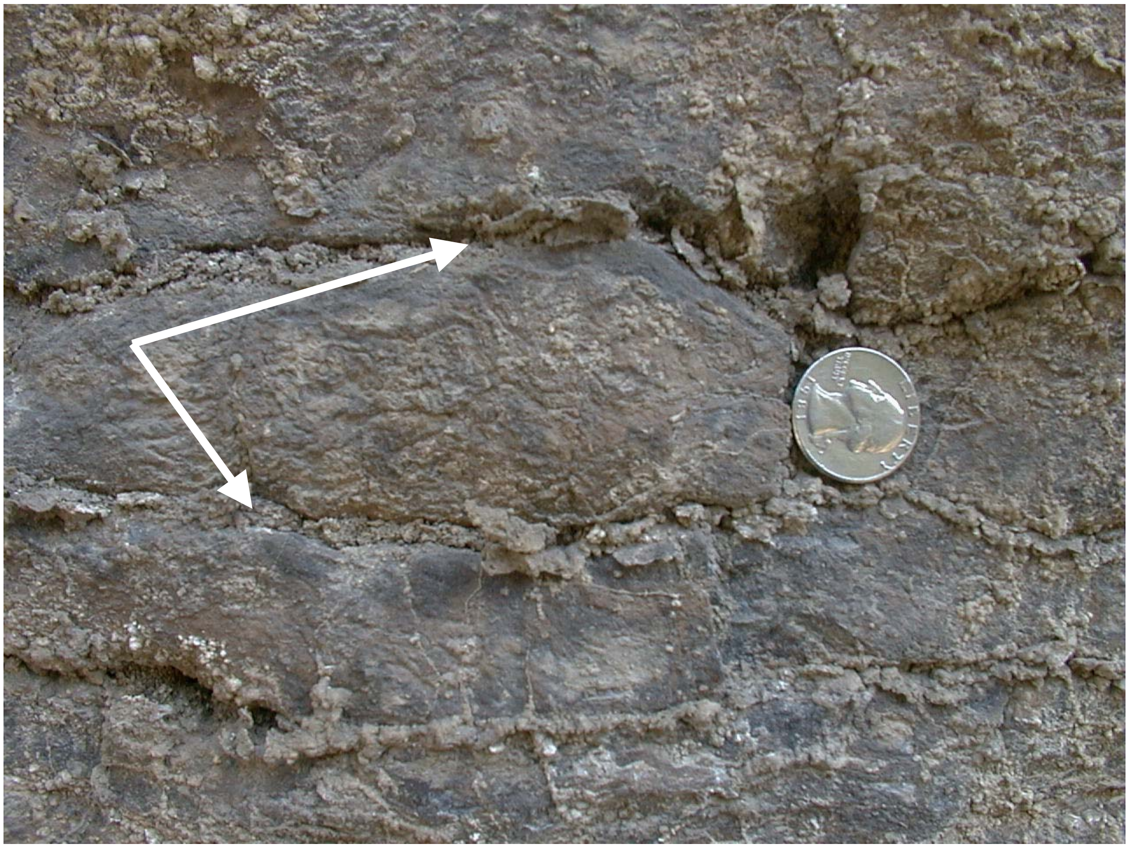


Figure 7-7. Gypsum sandwiched between thin beds of Vanport Limestone.

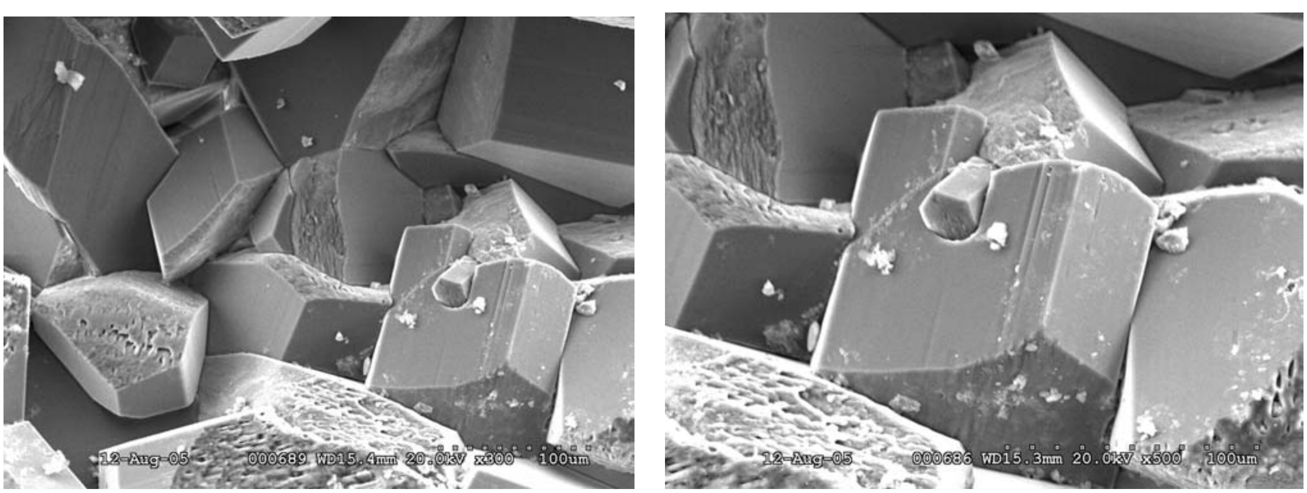
Figure 7-8. Close-up view of sparkling gypsum coating the surface of the limestone.

Figure 7-9. A close-up view of the lower Vanport Limestone with dendritic gypsum filling the fractures.

Secondly, sulfate ions must be generated. Sulfur must be oxidized and then sent on a search for the calcium ions freed from the limestone dissolution process to make the gypsum. Where to find some sulfur?

One of the most common sources of sulfur is found within pyrite, FeS_2. The Vanport could be a likely candidate since pyrite is a fairly common accessory mineral in limestone and in shales associated with limestone (White, 1988). With the abundant draping of gypsum over the surface of the limestone observed at the Meritex site, there clearly has to be enough gypsum in solution to achieve saturation and trigger the precipitation of the gypsum.

We have observed microscopic pyrite in the lowermost beds of the Vanport. If the gypsum crystals had been restricted only to the lowermost beds of the outcrop, then one could make a case that the lowermost Vanport was the source of the pyrite. But the gypsum appears to occur at different levels. This would support an interpretation that the gypsum is being controlled by a source up-gradient from the limestone outcrop.



a.) b.)

Figure 7-10. Scanning electron microscopic view of monoclinic gypsum crystals. a.) 300x, b.) 500x

A much better source for pyrite is the overlying coal-bearing beds associated with the Kittanning suite of rocks. This has also been suggested by Sasowsky and others (2003) and Keith Brady (2005, personal communication)

In this series of reactions, pyrite is oxidized to release dissolved Fe^{2+}, SO_4^{2-} and H^+ ions.

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{3+} + 2\ SO_4^{2-} + 2H^+$$

The primary reaction begins with the oxidation of pyrite in an aqueous solution to produce, in essence, sulfuric acid. Further oxidation produces the SO_4 (sulfate) ions. When the acidic water comes into contact with the limestone, the acid becomes neutralized, with the SO_4 ions being unaffected. Evaporation of solution containing Ca^{2+} and SO_4^{2-} causes them to combine to form gypsum (White, 2005).

$$Ca^{2+} + SO_4^{2-} + 2H_2O \rightarrow CaSO_4 + 2\ H_2O$$

The iron in the pyrite can undergo further oxidation and change the ferrous iron (Fe2+) to ferric iron (Fe3+), which in turn can be precipitated as $Fe(OH)_2$. This precipitation of the iron as a hydroxide is usually in the amorphous form called limonite (White, 1988). This phase of the reaction series may have had a bearing on the development of the Buhrstone iron ore and accounted for the "ferriferous" nature of the Vanport (see discussion on the Ferriferous Limestone).

Another possibility is that this exposure of Vanport is a relict of a cave and that the gypsum actually precipitated on the walls of the cave from the oxidation of pyrite within the limestone. Gypsum and selenite crystals have been reported in Vanport caves by White (1976). The oxidation of pyrite in caves can result in minor gypsum speleothems, or the gypsum can appear as a granular crust formed by the seepage of water from pores in the wall rock of caves. As old crust becomes detached and falls off, new crust forms behind it (White, 1988). This formation of cave gypsum is somewhat analogous to what is being observed on the face of the limestone, except that this is not a cave.

Perhaps the gypsum precipitation process did not require any lengthy period of time. It may be likely that the precipitation of the gypsum was occurring during subsurface limestone mining activity – a man-made cave if you will.

The precipitation of gypsum is also having an impact on the creation of geodes. In Section 2, at the first major parting (see Figure 7- 18), probing in the residual material may unearth "geodes" formed by the cementation of the residual material by the gypsum (Figure 7- 11).

Figure 7-11. Gypsum-cemented limestone residuum forming proto-geodes.

A Note on the Ferriferous Limestone

The Vanport, or Ferriferous, Limestone was a well-known rock unit in western Pennsylvania by the time H.D. Rogers came visiting. Rogers (1858, p. 491) states that the Ferriferous limestone was so called because in many localities, "a very valuable deposit of iron rests directly upon it [the limestone], while in other localities the bed of limestone itself seems to be divided between carbonate of lime and carbonate of iron." I.C. White (1878) used the name "Vanport" as a synonym for the Ferriferous limestone. He used it in reference to quarries "…near Vanporte [sic] on the Ohio, 3 miles below the mouth of the Big Beaver [River] . . ." (White, 1878, p. 61).

The "Ferriferous" tag placed on the unit came about due to the occurrence of iron ore in the upper beds of the Vanport. The "Buhrstone" iron ore (Clarion Iron Ore of White, 1879), a relatively thin sideritic bed, was typically present atop the Vanport across a large portion of western Pennsylvania and eastern Ohio.

Immediately below the Buhrstone, the Vanport can exhibit a thin, ferriferous zone of limonitic, punky limestone or shale that is cemented with iron. The uppermost Vanport is argillaceous and takes on the appearance of other marine zones, notably those that occur in the Conemaugh Group, such as the Brush Creek and Pine Creek. Comparatively, these units typically exhibit a relatively thin bed of limestone followed by a layer of iron-bearing shale that grades upward into a non-ferrous shale sequence. Sideritic beds have been observed overlying the Pine Creek marine beds in Westmoreland County. The inference is that the sedimentologic package is one that is repeated throughout the Pennsylvanian marine zones.

The "ferriferous" part of the Vanport appears to be related to oxidized iron that came, in part, from the dissolution of the limestone. Once the carbonate minerals had been leached out, a residual framework remained that may have been later enriched by percolating iron-laden waters from the overlying Kittanning beds. White (1879) talks of the Houk & Grannis drift (the Big Bank), where the "Clarion ore" was found to be 22 feet thick, replacing the Ferriferous limestone (Vanport) entirely. White (1879, p. 40) goes on to state that, "It is a very common thing for the limestone to come in and cut away a considerable portion of the ore, and sometimes nearly all, and again, in the midst of the ore, we often find lenticular or irregular masses of limestone wholly unchanged." Clearly, the ferriferous part of the Vanport is quite variable with regard to its thickness as well as geographic distribution. In general, White (1878) writes in the Report of Progress for the Beaver River District that the Buhrstone does not attain much importance, as it is usually too thin to warrant mining.

At the Vanport section along PA 108 just west of Harlansburg, the Lower Kittanning sandstone overlies the Vanport. At the contact between the two units there is a limonite/goethite zone approximately 0.3 m (1 foot) thick. Here the iron ore is incorporated into the sandstone as irregularly shaped concretions, some lined with goethite, but the majority lined with the characteristic yellow-brown and yellow-red limonite.

At the Meritex site, the Buhrstone ore is visible atop the limestone at "the cave" in Section 1. The bed itself is approximately 10 cm (3 inches) thick (Figure 7- 12).

There is a record that the Wampum Furnace made a "run" of the native ore and found it to be unsatisfactory. It was thought that the problem was with the furnace and not the ore. The average amount of iron was 45 percent. Successful runs generally occurred where the local ore had been mixed with "Lake" (Great Lakes) ore (White, 1879).

Figure 7-12. The Buhrstone ore overlying the Vanport Limestone.

Vanport Fossils

The Vanport generally is very fossiliferous. However, they are not readily apparent at the Meritex site due in part to the gypsum encrusting much of the outcrop.

Fossils are generally on the small side and sometimes difficult to see. Representative types include brachiopods, gastropods, bryozoans, and crinoid columnals. The crinoid columnals can be rather large (up to 1.5 cm [0.5 inches] in diameter) and can be observed along weathered bedding surfaces, sometimes in lengths up to 1 meter (3 feet). They are generally four to ten cm (1.5 to 4 inches) long. The larger columnals tend to occur in the upper, more planar limestone beds. At an outcrop along Toll 60 (Day 2 road log mile 19.9 - both sides of the highway on the upper parts of the embankments amidst the crown vetch), these columnals can often be found weathered free from the limestone matrix. Examples of fossils at STOP 7 can be observed at the Blocks II (Figures 7-3 and 7-13).

Attempts have been made by one of us (Kochanov) to obtain a representative sampling of the fossils. Due to the relatively small size, a hands-and-knees approach to collecting has been found to be the best method. Weathered slabs are also good to collect. At the east end of Section 2 (at the breakdown), fossils can be found weathered free of the limestone. Quaternary O (a surfactant) has been used in an attempt to disaggregate the more argillaceous portions of the Vanport in order to recover the residual fossils and minerals. That process is ongoing, with several genera of ostracodes, foraminiferans, and juvenile stages of gastropods, brachiopods, bryozoa, and crinoidal debris being observed.

One interesting note is the occurrence of the encrusting foraminiferan *Tolypammina*. At Section 2, examine the planar limestone beds at the base of the Vanport, just above the Scrubgrass coal zone. On the bedding surfaces, you should be able to see the white outline of the microfossil in marked contrast to the dark-gray matrix. They will appear as micro-sized worm-like tubes that end in a spiraled coil at one end. Depending on the orientation of the fossil, the test may appear quite convoluted (Figure 7-14).

Figure 7-13. Photo of pen, with large crinoid columnal on weathered block of Vanport Limestone for scale.

At first it was thought that the white outline was gypsum, since small gypsum crystals are also visible on the bedding surfaces along with these fossils. Analysis of the white outline indicates that they are composed of calcite (John Barnes, 2005, personal communication) (Figure 7-15).

A systematic review of the invertebrate fossils found at this site is ongoing, and identification to a specific level will have to await more detailed study. Genera found thus far include:

Foraminiferans: *Tolypammina sp.*
Coral: *Lophophyllidium sp.*
Bryozoans: *Fenestrellina sp.; Rhombopora sp.*
Brachiopods: *Dictyoclostus? sp. Phricodothyris sp.; Anthracospirifer sp.; Composita sp.; Beecheria sp.; Hustedia sp.*
Gastropods: *Platyceras sp.; Naticopsis sp.; Euconospira sp.; Amphiscapha sp.*
Cephalopods: *Orthoconic type* (possibly *Pseudorthoceras or Mooreoceras)*
Crinoids: *Columnals*
Arthropods (Ostracodes): *Bairdia sp.; Cavellina sp.*

Karst and Cave Development

The “cave” along the side of the hill at Section 1, and portions of the outcrop at Section 2, serve as leads into a discussion on karst development within the Vanport Limestone.

Karst generally refers to the topographic features that form on soluble bedrock, typically limestone and dolostone, by the process of dissolution. Features such as caves, sinkholes, closed depressions, and losing streams are characteristic of karst areas.

As discussed earlier in the development of gypsum, the dissolution process uses carbonic acid as the primary agent to dissolve carbonate bedrock.

Much of the literature on Vanport karst comes largely from the caving community (Stone, 1932 and 1953; White, 1960 and 1976, White and Fisher, 1958; Fawley and Long, 1997; Sasowsky and others, 2003).

In spite of having some of the most extensive caves in Pennsylvania, such as Harlansburg Cave, with over 6.6 km (four miles) of passage (Fawley and Long, 1997), the Vanport Limestone is basically devoid of surface karst features (White, 1960). This can be attributed to its relatively limited outcrop exposure and typical occurrence along hillsides, where outcrops are often covered by colluvial material. In Lawrence County the limestone ranges from 4 to 7 m (13-23 feet) in thickness (Miller, 1934).

Maze-like caves are characteristic for the Vanport (Stone, 1932; White, 1976). Stone (1932, p. 9) describes the Vanport Hineman Cave in Armstrong County as a "…maze of passages in all directions, forming a network rather than a branching pattern."

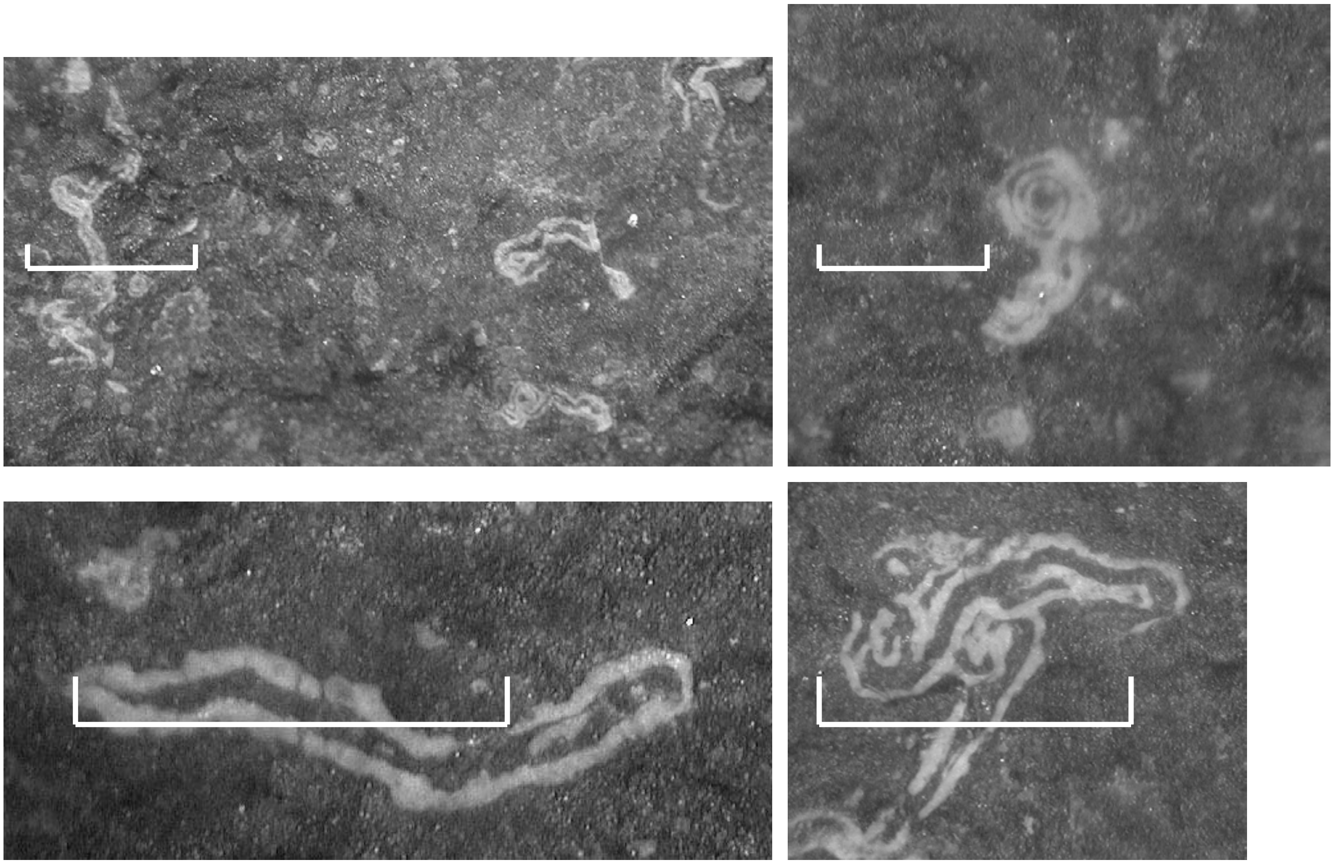


Figure 7-14. Various views of the encrusting foraminiferan *Tolypammina*. Bar in all photos is 2mm.

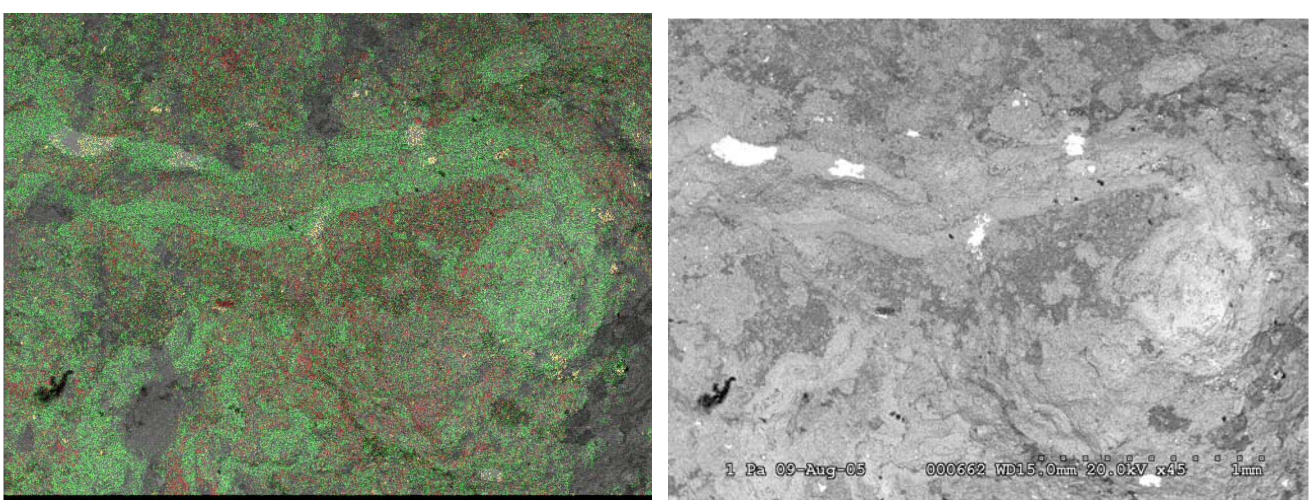


Figure 7-15. SEM photomicrographs of *Tolypammina sp.* at 45X. Left photograph shows that the test of the fossil is composed of calcite (green). Silica is red.

In general, the Vanport caves seem to be confined to the upper (gray) limestone, which lies directly beneath the Buhrstone iron ore (White, 1976). The lower (blue) limestone is too argillaceous to have cave development (White, 1976). At this locality, the “blue” limestone is restricted to the bottom meter in Section 2.

It is not clear whether the cave in Section 1 is a true cave (a cave being defined as a passage large enough for an individual to move through). The large amount of talus in front of the entrance may be covering a much larger opening. Note that the opening occurs at the top of the Vanport immediately below the Buhrstone iron bed (Figure 7- 16).

