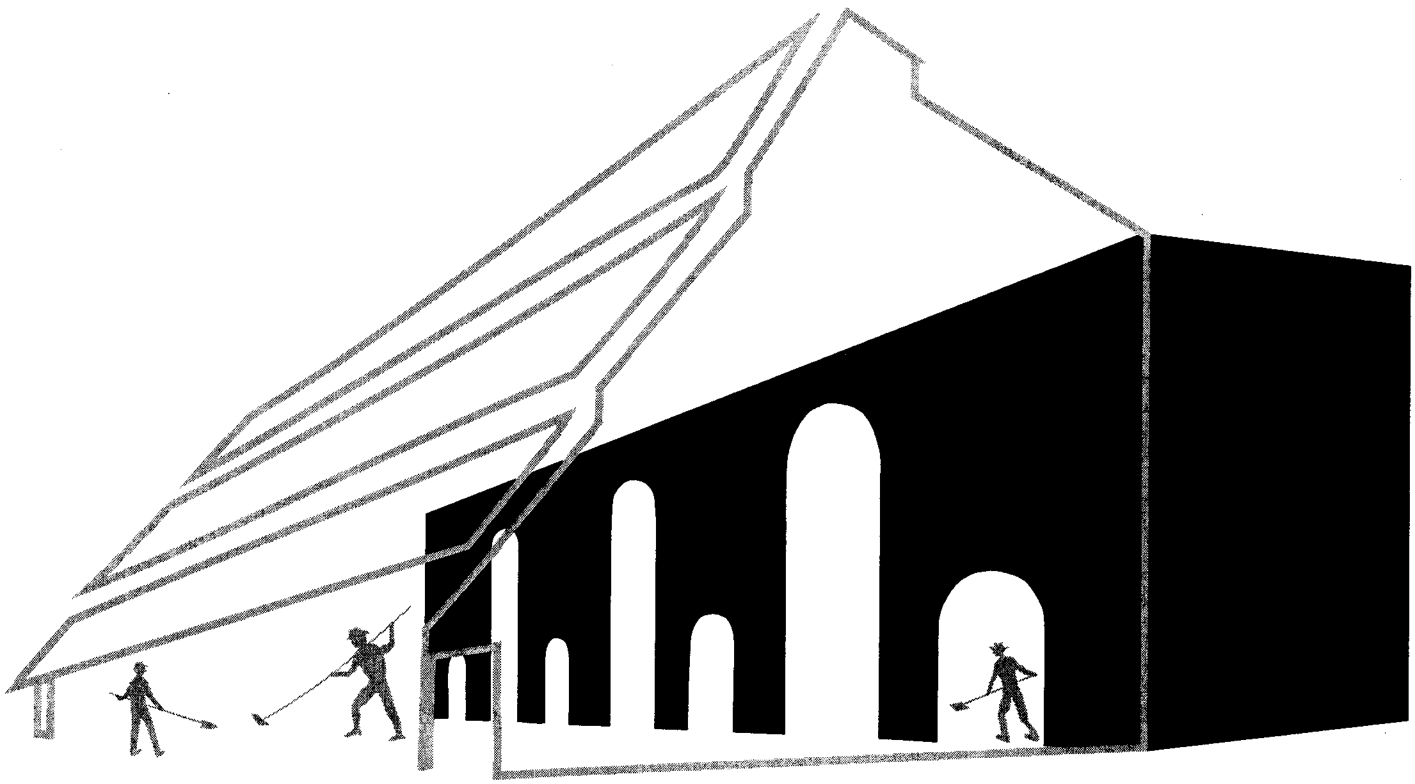
GUIDEBOOK

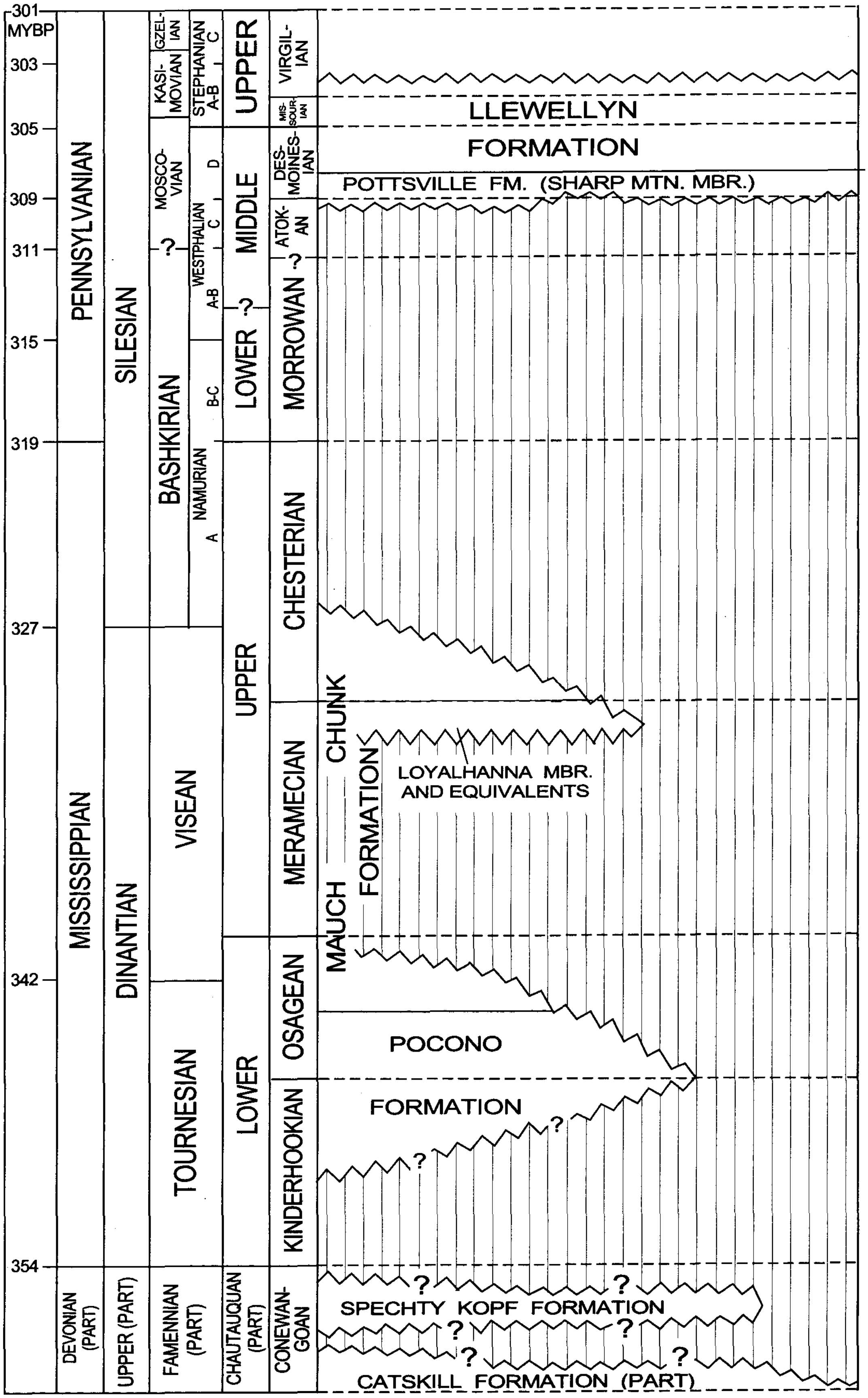
# 62[nd] Annual Field Conference of Pennsylvania Geologists

## Geology of the Wyoming-Lackawanna Valley and its Mountain Rim, northeastern Pennsylvania



October 2, 3, and 4, 1997
Scranton, PA

Hosts: Pennsylvania Geological Survey
Bloomsburg University
Luzerne County Community College
Everhart Museum
Anthracite Heritage Museum




Stratigraphic correlations of the Pennsylvanian, Mississippian, and uppermost Devonian of the Lackawanna synclinorium (Northern Anthracite field). Adapted from Edmunds (1996).

Guidebook for the
62nd Annual Field Conference of Pennsylvania Geologists

# GEOLOGY OF THE WYOMING-LACKAWANNA VALLEY AND ITS MOUNTAIN RIM, NORTHEASTERN PENNSYLVANIA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October 2-4, 1997

*Hosts:* PA Geological Survey, Bloomsburg University, Luzerne County Community College, Everhart Museum, and Anthracite Heritage Museum.

*Headquarters:* Radisson Lackawanna Station Hotel, Scranton, PA

*Cover:* A ghostly restoration of the old stone blast-furnace stacks of the Lackawanna Iron and Coal Co., Scranton Iron Furnaces Historical Site (PA Museum and Historical Commission), Scranton, PA. (Artwork by John G. Kuchinski, PA Geological Survey.)

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**Frontispiece.** 1996 Field Conference of Pennsylvania Geologists group photograph at Meadow Grounds Lake dam, Fulton Co., PA.

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# PREFACE

Welcome to Scranton and the 62nd Annual Field Conference of Pennsylvania Geologists! It's been quite some time since the Field Conference met in the Wyoming-Lackawanna Valley, since 1971, in fact—when it was held in Wilkes-Barre. The last Field Conference to be headquartered in Scranton was in 1936, more than sixty years ago. Leaders of that conference were Benjamin L. Miller, Donald M. Fraser, and Lawrence Whitcomb.

Founded on iron ore and built on anthracite, Scranton has changed a lot since 1936. Anthracite is no longer "king," and the city has lost a third of its population. Down from being the third largest city in the Commonwealth, with a population of more than 125,000, Scranton is still fifth largest—home of nearly 82,000 people. Scranton has a long and fascinating history. Established in the 1840's, decades after Wilkes-Barre, its sister city in the "Valley," it soon far outstripped its southwestern neighbor—and by the end of the 19th century, Scranton was clearly the dominant city of the entire Anthracite region. But with the accelerating decline of the "hard coal" industry after World War I, the city fell on increasingly hard times. Over the last decade, however, thanks to a large infusion of federal funds and the rise of Steamtown, Scranton's future is looking brighter. It has several excellent museums (two of which we will visit during pre-conference activities), an active parks department, one of the best coal-mine tours in Pennsylvania, a majestic and historic downtown hotel—and Steamtown National Historic Site. Not bad for a city which thirty years ago was "on the ropes."

Ah, but we are here for the GEOLOGY! And what magnificent geology it is! In fact, the Field Conference may not do it justice. Eleven, actually twelve, stops—dealing with bolide impacts, fossil stumps, unconformities, anthracite, glaciers, and much else. We will see beautifully scenic spots like The Tubs and Nay Aug Park Gorge—and we will visit a landfill. We will have controversy and speculation: How did Archbald Pothole really form? Did the continental glacier stagnate or retreat in an orderly fashion? What is it with the Mauch Chunk and Spechty Kopf? Why do they never look the same from one place to another as you go northeast up the Valley? Is the Spechty Kopf the record of a bolide (meteorite) impact? What is the nature of the unconformity under the "Loyalhanna"? Unfortunately, we will only touch on two of the great mysteries of the Lackawanna synclinorium: Is it a Plateau or Valley and Ridge structure? Why do three rocks formations (each several to many hundreds of feet thick at the southwest end of the valley) disappear toward the northeast end—with the Pennsylvanian-age Pottsville Formation resting on the Upper Devonian Catskill Formation at Forest City? Some of us believe there is something unique about the structural history of the Lackawanna synclinorium, something going far back in geologic time. Others don't think so. These are the things that we will "hash out" on the Field Trip(s).

I dedicate this guidebook to Dr. Frank W. Fletcher, Professor of Geological and Environmental Sciences at Susquehanna University. Thirty-five years after the "Von Schlieffen Plan" lectures—a sincere, if belated, "Thanks!"

Jon D. Inners

**Acknowledgments**

Aside from the leaders, other contributors, and host institutions mentioned on the title page of this guidebook, the Field Conference owes a great debt of gratitude to many businesses, groups, and people for assisting with the planning and organization of this meeting. Particular thanks go to Gerald Ahnell and our corporate financial sponsors: **Hydro-Geo Services, Inc., Ceco Associates, Inc., Geosceince Engineering Co., Inc., Northeastern Environmental Associates, Inc., Ecoscience, and Datum Products.** Ms. Kelly Stanton of the Radisson staff was of great assistance in arranging a reasonable food and lodging package. Permission to visit stops on private property was granted by Mr. Louis DeNaples, Mr. Bernard C. Banks (American Asphalt Paving Co.), Mr. Thomas Reese (Pennsylvania American Water Co.), and Mr. Ben Brown (Keystone Sanitary Landfill, Inc.). Richard N. Cochrane, P.E., Pennsylvania Department of Transportation, made the protective arrangements which allow us to stop along various interstate, federal, and state highways. The Scranton and Luzerne County Parks and Recreation agencies facilitated arrangements for Pre-Conference and Conference Field Trip stops at Nay Aug Park and The Seven Tubs Natural Area, respectively. James LaRegina and Ruth Braun assisted with preparation of the Day-1 and Day-2 road logs. Professor Robert Janosov, Luzerne County Community College, readily agreed to deliver a post-banquet talk on the industrial history and landscape of the Wyoming-Lackawanna Valley. Jack Kuchinski and James Dolimpio, Pennsylvania Geological Survey (DCNR) drafted many of the illustrations. William Kochanov also drew several figures. Jody Zipperer and Sherry Rotharmel helped with word processing. Gary Fleeger was of constant assistance in the preparation of this guidebook.