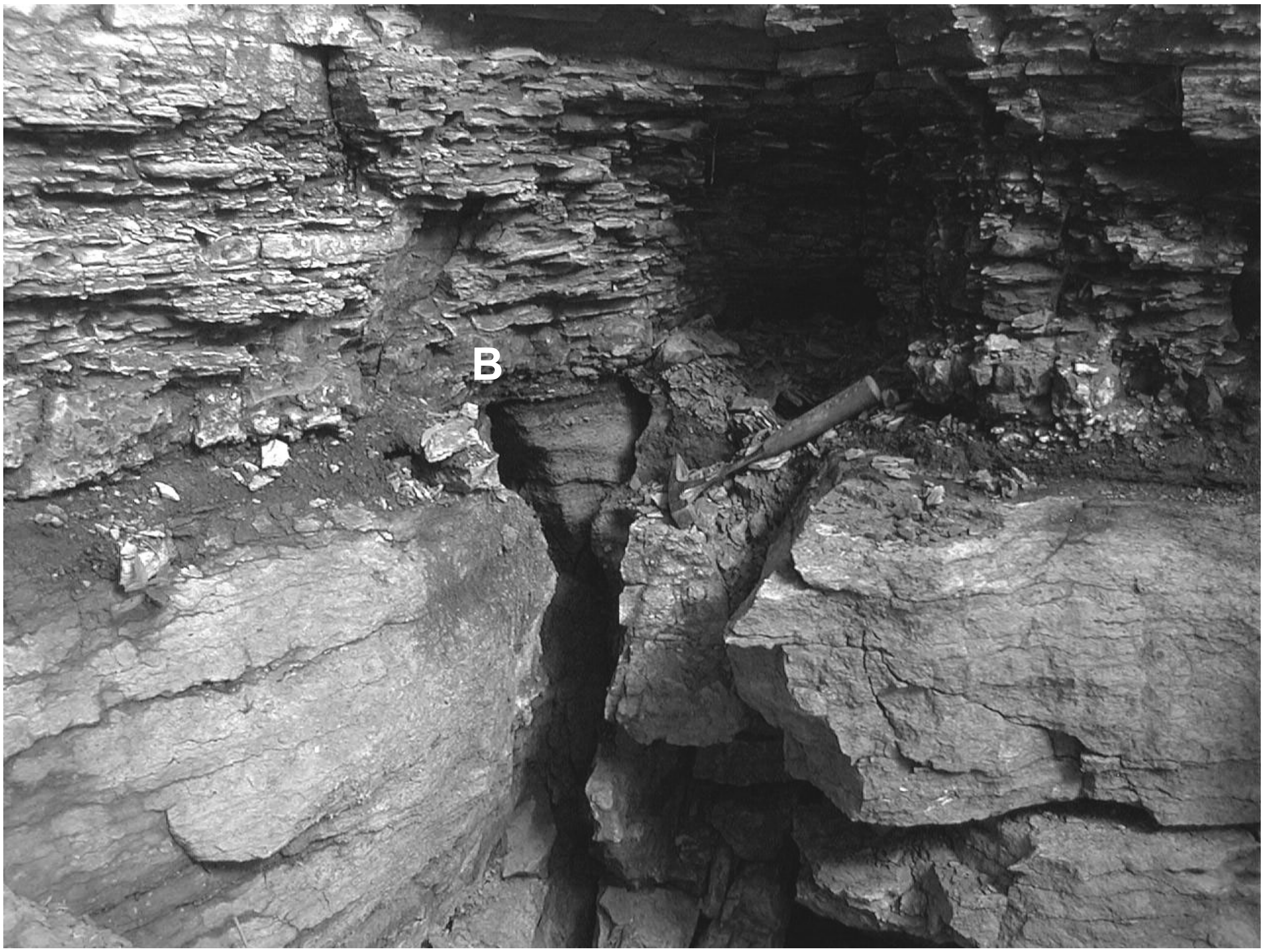


Figure 7-16. The Buhrstone iron ore (B) atop the “cave” in Section 1.

When examining the outcrops at Sections 1 and 2, as well as the outlying sections, notice that the joints are widely spaced. Where they do occur, a zone of vertical dissolution is apparent (Figure 7-17).

Look at the east end of the outcrop at Section 2. Note the dissolution zone that starts at the top of the outcrop that is similar to the patterns shown in Figure 7-17. From there, a stair-step pattern of preferred dissolution takes over, following bedding partings, and continues to the right (Figure 7-18).

One can see the high degree of increased permeability where there is nodular bedding. Refer to Figure 7-5, and one can visualize how groundwater would flow along the boundaries of the “individual nodules.” Dissolution would continue vertically until it meets up with the water table and begins moving in a more lateral direction to some discharge point, either a stream or spring.


Figure 7-17. Dissolution along joint surfaces at the outlier Sections.

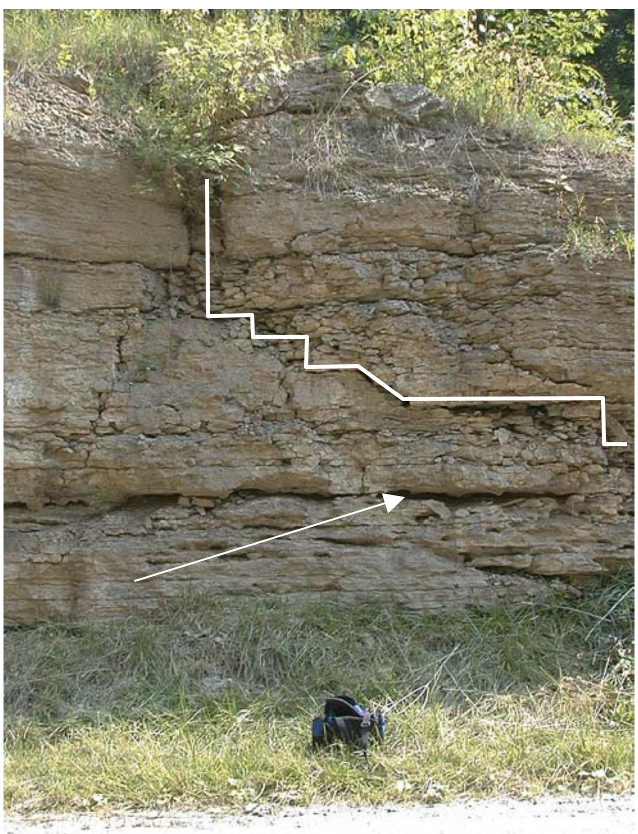



Figure 7-18. Section 2 outcrop showing stair-step dissolution of the nodular limestone. Note widened bedding parting towards the base of the exposure (arrow). Expanded view of area shown on right.

The widened parting shown in Figure 7- 18 gives all the indications that it was on its way to becoming the main passageway. The roof of the parting, and accumulation of residual material on the floor of the parting, provides some evidence that the dissolution process was hanging at this level for some period of time, albeit not long enough to develop a passageway of any significant size. It appears that the process had been put on hold simply due to the lack of water. (By the way, the gypsum geodes are found in this zone.) Initially a cave passage's size is dependent upon the amount of water moving through it.

Acknowledgements: John Barnes for x-ray diffraction and SEM work; Bill Bragonier and Vik Skema for discussing the Vanport; Keith Brady for discussing pyrite occurrence in the Lower Kittanning; Meritex for permission to allow the Field Conference to use this facility as one of our stops; Pennsylvania Geological Survey for its continued support.

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STOP 8- NEW CASTLE FAULTED FOLD

Leader- Thomas H. Anderson (text by Ronald B. Cole, Patricia A. Campbell, and John A. Harper)

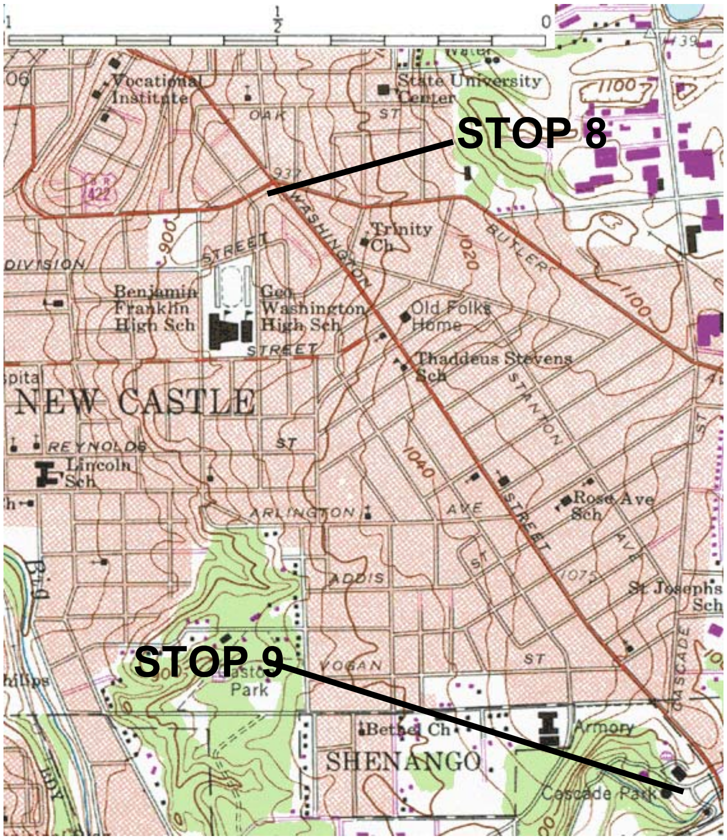


Figure 8-1. Location map for STOPS 8 (Faulted Fold) and 9 (Cascade Park). From New Castle South 7½' topographic map.

STOP 8 (Figure 8-1) is an unusual exposure (for this area) of a complex structure in the Pottsville. Such structures are seen periodically this far onto the Appalachian Plateau, but usually not one this well developed.

Stratigraphy

The identity of the strata at this locality is not intuitively obvious, nor are there good outcrop or core data nearby to support any suppositions. The strata consist of about four feet of sandstone underlain by a two- to 15-inch layer of nodular siderite and approximately four feet of silt-shale. The exact thicknesses are difficult to determine because of the complexity of the structure exposed here.

We have based the following "guess" as to the identity of the sandstone and underlying siltstones and shales on data from DeWolf (1929) and White (1879). For example, DeWolf's Plate IV (and p. 150) shows an outcrop about 500 feet south of the CVS locality, and at approximately the same elevation, that he identified as three feet of Upper Connoquenessing sandstone. The thickness of the outcrop is similar to that at CVS so it is likely that the two outcrops contain the same strata. But the identity of these strata is still in question.

According to the New Castle South 7.5-minute topographic map, the elevation of the CVS locality is about 950 feet above mean sea level (Figure 8-1 shows the intersection of PA 65 and Business Route US 422 as 937 feet and, given that the CVS parking lot slopes gently upward to the outcrop, and that the height of the concrete wall and fence is approximately eight feet, the top of the outcrop should be about 15 to 20 feet above the elevation at the intersection). DeWolf (1929, pl. 4) drew the 1,175-foot structure contour on the Middle Kittanning coal about 800 feet to the east-southeast of the CVS locality. The 1,150-foot structure contour lies 0.73 miles to the west along the Shenango River. The regional dip can be calculated at about 34 feet per mile west-northwest, indicating that the Middle Kittanning coal should be at an elevation of 1,170 feet at the CVS locality. The strata exposed at the CVS locality, therefore, lie about 220 feet below the Middle Kittanning. DeWolf (1929, pl. 6) indicates that the Upper Connoquenessing sandstone occurs at an average distance of about 250 feet below the Middle Kittanning coal. Regional variations in the Pottsville and Allegheny sections could account for this mere 30-foot discrepancy. It is also possible, as we will see at STOPS 10 to 12, that an as yet unnamed sandstone developed within the Mercer section in the New Castle area. This appears to be the most reasonable identity for the CVS locality sandstone.

White (1879) shows an average of 88 feet between the top of the Upper Connoquenessing and the top of the Lower Connoquenessing sandstones. Although these intervals vary considerably, it is unlikely that almost 40 feet of section would be taken up with expansions within these sandstones, especially considering our current knowledge of the Mercer sandstone that developed within the New Castle area.

Until further data support an alternate interpretation, we are calling these sandstones, siltstones, shales, and siderites part of the Mercer section of the Pottsville Formation.

Fold Description

The study area is located in the town of New Castle in north central Lawrence County in western Pennsylvania (Figure 8-2). Deformation at New Castle includes a tight, asymmetric anticline (referred to herein as the New Castle fold) within the Pottsville Formation. The anticline has an amplitude of at least 20 feet and a wavelength of about 90 feet and is cored by a thrust fault that tips out in the nearly overturned frontal limb of the fold (Figure 8-3). The thrust fault is contained primarily within a shale interval and has up to a few meters of displacement in the fold core. The folded strata can be traced eastward and westward along the outcrop into flat-lying beds, although there is also a low amplitude fold and a possible thrust fault at the west end of the outcrop. The outcrop does not reveal enough of the vertical section to determine if strata above and below the New Castle fold are also deformed.

The New Castle fold trends nearly north-south (hinge-line trend is approximately 005) and verges towards the east (Figures 8-3 and 8-4). In a regional context, the fold is located in the homoclinal portion of the Appalachian Plateau physiographic province (Figure 8-2), which includes predominantly undeformed foreland basin strata. The New Castle fold is enigmatic both with respect to it's location in the Plateau province and it's trend, compared with most regional structures in western Pennsylvania (Figure 8-5). Hypotheses for the origin of the New Castle fold include soft-sediment deformation (e.g., channel slumping) and tectonic deformation. The absence of dewatering structures together with the brittle deformation observed within the New Castle fold indicates that the structure is tectonic in origin and principally records contraction. This hypothesis requires the existence of at least two detachments that accommodate rotation of the bedding in the exposure of thin-bedded muddy layers from horizontal to more than 45^{o} (Figure 8-6). The lower detachment also accommodates development of the principal anticline. A panoramic photograph of structures is shown in Figure 8-6. Figures 8-6.1, 8-6.2, and 8-6.3 show the details of detachments that bound the rotated muddy layers at the east end of the outcrop. Figure 8-6.4 is a detailed photograph that shows a small back thrust within the core of the fold. The lack of features suggesting soft-sediment deformation does not preclude the process. Further study, including examination of thin sections, is needed to constrain soft-sediment versus tectonic origin. However, in view of the additional fact that no extensional features are present, one must conclude that the exposure is completely within the toe of an inferred slump. Figure 8-7 shows some characteristic features of slumping recorded by higher stratigraphic units to the southeast. If the deformation were tectonic in origin, then it was related to the late Paleozoic Alleghanian orogeny and/or to contemporary tectonic stress. One way to evaluate the possible tectonic origin of the New Castle fold is to compare the fold with other structural features across the Plateau province. The following paragraph describes deformation across the Plateau province of Pennsylvania (as shown in Figure 8-5) in order to provide a regional context for the New Castle fold.

Southeast of the New Castle fold, the Plateau province contains large-wavelength, low-amplitude folds that generally trend northeast-southwest and are parallel to the Appalachian structural front (the leading edge of the Appalachian fold-and-thrust belt). These folds include the Chestnut Ridge and Laurel Hill anticlines, which involve Upper Devonian through Carboniferous-age rocks at the surface and are interpreted to have formed in relation to motion along a décollment within Middle Devonian shale (Rodgers, 1963; Gwinn, 1964). Evans (1994) confirmed and defined the limit of a regional décollment within Middle Devonian shale units beneath the Appalachian Plateau in Pennsylvania (Figure 8-5). Gryta and others (1996) documented small-scale, south- to southeast-dipping thrust faults in Upper Devonian strata of northwestern Pennsylvania, and suggest that these structures may be rooted in a Middle Devonian shale décollment as described by Evans (1994). Frey (1973) and Beinkafner (1983) interpreted folds in the New York portion of the Appalachian Plateau to have formed above a décollment rooted in salt of the Silurian Salina Group. The fold described by Beinkafner is an anticline that is part of the Bass Islands Trend this trend includes multiple northeast-trending thrust faults that are rooted in the Salina Group and extends from western New York into northwestern Pennsylvania (Patenaude and others, 1986; Van Tyne, 1996) (Figure

8-5). On the basis of strained crinoid ossicles in Devonian and Mississippian strata and subsurface data, Hudak (1992) documented north-northwest layer-parallel shortening in northwestern Pennsylvania that was related to movement along a décollment rooted in shale of the Ordovician Queenston Formation. Collectively, these studies support the possibility that regional décollment(s) within Middle Devonian and older strata extend beneath the Appalachian Plateau and influenced deformation of overlying rocks. Other structural features within the Appalachian Plateau of Pennsylvania include regional northwest- and northeast-trending lineaments and faults (Parrish and Lavin, 1982; Lavin and others, 1982; Rodgers and Anderson, 1984; O'Neil and Anderson, 1985; Palmquist, 1985; Pees, 1985; Alexandrowicz, 1999; Alexandrowicz and Cole, 1999), a northeast-trending basement graben structure known as the Rome trough (Shumaker, 1996), small-scale northeast- and northwest-trending folds in Devonian and Mississippian rocks (Decker, 1920; Eaton, 1955; Brock, 1975; Wegweiser and Babcock, 1996), and north-south-trending faults (Alexander and others, 2005) (Figure 8-5).

The New Castle fold is oblique to most of the regional and local folds, thrust faults, and lineaments that have been documented across the Plateau province (Figure 8-5). Thus, there is not a simple co-kinematic relationship between the New Castle fold and structures across the Plateau that may have formed during the Alleghanian orogeny. This is also evident by comparing the interpreted Alleghanian shortening directions in the Plateau province with the New Castle fold trend. In particular, Evans (1994) interpreted three phases of shortening in the Plateau region during the Alleghanian orogeny. The first phase occurred early in the orogeny and involved NNW shortening. The second phase, which Evans (1994) interpreted as the main phase of deformation, involved NW shortening. This episode of shortening is also documented on the basis of strain analyses by Smart (1989) and Hudak (1992) for areas farther to the northwest in the Plateau (Figure 8-5). The third phase occurred late in the orogeny and involved WNW shortening. Evans (1994) suggested that deformation during each of these phases involved movement along a regional décollment that formed within Middle Devonian shale. The trend of the New Castle fold is most consistent with Evans' late stage of WNW shortening, and so could have formed during later phases of the Alleghanian orogeny. The New Castle fold is situated within the limits of the Middle Devonian décollment defined by Evans (1994), and, accordingly, may be a detachment-related fold. Interestingly, the New Castle fold is subparallel to a set of inferred north-south-trending basement-involved faults that are mapped in western Pennsylvania and western New York (Figure 8-5) (Alexander and others, 2005). Displacement along such faults in western Pennsylvania could have influenced the trend and position of ramping from a décollment. In this case, the New Castle fold could be a Late Paleozoic detachment-related fold that was influenced by a basement structure. Alternatively, the New Castle fold is also consistent with shortening under contemporary tectonic stress (Figure 8-5). Patterns of jointing as well as small-scale "pop-up" folds in northwestern Pennsylvania have been attributed to deformation associated with the contemporary tectonic stress field (Evans, 1994; Gryta and others, 1996).

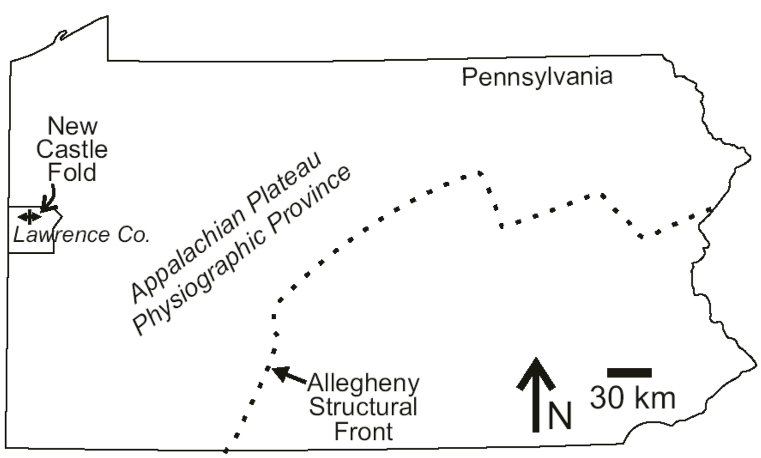


Figure 8-2. Map of Pennsylvania showing the location of the New Castle fold in Lawrence County within the Appalachian Plateau physiographic province.

Figure 8-3. Photograph of the New Castle faulted fold.

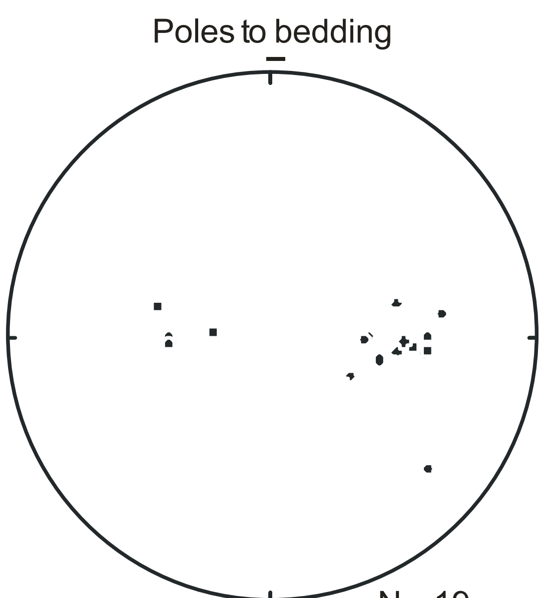


Figure 8-4. Lower hemisphere equal area projection of poles to bedding around the hinge area of the New Castle fold. On the basis of a best fit great circle through the poles to bedding, the hinge line of the fold trends about 005, or nearly north-south.