# THE RADISSON LACKAWANNA STATION HOTEL

The headquarters hotel of the 62nd Annual Field Conference of Pennsylvania Geologists is one of the architectural gems of northeastern Pennsylvania. It was formerly (until 1972) the Scranton passenger station and operational headquarters of the Delaware, Lackawanna & Western Railroad, and after merger of the DL&W with the Erie Railroad in 1960, one of the main passenger stations of the Erie-Lackawanna Railroad. Constructed between 1906 and 1908 during the presidency of William Truesdale (who carried out a major modernization of the DL&W), the station was designed by Kenneth Murchison, a prominent New York architect who had also designed stations in Buffalo, Hoboken, and Baltimore. It was originally five stories high, with a sixth added in 1923.

The station is in the French Renaissance or "beaux arts" style, popular from about 1890 to 1920 and characterized by grandiose composition, use of large columns, and neoclassical facades. The exterior is mainly Indiana limestone, with several sidewalk-level courses of gray granite. The interior is majestic and features at least two kinds of brecciated Italian marble (light-brown Sienna and another dark-red type). Numerous facings (e.g., the top of the check-in counter) are brecciated green Alpine serpentine marble (*verd antique*). The waiting room is capped by a barrel vaulted ceiling of leaded glass. But the most distinctive feature of the interior are 36 tile panels, completely encircling the "waiting room," that depict scenes along the "Route of Phoebe Snow" from Hoboken to Buffalo. (Twelve of these are various views of the Delaware Water Gap!)

After the Erie-Lackawanna went bankrupt in 1972, the station fell into disuse. It was revitalized as the "Hilton at Lackawanna Station" and reopened on New Year's Eve, 1983. Radisson took it over in September, 1995. (Information for this write-up was obtained from *Radisson Lackawanna Station Hotel, Scranton—Historical Perspective* [Laura G. Flanagan] and *Scranton's Architectural Heritage* [Lackawanna Heritage Valley Authority]).

The Radisson Lackawanna Station Hotel as seen from the Scranton Iron Furnaces.

Photo courtesy of Paul Thomas Studios, Shamokin, PA.

# Physiography and Quaternary History of the Scranton/Wilkes-Barre Region

by
Duane D. Braun

The Scranton/Wilkes-Barre urban corridor occupies the center of the Lackawanna synclinorium, the coal-bearing part of which constitutes the Northern Anthracite field (Figure 1). The area lies within the glaciated part of the Ridge and Valley physiographic province (Sevon, 1996). The floor of the valley in the Wilkes-Barre area is occupied mainly by the floodplain and glacial outwash terraces of the North Branch Susquehanna River and is known locally as the Wyoming Valley. North of there in the Scranton area, the synclinal valley is occupied by the much narrower floodplain and outwash terraces of the Lackawanna River. That river valley is incised into rolling hills underlain by the Llewellyn Formation and locally is called the Lackawanna Valley. In the Wilkes Barre area, each limb of the synclinorium is marked by a pair of homoclinal ridges, the outer ridge underlain by the Pocono Formation and the inner ridge underlain by the Pottsville Formation (Figure 1). In the Scranton area and to the north, each limb is marked by a single homoclinal ridge, often with multiple knobs. This change in ridge form from south to north is caused by the unconformity under the Pottsville Formation that, going northward, progressively cuts out the Pocono, Mauch Chunk, and Spechty Kopf Formations. North of the Scranton area the homoclinal ridge crest is underlain by the upper Catskill Formation (Duncannon Member) while the Pottsville Formation forms a series of small rounded flatirons on its dipslope flank. In places, particularly north of Scranton, the homoclinal ridge on the north limb of the synclinorium is broken by glacially deepened wind and water gaps into a series of rounded flatirons.

During the Quaternary, the Scranton/Wilkes-Barre area has been affected by a climate that alternated between cold, glacial-periglacial conditions and warm, humid-temperate interglacial conditions. About ten such alternations have affected northeastern Pennsylvania during the last one million years (Braun, 1988, 1989, 1994). There is evidence for at least three different glacial advances across the Scranton/Wilkes-Barre area in that there are three glacial limits of distinctly different age to the southwest of the area (Figure 2) (Braun, 1994). The farthest to the southwest and oldest glacial limit is considered to be of pre-Illinoian-G age (850 Ka). The next distinct glacial limit is considered to be of either late Illinoian (150 Ka) or pre-Illinoian-B (450 Ka) age and is only about 10 miles beyond the most recent, late Wisconsinan-age (20 Ka) glacial limit. Other glacial advances have approached the area and caused severe periglacial activity (Braun, 1988, 1989, 1994).

The earlier glacial advances across the Scranton/Wilkes-Barre area should have accomplished some erosional work and initiated most if not all of the glacial scour and drainage derangements observed today. The older glacial termini are parallel to the Late Wisconsinan terminus (Figure 2) and glacial striations in the area covered by the older glaciations are in the same direction as striations within the late Wisconsinan limit (Braun, 1994). This indicates that the older glaciers moved across the region in about the same direction as the late Wisconsinan ice and that they should have eroded and deposited in a pattern generally like that of the late Wisconsinan. Preglacial valleys oriented near parallel to ice flow, such as the Wyoming-Lackawanna Valley, would tend to be significantly scoured and partly back filled in each glaciation. Valleys oriented transverse to ice flow, such as valleys of tributaries entering the Wyoming-Lackawanna Valley, would be the least scoured and the most backfilled, sometimes becoming completely buried. The series of drainage derangements and ice marginal sluiceways discussed below were probably initiated by the earliest glaciation and enlarged by each succeeding glaciation.

The buried valley of the Susquehanna River (the Wyoming Valley part of the North Branch Susquehanna River valley) (Hill, 1885; Corss, 1904; Darton, 1914; Ash, 1950; Hollowell, 1971) is the best example of the amount of collective scour by the Pleistocene glaciations that crossed northeastern Pennsylvania. The bedrock surface of the Llewellyn Formation lies from 100 to more than 300 feet

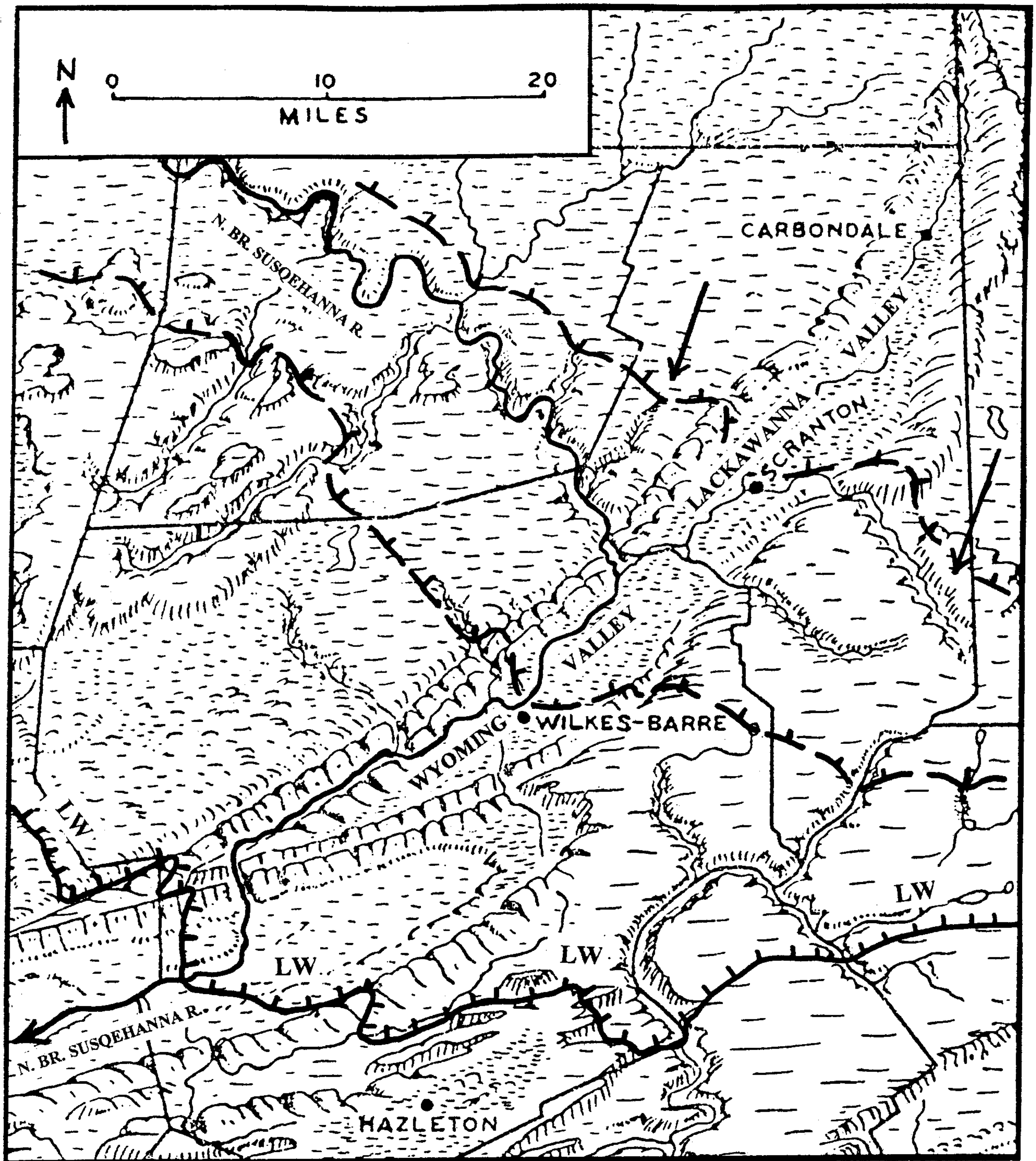


Figure 1. Physiographic map of the Scranton/Wilkes-Barre region. Arrows show regional ice-flow direction. Solid line with tick marks and labeled LW marks the Late Wisconsinan glacial limit. Lines of dashes with tick marks represent schematic recessional ice margin positions showing lobation of the glacier across the Wyoming-Lackawanna Valley. Other solid lines crossing the area are county boundaries.

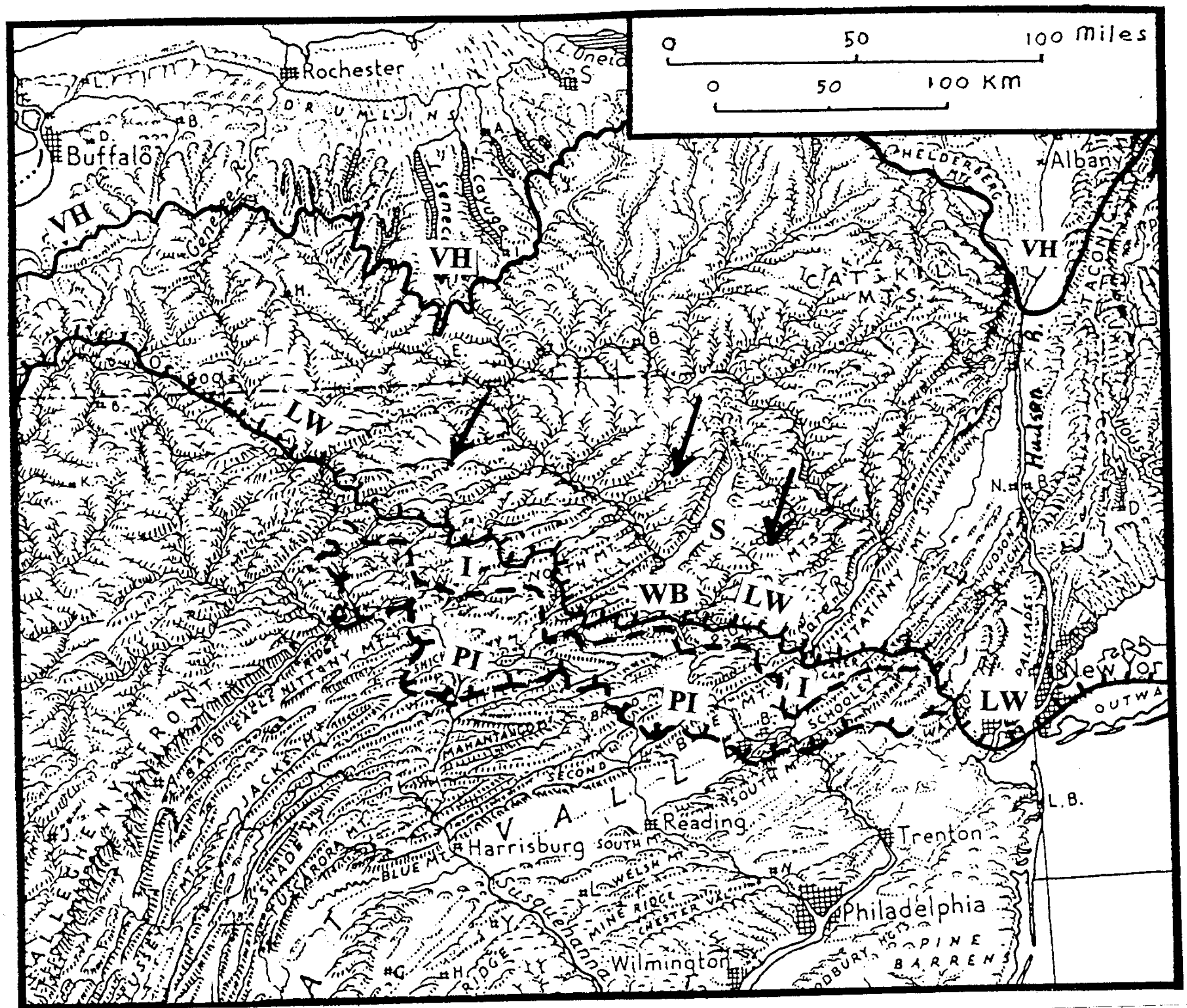


Figure 2. Physiographic map showing the glacial limits of various ages in eastern Pennsylvania and southern New York State. Regional ice flow directions shown by arrows. S = Scranton; WB = Wilkes-Barre; VH = Valley Heads (15 Ka); LW = Late Wisconsinan (20 Ka); I = Illinoian (150 Ka) or pre-Illinoian B (450 Ka); PI = Pre Illinoian G (850 Ka).

below the Susquehanna River channel in the Wyoming Valley (Figure 3). (This has led to a series of coal mine flooding disasters when the miners tunneled into the saturated gravels below river level.) In map view, the bedrock surface is a large, elongate depression covered by a series of smaller elongate depressions and ridges (Figure 3). A few miles downstream of the Wyoming Valley the river is on bedrock. The river would not be expected to be capable of scouring to such a depth while flowing in a broad lowland and the river today scours down at most a few tens of feet in major floods. (The "deeps" on the lower Susquehanna River [Mathews, 1917; Inners and others, 1978; Thompson, 1988], elongate depressions as deep as 100 feet cut in crystalline bedrock, form where the river is constricted to a narrow, steeply sloping bedrock gorge.) A combination of glacial ice and subglacial meltwater scour is the only viable erosion agent capable of such deep and areally extensive scour.

This elongate scour depression is much smaller than the Finger Lake scour depressions in New York State, but the rock under the Wyoming Valley is more resistant than in the Finger Lakes. Also the site is much closer to the southern limit of glaciation so ice cover was thinner and shorter lived than in New York State. These observations suggest that, in valleys parallel to glacial flow, glacial erosion has been significant even near the edge of the Laurentide ice sheet. (Note that the depth of the bedrock surface below the river bed is a measure of the *minimum* depth of glacial erosion. The bedrock river channel in the narrows downstream of the Wyoming Valley has also been undergoing erosion during glacial and interglacial times. The preglacial elevation of the river bed is an unknown distance above the present bed elevation. This difference in elevation would have to be added to the present difference in elevation between the river bed and the underlying bedrock surface, to get the total depth of glacial scour in the Wyoming Valley.)

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

The total duration of Late Wisconsinan ice cover is on the order of 6000 years at the northern boundary of Pennsylvania and 1000 years at the terminal position in northeastern Pennsylvania. The late Wisconsinan ice advanced across the Buffalo, New York area at 24.5 Ka (Muller and Calkin, 1993) and probably entered Pennsylvania at about 23 Ka. The glacier reached its terminal position at about 21 to 20 Ka in adjacent states (Cotter, 1983; Cotter and others, 1985; Lowell, 1991) and probably also in Pennsylvania. Retreat from the terminal position started around 19 Ka (Cotter, 1983, Cotter and others, 1985) and reached the Finger Lakes at about 16 Ka (Muller and Calkin, 1993). A reasonable estimate for the ice recession to reach the northern edge of Pennsylvania is about 17 Ka. This means that it took about 2000 years for the ice to retreat the 70 miles (along a S $20^0$ W flowline) from the terminal moraine through the Scranton area to the New York line. If the ice retreated at a steady rate (assuming no significant readvances) it would have taken about 30 years to recede one mile. At that rate, the ice would have crossed a single 7.5' quadrangle in about 250 years and the distance from Wilkes-Barre to Scranton in about 450 years. This first order of magnitude or "back of envelope" estimate of the rate of recession is useful in considering how long individual glacial erosion and deposition features took to form.

In general, much of the glacial scour occurred during the ice's advance to and stabilization at its terminus, with lesser amounts occurring as it receded. The late Wisconsinan glacier then did all its erosion in about 4000 years at the northern edge of Pennsylvania and 1000 to 2000 years near the terminus. Conversely, much of the glacial deposition occurred as the ice was receding so the bulk of glacial material in northeastern Pennsylvania was deposited in about 2000 years. In any particular 7.5' quadrangle, the materials were deposited within 200 to 300 years. Ongoing mapping of the glacial

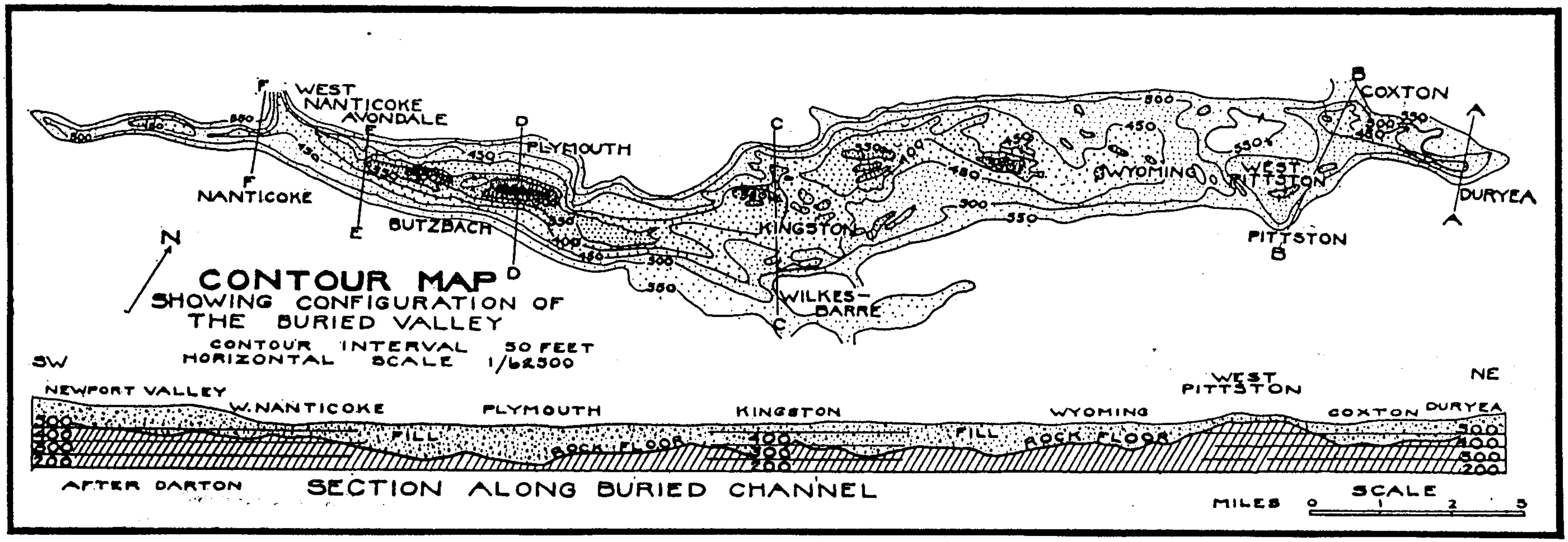


Figure 3. Contour map showing the elevation of the glacially scoured bedrock surface under the Wyoming Valley ("buried valley of the North Branch Susquehanna River") (Itter, 1938, Fig. 42). Valley floor ground surface is about 550 feet throughout the area.

deposits in northeastern Pennsylvania suggests that several (5 to 15) short lived still-stands of the glacier occurred, where it deposited a belt of abnormally thick material, as it receded across an individual 7.5' quadrangle. From the time estimates above, each of these belts of thick till or ice-contact sand-and-gravel should have taken only a few years to, at most, a few decades to form. Overall, things happened rapidly at any particular place in northeastern Pennsylvania as the ice retreated.

The late Wisconsinan glacier advanced across the region in a general S20$^0$W direction (Figures 1 and 2). In the Scranton/Wilkes-Barre area the ice flow direction was influenced locally by the strike ridges on the limbs of the Lackawanna synclinorium. As the ice flowed obliquely over each of those ridges, a reentrant would have been formed in the ice front as it "wrapped around" the ridge crest obstruction. On the floor of the synclinorium the ice would have formed a protuberant lobe (Figure 1; see also Figure 7). This lobation of the ice front upon advance and retreat of the glacier is reflected in changes in the direction of glacial striations on the flanks of the ridges. On the northwest flank of a ridge the ice flow was turned more to the southeast. On the southeast flank of a ridge the ice flow was turned more to the southwest.

The late Wisconsinan glacier flowed obliquely across the Lackawanna synclinorium and created three lithologically distinct tills in the Lackawanna valley (Figure 4). On the north side of the valley, along the dipslope of the strike ridge, is a "redbed till" that has a reddish-brown matrix and abundance of red sandstone and shale clasts. The red material had been carried over the strike ridge from the Catskill Formation outcrop belt that runs along the northwest side of the syncline. Once the glacier advanced across a few hundred to a few thousands feet of the Llewellyn Formation outcrop, it produced a "coal till." The till matrix has a dark-gray color from the ground up coal and carbonaceous shale. The clasts are primarily micaceous sandstone, dark-gray siltstone and shale, and coal. The abundance of coal clasts tends to increase towards the eastern edge of the Llewellyn outcrop. Once the glacial ice continued southwesterly beyond the Llewellyn outcrop, it over-ran the Pottsville and younger formations on the dipslope of the southeast flank of the syncline. In the Scranton area and northward, where there are no Mauch Chunk redbeds, a yellowish-brown (oxidized) or grayish-brown (unoxidized) "gray sandstone till" was produced. South of Scranton, where there is a significant thickness of Mauch Chunk redbeds, the till on the southeast flank of the syncline is another "redbed till" but with a minor component of erratic Pottsville and Llewellyn clasts. Southeast of Moosic Mountain is another belt of "redbed till" on the upper Catskill Formation outcrop.

The thickness of the till is primarily controlled by the direction of ice flow relative to the bedrock topography and the longevity of still-stands in the glacial recession. The Scranton area well exemplifies the deposition of thick till "shadows" or "tails" in the lee of bedrock obstructions. The strike ridge on the northwest side of the Lackawanna synclinorium lies obliquely across the ice flow and its entire southeast flank is covered by a thick "till shadow" that is typically at least 30 feet and sometimes over 100 feet thick. Individual bedrock knobs in the rolling hills on the floor of the syncline often have distinct tails or form the cores of drumlins (Figure 5A). A combined crag-and-tail and an ice-margin still-stand feature is shown in Figure 5B. Tributary valleys transverse to ice flow are often partly to completely filled by till. The Hull Creek buried valley (see Figure 9) is described later in the discussion on stream derangements.

Glacial meltwater derived sand-and-gravel deposits in the Scranton/Wilkes-Barre area are of two types, ice-contact stratified drift on the flanks of the Wyoming-Lackawanna Valley and outwash on the floor of the Wyoming Valley (North Branch Susquehanna River valley) and the Lackawanna River valley. In the Wyoming Valley area Itter (1938) suggested that all the valley-side sand-and-gravel deposits (his 685 to 675-foot terrace) were formed by meltwater flowing beside a long, stagnant ice mass occupying the floor of the valley (Figure 6). (During that era, regional stagnation of the glacier was a popular amongst Pleistocene geologists). Careful reading of Itter's discussion, comparison of his sites with more recent glacial deposit mapping (Hollowell, 1971) and the Luzerne County soil map (Bush, 1981),

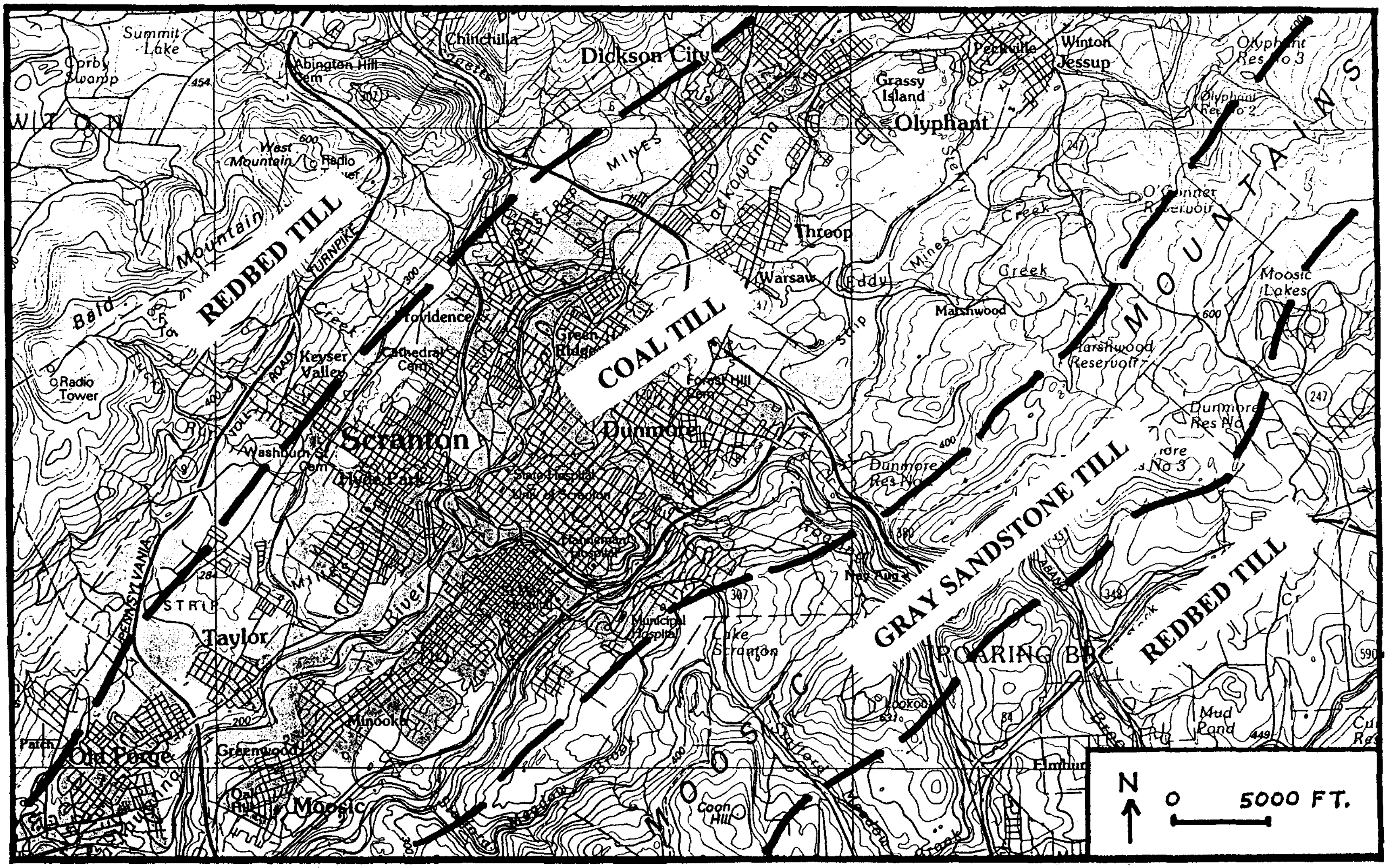


Figure 4. Topographic map of the Scranton area showing the belts of till with differing clast and matrix lithology.