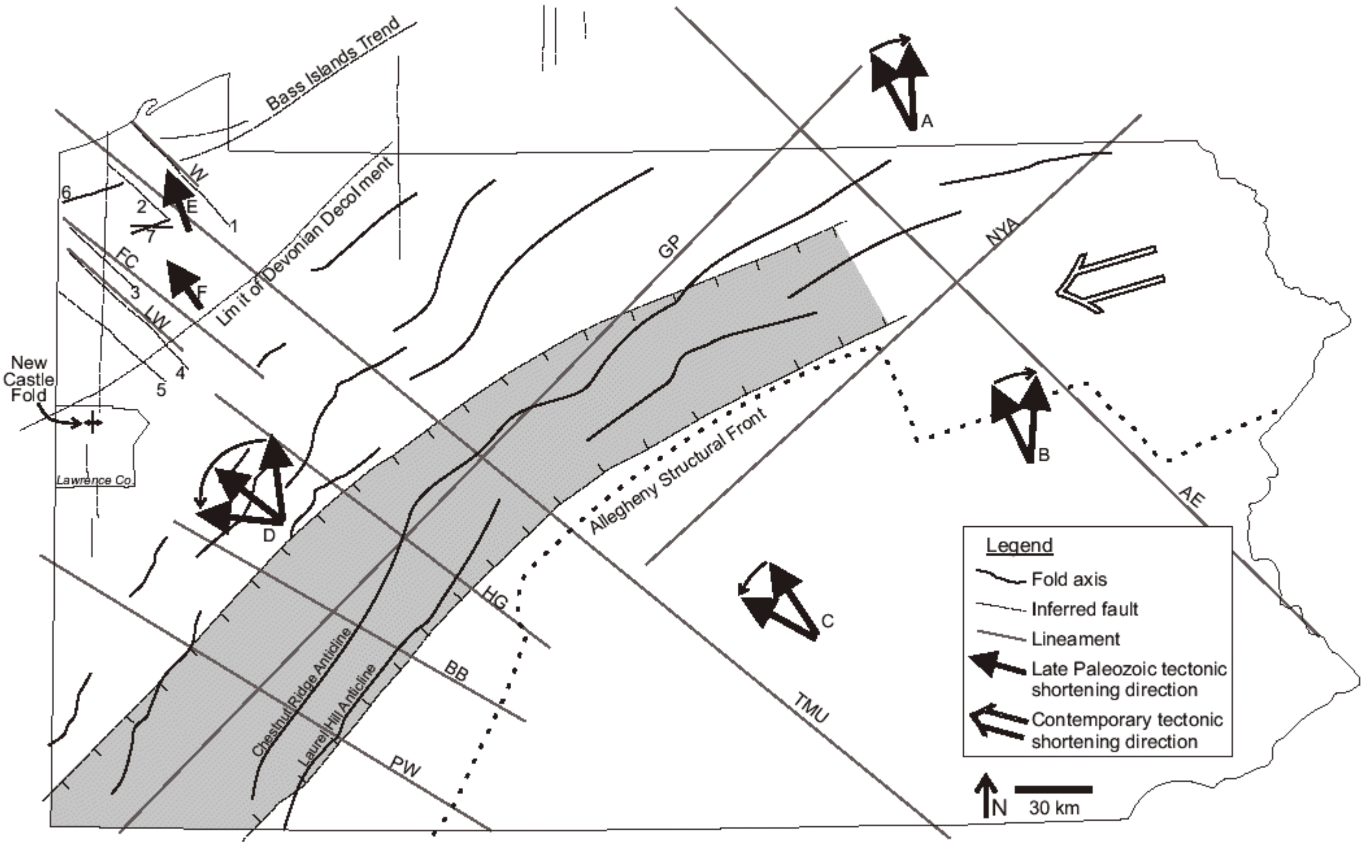


Figure 8-5. Map showing structural features across the Appalachian Plateau physiographic province of Pennsylvania, and directions of inferred Late Paleozoic tectonic shortening. Lineament abbreviations are as follows: NYA = New York-Alabama, GP = ???, TMU = Tyrone-Mt. Union, HG = Home-Galitzin, BB = Blairsville-Broadtop, PW = Pittsburgh-Washington, LW = Lake Wilhelm, FC = French Creek, and W = Waterford (Parrish and Lavin, 1982; Rodgers and Anderson, 1984; O'Neil and Anderson, 1985; Palmquist, 1985; Pees, 1985). Structures numbered 1 through 6 are sub-surface features interpreted from structure contour maps (Alexandrowicz, 1999; Alexandrowicz and Cole, 1999). Fold axes numbered 7 represent the average axial trends of small-scale anticlines found along stream valleys in the Crawford County region (Decker, 1920; Eaton, 1955; Brock, 1975). The hachured and gray shaded region shows the location of the Rome trough (Shumaker, 1996, and references therein). Late Paleozoic shortening directions (labeled A through E) are based on interpretations of Geiser and Engelder (1983) (A), Gray and Mitra (1993) (B), Wise (2004) (C), Evans (1994) (D), Hudak (1992) (E), and Smart (1989) (F). Where multiple shortening directions are interpreted for a region, the small curved arrows show the time progression of shortening, generally corresponding with earlier and later phases of the Alleghanian orogeny. The orientation of contemporary tectonic shortening is from Zoback and others (1989). The Appalachian structural front represents the boundary between the Alleghanian fold and thrust belt (Valley and Ridge physiographic province) to the southeast and the Alleghanian foreland region (Plateau physiographic province) to the northwest.

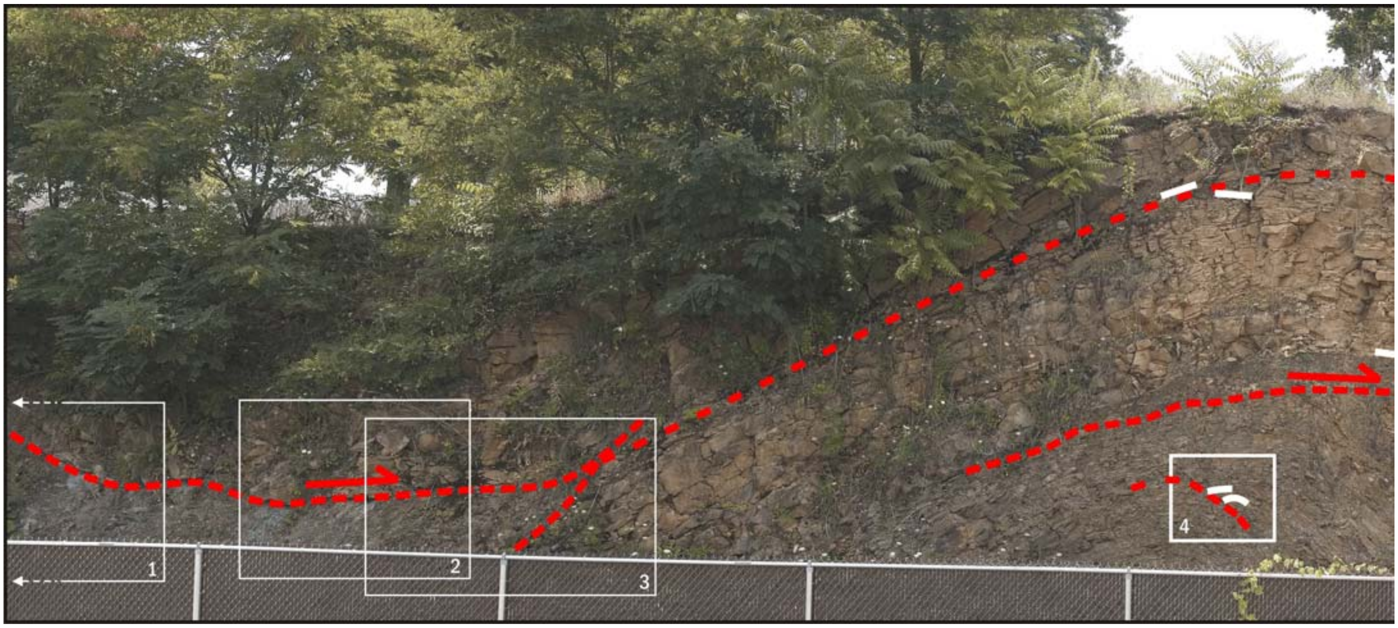
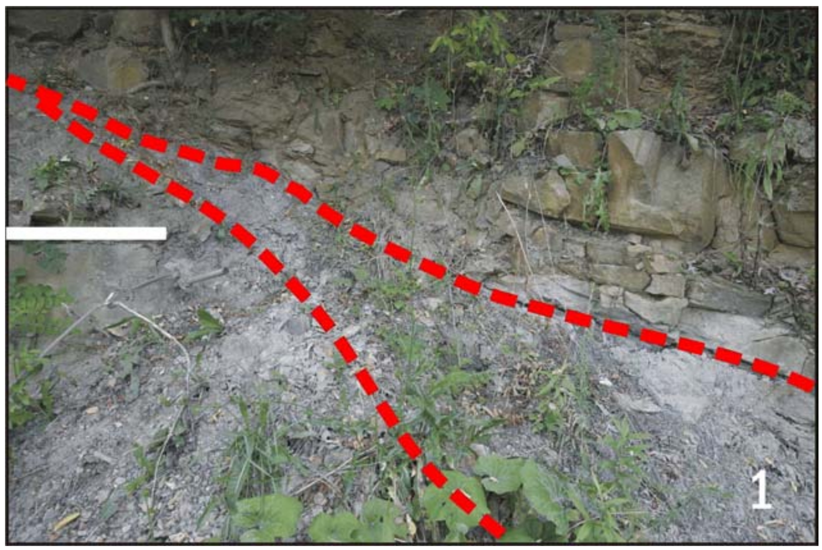
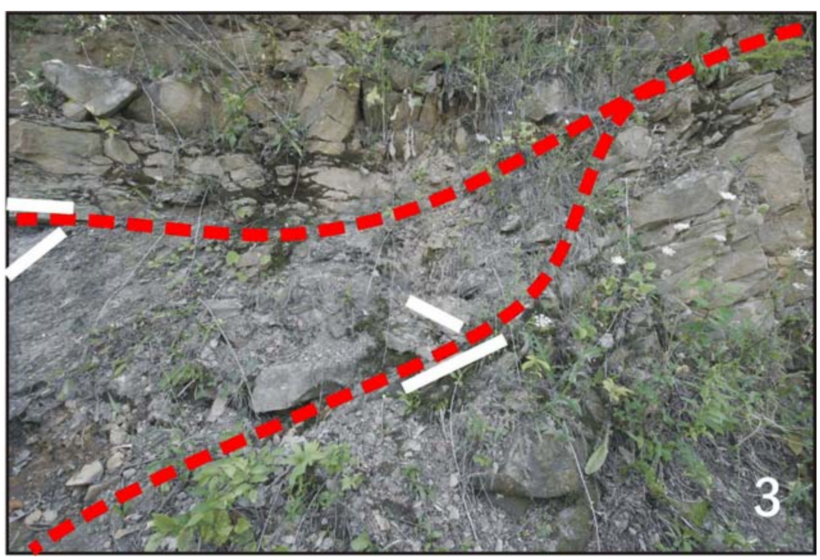
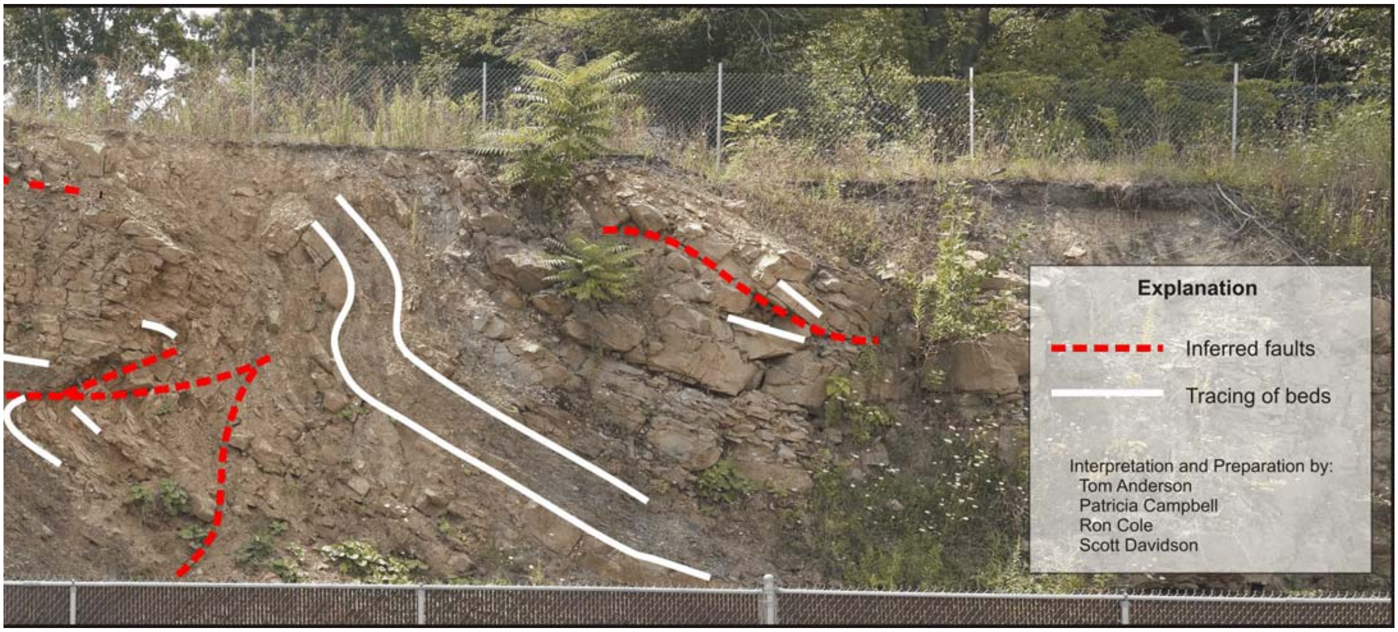


Figure 8-6. A composite of photographs that shows faulted and folded strata stratigraphically low in the section of Pennsylvanian age. The rock face is exposed in New Castle, Pennsylvania. Details of the outlined areas are illustrated in Figures 8-6.1 through 8-6.4.





Figures 8-6.1, 8-6.2, and 8-6.3 - A sequence of close-up photos, taken from east to west, showing inferred faults (black lines), including detachments and ramps that bound the thin-bedded mudstone (beds highlighted by white lines).



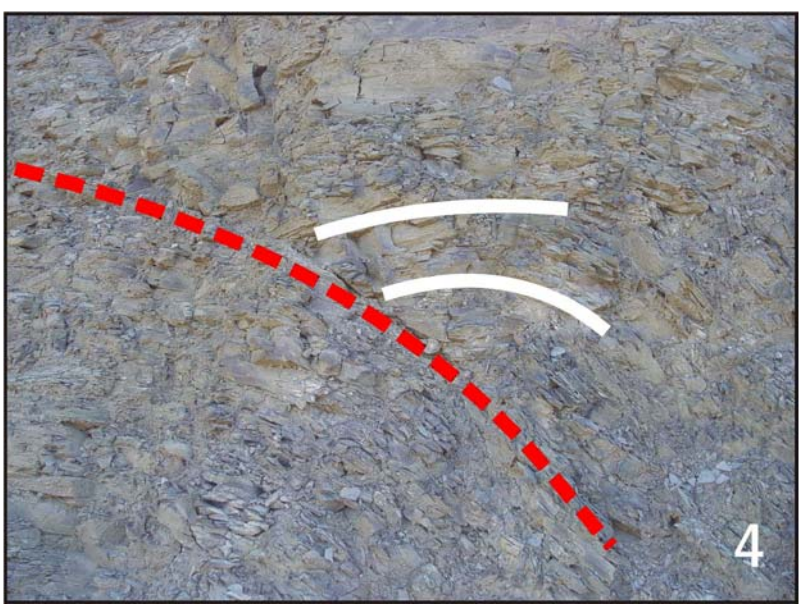


Figure 8-6.4 - A close-up photo of the core of the anticline upon which a fault (shown in black) with small displacement is inferred based upon discordant dips of thin beds (white lines).

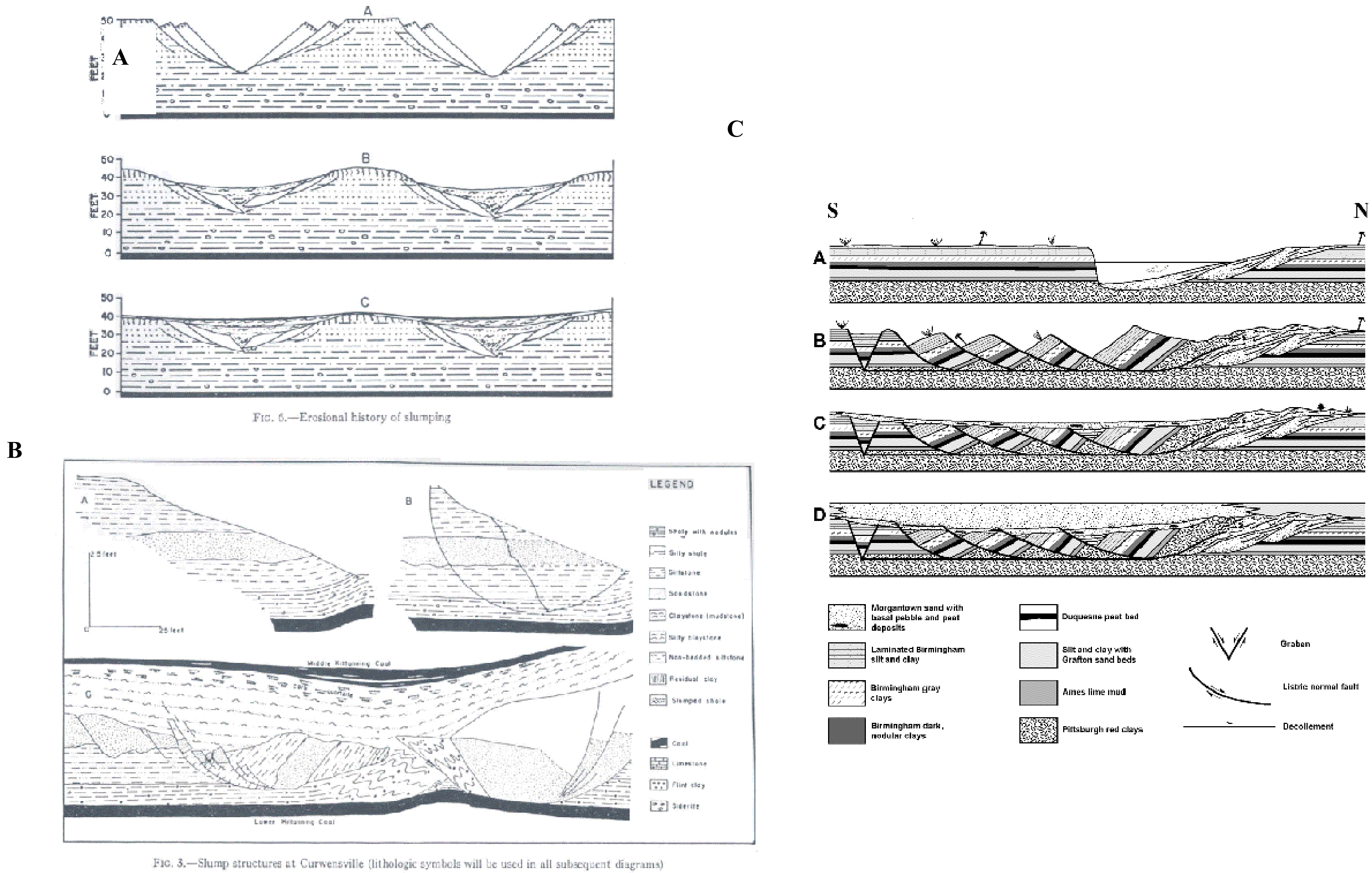


Figure 8-7. Sketches of some slump structures in southwestern Pennsylvania. Note extensional structures except at toe of slump where semi-lithified sediment may participate in folding. A and B are from Williams and others, (1965). C is modified from Shultz and Harper (2000).

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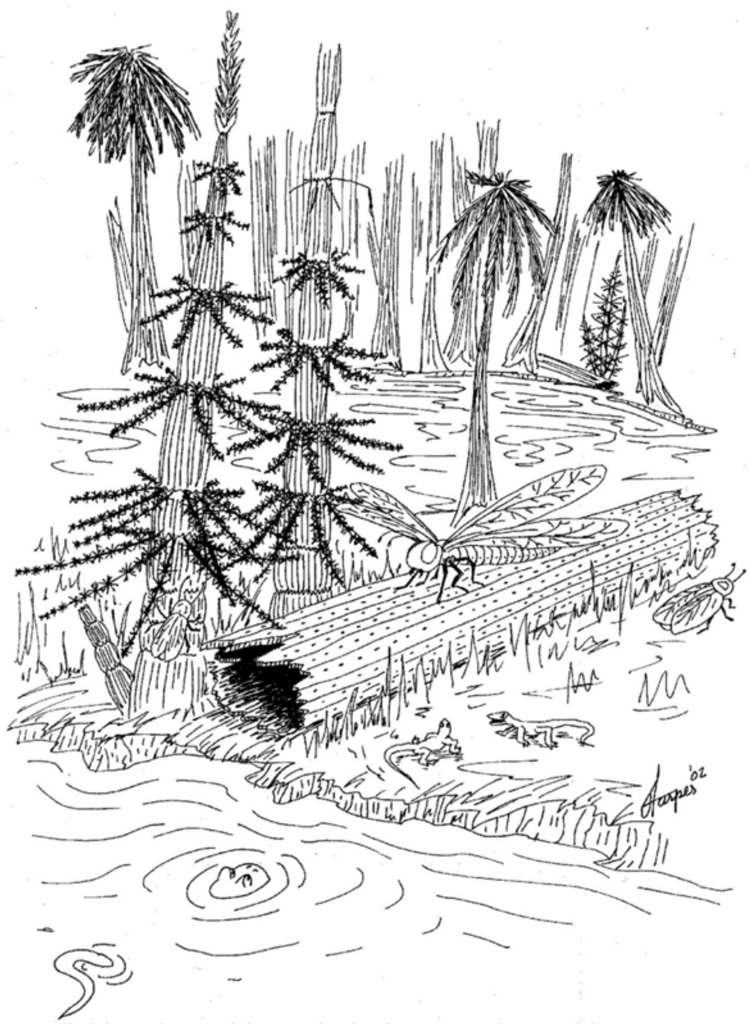
GREAT MOMENTS IN GEOLOGIC HISTORY
Part 9 - The Pennsylvanian



"Those damned bugs think they own the world. Boy, just give me a few hundred million years of evolution and I'll show them a thing or two!!!"

STOP 9- CASCADE PARK (LUNCH) AND GLACIAL DRAINAGE DIVERSIONS
Leader- Gary M Fleeger

From the City of New Castle web page at http://www.newcastlepa.org/Government/Recreation/Cascade_Park/cascade_park.htm.

“Seldom was the name Cascade Park printed or spoken of in the early part of the 20th century without the adjective "beautiful" preceding it. From two years before the turn of the century, the little picnic grove grew to be one of the region's most scenic and popular recreation spots. Cascade Park was once one of the most beautiful recreation areas in western Pennsylvania.

“Originally known as Big Run Falls, the site was purchased in 1892 by Col. Levi Brinton. Around the turn of the century, power companies were finding it profitable to develop amusement parks. In 1897 Col. Brinton sold the property to New Castle Traction Co., which later became Pennsylvania Power Company.

“After extensive landscaping and addition of numerous rides, the company held a contest to name the park. In deference to its cascading waterfall, it became known as Cascade Park. Cascade Park opened May 29, 1897. Cascade Park soon became a popular excursion point from much of western Pennsylvania and eastern Ohio. Special excursion trains would arrive in New Castle on East Washington Street and streetcars would carry passengers to the Park. Up to 7,200 people could be transported daily to the Park. The company built a theater, a baseball park, a roller coaster, and installed a merry-go-round. The company built the largest dance pavilion, which is still standing, in Pennsylvania in 1898, lighted with 45 arc lights. A lake for boating, swimming and skating, as well as a zoo and a picnic grove, were added the following year.

“By 1925, the city claimed there were few cities the size and age of New Castle which could boast such a beautiful park. It was said to have the most beautiful natural scenery in western Pennsylvania and could accommodate up to 25,000 persons.

“The midway boasted 17 rides, numerous eating places, concessions, boating and an open-air theater. Cascade Park also offered a 15-acre lake and a tourist camp with cooking and recreation houses in the picnic grove where tables could accommodate more than 2,000 campers. In the 1920's, popcorn and peanut vender Billy Glenn, built the first swimming pool, bath house and fun house, the Gorge roller coaster, and set up a parking lot.

“During the Big Band era, many popular dance bands found receptive audiences at Cascade Park. Guy Lombardo appeared several times. Other musicians included Paul Whiteman and Vaughn Monroe. Danny Thomas played an engagement here.

“In 1934, Pennsylvania Power Company turned the park over to the City of New Castle to be used forever as a public recreation area. Park attendance declined in the second quarter of the century. Over the years, the Park has been known for the trees and flowers, notably the Floral Steps, that enhanced its natural beauty. Another jewel of the park was the lake, achieved by constructing a dam on Big Run. The lake provided swimming and boating in the summer and ice skating in the winter. Fishing in the lake was also a popular pastime. The lake ceased to exist after the dam cracked.

“The park was rediscovered in the late 1970's. The first to come to its aid was the Paws and Taws Square Dancers, who were looking for a wooden dance floor to call their own. Dismayed at the condition of the park pavilion, the dancers raised the funds in 1976 for repairs and renovations. The community followed the club's lead. In 1980, a group of volunteers organized as the Cascade Park Development Committee. Its first project was a master plan to restore the neglected park, and a commitment from the City that all future development at the park must reflect the Victorian style of the earlier structures.

"In that decade, the amusement rides were removed from the park, the Floral Steps were repaired, buildings improved, public restrooms constructed, and a playground installed. Local garden clubs adopted the Park and now plant and maintain flowers, trees and shrubs growing there. Events such as the annual "Back to the 50's" celebration, are now breathing new life into the park. These and other festivals during the year are again attracting people from near and far to one of New Castle's most cherished legends."

Geology

Big Run flows over Homewood (?) sandstone here in Cascade Park. The Falls is a cataract (single drop), not a cascade (numerous small drops), and therefore, the park is misnamed.


Figure 7-1- Big Run Falls over Homewood (?) sandstone in Cascade Park.

Big Run has been considered for many years to have been the original bedrock valley of Slippery Rock Creek (Leverett, 1902, 1934; DeWolf, 1929; Richardson, 1936; Preston, 1977). The original bedrock valley of Slippery Rock Creek itself was the result of a drainage diversion. Slippery Rock Creek now flows through the gorge at McConnells Mill State Park and enters Connoquenessing Creek near Ellwood City. The diversion was most likely a glacial diversion associated with glacial Lakes Watts and Edmund during the Pleistocene. Which glaciation was responsible for the diversion is not certain, and there are those who believe that the diversion is unrelated to glaciation (D'Urso, 2000).

Data from water well logs suggest that pre-glacial Slippery Rock Creek did not follow the course of Big Run into the Shenango River at New Castle. The bedrock floor of the Big Run valley, two miles northeast of here, is 30 feet lower than the sandstone ledge (960 feet) here in Cascade Park, and over 50 feet lower another mile upstream (Figure 7-2). These water well data suggest that the preglacial course of Slippery Rock Creek followed the current Big Run valley from Kennedy Mill west to Mount Herman Church, and then north and northwest into the current Neshannock, Little Neshannock, Lackawannock Creek, and Shenango River valleys, and on to the Erie basin. However, Poth's (1963) bedrock topography map shows the floor of the valley north of Mount Herman Church sloping southward toward the current Big Run valley. None of the wells in that area that Poth used to construct the map reach bedrock, so he could not determine which way the bedrock valley floor slopes. He may have chosen to show it sloping to the south to be consistent with the interpretation of preglacial Slippery Rock Creek flowing west to New Castle. Carswell and Bennett's (1963) drift thickness map, adjacent to Poth's map to the west, suggests, by the dendritic pattern of the contours, that the valley north of Mount Herman Church slopes to the north and northwest. Additional, adequately deep water well data in that area are necessary to determine the direction of bedrock valley slope.

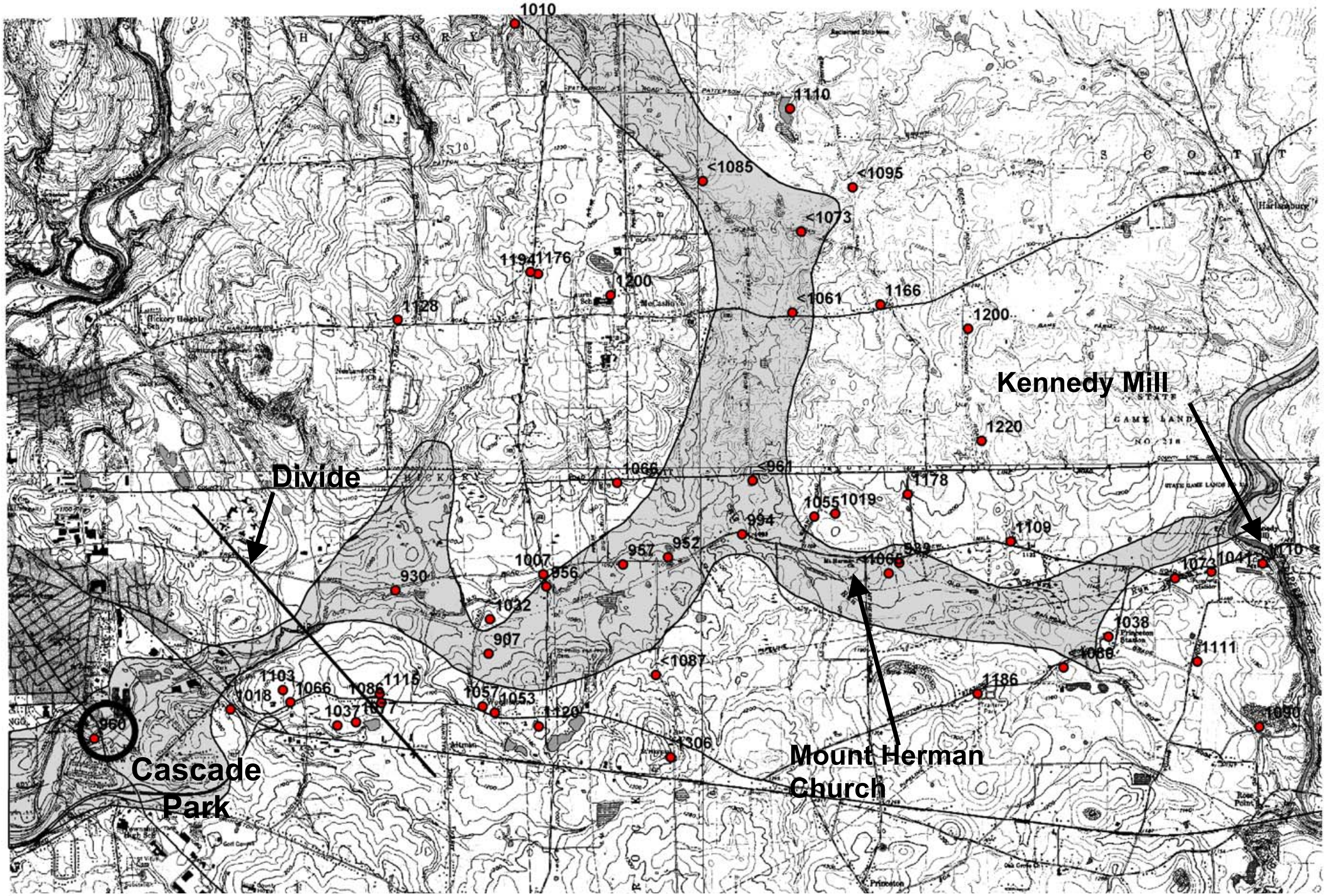


Figure 7-2- Map with well locations and bedrock elevations. The areas where the bedrock surface is less than 1,000 feet in elevation are shaded. The contours in the northeastern quarter of the map are modified from Poth (1963) using data from well records for wells drilled since the early 1960s. Cascade Park is highlighted in the southwestern corner of the map. The bedrock constriction to the northeast of Cascade Park suggests the presence of the divide, which has been post-glacially eroded by Big Run. From the New Castle South, New Castle North, Harlansburg, and Porterville 7½' topographic quadrangle maps.

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GRAYWACKE - An advanced form of senility, especially prevalent among sedimentary petrologists.

STOPS 10 and 11 - US 422 AT MORAVIA STREET INTERCHANGE

Leader- Viktoras Skema

INTRODUCTION

The road cuts along US 422 south of New Castle from the Moravia Street interchange eastward up the hill to the Martha Street overpass provide an excellent exposure of the rocks in the upper half of the Pottsville Formation and lower part of the Allegheny Group (Figure 10-1 and 10-2). This is particularly true of the cuts on the south side of the highway along the eastbound lanes. Starting along the entrance ramp from Moravia Street, this long, nearly continuous cut provides an uninterrupted 200-foot thick section from just below the apparent Lowellville Limestone horizon to the Vanport Limestone (Figure 10-2). All parts of the section are relatively accessible. There are no significant errosional discontinuities in the section. From a stratigraphic standpoint, this a rare section that presents the complete record of the transgressive and regressive sedimentation associated with the repeated migration of the coastline through this area of western Pennsylvania. It is a better reference section of the Lower and Upper Mercer Limestones and the poorly understood Mount Jackson coal (also referred to as the Tionesta or Homewood) than the type sections and locales first described in the nineteenth century because it is free of the typical stratigraphic confusion resulting from fluvial channel-produced discontinuities. The characteristic features of these beds are well displayed and their stratigraphic relationship to the other key beds in this part of the section can be easily seen.

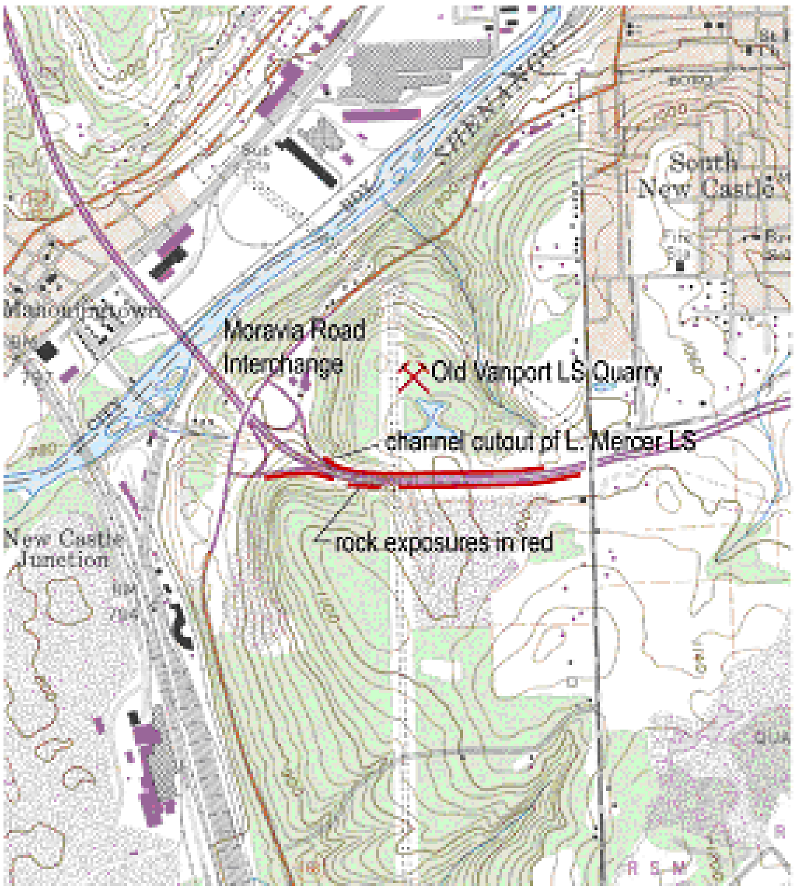


Figure 10-1. Location of road cut exposures at Moravia Street Interchange with US 422 near New Castle, Pennsylvania.

SEDIMENTOLOGY

There are two conspicuous features in the road cuts at the Moravia Street Interchange. The most apparent one is the lack of sandstone. There are only seven thin sandstone beds in the section. Five are rootworked paleosols. The thickest of these sandstones, where measured, is a three-foot thick bed between the Clarion coal and the Scrubgrass coal. Thickness of this bed changes laterally. It appears to have a maximum thickness of approximately ten feet on the north side of the highway, where it is inaccessible. Over all, this particular locale seems to have been only slightly affected by the higher energy, sandstone-producing fluvial depositional systems so prevalent in this part of the geologic section. Except for a small downcut channel at the Moravia Street entrance ramp no other erosive channels are present on the south side of the highway where the section was measured. For the most part, only the finer sand and silt of distal levee and over bank environments were deposited during the fluvial phase of each cycle. As a consequence, there was very little erosional removal from down-cutting fluvial channels, and most of the original sediment deposited here was preserved. Also, there were no thick deposits of relatively uncompactable sand creating topographically positive areas that affected subsequent sedimentation. The original alternating lithologies associated with the many cycles of sea level rise and fall occurring at that time have been nearly perfectly preserved at this locale.

One does not have to look far, however, to see the more typical stratigraphic disruption so prevalent in this part of the geologic section. An erosive downcutting channel is dramatically exposed on the north side of the highway at the westbound Moravia Street exit (Figure 10-3). This channel has cut out and removed an important marker bed, the Lower Mercer Limestone, along with the associated underlying coal, and most of the underclay and shale below. It appears to have been an abandoned channel that slowly filled with fine-grained sediment, and contains very little sand. There are large subvertical plant roots present in places. Much of the channel bottom has an unusual lining composed of a mixture of clay and abundant sideritic breccia. A few marine fossils have been found in some of this sideritic lag indicating that it may be the altered remnant of the Lower Mercer Limestone. A possible scenario explaining this siderite deposit is removal and destruction of the limestone through fluvial cut bank erosion of soft unconsolidated underclay undermining the overlying, partially lithified, brittle limestone and causing it to slide and collapse into the river. This was then followed by sideritization of the limestone pieces by iron-saturated water. A smaller fluvial channel is also present in the road cut across the highway at the Moravia Street entrance ramp to eastbound 422 (Figure 10-4). This channel is lower in the section and contains somewhat more sand. Most of the sandstone is extremely silty and argillaceous and contains carbonaceous plant roots. One sandstone bed in this channel is extensively bioturbated. The upper surface of this bed, which can be examined on a detached block lying at the side of the road, is covered with small sand filled burrows and carbonaceous roots.

The other striking feature of the US 422 cuts at Moravia Street is the presence of a large quantity of siderite in the section. Many of the dark shales above the coals in the marine phase of each cycle contain siderite nodules, thin disc of siderite, and thin siderite beds (Figure 10-4 and 10-5). There are also beds of aggregated siderite nodules and scattered nodules just below the paleosols. The nodules in these two settings have different textural characteristics. Siderite in the dark shales associated with the marine transgressions is massive and often has septarian fracturing in the center of the nodules. These open cracks are often mineralized, containing calcite, barite, and the zinc minerals, sphalerite and wurtzite among other minerals and clay. Some of the siderite in this setting also contains marine invertebrate fossils. The nodules from the dark shale above the Vanport Limestone commonly contain marine fossils. This shale is inaccessible from the road, but weathered out nodules can be found in the talus at the base of the road cut directly below the shale exposure, especially on the north side of US 422. Marine fossils can also be found in siderite nodules in the thick dark shale above the Upper Mercer Limestone and at the Lowellville Limestone horizon at the bottom of the section. John Harper found a *Derbyia* brachiopod in a siderite nodule at the Lowellville horizon (Figure 10-6). Interestingly it has been mineralized to sphalerite. The nodules found at the bottom of paleosols are not massive, but instead are composed of an aggregate of small siderite spherules.

The likely primary source for all of this iron was the extensive leaching of acidic soils that was occurring at the time in a near equatorial (Elridge and others, 1996) (Figure 10-7), humid to everwet climate (Cecil, 2003). Large amounts of iron were dissolved out of the vegetation-covered soils that were forming on the subaerially exposed upper portions of the fluvial sediment deposited over large alluvial and delta plains and also forming in the distant uplands. These ancient soils are now

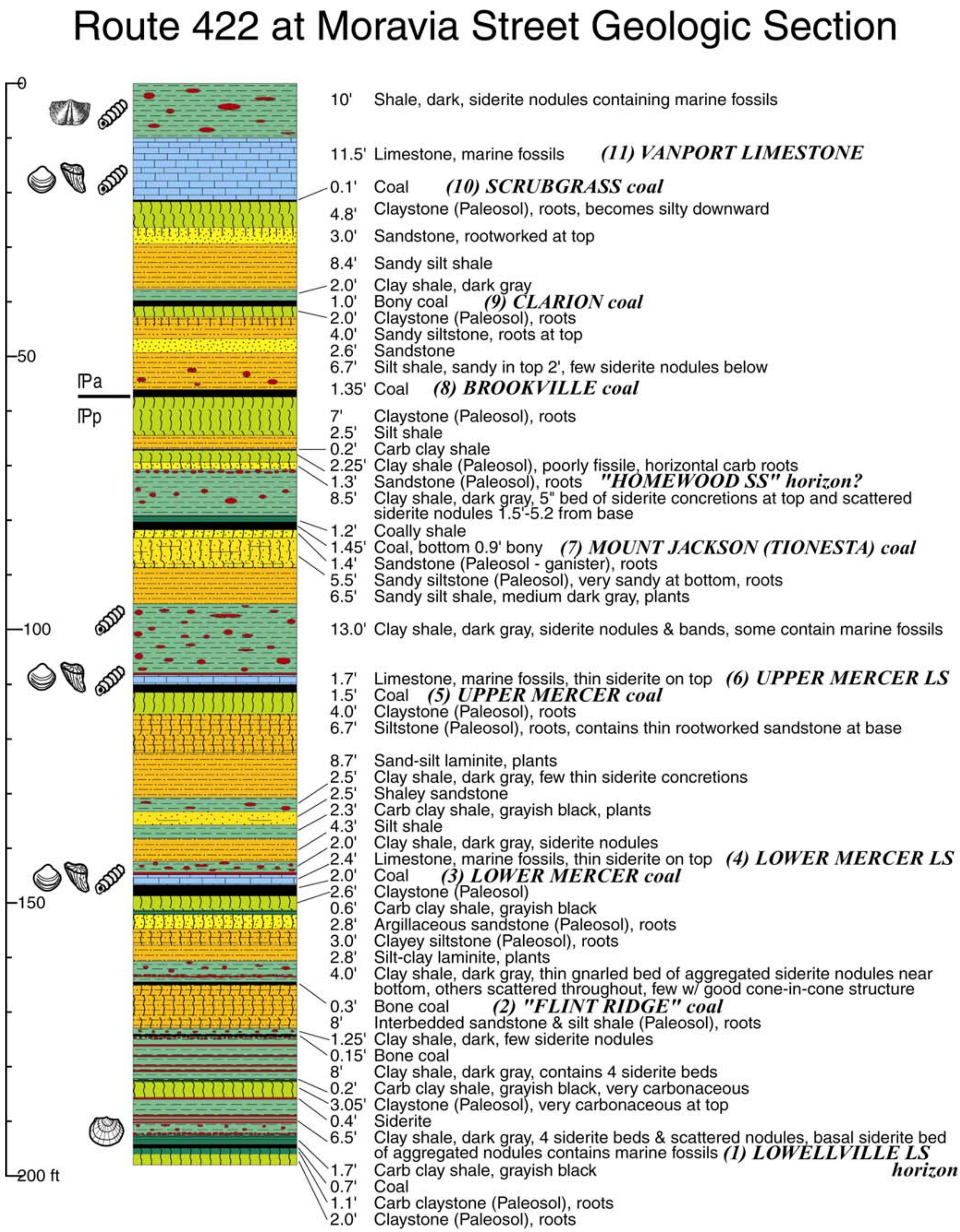
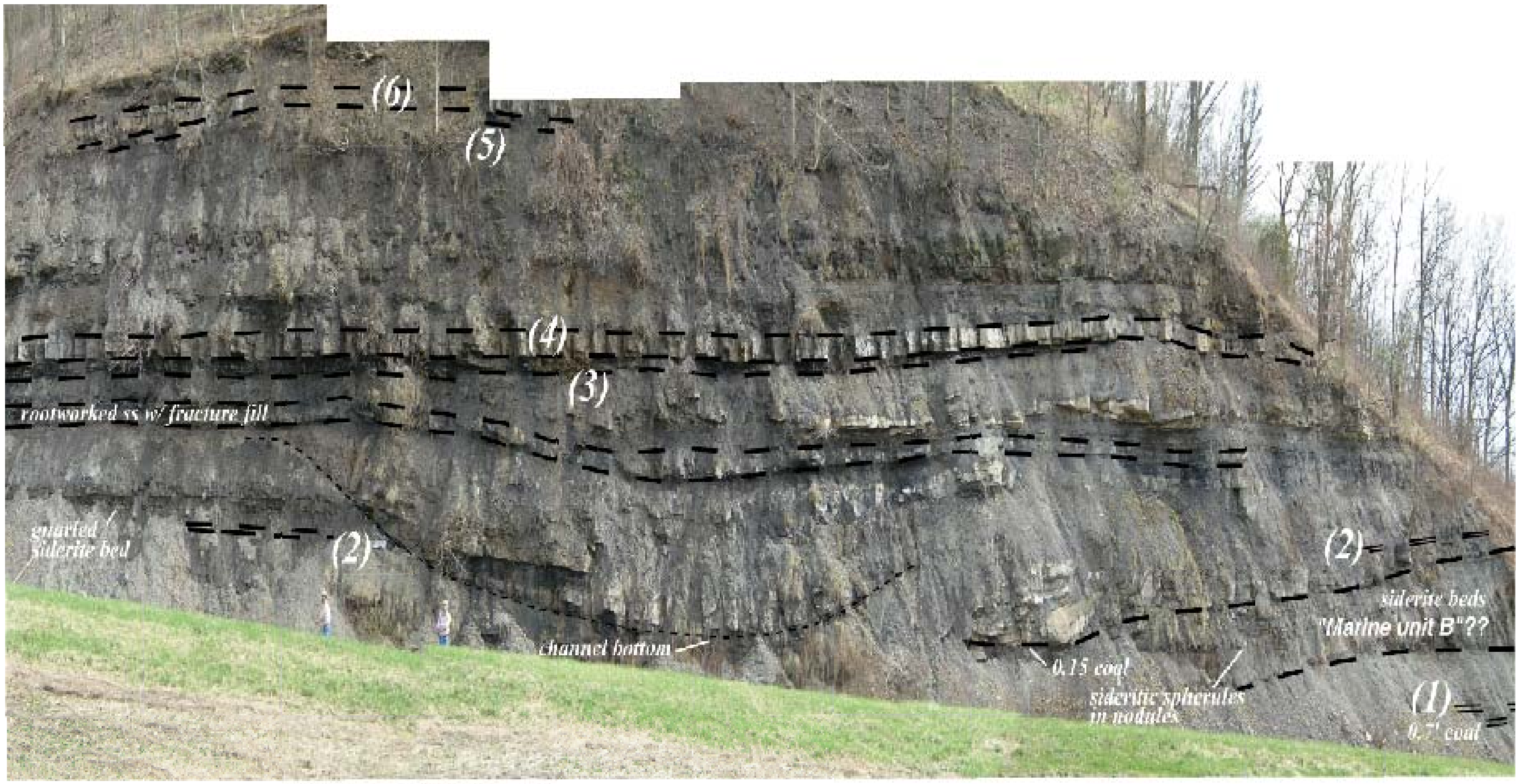


Figure 10-2. Geologic section of the long road cut exposure on the south side of US 422 at the Moravia Street Interchange.

Figure 10-3. Fluvial channel cutout at westbound US 422 exit ramp to Moravia Street. Numbers in parentheses denote key stratigraphic beds and are indexed to names on Geologic Section (Figure 10-2).

the bleached underclay beds prominently visible in the cuts. Iron solute was carried off in acidic rivers to estuaries, bays, and near shore depositional environments where it reprecipitated forming siderite nodules and thin beds at or close to the sediment-water interface. Carbonaceous plant material, calcareous shell debris, and organic waste material all appear to have been the loci for this microbially induced precipitation (Blaine Cecil, 2005, personal communication). These are now the fossiliferous siderite nodules in the dark shales. Extensive widespread precipitation also appears to have occurred entirely covering large areas of subaqueous sediment surfaces. These surfaces became extensive thin siderite beds. This possibly was the process that produced the four thin siderite beds near the bottom of the section in the dark shale exposed at the Moravia Street entrance ramp on the south side of the highway (Figure 10-5). The top surface of the uppermost of these siderite beds can also be seen in the ditch at the base of the cut along the exit ramp to Moravia Street on the other side of the highway (Figure 10-8). The surface of this bed contains ripple marks ruling out the possibility that these beds are diagenetic concretionary deposits such as hardpans pedogenically deposited at the bottom of soils. It is speculated that these may have developed on the subaqueous surfaces of particularly organic rich beds in a near shore marine sedimentary environment. The thin siderite beds found on both the Upper and Lower Mercer Limestones may have also formed in the same way. In river channel bottoms the dissolved iron reprecipitated on plant logs and other carbonaceous lag material, often thoroughly sideritizing them. Calcareous lag debris was also sideritized. The sideritic lag at the bottom of the erosive channel at the Moravia Street exit ramp is an excellent example of this type of occurrence.