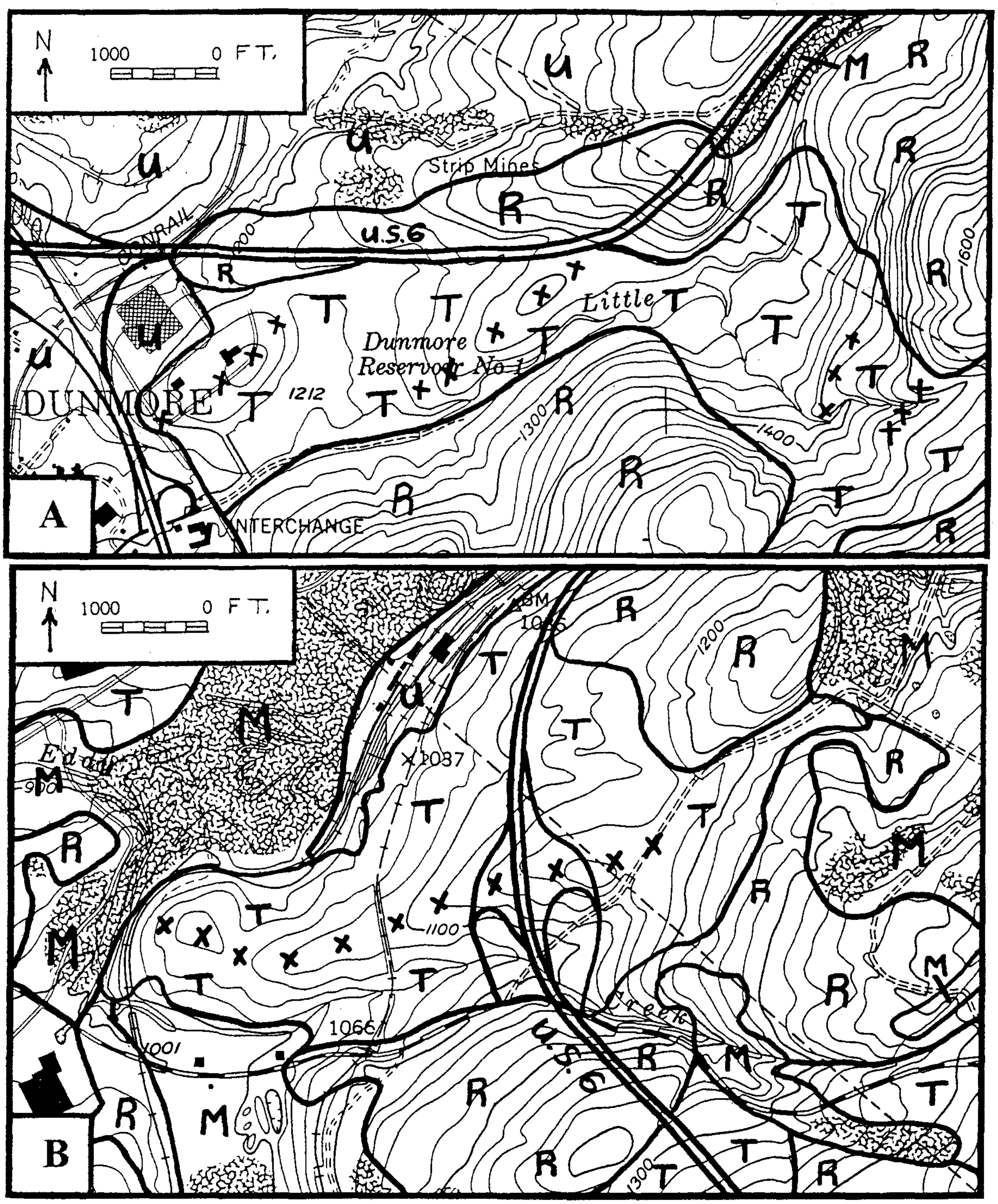


Figure 5. Parts of the Olyphant 7.5' surficial geology map (Braun, in preparation). A. In the center of the map a bedrock crag has a till "tail" extending to the southwest (line of x's). At the N in the words "Reservoir No. 1" is a 40-foot-high "coal-till" outcrop. The other line of x's to the west marks the crest of a drumlin formed in till. B. Ridge (line of x's) formed in "coal till" from 50 to 100 feet thick (determined from cuts in new U.S. 6 and abandoned railroads). M = coal-mine waste; R = bedrock (<6 ft till cover); T = till (> 6 ft thick), U = urbanized (cut & fill).

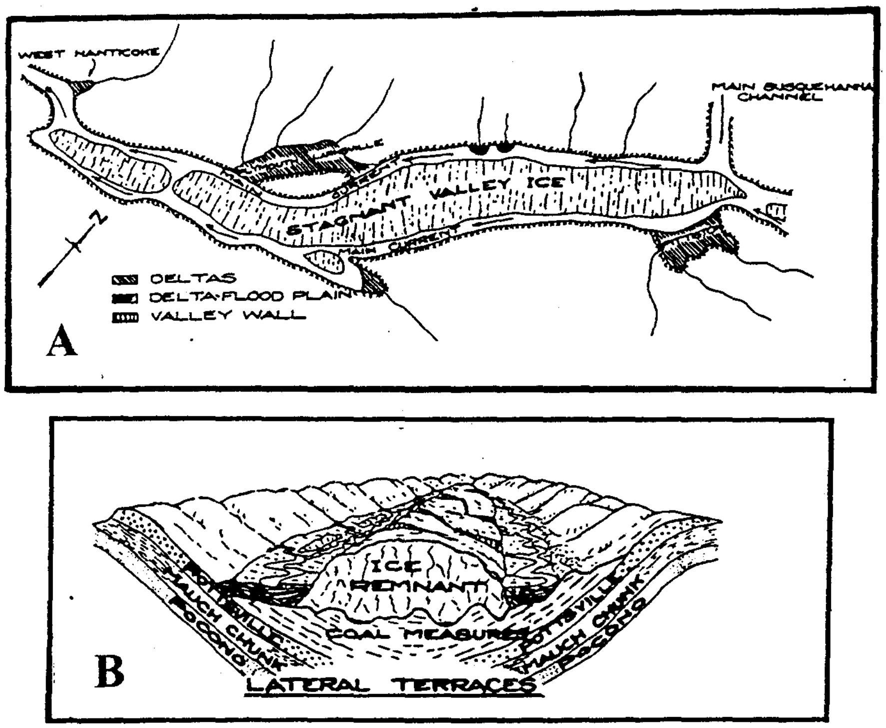


Figure 6. Hypothesized stagnant ice mass in the Wyoming Valley. A. Sketch map showing the stagnant ice mass bounded by a pair of meltwater streams that formed a continuous kame terrace along the flanks of the valley. Deltas formed in reentrants in the sides of the valley (Itter, 1938, Fig. 45). B. Cross-section sketch of the stagnant ice mass bounded by kame terraces (Itter, 1938, Fig. 46).

and examination of borehole records in the buried valley area (Ash, 1950) indicated that Itter's interpretation is problematic. He himself emphasized the discontinuous and irregular form of his "terrace" but attributed such features to irregularities along the edge of the stagnant ice tongue. One of his key lines of evidence, the continuous distribution of crystalline clasts along the northwest side of valley, shows that he had mistakenly included lower outwash terraces in the Wyoming-Pittston area in his higher valley-side terrace. Peltier (1949) also envisioned that the valley-side kame terraces formed beside a continuous stagnant ice mass in the Wyoming Valley. He correlated those kame terraces with his second kame terrace at the glacial terminus, 15 miles downstream of the Wyoming Valley. Peltier did correctly separate out the lower, more continuous crystalline clast-rich outwash terraces from the higher, discontinuous local clast-rich terraces segments.

The discontinuous and irregular nature of the valley side kames can be more simply explained as a series of segments associated with a sequence of different ice margins (Figure 7). Each ice margin would represent a relatively short still-stand of the ice as it more or less continuously retreated across the region. This is what has been observed from detailed mapping in valleys oriented near parallel to and draining away from the ice in southern New England (the morphologic sequence or stagnation zone retreat concept, Koteff, 1974) and in nearby areas in Pennsylvania (Braun, ongoing mapping). The largest masses of sand and gravel are deltas built into the Wyoming Valley from ice-marginal meltwater sluiceways. These deltas have a similar top elevation and suggest a single proglacial lake in front of the gradually retreating glacier in the Wyoming Valley. The existence of such a lake, here called Glacial Lake Wyoming, is indicated by borehole logs describing a "blue clay" layer, often several tens of feet thick, under the outwash terrace gravels on the floor of the Wyoming Valley (Ash, 1950). Such "blue

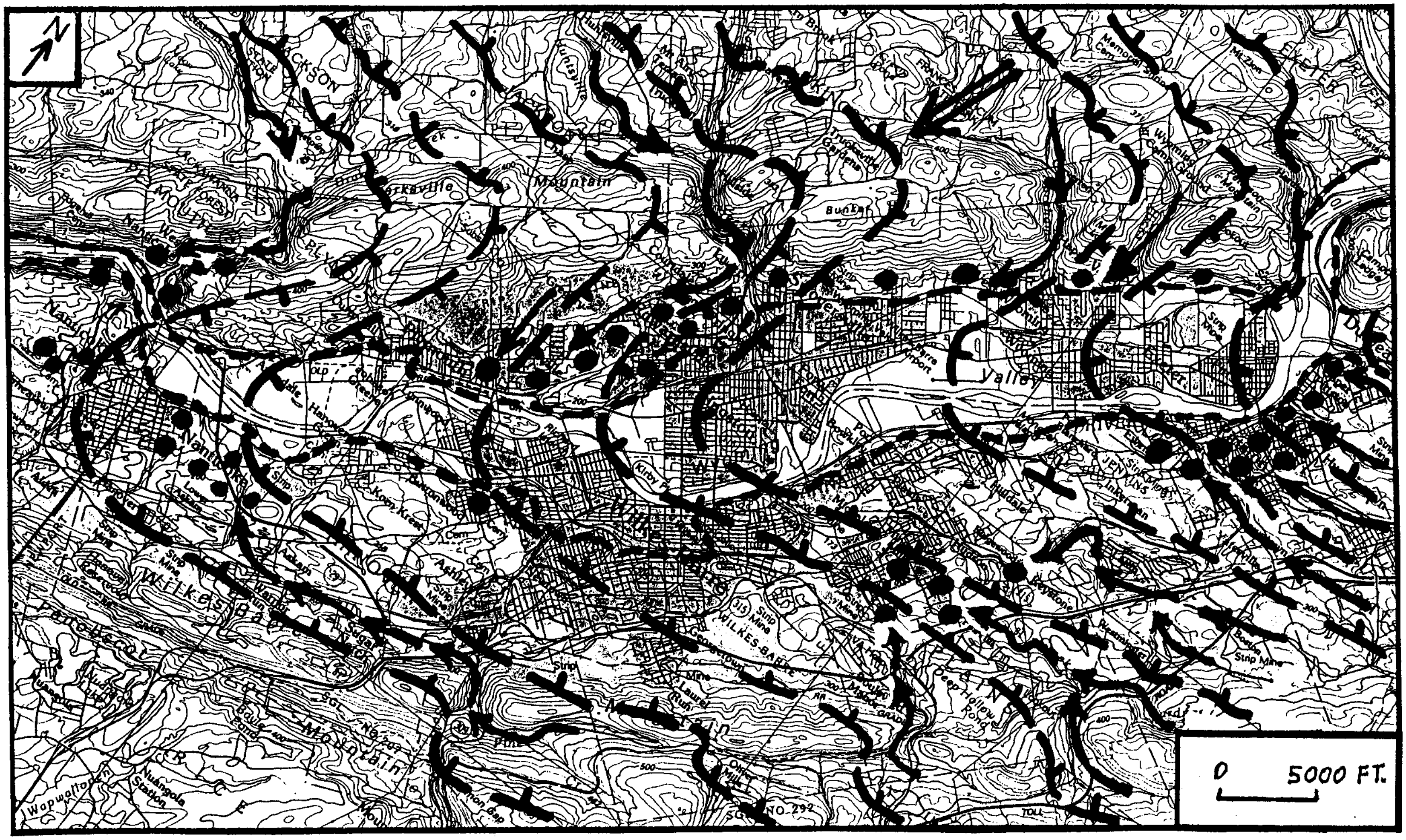


Figure 7. Systematic glacial-retreat interpretation of the kame terraces and kame deltas (labeled as dots) on the flanks of the Wyoming Valley. The sequence of ice margins ( dashed lines with tick marks pointing towards the ice) are constrained by regional ice-flow direction (double line arrow), location of ice marginal channels, and the location of the kames. The younger outwash that forms the floor of the Wyoming Valley is outlined by two lines of short dashes.

clay" intervals in borehole logs have often, upon more detailed examination, been found to be clay-rich, glacial lake varves.

The proglacial lake was probably impounded by the Wisconsinan "terminal moraine" (actually a thick, frontal-kame fan deposit [Inners, 1978; Braun and Inners, 1988]) near Berwick, Pennsylvania. Other deltas with top elevations like those in the Wyoming Valley exist between the terminus and the Wyoming area (south of Shickshinny and at Hunlock Creek). The sill of such a glacial deposit dammed lake would be lowered as the ice retreated. At the same time the area progressively upstream would tend to be progressively more downwarped. After rebound, this could produce a series of delta tops at the same elevation throughout the region. The detailed work necessary to really work out such a problem, however, is an order of magnitude more than can be expended in the current "detailed reconnaissance" effort to map the glacial deposits of the entire northeast Pennsylvania region.

The interaction of the directions of preglacial drainage, ice-flow direction, and the selective deposition of glacial deposits produced a series of drainage derangements along both flanks of the Lackawanna synclinorium. These involved the burial of preglacial valley transverse to ice flow, the cutting of new ice marginal sluiceway gorges and the cutting of new post-glacial (interglacial actually) gorges. Itter (1938) noted many of the drainage changes in the Scranton region (Figure 8), particularly the diversion of Roaring Brook to its present course through Nay Aug Park Gorge (Figure 8 and Appendix A-2, Pre-Conference Field Trip 2, Figure A9).

In general, transverse-to-ice-flow valley segments have been abandoned due to blockage by glacial deposits and near-parallel-to-ice-flow valley segments have been deepened and extended northward to capture drainage from adjacent basins. (For a more extensive discussion of the Roaring Brook example, see Appendix A-2, p. 172-175.) Apparent contradictions to this general rule are Leggetts Creek (Figure 8, site A) and Stafford Meadow Brook (Figure 8, site E), both of which apparently have been turned northward. But where Stafford Meadow Brook presently turns northeast to flow up the abandoned Rocky Glen sluiceway, there are historic embankments that divert it in that direction. In prehistoric times it apparently drained southwestward down the sluiceway to Spring Brook. The Leggetts Creek diversion took place amongst thick glacial deposits of the "till shadow" on the northwest flank of the Lackawanna synclinorium. In such areas, the melting out of buried ice masses can produce lows spots to capture the drainage in any direction.

On-going mapping of the glacial deposits by Braun (Scranton 30' x 60' quadrangle, in preparation) has revealed a number of other "buried valley" sites in the area. One of the best examples of a preglacial valley buried by glacial deposits is Hull Creek (Figure 9). That creek flows southeasterly through a deep water gap in the strike ridge on the north flank of the Lackawanna synclinorium. The upper walls of the water gap have prominent ledges of Pottsville conglomerate. But the floor of the water gap has no such ledges where the Pottsville should outcrop. Instead, it has 50- to 100-foot-high outcrops of glacial till on the outsides of bends in the creek (Figure 9, from St. Michaels Cemetery to the word "Scott"). As the creek enters the broad Lackawanna Valley, it trends a bit more southeasterly and enters a narrow bedrock gorge (Figure 9, from just upstream of the Roosevelt Highway to the words "St. Nicholas Cemetery"). At the entrance to the bedrock gorge the stream immediately goes from being incised in glacial till to being incised in bedrock , with a steeply inclined contact between the till and the bedrock. The gorge itself is cut in the moderately resistant sandstones, shales, and coal of the Llewellyn Formation. These features are the typical "signature" of a stream that has missed its older, now buried course.

The buried course of Hull Creek runs directly towards the Lackawanna River, in line with the course of the creek in the water gap (Figure 9, line of x's). The stream follows its original course in the water gap but then angles off to the south of its original course as it enters the Lackawanna Valley. The creek has not yet cut back down to the resistant Pottsville bedrock in the water gap because it has become "hung up" on bedrock downstream of that where it "missed" its preglacial course. Now it is

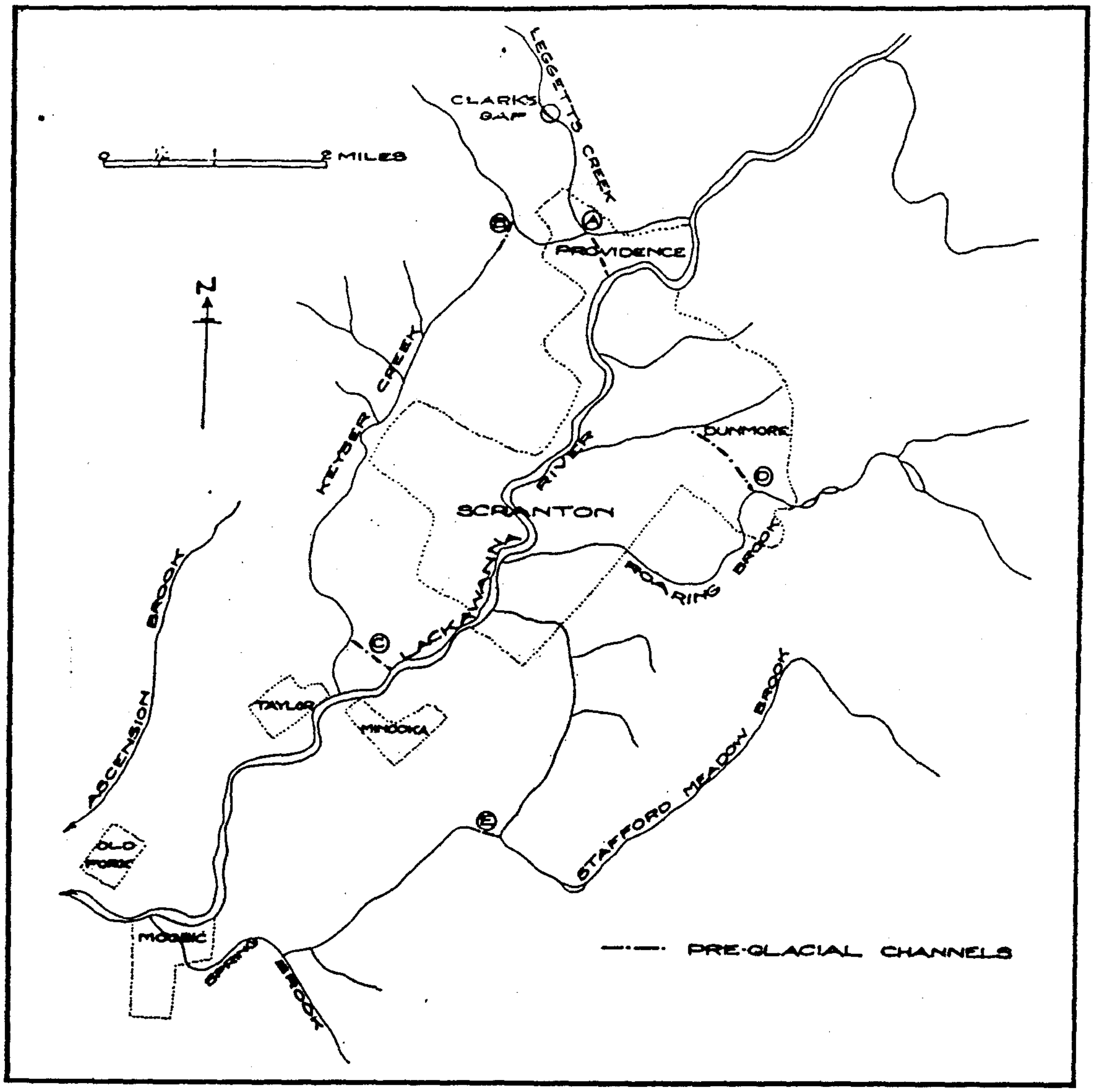


Figure 8. Drainage derangements caused by glacial activity in the Scranton area. Circled letter sites are abandoned preglacial stream valleys (Itter, 1938, Fig. 18).

carving a bedrock gorge in what was the southwest side of its preglacial valley. Hull Creek was forced more to the south at that point because of the "till shadow" effect and the ice lobation in the Lackawanna Valley (both discussed previously). The buried course is shown clearly on the map (Figure 9) as a strip of housing developments that runs up the slope through a gap in the strip mines. This is the only gap in the strip mines on the slope above the town of Blakely and the gap exists because there wasn't any coal at a shallow depth to strip! There is a minimum thickness of 150 feet of till filling the original valley at the entrance to the present bedrock gorge. It is not known how much deeper the old valley is at that point, but downward projection of angle of the steep upper bedrock walls of the water gap suggests at least another 100 feet of till lies below stream level. These thicknesses of till are far more overburden than the early strip mine operators would have found profitable to move, thus the gap in the strip mines on the mountain side.

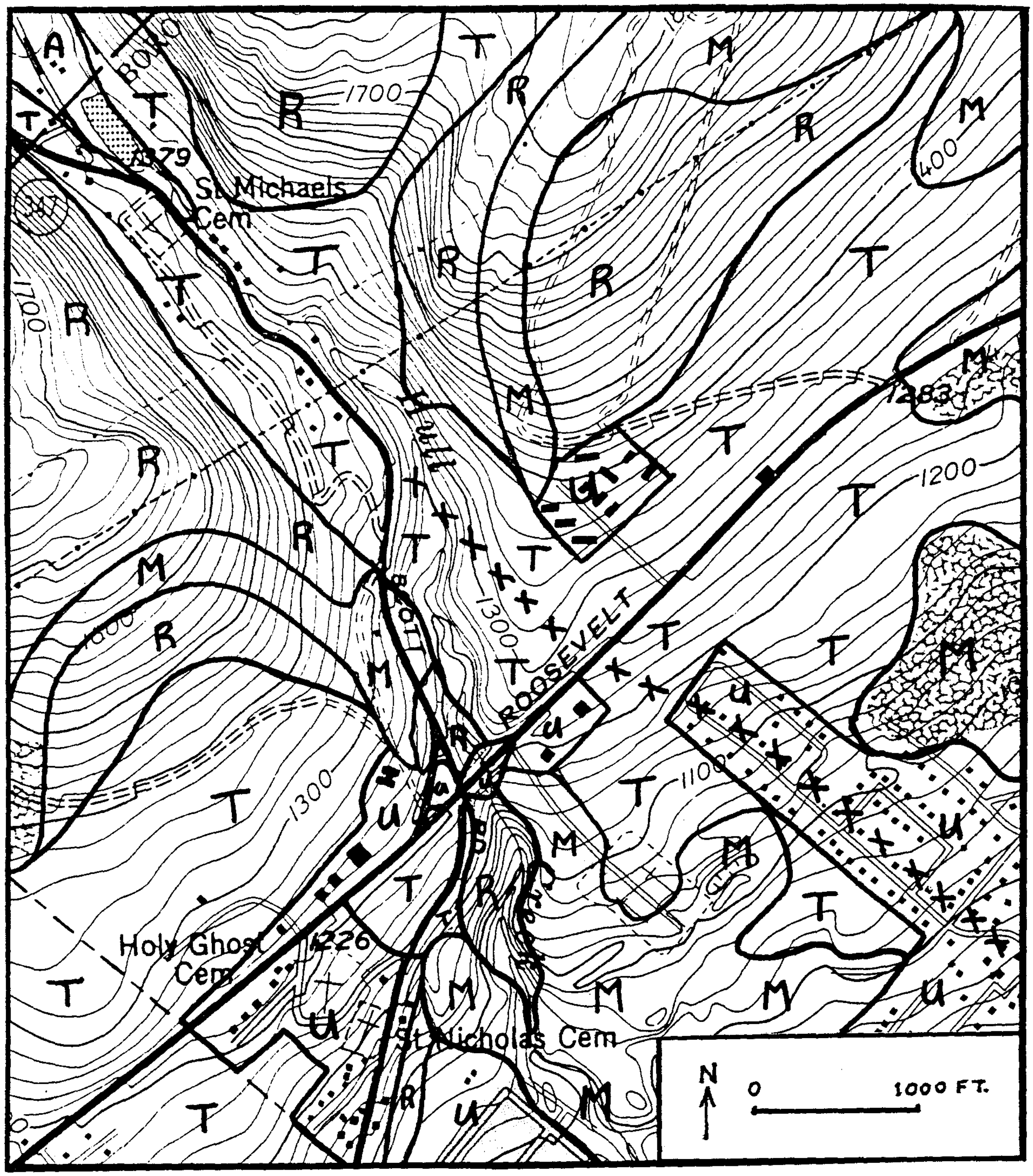


Figure 9. Northwest corner of the Olyphant 7.5' surficial geologic map (Braun, in preparation). Line of x's marks the centerline of the buried valley of Hull Creek. M = coal mine waste; R = bedrock (<6 ft of till cover); T = till (>6 ft thick); U = urbanized.