(1) "Lowellville Limestone" horizon
(2) "Flint Ridge coal"
(3) Lower Mercer coal
(4) Lower Mercer Limestone
(5) Upper Mercer coal
(6) Upper Mercer Limestone

Figure 10-4. Road cut at Moravia Street ramp to eastbound US 422. Numbers in parentheses denote key stratigraphic beds and are indexed to names on Geologic Section (Figure 10-2). Vertical scale exaggerated. Notice that there are two Gary Fleegers. No amount of vertical exaggeration or cloning could improve the appearance of Gary. (Editor's note: You can't improve on perfection!)

Figure 10-5. There are abundant siderite nodules and beds present in the dark shales in the upper Pottsville and lower Allegheny.

Figure 10-6. Bed of siderite nodules above the lowest coal in the section at Moravia Street entrance ramp to eastbound US 422 were found to contain the marine brachiopod *Derbyia.*

This period of prolific siderite deposition continued to about the Westphalian C and D Stage boundary, occurring at about the Brookville coal horizon in western Pennsylvania (Edmunds, 1996), at which time the climate began drying somewhat and there was a shift to pyrite being the dominant iron precipitate (Blaine Cecil, 2005, personal communication). A dramatic photograph of a large road cut in central West Virginia shows the manifestation of this change from siderite to pyrite in the color of the fluvial sandstones (Figure 10-9).

Some of the iron leached out of these acidic soils was transported only a short distance downward to a lower soil horizon where it reprecipitated in pore surfaces along plant roots and formed irregular shaped, sometimes subvertical siderite nodules (Retallack, 1988). On close examination these nodules are seen to be composed of an aggregation of fine to coarse-grained siderite spherules. Individual spherules can also be found scattered throughout the lower parts of the paleosol horizons. They can also form as a horizontal layer of nodules at the bottom of the soil or a short distance below it. Examples of this type of mineralization can be found in the 0.4-foot thick siderite bed at the base of underclay near the bottom of the section at the Moravia Street ramp onto eastbound 422 (Figure 10-4).

Rootworked argillaceous sandstone positioned below the Lower Mercer Limestone and coal horizon contains a curious looking subvertical fracture system. The fractures are filled with lithified material that is more resistant than the enclosing sandstone and pronouncedly raised. These fracture fill deposits are confined to only the sandstone and occasionally penetrated a short distance into the siltstone below. They have very limited extent laterally. In the road cut at the Moravia Street exit ramp from westbound US 422 they are seen only near the channel cutout (Figure 10-10). Across the highway they are only apparent at the cut at the east end of the entrance ramp and probably close to the same channel (Figure 10-11). It is impossible to definitely determine if the channel is present on this side of the highway because a stream valley filled with glacial sediments has removed the strata for a short distance at this end of the road cut. However, sandstone above the Lower Mercer Limestone thickens at this end of the exposure and cuts through the overlying dark shale and in places through the limestone, indicating the likely close proximity to the east of the same erosive channel as seen on the other side of the highway. The fractures here appear to be systematically arranged into a roughly

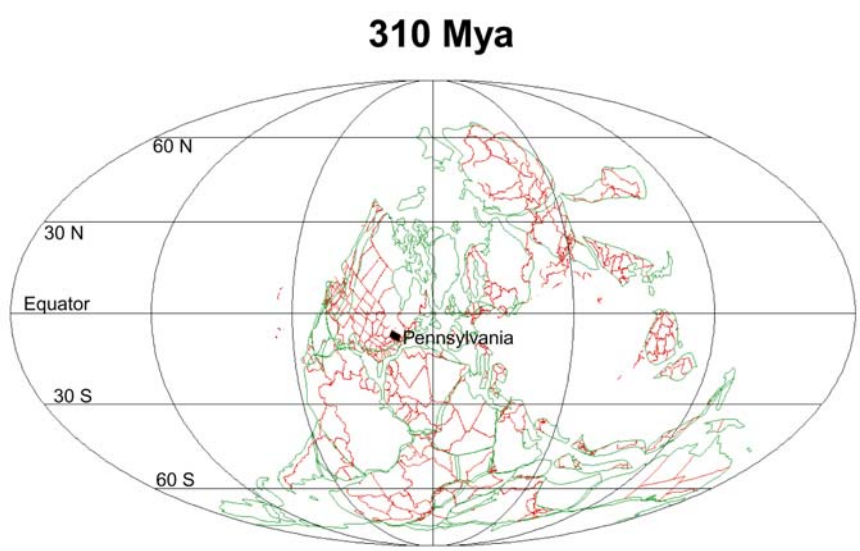


Figure 10-7. Geographic position of Pennsylvania at the time upper Pottsville and lower Allegheny deposition in New Castle area. Figure modified from Elridge and others, 1996.

Figure 10-8. Top surface of siderite bed in the lower part of the section contains ripple marks.

Figure 10-10. Prominent fracture fill material in arenaceous paleosol adjacent to fluvial channel cutout at Moravia Street exit ramp.

Figure 10-9. A photograph of a large road cut on I-79 in central West Virginia shows the change in Fe precipitate form at the Westphalian C to D stage boundary (black line). Fe precipitated as siderite in the gray fluvial-channel sandstones below the boundary and as pyrite in the yellow-orange sandstones above the boundary. This change occurred between the Vanport Limestone and the Lower Kittanning coal horizon in Pennsylvania. (photo provided by Blaine Cecil of the U.S.G.S.)


Figure 10-11. Raised fracture fill material in arenaceous paleosol on south side of US 422 at eastbound entrance ramp from Moravia Street.

orthogonal pair of sets. A view of this pattern along the bedding plane can be seen in a detached block at the exit ramp on the north side of the highway (Figure 10-12). It is very prominently displayed in this block because the matrix is a darker clay rich layer that is probably the layer seen in the middle of the sandstone in-place in the cut above. There is a dominant fracture that nearly crosses the entire width of the block along the bedding plane, ending abruptly near one edge. Several smaller secondary fractures branch off the main fracture at roughly right angles. Neither of these elements penetrates far into the bed. However, when examining this same third dimension in a cross-sectional view of the sandstone bed in the road cut, these thin, subvertical, raised features penetrate much more of the bed- the entire thickness in some cases. X-ray diffraction analysis of the fill material in comparison to the parent sandstone indicates that the two are nearly identical. The only difference appears to be the presence of trace amounts of calcite in the fill material.

Considering their composition and position close to the channel, a possible explanation for the formation of these unusual fracture-fill deposits is that they formed as a precipitate of unusually alkaline ground water affected by the limestone breccia lag deposit at the channel bottom. In the supposed sequence of events, first a network of small fractures developed in the partially lithified sandstone bed adjacent to the abandoned channel, and acted as a conduit for calcite saturated ground water. Small amounts of calcite precipitated in the porous sandstone adjacent to the cracks, making a narrow band of calcite cemented sandstone that was slightly harder than the parent clay rich material present throughout most of the bed. A precipitate of pedogenically-produced silica may have also been involved in the hardening of the fracture-fill material and would be indistinguishable from the sandstone quartz in the x-ray diffraction analysis results (R.C. Smith, III, 2005, personal communication). The underlying bed of sandy siltstone has the same distinctive yellowish color as the fracture-fill material and may have been involved in the same process.

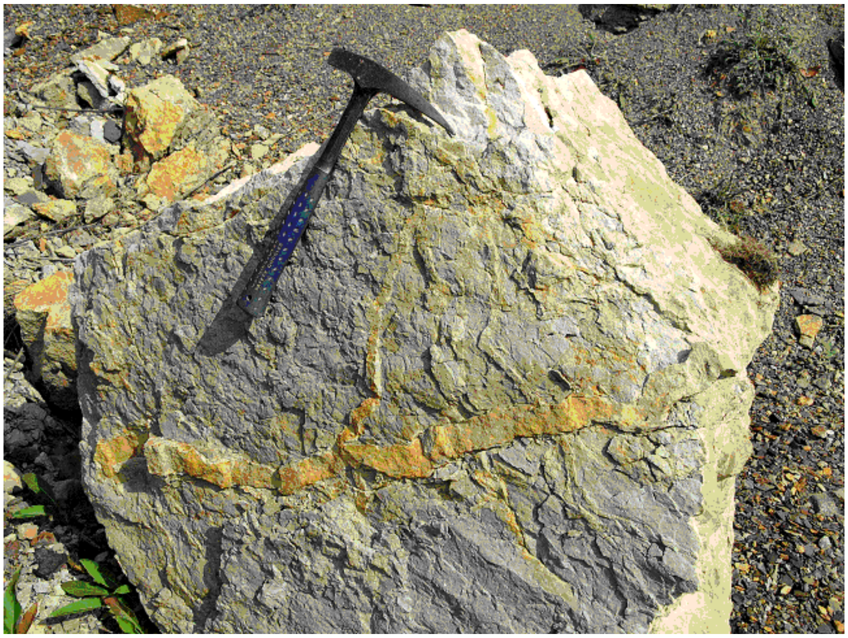


Figure 10-12. Fractures along bedding surface of arenaceous paleosol can be seen on a loose block at Moravia Street exit ramp.

A modern example of another type of chemical deposition can be seen three-quarters of the way up the hill on the south side of the highway. A thick coating of porous calcareous material covers the lower portion of the road cut and hides the Brookville coal and overlying shale (Figure 10-13). This impressive deposit of tufa has formed in the brief 40 years that has elapsed since the highway was constructed. This kind of deposit forms primarily because of enhanced degassing of CO_2 from water supersaturated with dissolved calcite (Chen and others, 2004; Ford and Pedley, 1996). All of the elements required to enable this type of deposition are present at this road cut. Remnants of the thick Vanport Limestone lie just below the surface of a broad flat vegetated area above the cut. An abundance of plant root generated CO_2 in the topsoil layer reacts with rainwater to form carbonic acid (R.C. Smith, III, 2005, personal communication). The acidic water flows into joint fractures and bedding planes of the shallowly positioned limestone. Claystone directly under the limestone acts as a barrier to downward drainage forcing lateral flow and increasing retention time of acid in limestone and resultant dissolving of calcite. The supersaturated alkaline water containing Ca and bicarbonate ions flows from the rock at a perched spring at the claystone–limestone contact and cascades about forty feet down the face of the road cut. The aerating effect of the fall allows substantial amounts of CO_2 to escape from solution leaving behind mostly $CaCO_3$ precipitate in the water, which coats the lower portions of the road cut. Mosses, algae, and bacteria establish themselves on this coated surface and build terrace structures that dam the water helping to increase calcite precipitation. Some of the bacteria actually synthesize additional calcite independently. Careful study of a similar deposit along the Youghiogheny River Rail Trail has revealed petrified mosses and other objects that don't decay or move fast enough to escape (J.R. Shaulis, J. R., 2005, personal communication).

Figure 10-13. Tufa deposit covers lower portion of road cut below exposure of Vanport Limestone bed. Cascade of calcium bicarbonate-saturated water is aerated in fall and forms calcite precipitate quickly coating everything. John Harper better move fast.

STRATIGRAPHY

The shoreline of an extensive shallow inland sea that covered much of the mid-continent passed through this area repeatedly during the Middle Pennsylvanian Period when these rocks of the Westphalian C stage were deposited. Evidence of these marine transgressions is obvious at four horizons exposed in these cuts. Limestone and/or dark shale containing marine fossils lies directly on terrestrial deposits of coal and ancient soils at the Vanport, Upper Mercer, Lower Mercer, and the "Lowellville" horizons (Figure 10-9). At least two other horizons may also reflect marine transgressions. The Brookville and the very speculative "Boggs Ore" horizon have the same sequence of dark shale overlying coal (or a concentration of carbonaceous plant material in the case of the "Boggs Ore"), and a paleosol. Brackish water fossils have been found regionally in the dark shale above the Brookville coal. Similar fossils have been reported across the border in Ohio in a siderite-rich dark shale identified as "Marine unit 'B" (Slucher and Rice, 1994) positioned stratigraphically between the Lower Mercer Limestone and the Lowellville marine zone. The dark shale containing siderite beds exposed at the west end of the Moravia Street entrance ramp on the south side of the highway might be the "Marine unit 'B'" horizon (Figure 10-4). There are several other horizons in the section where dark shale overlies either coal or very carbonaceous shale and underclay making a total of nine horizons possibly marking relative sea-level fluctuation. In these, however, one or more of the component beds defining the terrestrial-to-marine cycle are questionable: 1) the dark shales contain no fossils, bioturbation, or siderite nodules indicating a marine transgression; 2) carbonaceous material is very thin and clay rich and could have been deposited in a very ephemeral setting not indicative of the long standing terrestrial swamps that produced the thick coals; and 3) the underclays contain only weakly-developed paleosol profiles that did not require the lengthy subaerial exposure needed to produce the extensive thick soils with well developed profiles indicative of periods of major sea level drop.

The following is a description of some of the noteworthy characteristics of the stratigraphically important beds found in this section at the Moravia Street Interchange.

Vanport Limestone (11)

The Vanport Limestone has been thoroughly described by Kochanov and Bragonier elsewhere in this guidebook and needs very little discussion here. It is about 12 feet thick and situated near the very top of the section. The limestone on both sides of the highway lies at or very near the surface of a broad, flat hilltop area, enabling easy removal (Figure 10-14). It was one of the earliest mined limestone deposits in the area. White (1879) reported that at the time of his visit in 1877, Green, Marquis, & Johnson had already extensively quarried the deposit at this site (Figure 10-1). He described the bed here as consisting of 9 feet of "gray" limestone over 3 feet of "blue" limestone and wrote that it was covered by only a very thin coating of glacial debris. He described a 6-inch layer of fireclay 2 feet above the bottom of the "gray" limestone. Only the "gray" limestone was mined and shipped to New Castle to be used as flux in the iron furnaces (White, 1879, p 141). Regionally, the Vanport Limestone is the premier stratigraphic marker because it is one of only a very few limestones in this part of the section and because it is exceptionally thick. Over much of the area, its identity cannot be mistaken with that of any other bed.

Figure 10-14. Lower Allegheny Group rocks on north side of US 422 east of Moravia Street. Numbers in parentheses denote key stratigraphic beds and are indexed to names on Geologic Section (Figure 10-2).

Brookville coal (8)

The Brookville coal is at the bottom of the Allegheny Group, referred to as the "Lower Coal Measures" by Rogers (1858). This Group of rocks contains a remarkable amount of minable coal over a very wide area encompassing the northern Appalachian, Illinois, and Mid-Continent basins. The base of the Brookville coal is the boundary between the Allegheny Group and the Pottsville Formation below. The Brookville coal marks a point in the slowly shifting climate that ushered in the beginning of more luxuriant and, probably, longer-lived peat swamps. This change in coal character becomes more obvious at the Lower Kittanning coal horizon and continues up through the Upper Freeport coal (C. Eble, 2005, personal communication). One of the distinguishing features of the Brookville horizon is a very well developed soil profile in the underlying paleosol, probably the most extensively developed in this part of the section, with a thick leached zone at its top and large sideritic hard pan-type deposits of sideritic concretions in the subsoil horizon. Chemical activity at the top of the soil was so intense, and of long enough duration, that some silica was also dissolved along with iron. It is not uncommon to find growth of euhedral secondary quartz in some of the concretions at the bottom of this paleosol throughout Western Pennsylvania. In some places, pedogenesis was deep seated enough to effect the rocks directly overlying the Mount Jackson (Tionesta) coal below.

The dark shale above the Brookville coal regionally contains siderite nodules and brackish-water fossils in places. However, no fossils were found above the Brookville coal at the Moravia Street interchange cuts and only a few scattered nodules restricted to the basal portion of the shale were present. The shale is very silty where it was measured on the south side of the highway and becomes sandy on the other side of the highway where thin sandstone beds appear to be common (Figure 10-14 and 10-15). A fluvially deposited sandstone lies directly on the Brookville coal at STOP 12 a few miles to the northwest, and this coarser shale here at the Moravia Street Interchange may be a distal component of that fluvial sedimentation. Absence of brackish water fossils would be expected in that case.

Mount Jackson (Tionesta) coal (7)

The coal above the Upper Mercer Limestone and associated dark shales that is conspicuously perched on a sandstone bed appears to be persistently present throughout Mercer and Lawrence Counties, and is a good stratigraphic marker. Like the Mercer coals, it contains a considerable amount of pyrite and clay and has very little commercial value. It was mined locally in the nineteenth century in a few scattered places in the western part of the county, mostly “to supply many farmers with a very bad fuel when no other is at hand” (White, 1879, p56). The closest mine operated about ¾ of a mile south of these cuts where the coal was called the “Shields coal”. White reports that an attempt was made to mine the coal in the nearby ravine to the north of STOPS 10 and 11, but aborted because of the poor quality of the coal. The coal has had many names. Rogers, and initially White, called it the Tionesta (Rogers, 1858 and White, 1879). White and Lesley decided to adopt a more local name because of uncertainty in correlation to the type locale of the Tionesta in Forest County and renamed it the Mount Jackson (White, 1880). DeWolf (1929) referred to it as the Homewood coal. The coal has also been called the “4 foot vein” and “Dirt vein”. It truly is the coal of many names. Ironically, in more recent times, outside of Lawrence County, its identity has completely disappeared, and any coal at its horizon is considered to be one of the “Mercers.” It has become the “no name” coal. Here at the US 422 - Moravia Street interchange, the Mount Jackson (Tionesta) coal is a dull, bony coal with a 0.2-foot thick coaly shale parting in the middle. It is underlain by 1.3 feet of rootworked, white sandstone that is extremely hard. The sandstone is so well cement with silica that individual quartz grains are not discernable. This type of deposit at the top of a sandy paleosol is called a ganister, and is siliceous enough that sometimes it is mined to make glass (Figure 10-15). There is a 5.5-foot bed of rootworked siltstone below the ganister. This bed is very sandy at the bottom and very clay rich at the top. A sandy paleosol is often present under the Mount Jackson (Tionesta) coal regionally, and is a distinguishing feature of the coal. In North Beaver Township to the west, in the vicinity of Mount Jackson, White (1879, p.125) describes seeing the ganister component as “rough and forbidding” blocks scattered over a farm field.

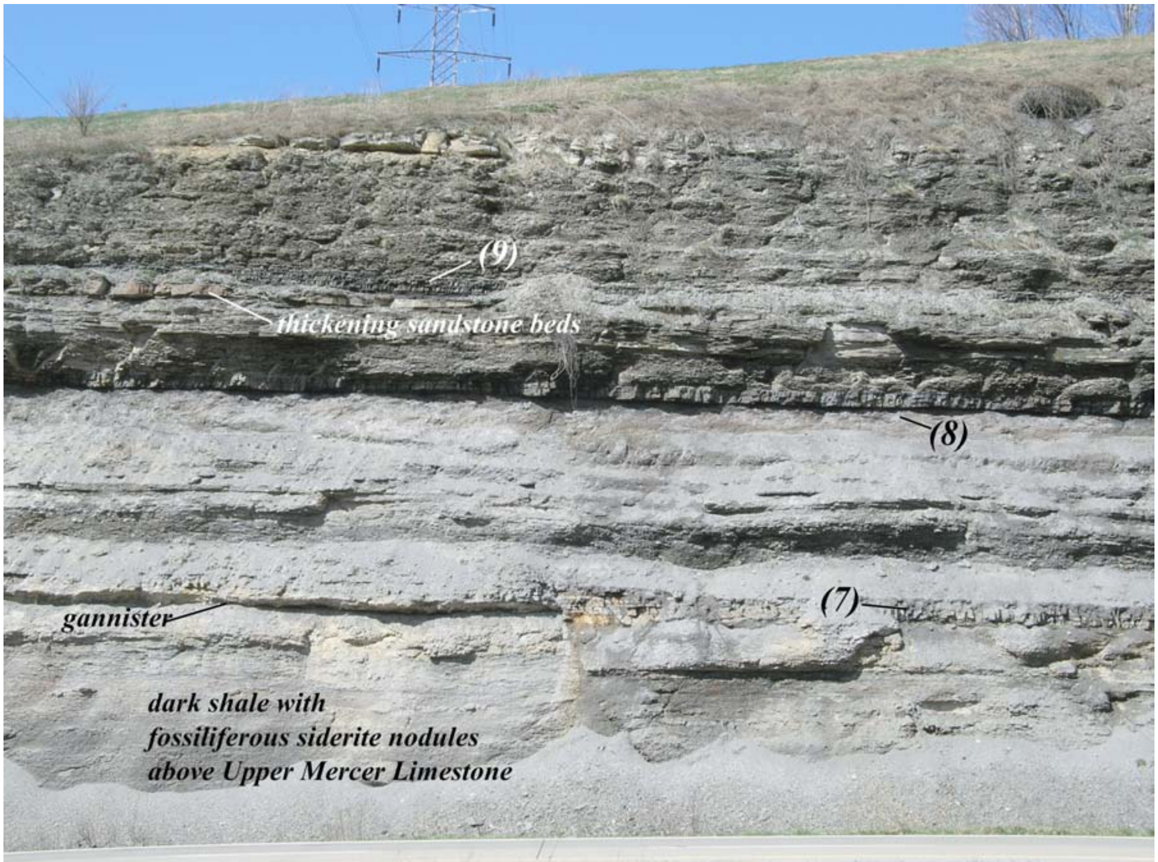


Figure 10-15. Sandstone in the silt shale above the Brookville coal (8)appears to thicken to the northwest. An arenaceous paleosol with ganister at its top lies directly below the Mount Jackson (Tionesta) coal (7).

Upper Mercer Limestone (6) and Lower Mercer Limestone (4)

The Mercer Limestones are the first widely deposited marine units in this region, followed later by the extensively deposited marine beds of the lower half of the Allegheny - the Vanport, Columbiana, and Washingtonville marine zones. They are identical in appearance and closely resemble the Vanport Limestone. Harper (this guidebook) provides detailed information concerning paleontology, lithologic characteristics, and stratigraphy of the Mercer Limestones and associated beds.

These limestones are excellent stratigraphic marker beds when paired. Confusion ensues when only one of these limestones is present, but since the interval between the two is never great, mistaken identity only affects stratigraphic resolution of a very fine scale. Of course the minor miscorrelation that may result from the confusion becomes frustratingly significant when trying to precisely identify individual coals for the purpose of constructing an accurate coal map. In this case it is important to attempt to identify any depositional trends of the individual limestones that may shed light on which of the two limestones is more likely to be present when only one is found. Based on descriptions obtained from various reports of the geology in this region, there are two distinguishing characteristics of the Mercer Limestones that might help in identification of one from the other when only one is seen. The first is that the Lower Mercer Limestone often is separated from the Lower Mercer coal below, whereas the Upper Mercer is always directly over the coal. The second is that the fossiliferous siderite at the top of the Lower Mercer Limestone is separated from the limestone by shale at some locales (Slucher and Rice, 1994; Banks and Feldman, 1970). Problems of identifying one Mercer Limestone from the other are apparent in the literature. Previous stratigraphers, beginning with Rogers (1858) and

White (1879 and 1880) have all expressed the belief that the Lower Mercer is more widely deposited than the Upper Mercer. Interestingly, DeWolfe (1929, p. 52) also repeats this opinion. Yet in examining his extensive cross sections (plate VII and VIII), it was noticed that of the seven sections that contain only one Mercer Limestone and have the added stratigraphic control of the Vanport Limestone, the limestone is identified as the Upper Mercer more often than it is identified as the Lower Mercer. This prevailing concept that the Lower Mercer is more extensive than the Upper Mercer has led to misidentification of the Upper Mercer Limestone in some cases. This firmly established opinion probably should be carefully reexamined.