As the glacier continued its recession north of Pennsylvania, cold periglacial climatic conditions prevailed in the area for several thousand years. At that time, the exposed sandstone ledges were frost riven and shattered. These processes resulted in a boulder colluvium mantle often extending 500 feet, and, in places, as much as 1000 feet, downslope of individual sandstone ledges. A few exposures show late Wisconsinan till or ice-contact sand and gravel under the boulder colluvium.

The glacial till deposits themselves have been "mobilized" on the slopes by gelifluction. On the upper to middle parts of the slopes, the upper 2 to 3 feet of material is colluvium derived from till. The material often shows a well developed downslope fabric (tabular clasts near parallel to the ground surface). On the lower parts of the hillslopes the "colluviated till" is often 5 or more feet thick.

In the latest Pleistocene, after 13,000 BP (Dalton and others, 1997), and throughout the Holocene, forest vegetation became well established in the area. This acted to reduce erosion and sediment load so the streams started to incise into the glacial deposits. Itter (1938) noted that the amount of erosion in post-glacial times has been comparatively slight because the depositional features originating near the close of the Pleistocene have not been significantly altered. In fact, within the Lackawanna synclinorium, man has moved far more earth material through coal mining and urbanization than the natural erosion processes have during the entire Holocene.

In the Holocene the only areas of sediment deposition have been on the floodplains of the larger streams in the region, particularly along the North Branch Susquehanna in the Wyoming Valley area. Those deposits are primarily overbank deposits that drape the lower portions of the outwash terraces. Small scale climatic changes during the Holocene may be reflected in changes in the rate of that overbank sedimentation. Locally, lateral migration of the channels have left scroll and abandoned-oxbow landforms on the floodplains.

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# Structural Geology of the Wyoming-Lackawanna Valley

by
Norman M. Gillmeister

The Wyoming-Lackawanna Valley is part of a large synclinorium that is underlain by coal-bearing rocks of the Llewellyn Formation. The "coal basin" part of the structure (Northern Anthracite field) is about 62 miles long and 5 miles wide (Figure 10). The Sharp Mountain Member of the Pottsville Formation forms the base of the Pennsylvanian-age rocks in the area, and rests on a thick section of Mauch Chunk Formation (White, 1883) at the western end of the basin, but on Devonian-age Catskill Formation at the northeast end (Edmunds, 1988). The angular unconformity that accounts for the missing part of the stratigraphic section implies increasing uplift and erosion toward the north during the relatively short time interval between deposition of the youngest preserved parts of the Mauch Chunk and deposition of the sediments of the Sharp Mountain.

The inferred episode of uplift is probably reflected by the change in paleocurrents from the southeast, for the parts of the Pottsville older than the Sharp Mountain Member, to paleocurrents from the northeast for the Sharp Mountain (Robinson and Prave, 1995). The presence of detrital zircons in the Sharp Mountain as young as 380 million years (Gray and Zeitler, 1994) can also be explained by erosion and redeposition from older Paleozoic rocks to the north and east (e. g., Catskill and Pocono Formations). One possible explanation for the observed upwarping (Robinson and Prave, 1995) is that tectonic loads and the associated depocenter for sedimentation in the Appalachian foreland basin shifted to the south after deposition of the Tumbling Run and Schuylkill Members of the Pottsville, causing a foreland bulge to also migrate southward from the craton.

Detailed geological mapping of the Wyoming Valley has been very limited since the work of the 2nd Geological Survey of Pennsylvania (Ashburner and others, 1883-1889), partly because of the high quality of the original work (Dodge, 1988). Darton (1940) summarized much of the data available from mining companies at that time, and Bergin (1973, 1976) has extended the compilations in the Wilkes-Barre area. Much of this summary is derived from the above sources and from mapping in the western part of the basin.

The general outlines of the overall structure of the coal basin are clear. Its northern part is a nearly flat-bottomed asymmetric syncline with only very minor internal structural complications. The trend of the basin near Forest City is about N15°E. This changes to about N60°E south of Archbald and to N70°E to the west of Wilkes-Barre. The plunge of the basin is very gently toward the southwest, taking the lowest coal from elevations of 1900 feet north of Forest City to about sea level in the area from Olyphant to Scranton. The greatest preserved thickness of coal-bearing rocks is between Wilkes-Barre and Nanticoke, where the Lower Red Ash (i. e., lowest) coalbed is found at more than 1500 feet below sea level. The elevation of the Lower Red Ash coal then gradually increases to the west, along the axis of the basin, until it reaches nearly 1400 feet above sea level west of Shickshinny.

The asymmetry of the basin is defined by a steep northwest limb to the northeast of Wilkes-Barre. In addition, a kink band northwest of a line from Dickson City to Blakely causes even steeper south dips. The sense of asymmetry reverses west of Wilkes-Barre, since the southeast limb of the basin steepens near Warrior Run and becomes vertical to locally overturned from west of Wanamie to west of the Susquehanna River. The north limb of the basin only dips from 20 to 35 degrees to the south in this area.

Second-order folds occur in all parts of the basin, but become prominent to the west of Avoca (Figure 10). These folds all trend about N70°E to nearly east-west, which makes them pronounced cross-folds (at high angles to the trend of the first-order structure) in the northern part of the basin. They parallel the basin trend to the west of Wilkes-Barre. Structural relief of the folds seems to increase with the thickness of the preserved coal measures, reaching about 1000 feet for the folds between Wilkes-Barre and Nanticoke.

Folds in the more highly deformed western part of the basin are generally disharmonic (Figures 11-14, 18) and range in geometry from kink folds with angular hinges to classical concentric folds. Fold form seems

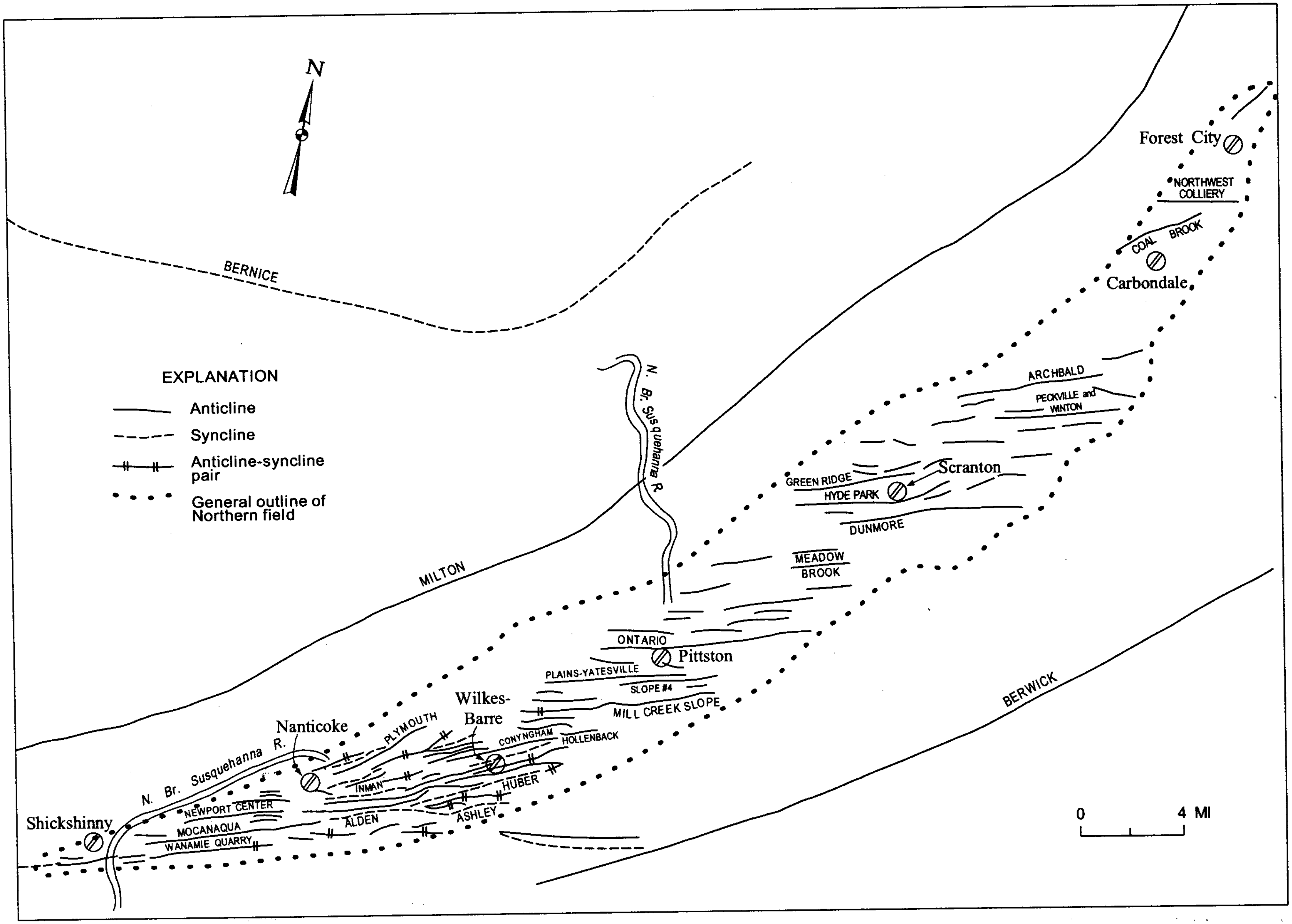



Figure 10. Structural axes of the Northern Anthracite field (after R. T. Faill, manuscript map).

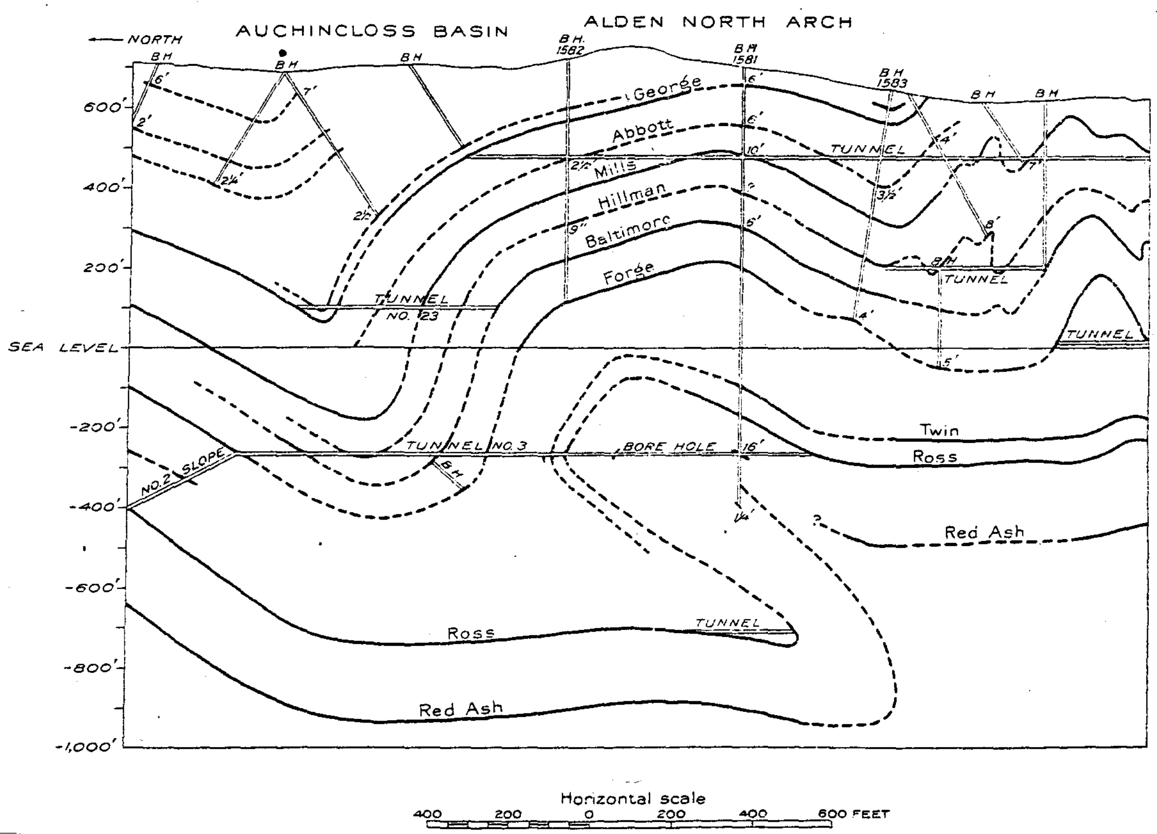



Figure 11. This section from Darton (1940) shows the disharmonic nature of the Alden anticline in a section drawn 700 feet west of the Auchincloss No. 1 shaft. Near the surface the fold is essentially upright and concentric, but the Twin coal outlines an overturned anticline at depth. The geometry of the Red Ash coal is consistent with the formation of the Alden anticline as a fault propagation fold associated with a south-dipping thrust that has to root below the Pottsville Formation. The following applies to all sections from Darton (1940): solid lines represent mined coal; broken lines represent inferred location of coal; BH indicates borehole; numbers are thickness of coal in boreholes.

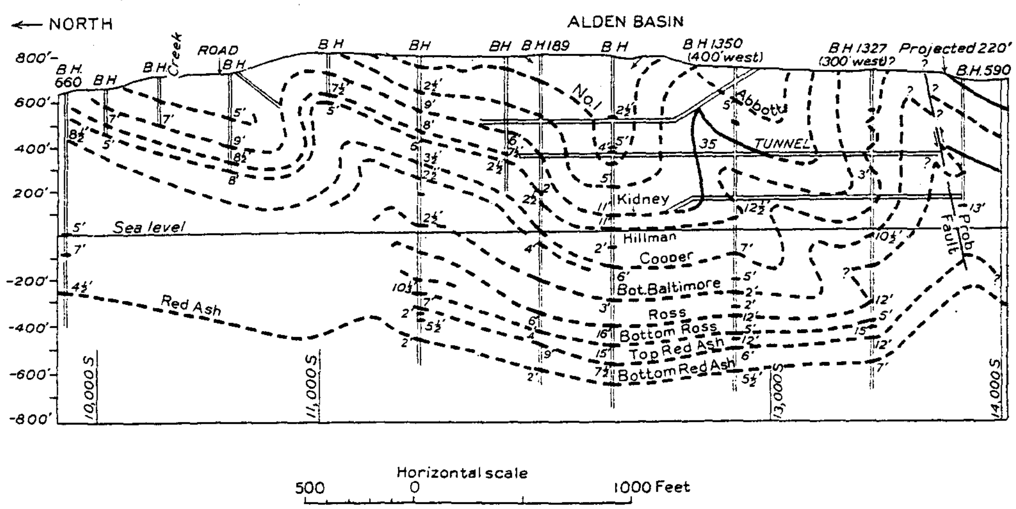



Figure 12. This section shows a relatively undeformed Lower Red Ash coal, overlain by increasingly deformed rocks. Note the obviously disharmonic nature of the folding. The section (from Darton, 1940) is drawn 1600 feet west of Wanamie No. 18 shaft.

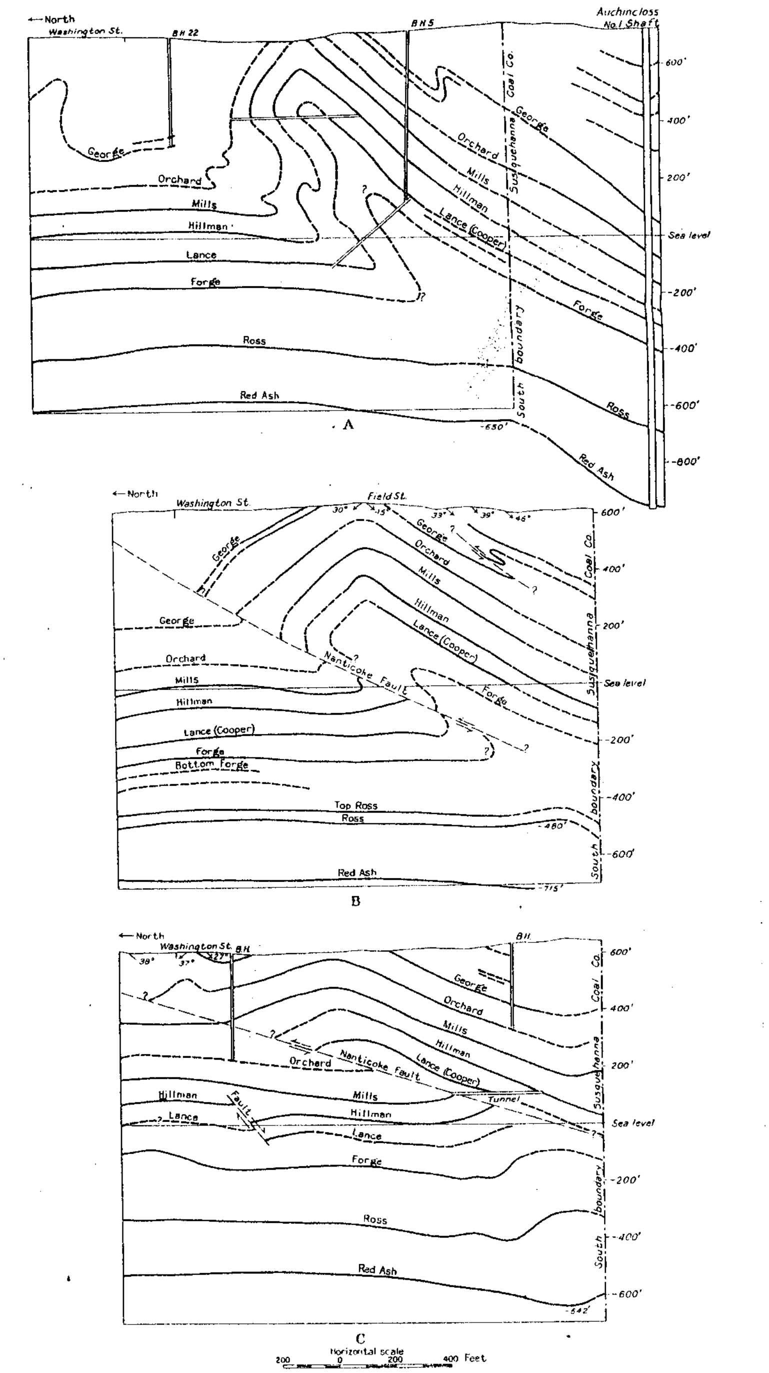



Figure 13. These sections of the Nanticoke anticline (see Figure 10) demonstrate a progressive change in the type of deformation seen along strike from west to east . The Nanticoke fault in section C has an apparent net slip of 800 feet, as measured on the Mills coal, and appears to ramp up-section from above the Ross coal. Strain is accommodated by brittle deformation with little evidence for plastic deformation, that is, folding. Section B shows an almost equal partitioning of strain between faulting and folding, whereas section A is characterized by dominantly plastic strain. Note that the amount of strain is nearly the same in sections A and C. That would be reasonable if the Nanticoke fault is essentially parallel to bedding on the south end of the sections and if the Nanticoke anticline in section a is a fault-propagation fold.. All sections are from Darton (1940). Section A is drawn through the Auchincloss No. 1 shaft and sections B and C are 900 feet west and 2400 feet of A, respectively.

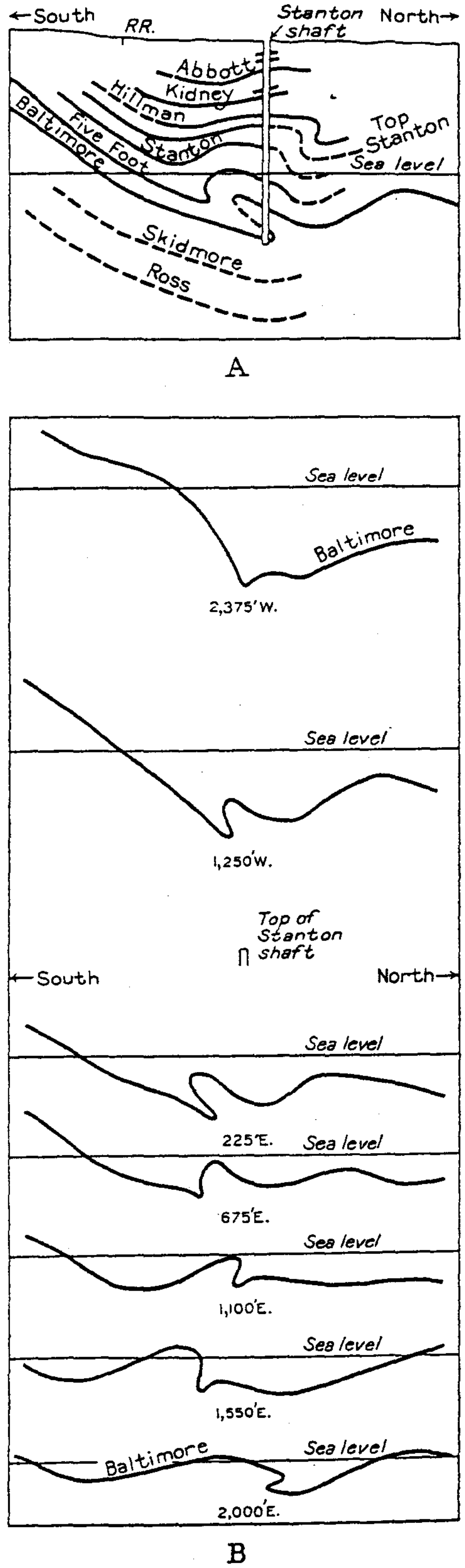



Figure 14. Serial sections, looking west, centered on the Stanton shaft in South Wilkes-Barre. Section A shows the disharmonic nature of the folding in section through the Stanton shaft. Section B shows the geometry of the Baltimore coal horizon. Section locations are given in feet east or west of the Stanton shaft. Note the marked geometric variability of the folding along -strike, as well as in section.

to be independent of lithology since third-order folds in Pottsville conglomerate are observed to span the whole range of geometries. Some fold structures tend to die out up-section and probably represent fault-propagation folds (Suppe, 1985) associated with thrust faults that root below the Lower Red Ash (Figure 11). Other folds increase in amplitude and complexity going up-section and probably formed as volume-accommodation structures by sliding on the high ductility coal beds as the basin margins were squeezed inward (Figure 12) or as fault propagation folds associated with thrust faults ramping up out of one of the higher coals (Figure 13A-C). Figure 14A-B illustrates that folds in the coal measures are not only variable in geometry in cross-section, but also along strike.

Out-of-basin thrust faults, such as the Warrior Run fault, have been mapped by Darton (1940) and Bergin (1973, 1976) in the western part of the valley. Net slip on these faults generally does not exceed 400 feet. Smaller examples of such thrusts are shown in Figure 15 and the description for STOP 2 (this guidebook, p. 90-93).

Structures that have features of both folds and faults are present on the northern margin of the basin. These consist of large kink bands that cross the basin margin at small angles, forming prominent asymmetric kink folds in the rocks of the Mauch Chunk Formation and, locally, high angle reverse faults in the more brittle rocks of the Pottsville Formation. Near Mocanaqua, rocks of the Mauch Chunk Formation are in fault contact with Llewellyn lithologies because of such a fold-to-fault transition. Structural data from three such kink folds between Mocanaqua and Retreat State Prison are shown in Figures 16A-C. Darton (1940) shows some apparently related features, with the same orientation, on both the northern (near Kingston) and southern margins of the basin.

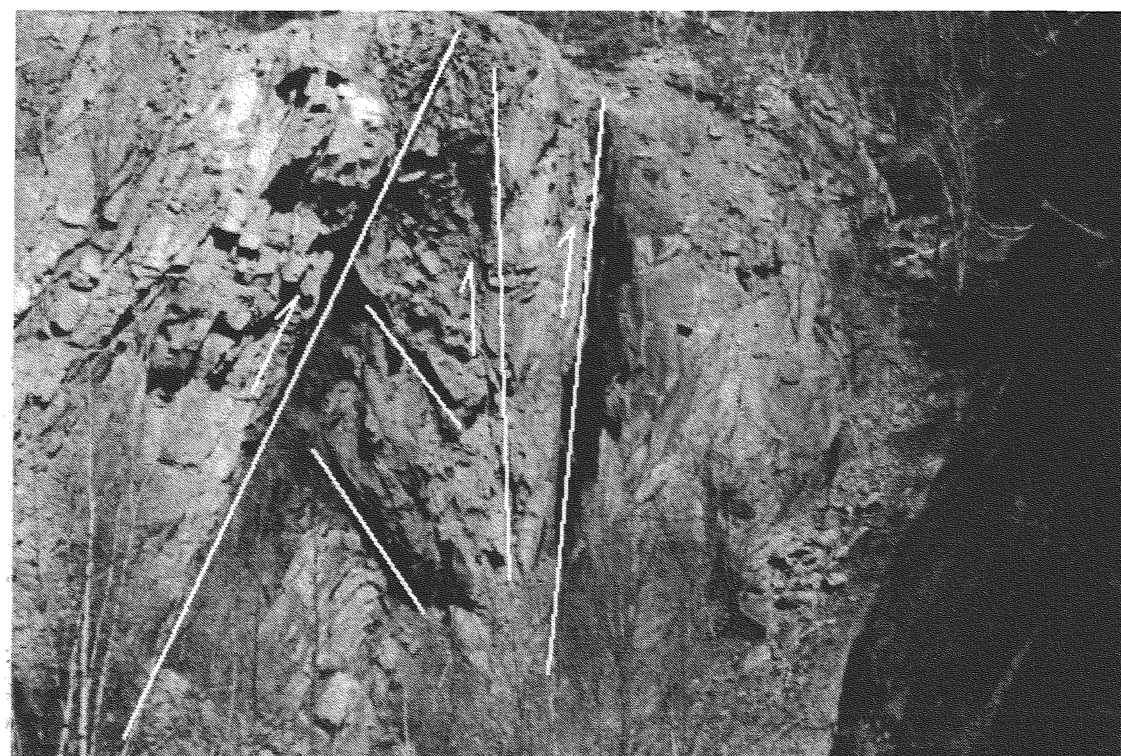
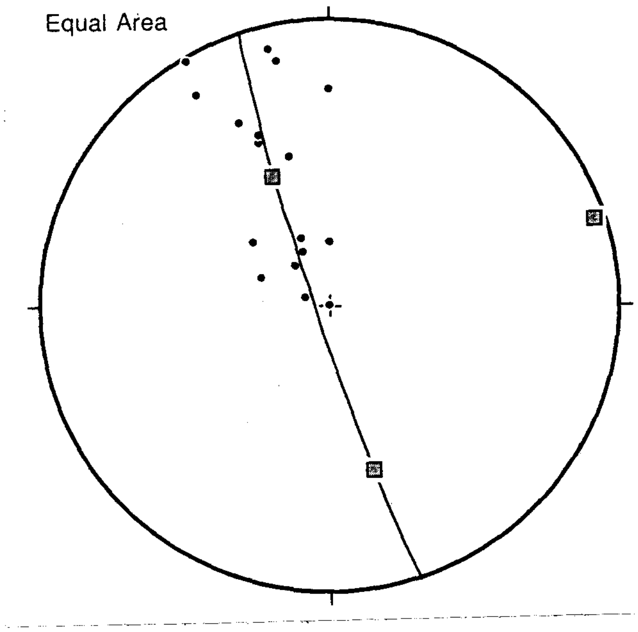
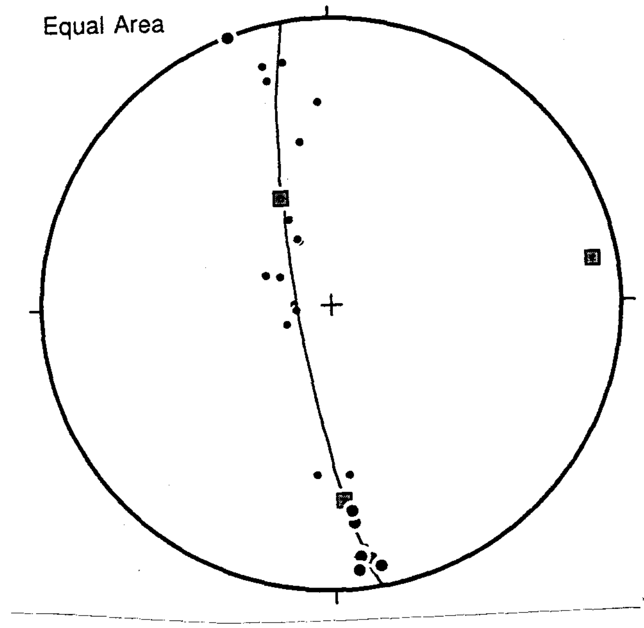