“Flint Ridge” coal (2), “Boggs Ore”, and Lowellville Limestone (1) of Ohio

The traditional stratigraphic nomenclature used in western Pennsylvania for the Pottsville Formation is not useful in the New Castle area for the strata below the Lower Mercer Limestone and coal, and may not be applicable to most of Lawrence and Mercer Counties. The Pottsville was considered a Group by Carswell and Bennett (1963) and divided into, in descending order, the Homewood, Mercer, Connoquenessing and Sharon Formations. The Homewood and Connoquenessing have long been thought to consist primarily of sandstone covering a wide area, with the Connoquenessing sandstone split by a minor shale bed containing the thin Quakertown coal. In much of the New Castle area there is virtually no sandstone in the entire Pottsville Formation. Instead there are numerous cycles containing a sequence of fluvially deposited silt-shales and thin sandstones, paleosols, thin clayey coals, and dark shales with siderite nodules. There are seven of these present in the Pottsville at the US 422 and Moravia Street Interchange, with three definitely containing marine fossils (Figure 10-2). Four are in the 50-foot section below the Lower Mercer Limestone. The Pottsville section here looks more like the one described in Ohio. Three marine units have been widely recognized in the Pottsville of east-central and northeastern Ohio (Slucher and Rice, 1994). They are the Upper Mercer, Lower Mercer, and Lowellville Limestones. The Mercer limestones are clearly present in the Moravia Street exposures, and a marine brachiopod found by John Harper near the bottom of the section is probably in the Lowellville marine zone. A fourth marine zone named “Unit B” by Slucher and Rice (1994) containing sparse brackish-water fossils is also present between the Lowellville and Lower Mercer. However, no such zone containing brackish-water fossils was identified in these cuts. An unusually siderite-rich zone between the Lower Mercer Limestone and the Lowellville marine zone may prove to be related to “Unit B” upon further examination (Figure 10-4 and 10-5).

Figure 10-16. A thin layer of siderite nodules with a peculiar gnarled structure is present above the “Flint Ridge” coal in the local area

There is a thin, inconspicuous, bony coal bed approximately fifteen feet below the Lower Mercer coal on both sides of the highway at the Moravia Street interchange. Since there is absolutely no good reference in the Pennsylvania literature to a coal this close below the Lower Mercer coal, it is necessary to draw on the classical Ohio nomenclature (which seems to include every stray coal and fossil horizon deposited in the Pottsville down to the level of the "Guinea Fowl") and call it the "Flint Ridge" (Sturgeon and Hoare, 1968, pp 6-11; Bownocker and Dean, 1929, as cited in Slucher and Rice, 1994, p29). This is done with the understanding that the type section of the "Flint Ridge" is distant and the correlation is very tentative. Additional work is needed to determine the extent of this bed and whether establishing a local name is justified, or whether any name is required for that matter. The thin coal is significant mainly because, a short distance above it, there is a thin layer of aggregated sideritic concretions that have a peculiar gnarled structure (Figure 10-16). This unusual sideritic bed appears to be persistently present at least locally. White (1879) reported finding a similar bed in the nearby hollow to the north of the Moravia Street cuts and also about a mile to the south, near where the Shenango and Mahoning Rivers merge to form the Beaver River. He described "curiously shaped markings and cavities, which probably represent casts of fucoids" (trace fossils of burrows) on the underside of the bed (White, 1879, p 143). He reported that the bed was drift mined at the site one mile south and the ore taken to the furnaces in New Castle. It averaged 45% metallic iron but contained too much phosphorous.

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STOP 12. US 422 at Toll 60 Interchange

Leader: Viktoras Skema

INTRODUCTION

The roadcuts along US 422, and in the canyon-like northbound exit ramp of Toll 60 (Figure 12-1), display nearly the same section seen at the Moravia Street interchange (Figure 12-2). It includes the very bottom of the Allegheny Group rocks and the upper part of the Pottsville Formation down through the Mercer horizons. Stratigraphically significant beds are the Brookville coal, Mount Jackson (Tionesta) coal, one of the Mercer limestones, and probably both the Upper and Lower Mercer coal. However, there are considerable differences in specific lithologic features and in the overall character of this section. Unlike the Moravia Street section, here, sandstone is the dominant lithology. Sandstone totals 90 feet in the 160 feet of section measured at STOP 12. This includes the roadcuts and a nearby stream cut exposing lower rocks. Most of the sandstone is divided into three thick beds. The uppermost of these has been called the Homewood Sandstone, but appears to have been misidentified again, as at the previous stops of this field trip. Though the fluvial systems that deposited these three sandstones do not appear to have removed any key beds, they seem to have had a pronounced influence on sedimentation. There is dramatic compression of the section here. The interval between the upper and middle sandstone at STOP 12 is approximately equivalent to the section from the Brookville coal down to the rootworked sandstone just below the Lower Mercer coal at STOP 10. This interval has been reduced from 96 feet, measured at the Moravia Street interchange, to 50 feet here at the Toll 60 interchange (Figure 12-3). The major missing component is the marine transgressive phase of the depositional cycles. There are virtually no dark shales containing nodular siderite, and except for a limited exposure of one of the Mercer Limestones along eastbound 422 in the extreme southwestern part of STOP 12, only a thin, fossiliferous siderite bed is found in place of limestone. There is no evidence of removal by erosive downcutting of fluvial channels, as seen at Moravia Street. The overriding factor seems to be a substantial decrease in the amount of sediment. Stratigraphic analysis of the section here is complicated because most of the reliable marker beds, the marine zones, are missing. STOP 12 is a prime example of the difficulty in understanding the stratigraphy of the Pottsville.

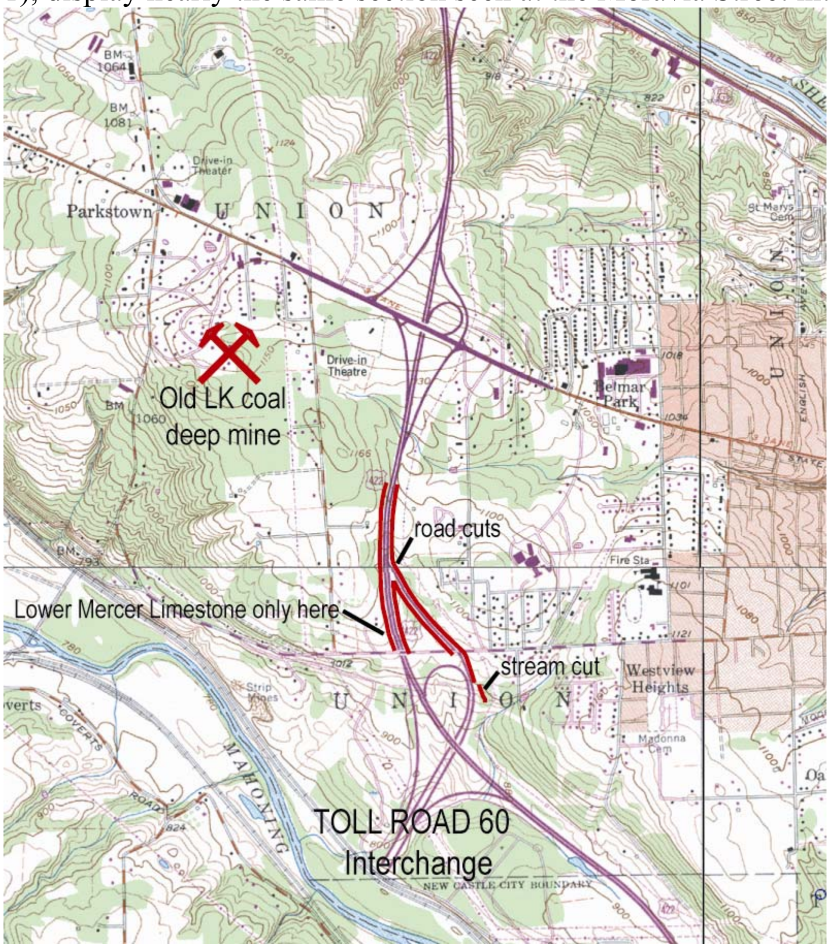

Figure 12-1. Location of roadcuts along US 422 and Toll 60 interchange.

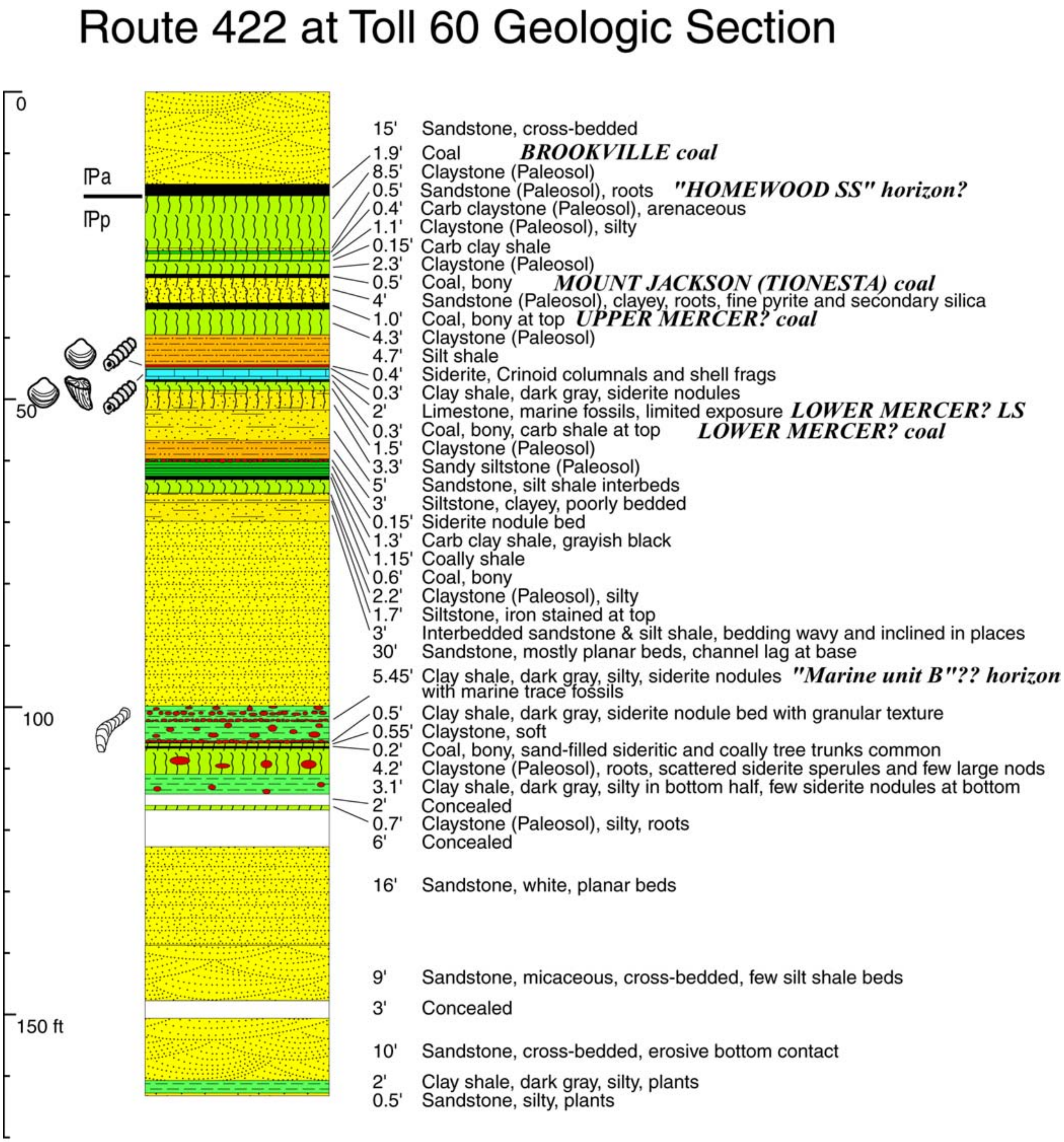

Figure 12-2. Geologic section of rocks exposed at US 422 and Toll 60 interchange. "Marine unit B" and lower rocks were measured in stream cut a short distance southeast of the Toll 60 North exit ramp road cuts.

STRATIGRAPHY

Thick sandstones, and the associated lack of marine zone marker beds, greatly hamper accurate stratigraphic correlation of the rocks exposed at STOP 12. This is not an uncommon situation, and the early mappers in this area faced it often. The rock exposures they had to work with were limited, for the most part, to natural occurrences of resistant sandstone beds and some protected, underlying, softer rock in stream cuts and along steep slopes. Exposures like the one at the Moravia Street interchange did not

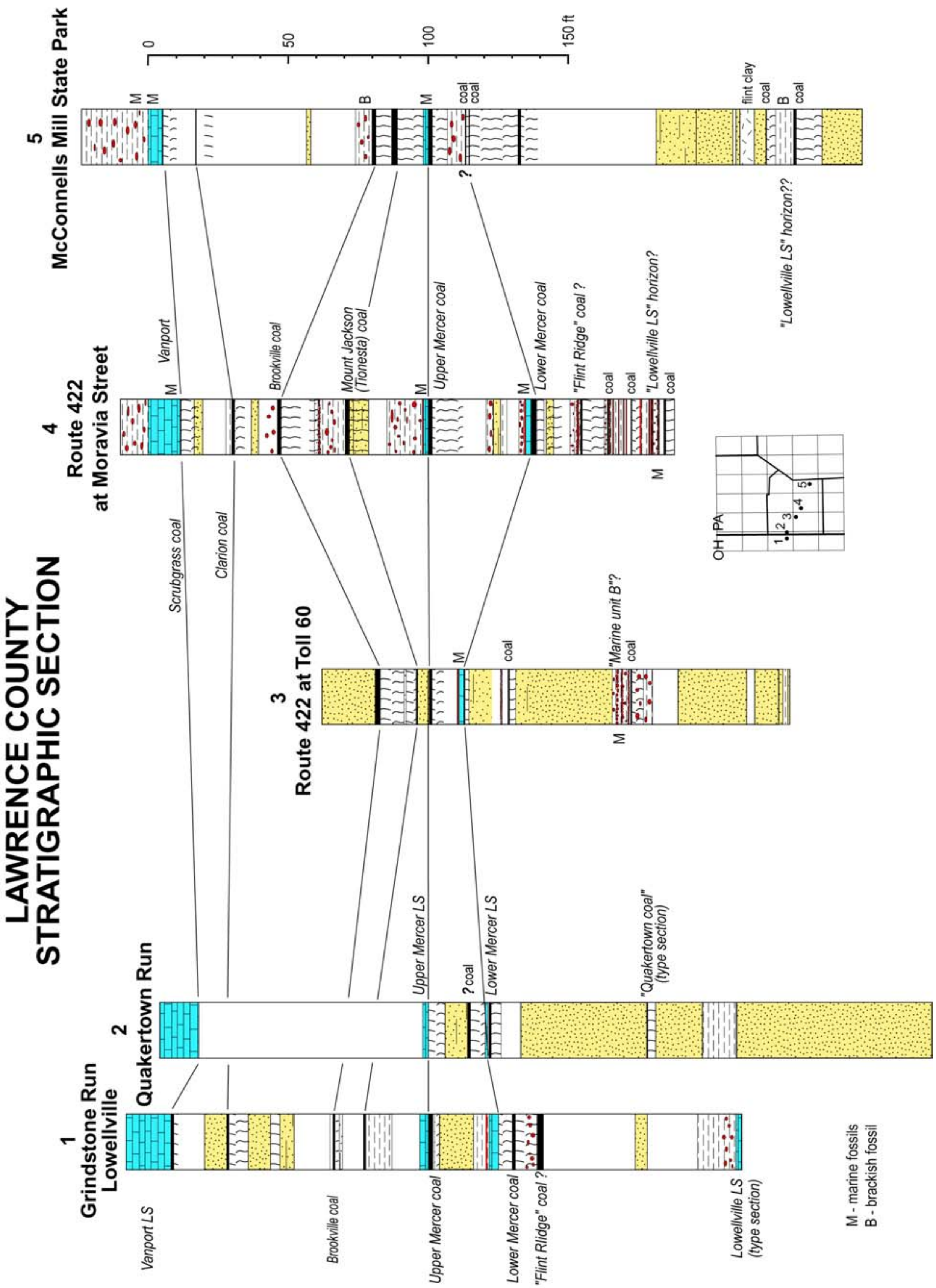

Figure 12-3. Stratigraphic section of Lawrence County area including US 422 road cuts. McConnells Mill State Park section is a Pennsylvania Geological Survey measured section of cored drill hole. Grindstone Run section from Banks and Feldman (1970). Quakertown Run section from White (1879).

exist. As a result, they were often forced to attempt to correlate fluvially deposited sandstone bodies, which by their nature are laterally discontinuous. Geographically restricted, shoestring-shaped deposits of similar-looking, thick sandstone can probably develop in any of the fluvial phases of the many cycles in this part of the section. It is impossible to follow these very far without mistakenly jumping stratigraphic horizons to vertically adjacent sandstones. Yet, it was exposures of thick sandstones and shortened sections of softer shales like these seen at the Toll 60 interchange that were most used in developing the stratigraphic interpretation now in use. These areas are actually the most complex stratigraphically, and the least useful in constructing a regional framework.

Three thick sandstone beds are exposed in the cuts here. There is a 15-foot-thick sandstone at the top of the section, a 30-foot bed in the middle and a 40-foot bed at the bottom. The traditional inclination is to first key in on these sandstones in order to determine the stratigraphy at this site. The immediate assumption would be that the upper sandstone is the "Homewood," underlain by the "Mercer Formation" containing primarily shales, coals, and one thin marine limestone. The massive sandstone forming the lower walls of the Toll 60 canyon would be identified as the "Upper Connoquenessing", and the lowest thick sandstone exposed in the stream channel as the "Lower Connoquenessing". The thin sequence of dark shale, thin coal, and underclay separating the lower two sandstones would be considered the "Quakertown" coal and associated shales. DeWolf (1929) interpreted the stratigraphy exactly this way. His economic geology map in the New Castle Atlas (pl. IV) shows the "Homewood" (Mount Jackson) coal crop line passing directly through STOP 12, and he indicates two stations where he observed the coal that are at the outcrop areas of the Brookville coal exposed in the highway cuts. A closer examination of the key beds in this section indicates that this traditional interpretation may be incorrect.

Carswell and Bennett (1963, pl. 1) mapped the Lower Kittanning coal horizon on the high hill directly to the west of these cuts on US 422. White (1879, pp 186-187) reported that the Lower Kittanning coal was deep mined near the top of this hill . The site is approximately where the shopping plaza is situated just south of State Street (Figure 12-1). The vertical distance between this mined coal and the coal along the highway directly below the uppermost sandstone is approximately 90 feet. This is the expected interval between the Lower Kittanning and the Brookville coals. The beds at the top of the cut above the sandstone overlying the Brookville coal are covered with a thin veneer of glacial till, and the Vanport Limestone could not be found for additional confirmation of the coal's identity. However, loose pieces of marine limestone and coal were found a short distance above the sandstone at about the expected horizon of the Vanport. The coal here at STOP 12 also is similar to the Brookville coal at Moravia Street in that it is underlain by a well-developed paleosol. It is the thickest and best-developed paleosol at both sites. The coal below the Brookville lies directly on a four-foot- thick, rootworked, pyritic, argillaceous, sandstone paleosol. This combination of lithologies resembles the Mount Jackson (Tionesta coal) horizon seen throughout the area. This again suggests that the coal in question is not the Mount Jackson (Tionesta) coal but the Brookville, and that the thick sandstone above it is not the Homewood Sandstone, but rather sandstone in the lower part of the Allegheny Group (Figure 12-4). The best development of sandstone in the Moravia Street cuts, as modest as it was, also occurred above the Brookville coal, and not at the "Homewood Sandstone" horizon.

Stratigraphy becomes more difficult to interpret below the Mount Jackson (Tionesta) coal because of the compression of the section and the lack of clearly discernible marine-zone marker beds. One of the Mercer limestones is present in the roadcuts at STOP 12, but it is difficult to determine which. The limestone is present only on the west side of US 422 at the exit ramp to Toll 60 South, and is replaced by a thin, fossiliferous siderite bed throughout the rest of the stop area (Figure 12-5). In his description of the two Mercer limestones at Quakertown Run (Figure 12-3), 6 miles west of STOP 12, White (1879, p. 194) notes that, in a distance of 100 yards, the Lower Mercer "undergoes a strange

Figure 12-4. Brookville coal along US 422 at Toll 60 interchange is overlain by thick sandstone that has been misidentified as the “Homewood Sandstone” in the past.

Figure 12-5. Lower Mercer Limestone is present only in the southwestern-most roadcut at STOP 12. Thin fossiliferous siderite found at same horizon is continuously exposed throughout the site.

metamorphism,” changing from a “blue limestone” to “a brown silicious iron ore”. Two miles farther west into Ohio, in Lowellville along Grindstone Run, there is a thin, nodular, blue, fossiliferous “ore” above the three-foot-thick Lower Mercer Limestone, separated from the limestone by two inches of “soft” shale (Banks and Feldman, 1970). At STOP 1 in Hells Hollow the interpreted horizon of the Lower Mercer Limestone contained a thin fossiliferous siderite bed. These descriptions resemble the marine limestone here at STOP 12, and provide some evidence that it may be the Lower Mercer. If the detached, fossiliferous siderite bed is uniquely associated throughout the region with the lower of the two Mercer limestones as seen in Quakertown Run and Lowellville, then the limestone at STOP 12 is the Lower Mercer, and the one-foot-thick coal, nine feet above the limestone, is probably the Upper Mercer, and is separated from the Mount Jackson (Tionesta) coal by only four feet of rootworked, argillaceous sandstone. There is no trace of the Upper Mercer Limestone horizon. This is an extremely short interval and a strange sequence of lithologies between the Upper Mercer and Mount Jackson (Tionesta), but it may be the result of the shortening of the section caused by thick uncompactable sand below.

Identity of the coal below the Lower Mercer horizon, just above the thick middle sandstone, is difficult to determine. A single bed of siderite nodules appears above it. These nodules do not display

Figure 12-6. Stream cut waterfall exposure near southeastern end of roadcut in exit ramp of Toll 60 reveals thin coal overlain by dark sideritic shale and base of the thick middle sandstone seen at the canyon-like ramp cuts. Some of the nodules contain trace fossils.

Figure 12-7. *Zoophycos marginatus* (Lesquereux) traces in siderite nodule from dark shale directly below thick sandstone exposed in canyon-like exit ramp of Toll 60.

the peculiar gnarled appearance of the bed seen at the Moravia Street interchange. It would not be unreasonable to assume that the thick middle sandstone is related to the lower erosive channel exposed at the entrance ramp at STOP10. If this is true, then the coal with the siderite nodule bed above at STOP 12 cannot be the "Flint Ridge," inasmuch as that coal was cut out by the channel. The coal here may be related to the thin, carbonaceous clay shale and rootworked sandstone containing filled fractures situated above the channel and below the Lower Mercer coal at STOP 10 (Figure 10-2 and 10-4).

Continuing downward with this increasingly speculative interpretation, a waterfall exposure in the stream cut (Figure 12-1) close to the southern end of the Route 60 exit ramp reveals dark shale that contains siderite nodule beds and numerous scattered nodules directly below the thick middle sandstone (Figure 12-6). No definite fossils were found in the nodules, but a few contained the trace fossils *Zoophycos marginatus* (Lesquereux) and, possibly, *Rhizocorallium* (Figure 12-7), and one possible impression of a partial *Orbiculoidea* brachiopod shell. A conspicuous bed of siderite nodules occurs at the base of the shale that are composed of sideritic spherules, some of which are very angular. A thin bone coal lies below the dark shale. This thin coal may be the “Flint Ridge” or one of the thin coaly horizons associated with the sideritic dark shale tentatively identified as “Marine unit B”?? at STOP 10 (Figure 10-4). This thin coal bed and overlying shale probably can be correlated with the thin “Quakertown” coal and shale section at its type section near the Ohio border 6 miles west of STOP 12 (White, 1879). The relationship to the Mercer limestones and the adjacent sandstones is similar at these two sites. A few loose siderite nodules containing *Hustedia, Lingula,* a few other unidentified brachiopods, crinoid columnals, and a horn coral (*Stereostylus*?) were found in the streambed below the waterfall (Figure 12-8). However, it is unlikely that they came from the dark shale in the falls because similar nodules were also found above the falls all the way up to the head of the stream. They look very similar to the fossiliferous nodules found in the dark shale above the Vanport Limestone and probably eroded out of that bed higher on the hill.

Figure 12-8. Loose siderite nodule in stream bed below waterfall contains marine brachiopod *Hustedia*. Similar nodules were found above falls well up the stream. Probable source was the Vanport marine zone higher on the hill.

The “Lowellville Limestone” horizon was not found. It may be that it is present in the eight feet of covered section below the waterfall, or it may be below the lowest thick sandstone. At its type section in Lowellville, it is 110 feet below the Lower Mercer Limestone (Figure 12-3). Slucher and Rice (1994, p. 34) place the Lowellville under the “Connoquenessing Sandstone.” Traditionally, it has been described as being in the lower part of the “Mercer Formation” above the “Connoquenessing”. It may be that all of this is correct. In areas where fluvial sandstone in the lower part of the “Mercer Formation” is fully developed there may be great expansion of the section between the Lower Mercer Limestone and the “Lowellville Limestone.” In areas like the Moravia Street interchange, where there is very little sandstone, the interval can be greatly reduced. The important consideration is that the “Connoquenessing Sandstone” is not continuous. It cannot be traced laterally with any confidence, and its use as a major stratigraphic marker should be discontinued. The same holds true for the “Homewood Sandstone.” As difficult as it is to precisely correlate between STOP 12 and the previous stop at Moravia Street, 2.5 miles away, using regionally widespread marine zone marker beds, it is impossible to attempt to use the traditional sandstone markers that are obviously discontinuous.

SEDIMENTOLOGY

The massive looking sandstone beds visible in the canyon-like exit ramp of Toll 60 North are quartzitic and generally fine grained. Only a few beds at the base, including the channel lag deposit exposed in the waterfall, attain medium grain size. Fine-grained, quartz-rich sand of this type undergoes very minor compaction during burial, and the presence of this sandstone is probably the major contributor to the substantial compression of the section above it, as compared to the section at the Moravia Street interchange. This relatively uncompactable sand, combined with the thick lower sand, created a topographically positive area that strongly affected subsequent sedimentation. During subsequent periods of marine transgression, the area probably was a shoal lacking space for normal sedimentation, and when sea level was down its slightly higher elevation had an effect on duration and form of soil development, and on amounts of erosion and peat accumulation. The net result of this reduced deposition here at STOP 12 was a 48% shortening of the section compared to STOP 10, 95% less dark shale with siderite nodules, equal total paleosol thickness, and 50% less coal and bone. These figures reflect a comparison of the section from the top of the thick middle sandstone up to the Brookville coal, and are based on the assumption that the lower erosive channel at the Moravia Street eastbound entrance ramp at STOP 10 is equivalent to the thick middle sandstone.

Primary structure is very difficult to see in the massive sandstone walls of the exit ramp of northbound Toll 60. Bed thickness is barely discernible because only short segments of the bounding surfaces of the beds, expressed as fine fractures, can be seen (Figure 12-9). Bed thickness ranges from less than one foot to a maximum of approximately 3.5 feet. These surfaces appear to be gently trough-shaped at the very base of the sandstone, becoming planar upward. The planar sets appear to be slightly wedge-shaped at the lower part of the sandstone and tabular upward. Foreset laminations are visible only on surfaces of the blast holes and in the protected area under the bridge at the south end of the exposure (Figure 12-10). They are closely spaced, planar, and parallel, and have an apparent maximum dip of 30 degrees to the northwest. It is very difficult to see their terminations at the bottoms of the beds, but they vaguely appear to be abruptly asymptotic, turning sharply very near the lower bounding surface. The base of the sandstone is seen only at the waterfall in the stream cut near the southeastern end of the ramp exposure (Figure 12-1 and 12-4). There is a structureless bed of channel-lag material at the bottom of the sandstone containing abundant siderite nodules and tree trunks (Harper, this volume, his Figure 6) in a medium-grained quartz matrix. At the top of the sandstone, there are distinctive wavy sandstone beds that become thinner and climb up and away from the main sandstone body at a low angle (Figure 12-11). These appear to be scroll ridges and mud filled swales in the upper parts of point bars, and possibly levee deposits (Reineck and Singh, 1975, p 231-238). All of these features are consistent with the idea that this sandstone was deposited in a fluvial system (Conybeare and Crook, 1968; Davis, 1983, p. 250-258).

Figure 12-9. Thick middle sandstone at STOP 12 exposed in canyon-like exit ramp of Toll 60 North. Bedding planes and primary structures are very difficult to see. Subtle discontinuous horizontal fractures are planar bedding planes.

Figure 12-10. Foreset laminations in thick middle sandstone at STOP 12 dip 25-30 degrees to the northwest, and are visible only under the bridge at the southeast end of the exposure along exit ramp of Toll 60 North , and in blast holes.

Figure 12-11. Thin, climbing, wavy sandstone beds at top of thick middle sandstone at STOP 12 are interpreted as scroll ridges and mud-filled swales in upper part of point bar. Photo is stretched vertically.

The terminal end of the Lower Mercer Limestone can be seen along eastbound US 422 at the beginning of the ramp to Toll 60 South, and is an interesting feature. It is overlain by thin dark shale that has a fossiliferous, 0.4-foot-thick siderite bed above it. The limestone thins northward and disappears over a distance of several hundred feet, and only the siderite bed remains throughout the rest of the area at STOP 12 (Figure 12-12). The limestone is discontinuous in this exposure, abruptly thinning and disappearing for a short distance at several places (Figure 12-5). The siderite bed appears to be a lag deposit containing primarily crinoid columnals and shell hash. No meaningful correlation can be determined from so limited an observation, but there appears to be an interesting vague relationship of thickening siderite at these breaks in the limestone. These breaks may be narrow, small channels of faster current where more lag collected.

Figure 12-12. Termination of Lower Mercer Limestone exposed along eastbound US 422 near entrance ramp of Toll 60 South. Fossiliferous siderite bed continues throughout site. Upper Mercer coal is only three to four feet below Mount Jackson (Tionesta) coal here, separated by rootworked argillaceous sandstone.

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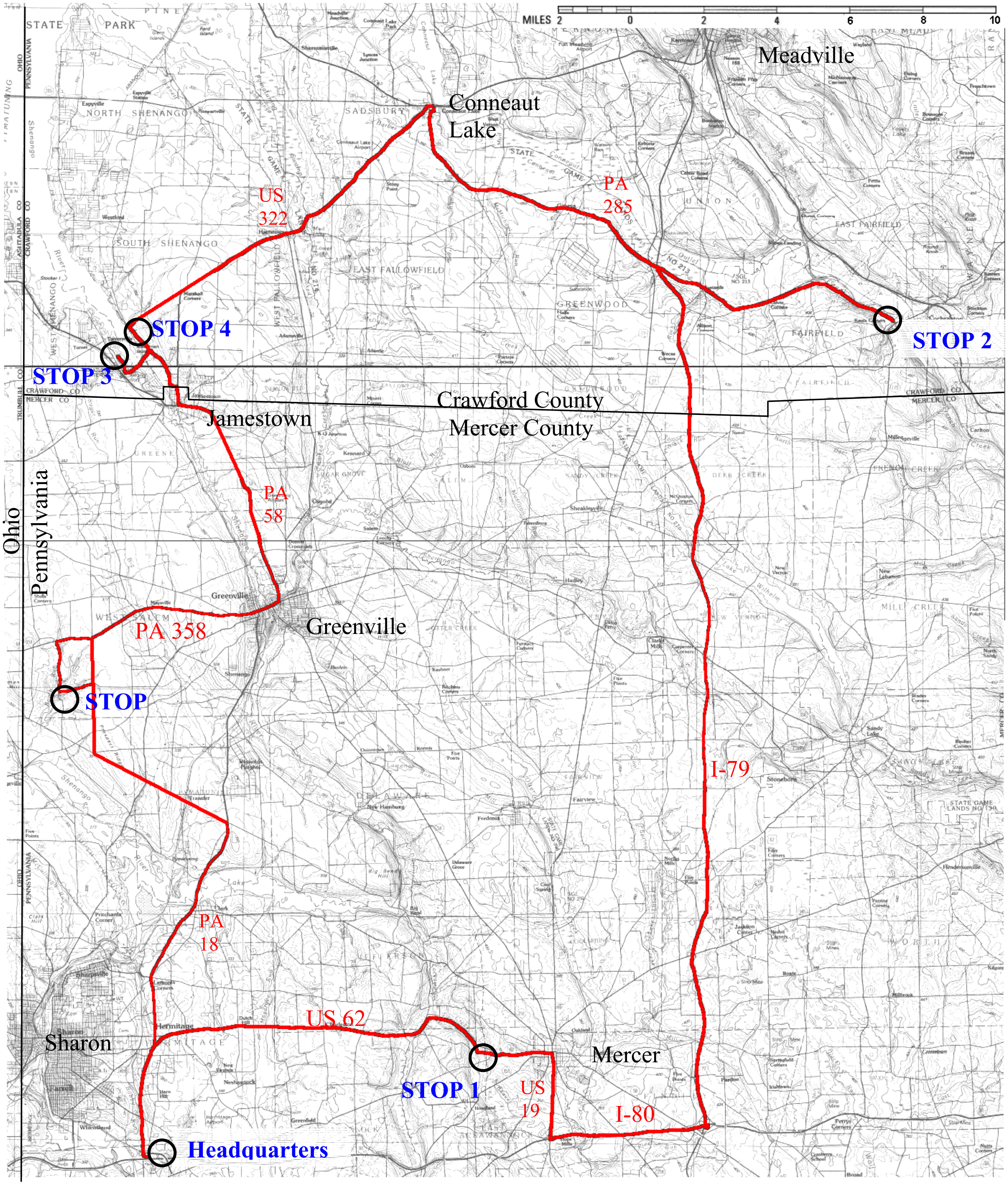


Route map for Day 1 of the 2005 Field Conference of Pennsylvania Geologists

ROADLOG

DAY 1

Int	Cum	Description
0.0	0.0	Leave Radisson parking lot.
0.1	0.1	Turn right onto PA 18 N.
0.1	0.2	Pass under PA 60.
0.4	0.6	Tam O'Shanter Golf Course on right.
0.6	1.2	Traffic light at PA 518 (Longview Road). Continue straight on PA 18 N.
1.7	2.9	Traffic light at Morefield Road.
0.3	3.2	Bear right onto US 62 N (Shenango Valley Freeway)- stay in right lane.
0.3	3.5	Bear right, staying on US 62 N (East State Street).
0.7	4.2	Traffic light at Keel Road. Continue straight on US 62
0.1	4.3	Cut through Homewood sandstone as road ascends Keel Ridge.
1.1	5.4	Hickory VFW on right, where Fleeger's first cousin once removed had her wedding reception (July 2, 2004).
0.6	6.0	Flashing yellow light at Neshannock Street. Continue north on US 62.
0.7	6.7	Historical Marker to left reads: ***CLAY FURNACE**: First successful use of raw bituminous coal in place of charcoal, 1846; and of unmixed Lake Superior iron ore in 1856. Built 1845 by Vincent and Himrod; named for Henry Clay. The site is 2 miles away.*
0.7	7.4	Enter village of Charleston.
2.7	10.1	Cross Little Neshannock Creek.
2.3	12.4	Turn right onto White Road (T-496).
0.3	12.7	STOP SIGN. Turn left onto Old Sharon Road, the main road in the 1870s and 1880s when I.C. White worked in the area. Just after the intersection note (if it's still there) the beautifully constructed concave beaver dam (left of road) across Lackawannock Creek and its pond (right of road). The beavers ingeniously took advantage of the road fill and culvert to create a large pond with a minimal amount of dam construction. This valley is filled with over 250 feet of mostly outwash. 
0.4	13.1	Pull off on right side of road. Disembark. Buses will leave and return later, picking us up at White Road and the beaver dam. **STOP 1. HELLS HOLLOW. "MERCER LIMESTONE" TYPE SECTION**. See stop description on page 59.
0.2	13.3	Intersection with Bestwick Road. Continue straight on Bestwick Road.
0.2	13.5	Stop sign. Turn right onto US 62 N. Enter Borough of Mercer, incorporated in 1814. County seat of Mercer County. Named for Gen. Hugh Mercer, Revolutionary hero killed at the Battle of Princeton in 1777.
1.3	14.8	Traffic light in Mercer. Turn right at light onto US 19 South. Mercer County courthouse ahead.
0.1	14.9	Butler Street. Go straight at light
1.1	16.0	Hummocky topography of kames to the right
0.4	16.4	Cross Beaver Run

0.3	16.7	Atlantic State Materials sand and gravel pit in kame field. Drift thickness exceeds 250 feet here over the buried valley of Beaver Run, which is displaced 0.3 miles to the north by the kame field.
0.4	17.1	Turn left onto ramp to I-80 East
0.3	17.4	Merge onto I-80 East
0.1	17.5	Cross the buried valley of pre-glacial Neshannock Creek. Depth to bedrock is about 175 feet. The valley is blocked by the kames noted at mile 16.7.
0.6	18.1	Cross Neshannock Creek. Depth to bedrock is about 50 feet.
1.0	19.1	Cross over PA 258.
1.8	20.9	Cross under PA 58.
0.4	21.3	Bear right onto exit ramp to I-79 North.
2.7	24.0	Pass over Bessemer and Lake Erie RR main line.
0.1	24.1	Swamp on right in buried valley of Mill Creek. Depth to bedrock is about 70 feet.
0.5	24.6	Bedrock outcrop- Mercer Formation. Prominent hill to the left is underlain by the Homewood.
1.2	25.8	Cross Yellow Creek. Depth to bedrock is about 50 feet.
0.7	26.5	Pass under US 62.
2.0	28.5	Leave Kent Moraine. Remainder of Day 1 is behind the Kent Moraine.
0.6	29.1	Level ground moraine to left.
2.6	31.7	Descend through a kame terrace into the Little Shenango River valley.
1.0	32.7	Cross Little Shenango River.
1.1	33.8	Pass under PA 358.
2.9	36.7	Cross Lake Wilhelm in Maurice Goddard State Park. Lake Wilhelm was created by a dam near a bedrock constriction (old pre-glacial divide) in the Sandy Creek valley. From the old divide near the position of the dam, preglacial drainage flowed northwest into the Middle Allegheny River (modern Conneaut Outlet) and on into the Erie basin.
1.1	37.8	Pass under Georgetown Road.
0.6	38.4	Entrance to Rest Area and Weigh Station. Continue straight ahead.
2.0	40.4	Enter Crawford County at County Line Road overpass.
0.7	41.1	Pass under Mule Street.
1.4	42.5	Cross Rock Creek
0.7	43.2	Pass under Adamsville Road.
1.0	44.2	At Exit 141, bear right on ramp to PA 285.
0.4	44.6	Stop sign. Turn right onto PA 285 E toward Cochranton, following along Conneaut Outlet.
1.1	45.7	Village of Custards.
1.7	47.4	Mumford Chapel (on right) and cemetery (on left).
0.2	47.6	Small stream flows on Orangeville Shale on both side of the road.
0.8	48.4	Hummocky topography of kame terrace.
1.4	49.8	Descend from kame terrace to edge of French Creek floodplain. Steep bedrock hills are now to the right side of the road.
0.5	50.3	French Creek to left.
0.1	50.4	The confluence of Conneaut Outlet into French Creek is in the valley to the left.
0.3	50.7	View ahead to left of trailers on stilts.
0.9	51.6	Turn left into parking lot of Cochranton Community Church. Disembark.

STOP 2. COCHRANTON GLACIO-LACUSTRINE SEDIMENTS.

See stop description on page 69.

Leave STOP 2, turning right onto PA 258W and returning to I-79.

7.1	58.7	Pass over I-79 and get into left lane.
0.2	58.9	Bear left to stop sign and flashing light. Continue straight on PA 285 W, crossing US 19.
0.4	59.3	View of Conneaut Marsh to right, marks the course of the pre-glacial Middle Allegheny River (See STOP 2 description, Figure 2-3). Glacial diversions from an early glacial advance dammed this river. He overflow of the pre-glacial Upper and Middle Allegheny Rivers eroded the divides, and diverted the flow to the south, forming the current Allegheny River. Depth to bedrock exceeds 300 feet.

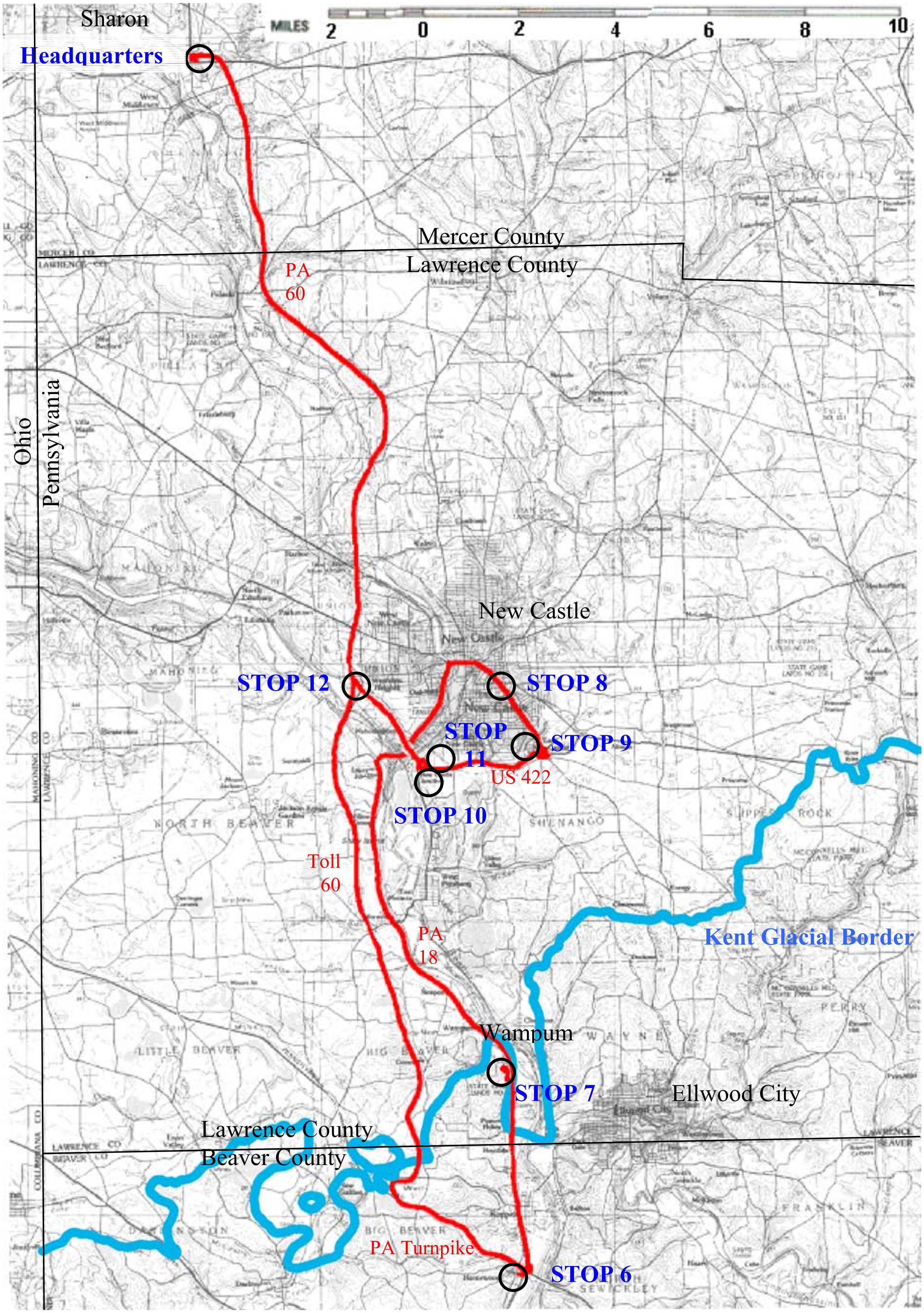
0.2	59.5	Gas well on right.
1.5	61.0	Another view of Conneaut Marsh to right. We will parallel the Conneaut Outlet all the way to Conneaut Lake.
0.3	61.3	Enter village of Geneva.
0.6	61.9	First of two gas wells to right within a short distance.
1.5	63.4	Cross old Erie-Lackawanna Railroad (now Norfolk Southern). Another gas well is just to right adjacent to railroad.
1.0	64.4	Pass McMichael Road
0.8	65.2	Cross Adsit Run
0.4	65.6	Adsit Cemetery to left.
1.2	66.8	Hummocky topography- kame terrace.
1.7	68.5	Enter borough of Conneaut Lake and turn right onto Richmond Street.
0.1	68.6	Stop sign at Second Street. Continue straight ahead.
0.1	68.7	Stop sign. Turn left onto First Street.
0.1	68.8	Stop sign at intersection with US 6-322 (Water St.), where there is a good view of Conneaut Lake ahead. Conneaut Lake, the largest natural lake completely within the state of Pennsylvania (Lake Erie is slightly larger), is a kettle lake. Turn left.
0.1	68.9	Traffic light at Second Street. Continue straight on US 6-322 W.
0.1	69.0	Traffic light at Third Street. Continue straight ahead.
0.1	69.1	Traffic light. Turn left on US 322 W-PA 18 S.
0.8	69.9	Two big granite erratics at entrance to driveway to right.
2.3	72.2	Passing down through belt of conspicuous kames, with house on top of one to right. The well at the house is 84 feet deep and did not reach bedrock.
0.5	72.7	Pymatuning Swamp on both sides of road. The road crosses the swamp near the divide between the Shenango River to the north (right), and Crooked Creek to the south (left). The depth to bedrock in this valley is not known, but it is more than 100 feet and probably more than 200 feet.

0.6	73.3	Historical Marker to right reads: ***ERIE EXTENSION CANAL**. Cut off from the rest of Pymatuning Swamp by a 3-mile bank, this became the 600-acre "Pymatuning Reservoir" of the canal, which lay at its western edge. Begun by the State in 1838; finished by the Erie Canal Company, 1843-44.*
0.1	73.4	Cross bridge over main line of the Bessemer and Lake Erie Railroad, which probably follows along the path of the old canal.
0.1	73.5	Stop sign in the heart of Hartstown. Continue straight on US 322 W.
3.2	76.7	Continue straight on East State Road, when US 322 bends left at Marshall Corners.
1.2	77.9	To left is the access road leading to a quarry in the Sharpsville sandstone. This quarry recently applied to reopen. After the water supply losses that resulted from the 1998 Pymatuning earthquake in this area, locals have been worried about the effects of blasting on their water supplies. However, the amount of energy in a quarry blast would be very small compared to the energy of an earthquake.
0.7	78.6	Stop sign at the end of East State Road, with Pymatuning Reservoir directly ahead. Turn left on East Lake Road.
0.2	78.8	STOP 4 of field trip is along Reservoir to right.
0.6	79.4	Turn right onto entrance road to Pymatuning State Park.
0.1	79.5	Gravel pit to left exposes outwash along the margin of the Shenango River valley. The area is also currently used by the park for storage of construction materials.
0.2	79.7	Pass over abandoned Penn Central railroad grade. According to Mr. Elisha Fields, 95-year old former owner of the Westford Feed Mill, the railroad was called the Pittsburgh/Erie division of the Pennsylvania Railroad. It had stations in Jamestown and Linesville and these connected with the main line in Conneaut Ohio. The railroad had mail service until the late 1930's or early 1940's and passenger service until the early 1950's. For much of its time, the line had two trains going each way – from Jamestown to Linesville. When service began to decline there was only one train going up the line and back again. The train brought coal and cattle feed to the Westford Mill. The local residents used coal for heating before propane was brought into the area. The train stopped running in the 1970's. The Westford Mill is still operating today selling a variety of goods to the residents of Westford.
0.2	79.9	Cross Pymatuning Dam, across the Shenango River, with reservoir to right.
0.3	80.2	Cross principal spillway of dam, with gatehouse to right.
0.1	80.3	Cross emergency spillway of dam.
0.3	80.6	Stop sign. Turn right onto park road.
0.1	80.7	Pymatuning State Park Office to left.
0.4	81.1	Turn right to parking area for Shelter #4. Disembark in parking area.
		STOP 3 AND LUNCH. PYMATUNING RESERVOIR.
		See stop description on page 80.
		Leave STOP 3, returning to East Lake Road.
1.7	82.8	Stop sign. Turn left onto East Lake Road.
0.6	83.4	Turn left into lifting station area.
		STOP 4. PYMATUNING STREAM CUT AND LAKE BLUFF.
		See stop description on page 81.
		Leave STOP 4, turning right (south) on East Lake Road.
0.6	84.0	Entrance to Pymatuning State Park to right. Continue straight ahead.
0.8	84.8	Walnut Creek Golf Course to right.
0.4	85.2	Jamestown Elementary School to right.
0.1	85.3	Enter Mercer County and borough of Jamestown, turning left on North Street at

		county/borough line.
0.2	85.5	Stop sign. Turn right onto Depot Street (US 322 W).
0.5	86.0	Traffic light. Turn left on PA 58 E (Liberty Street).
0.5	86.5	Jamestown Deer Park to left.
0.2	86.7	Home of a true, red-blooded, gun-totin' American to left.
1.0	87.7	Ascending "Earthquake Hill." Many homes on the top and sides of this hill lost the water from their wells after the 1998 Pymatuning earthquake. The wells at homes at the base of the hill began to flow (see article on the souvenir CD).
1.4	89.1	Walter Road to right. The owner of a house back this road was under his modular home, which was supported by cement blocks, when the earthquake occurred. He swears that his house rose 6 inches off of the blocks and dropped back down during the quake.
0.4	89.5	Harvest Baptist Church to right. Lighthouse hides new well replacing one that went dry after the earthquake. The dry well was between the lighthouse and the church, under the porch roof, preventing the driller from deepening the old well. The old well has been cemented over. To left here is entrance to Greenville Airport.
0.5	90.0	Pass Tanner Road on left. The largest concentration of earthquake-induced water losses occurred in wells along this road.
1.0	91.0	Field on right was flooded by discharging groundwater as a result of earthquake.
0.2	91.2	To left is main entrance to St. Paul Retirement Homes, which extends for considerable distance north along ridge.
0.4	91.6	In housing development to right, one home had in-ground pool those lining collapsed as a result of increase discharge of groundwater draining from the hill after the earthquake.
0.3	91.9	Enter borough of Greenville.
0.1	92.0	Traffic light at intersection with PA 18. Continue straight ahead. To left is Thiel College, a co-educational, liberal arts institution affiliated with the Evangelical Lutheran Church. Initially founded in 1866 as Thiel Hall in Phillipsburg (now Monaca), Beaver County, it was chartered as a college by the Commonwealth of Pennsylvania in 1870 and in 1871 moved to Greenville. Thiel is named for A. Louis Thiel, whose initial donation of $4000 to start the college came from funds received through stock transactions in the new Pennsylvania oil industry. The college has an environmental science major and offers several geology courses. Current student population is about 1250.
0.2	92.2	Cross Little Shenango River and Bessemer and Lake Erie Railroad tracks.
0.1	92.3	Traffic light at Shenango Street. Continue straight ahead.
0.1	92.4	Traffic light. Turn right onto PA 358 W (Main Street).
0.2	92.6	Traffic light at PA 58. Continue straight on PA 358 W.
0.2	92.8	Cross railroad tracks
0.1	92.9	Traffic light at Water Street. Continue straight on PA 358 W.
0.1	93.0	Cross Shenango River.
0.2	93.2	Traffic light at High Street. Continue straight ahead.
0.1	93.3	Traffic light at PA 18 S (Third Street). Continue straight on PA 358 W.
2.5	95.8	Enter village of Maysville.
0.5	96.3	Blinking traffic light at intersection with Good Hope Road in downtown Maysville.
1.5	97.8	Intersection with Summit Road. Turn left.
0.5	98.3	Summit Estates trailer court.
0.7	99.0	Turn right onto Woods Road. Woods Road runs on a narrow upland between two ravines.

0.9	99.9	Descend into valley of Booth Run.
0.1	100.0	Bear right onto Barry Road. Barry Road is named for Daniel Barry, a Mercer County resident since 1848 and located here in 1876.
0.2	100.2	Bridge over unnamed tributary to Booth Run that forms the ravine to the north of Woods Road.
0.1	100.3	GPAA to left.
0.4	100.7	Cross over Booth Run.
0.3	101.0	Bridge over tributary to Booth Run.
		STOP 5- BOOTH RUN SECTION. See stop description on page 91.
		Leave STOP 5, continuing ahead on Barry Road.
0.2	101.2	Little Booth Run section on right, behind house.
0.1	101.3	Booth Run flows on bedrock to right of road
0.1	101.4	To right is section measured by Shepps in 1952.
0.1	101.5	PA 358. Turn right. Ascend from Booth Run valley.
0.3	101.8	Greenville Sportsman Club on left.
0.3	102.1	Cross upland over buried Booth Run valley (>100 feet to bedrock).
0.5	102.6	Turn right again onto S. Summit Road.
2.5	105.1	Stop sign at Darien Road. Go straight.
0.6	105.7	Stop sign. Turn left onto Rutledge Road at end of Summit Road. Pymatuning Creek valley visible ahead to the right.
1.6	107.3	Stop sign at bottom of hill at PA 846. Continue straight on Rutledge Road and cross Chestnut Run. POOR VISIBILITY TO THE RIGHT. BE CAREFUL.
0.8	108.1	Enter village of Transfer. Transfer received its name because two railroads of differing gauge met here, necessitating the transfer of freight from one railroad to the other. Transfer was also the boyhood home of James E. Winner, Jr., creator of "The Club" and owner of our headquarters hotel.
0.4	108.5	Cross Norfolk-Southern Railroad tracks.
0.2	108.7	Cross Brush Run
1.0	109.7	Stop sign. Turn right on PA 18 S.
2.1	111.8	Crossing Shenango River Reservoir. It was built in 1965 as a flood control dam by the US Army Corps of Engineers.
0.3	112.1	Bridge over old Shenango River channel.
0.3	112.4	Traffic light at intersection with PA 258. Continue straight on PA 18 S. Tara, on left, is a restaurant and country inn, modeled after Tara from Gone With the Wind. Tara claims to be the largest American Civil War style plantation not located in the Deep South. It also is owned by James E. Winner, Jr. (see mile 108.1).
1.1	113.5	Enter city of Hermitage—suburban sprawl run rampant!
1.0	114.5	Traffic light at Lamar Road (PA 518). Just ahead to right is the Hickory Grill, a good place to eat! Continue straight on PA 18.
1.0	115.5	Stop light at Highland Road. Continue straight on PA 18 S.
0.4	115.9	Shenango Valley Mall on left
0.3	116.2	Traffic light at Business US 62 (State St). One half mile down State St. to right is the Avenue of 444 Flags, created during the Iranian hostage crisis in 1979. One flag was erected for each day US captives were held hostage (or as G.W. Bush would say, "held hostile").
0.1	116.3	Stop light at Glimcher Blvd. Continue straight on PA 18 S.

0.1	116.4	Traffic light at US 62, the Shenango Valley Freeway. Continue straight on PA 18.
0.3	116.7	Stop light at Morefield Road. Continue straight on PA 18 S.
1.7	118.4	Traffic light at PA 518 (Longview Road). Continue straight on PA 18.
0.6	119.0	Get into left lane when you see Tam O'Shanter Golf Course on left.
0.4	119.4	Pass under PA 60.
0.1	119.5	Turn left into entrance of Radisson.
0.1	119.6	Radisson parking lot. Disembark. End of Day-1 field trip!



Route map for Day 2 of the 2005 Field Conference of Pennsylvania Geologists

ROADLOG

DAY 2

Int	Cum	Description
0.0	0.0	Leave parking lot at Radisson.
0.1	0.1	Stop sign. Turn right onto PA 18 N.
0.1	0.2	Bear right onto ramp of PA 60 S.
0.2	0.4	Merge with PA 60 S.
4.7	5.1	Enter Lawrence County.
0.7	5.8	Pass under PA 208.
0.3	6.1	Bedrock outcrop on left- mapped by Carswell and Bennet (1963) as Connoquenessing Fm.
1.0	7.1	To right is a rolling kame terrace on the east side of the Shenango River valley. The drift is almost 200 feet thick here. The cultivated fields are part of an Amish farm.
3.0	10.1	Pass under Mitchell Road.
2.6	12.7	Cross Shenango River. The depth to bedrock is at least 100 feet, and probably closer to 200 feet.
0.2	12.9	Pass over US 422, which merges with PA 60 just to south.
1.3	14.2	Pass under State Street (US 224). Just to right is the site of Vik Skema's notorious "T-bone" collision, where he tried quite unsuccessfully to reduce by two George Bush's voting pool in Alabama.
0.6	14.8	Big cut in Pottsville Group, STOP 12 of this field conference.
0.3	15.1	Bear right onto Toll 60 S (part of PA Turnpike). Most of the roadcuts on Toll 60 expose bedrock in the thin drift areas high on the Beaver valley wall.
0.8	15.9	Cross Mahoning River. Depth to bedrock exceeds 200 feet.
1.6	17.5	Deep bedrock cut.
0.6	18.1	Cross Hickory Run, a tributary of the Mahoning River. Hickory Run flows on bedrock.
0.9	19.0	Turnpike toll booth.
0.9	19.9	Deep cut exposing fossiliferous Vanport Limestone at the top of the hill. Weathered rubble covering the slope, on both sides of the highway, yields large and small crinoid columnals, bryozoans, and fragmented brachiopods. Good collecting site!
0.5	20.4	Descend into pre-glacial valley of Little Beaver Creek. In places, Little Beaver Creek is a completely buried valley (no surface expression) more than 250 feet deep.
1.9	22.3	To left across the Beaver River is a good view of the CEMEX's Wampum quarry (Vanport Limestone).
0.2	22.5	Bedrock cut.
2.8	25.3	Approximate end of long series of bedrock cuts with poor exposure.
0.7	26.0	Enter Beaver County.
0.3	26.3	To right is a strip mine highwall. This is approximately the limit of the Kent glaciation. Although the route continues within the glacial border almost to STOP 1, the topography is now controlled completely by bedrock erosion.
0.4	26.7	Exit to right for PA Turnpike.
0.3	27.0	Turn right at end of ramp and get into left lane.
0.2	27.2	Bear left onto ramp to PA Turnpike.
0.9	28.1	Merge onto PA Turnpike.
1.5	29.6	Cuts in bedrock.
0.2	29.8	Another cut—lower Allegheny.
1.0	30.8	Bedrock cut, especially to left.

0.3	31.1	Bear right at Exit 13 onto ramp for PA 18.
0.5	31.6	Bear left to PA 18 S at split.
0.2	31.8	To right is a cut in the Homewood Sandstone.
0.1	31.9	Merge onto PA 18, just before PA Turnpike overpass.
0.1	32.0	Turn right into Buttermilk Falls Natural Area.
0.2	32.2	Turn into Homewood Church parking lot. Disembark.
		STOP 6. HOMEWOOD SANDSTONE (STEREO)TYPE SECTION.
		See stop description on page 97.
		Leave STOP 6, proceeding back to PA 18.
0.2	32.4	Stop sign. Turn left onto PA 18 N. BE CAREFUL: THIS IS A DANGEROUS TURN.
1.2	33.6	Enter village of Koppel, Founded 1912. Get into left lane.
		The village is named for Arthur (not Ted) Koppel. Arthur Koppel began in the light railway business at Berlin, Germany, in partnership with Benno Orenstein on April 1, 1876. In 1905 or 1906, the Arthur Koppel Company purchased 558 acres of land above the Beaver River in Beaver County, and began constructing a plant and a company town.
		A large sandstone quarry in the Homewood Sandstone operated here for many years. Large blocks were used for bridge piers and abutments, retaining walls, and foundations. Where the bedding was too thin for blocks, it was used to make silica sand. Stone from this quarry was used in the Market Street and Rockville Bridges at Harrisburg, the Henry Ford home at Dearborn, Michigan, (on this property, Skema, in his youth, was busted for trespassing) and numerous bridges in the Pittsburgh, Chicago, and Washington, D.C. area (DeWolf, 1929).
0.2	33.8	Traffic light at intersection with PA 351. Continue on PA 18 N.
1.4	35.2	Reenter Lawrence County.
0.3	35.5	Recross the Kent glacial border. Within the Kent border, topography is controlled by both bedrock erosion and glacial construction (moraines, kames, etc.).
1.1	36.6	Turn left at entrance to Gateway Commerce Center.
0.1	36.7	Stop sign. Turn right.
0.05	36.75	Turn left onto access road to Gateway Commerce Center.
0.05	36.8	To right is a large rounded glacial erratic.
0.2	37.0	Pull off on left just before portal of Gateway Commerce Center. Disembark.
		STOP 7. VANPORT LIMESTONE AT WAMPUM.
		See stop description on page 101.
		Leave STOP 7, proceeding back to PA 18.
0.4	37.4	Stop sign. Turn left onto PA 18 N.
0.2	37.6	Enter village of Wampum, founded 1796 and the hometown of professional baseball player Dick Allen. To right is the Wampum plant of CEMEX Corp. This plant is the oldest continuously operated Portland cement manufacturing site in the United States. It began operations in 1874. Cement from the plant was used in construction of the Brooklyn Bridge, which opened in 1883. When contractors recently repaired the bridge, the engineers specified that the cement come from the Wampum plant. The original plant was replaced in 1901, rebuilt in 1929, 1957, and 1969. CEMEX is now one of the top three cement manufacturers in the world, the largest in the US, with annual sales of $16 billion. CEMEX makes 8 types of Portland and masonry cements at this facility.
1.2	38.8	Blinking traffic light. Downtown Wampum to right
0.4	39.2	Borough of New Beaver.

2.4	41.6	Junction with PA 168 in village of Moravia. Continue straight ahead.
0.3	41.9	Historical Markers to left read: ***FRIEDENSSTADT***. *Founded 1770 by Christian Delaware Indians brought from upper Allegheny by Rev. David Zeisberger. Settling on the eastern riverbank on May 3, they moved to the west side about three months later*. AND ***FRIEDENSSTADT***. *Abandoned April 30, 1773, when its inhabitants, under the Rev. John Heckewelder, moved to new towns on the Muskingum in present Ohio. There some of them were massacred, March 8, 1782, by Pennsylvania militia*. In a clearing amid the trees fifty feet southwest of the markers on Donald Road (old PA 68) is a granite-erratic monument (erected in 1921) that reads: *This stone marks the site of the former Moravian Indian village of Languntoutenuck or Friedensstadt, or City of Peace, settled by the Moravian Indians in the spring of 1770. The majority of the members of this mission had belonged to the mission at Wyalusing, before moving to Lawunakhannek on the Allegheny River, from which place they removed to this site. In the spring of 1773 the inhabitants of this village moved to Gnadenhuetten and Schoenbrunn in the Tuscarawas Valley, where other Moravian missions were organized.* (Beyer, 2000; see Inners et al., 2002.)
2.6	44.5	Cross the Mahoning River. The valley is filled with at least 135 feet of outwash.
0.6	45.1	PA 108 W to left. Continue straight. Historical Markers to left read: ***KUSKUSKIES TOWNS***. *Important group of Indian towns on and near site of present New Castle. First inhabited by Senecas; but after 1756 chiefly by Delawares from eastern Pennsylvania. Abandoned during Revolutionary War.* AND ***C. FREDERICK POST***. *Sent by Provincial officials to draw Indian friendship away from the French, the Moravian missionary held councils at Kuskuskies Towns, August to November, 1758. His work, and the threat of Gen. Forbes' army, forced the French to leave present-day Pittsburgh on November 24, 1758.*
0.1	45.2	Cross railroad tracks. Enter City of New Castle
0.3	45.5	Stop sign. Turn left staying on PA 18 N.
0.1	45.6	Railroad underpass
0.1	45.7	Light at Cherry St. Continue straight
0.1	45.8	Light at Madison Ave. Continue straight.
0.1	45.9	Pass under US 422
0.6	46.5	Stay straight at light on Atlantic Ave. PA 108/18 (Mahoning Ave.) turns right.
0.2	46.7	Taylor Twp. Line
0.2	46.9	Union Twp line
0.7	47.6	Enter City of New Castle. New Castle, the seat of Lawrence County, was laid out by John Carlyle Stewart in April, 1798. Stewart named New Castle for his home of New Castle, DE, and laid out the downtown with two parallel main streets to resemble his hometown. It was incorporated as a borough in 1825 and a city in 1869. By the end of the 19th century it was a major industrial center served by several major railroads. New Castle is the tin plate, hot dog, and fireworks capitals of the world. New Castle played a significant role in the history of entertainment. Bob Hope began his career as a comedian in New Castle. He appeared at the Capitol Theater in 1927 with George Byrne, as Hope and Byrne, Dancers Supreme. When the master of ceremonies became ill, Hope was asked to introduce other acts on the show. His jokes

		and monologue during the several nights here were so well received that he decided that his destiny was in solo comedy.
		Warner Brothers also started here. See mile 48.6.
0.3	47.9	Turn right at light onto Washington Street
0.2	48.1	Cross Shenango River
0.1	48.2	Stay straight at light (Columbus St).
0.1	48.3	Stay straight at light (Beaver St).
0.1	48.4	Pass around the town square. Note the county Civil War monument, erected in 1897. Continue straight at the light at Jefferson St. in the middle of the square.
0.05	48.45	Stay straight at light (Cochran Way)
0.05	48.5	Stay straight at light (Mercer St).
0.1	48.6	Stay straight at light (Mill St). Warner Brothers started their first movie theater in New Castle in 1906. They were natives of Youngstown and rented a room on the 2nd floor of the Knox building on South Mill Street, borrowed chairs from a funeral parlor, and with their hand operated projector brought the miracle of moving pictures to Lawrence County. (....taken from Bridges to The Past published by the Lawrence County Historical Society)
0.1	48.7	Angle right at light (East St). Cross Neshannock Creek, which enters the Shenango River about a mile downstream.
0.1	48.8	Stay straight at light (PA 108/168 – Croton Ave.).
0.2	49.0	Lawrence County courthouse on left.
0.3	49.3	Jct PA 65 and Business US 422 (Taylor St). Continue straight at light.
0.1	49.4	Turn right into the CVS pharmacy parking lot. Disembark.
		STOP 8. NEW CASTLE FAULTED FOLD. See stop description on page 115.
0.2	49.6	Light at Junior High St. Go straight.
0.2	49.8	Light at Marshall Ave (on left) and Lathrop St (on right). Continue straight.
0.3	50.1	Light at Arlington St (on left) and Rose Ave (on right). Continue straight.
0.4	50.5	Turn right into the Cascade Park parking lot. **STOP 9 AND LUNCH. CASCADE PARK.** See stop description on page 125.
		Exit Cascade Park parking lot. Turn right onto PA 65 South (Washington St)
0.2	50.7	Cross Big Run
0.4	51.1	Turn right at the light onto the ramp to US 422 West
0.2	51.3	Merge onto US 422 West
1.0	52.3	Bridge over tributary to Big Run
0.2	52.5	Outcrop of Mercer Form on left. Mt. Jackson coal is near the top, and the Upper Mercer Limestone near the center of the roadcut.
0.8	53.3	Beginning of extensive outcrop on right (STOP 11)
0.2	53.5	Bear right onto exit ramp for PA 168 (Moravia St)
0.3	53.8	Turn left at the stop sign at the end of the exit ramp onto PA 168 South.
0.2	54.0	Turn left onto ramp to US 422 East.
0.1	54.1	Pull off on right side on entrance ramp.
		STOP 10. US 422 EASTBOUND AT THE MORAVIA STREET (PA 168) INTERCHANGE. See stop description on page 129.
		Leave STOP 10. Proceed down ramp to US 422 East.
1.2	55.3	Outcrop on Mercer Formation on right
0.3	55.6	Bridge over tributary to Big Run
0.9	56.5	Bear right onto exit ramp to PA 65
0.4	56.9	Turn left at the light at the end of the ramp onto PA 65 North
0.1	57.0	Turn left at the light onto the ramp to US 422 West

0.2	57.2	Merge onto US 422 West
1.0	58.2	Bridge over tributary to Big Run
1.1	59.3	Beginning of extensive outcrop on right.
0.1	59.4	Pull off on shoulder.
		STOP 11. US 422 WESTBOUND AT THE MORAVIA STREET (PA 168) INTERCHANGE. See stop description on page 129.
		Leave STOP 11. Continue West on US 422
0.1	59.5	Continue straight past the exit ramp for PA 168 (Moravia St).
0.3	59.8	Pass entrance ramp from PA 168.
0.2	60.0	Cross Shenango River
0.8	60.8	Pass over Toll 60 South
0.3	61.1	Pull off on shoulder.
		STOP 12. US 422 - TOLL 60 INTERCHANGE.
		See stop description on page 145.
		Leave STOP 12. Continue on US 422 West
		Merge with PA 60 North
0.7	61.8	Pass exit to US 224 East (State St)
0.3	62.1	Pass exit to US 224 West
0.8	62.9	Pass exit to US 422 (Sampson St)
0.7	63.6	Cross Shenango River (for the 8th and last time!!!).
2.5	66.1	Pass under Mitchell Road
1.0	67.1	Wilmington Twp. Line
0.2	67.3	Pulaski Twp. line
2.7	70.0	Connoquenessing Formation mapped by Carswell and Bennett (1963) on right
0.4	70.4	Pass under PA 208
0.8	71.2	Mercer County line
2.5	73.7	Pass over PA 18
1.2	74.9	Pass under PA 318 (Main St)
0.2	75.1	Pass exit ramp to I-80 East
0.3	75.4	Pass exit ramp to I-80 West. Get into left lane.
0.5	75.9	Pass exit ramp to PA 18 North
0.2	76.1	Turn left onto ramp to PA 18 South
0.2	76.3	Bear right onto PA 18 South
0.1	76.4	Immediately turn left into drive for Radisson, just before passing under I-80
0.1	76.5	End of Field Conference.

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