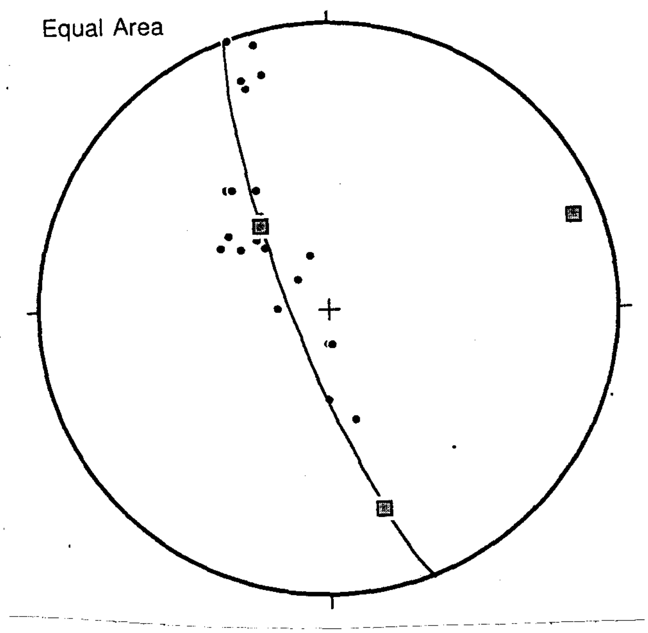
Figure 15. Thrust fault along the southern margin of the synclinorium, south of Wanamie. The lines locate some of the larger faults. The dark area on the right is the seat-rock of the Lower Red Ash coal. The larger thrusts shown here cut down-section to the east, accounting for a pronounced increase in the apparent thickness of the Pottsville Formation near Wanamie.




**A**




**B**




**C**

Figure 16. Stereograms (Schmidt net, lower hemisphere projection) of structural elements for three kink folds along the northern margin of the Wyoming Valley between Mocanaqua and Retreat State Prison. Small dots represent poles to bedding, large dots are poles to cleavage, squares are eigenvectors for a cylindrical best fit to the data. To put it simply, the square that plots farthest from the dots represents the bearing and plunge of the fold axis.

A. Data for a large kink fold near Mocanaqua. The fold axis plunges 4 degrees toward 72 degrees.
B. Data for a smaller fold to the east of 16A. This fold has a pronounced, nearly axial-planar, spaced cleavage. The fold axis plunges 10 degrees toward 81 degrees.
C. Data for a large kink fold at Retreat State Prison. The fold axis plunges 10 degrees toward 70 degrees.

The western part of the basin is characterized by a wealth of smaller structural features that are similar to those described by Nickelsen (1979, 1983) in the Western Middle field, both in terms of style and structural sequence. Early-formed conjugate strike-slip and thrust faults are present, as are all varieties of folds, including nearly isoclinal overturned folds, as well as "whalebacks." Small graben structures are also present on the steep limbs of folds. Some anticlinal folds that are cored by coal tend to resemble structures that are more commonly encountered in salt tectonics, such as walls with mushroom-like caps. That resemblance may not be too surprising, inasmuch as the low strength of coal mimics that of salt.

Second-order anticlinal folds can, in some cases, be shown to have formed by the imbrication of conjugate thrusts. Some of these small thrust faults are also excellent examples of the formation of fault-bend folds (Suppe, 1983). Other structures that are present include small fault duplexes (see STOP 3, this guidebook, for one possible example) and high-angle faults with both apparent normal and reverse displacements.

A valid conclusion from all of the above might be that the structural simplicity of the Wyoming-Lackawanna Valley has been greatly exaggerated.

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# The Pottsville Formation in the Lackawanna Synclinorium

by
William E. Edmunds

## INTRODUCTION

The Pottsville Formation of eastern Pennsylvania is a complex unit consisting dominantly of coarse clastics ranging from cobble conglomerate to coarse-grained sandstone with lesser amounts of finer-grained sandstone, siltstone and silt shale, claystone and coal. Maximum thickness is about 1,600 feet near Tower City in the Southern Anthracite field (Meckel, 1964; Wood and others, 1969). The Pottsville is divided into the Tumbling Run, Schuylkill, and Sharp Mountain Members in ascending order (Wood and others, 1956).

The Tumbling Run Member is conformable with the underlying Mauch Chunk Formation in the Southern and Middle Anthracite fields. This contact is somewhat diachronous, becoming younger northward. The upper contact between the Sharp Mountain Member and the overlying Llewellyn Formation is placed at the base of the Buck Mountain (No. 5) coal bed in the Southern and Middle fields and is conformable.

Read (1944) and Edmunds (1988, 1993) believe that the contact at the base of the Sharp Mountain Member is unconformable throughout all of eastern Pennsylvania. Edmunds also believes that sequential northward beveling of the Schuylkill and Tumbling Run Members below this unconformity is the principal (but not only) cause of the thinning of the Pottsville Formation (Figure 17).

## CONTACTS AND THICKNESS

In the Northern Anthracite Field (Lackawanna synclinorium) C. D. White (1904, p. 274) recognized that only the upper part of the Pottsville Formation (i.e., the Sharp Mountain Member) was present, based upon paleobotanical correlations. He also recognized that the basal contact was defined by an unconformity, which Read (1944) and Edmunds (1988, 1993) consider to be the same as the sub-Sharp Mountain unconformity in the Southern and Middle Anthracite fields. All workers since have agreed with White's conclusions (Read, 1944, p. 680 and chart 6; Wood and others, 1956, p. 2688; Meckel, 1964, p. 35-36; Kehn and others, 1966; Edmunds (1988, 1993).

It has been customary to equate the Buck Mountain coalbed with the Lower Red Ash coalbed in the Wyoming sub-basin and the Dunmore No. 3 coal in the Lackawanna sub-basin of the Northern field and to place the upper contact of the Pottsville (Sharp Mountain) at the base of these beds. However, C. D. White (1900, p. 269; 1912; p. 441) states that the Red Ash and Dunmore coals are older than the Buck Mountain coal and that the contact with the post-Pottsville rocks (now the Llewellyn Formation) should be higher, but without specifying where.

At the southwestern end of the Northern Anthracite field, all of the Tumbling Run and Schuylkill Members and the uppermost 1500 feet or so of the Mauch Chunk Formation are unconformably missing at the sub-Sharp Mountain unconformity. In that area the Sharp Mountain Member overlies approximately 1000 to 1200 feet of Mauch Chunk Formation (I. C. White, 1883, p. 191). Northward along the basin, erosion at the sub-Sharp Mountain unconformity sequentially removes the remaining Mauch Chunk, Pocono, and Spechty Kopf Formations, as well as some undetermined amount of Catskill Formation. At the north end of the Northern field, the Pottsville rests unconformably upon rocks of the upper Catskill Duncannon Member. The unconformity is the product of general uplift and southward tilting of the rocks of northeastern Pennsylvania in early Atokan time (Edmunds, 1988, 1993).

Because of the concentration of massive pebble conglomerates and conglomeratic sandstone in the lower part of the Pottsville Formation, it is usually not difficult to locate the unconformable basal contact at or near the lowest conglomerate zone. In many places the conglomerates may be underlain by

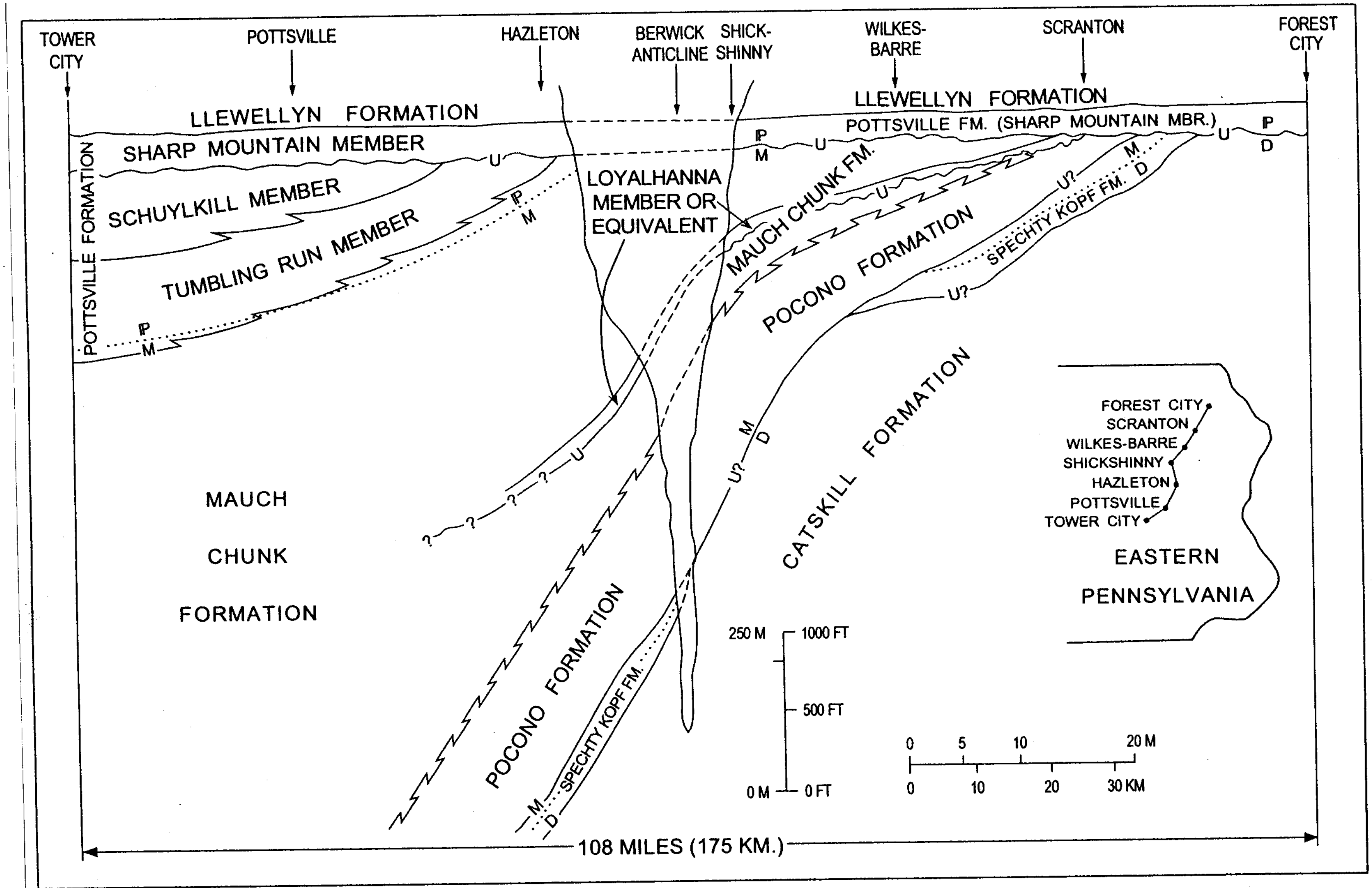


Figure 17. Generalized Late Devonian to Middle Pennsylvanian section across eastern Pennsylvania . U = unconformity; P = Pennsylvanian; M = Mississippian; D = Devonian. (Modified from Edmunds, 1993.)

up to 10 or 15 feet of the Campbells Ledge shale beds—in some cases with an additional underlying sandstone or conglomerate above the unconformity. In a few instances in the northern half of the basin, a coalbed has been reported at the Campbells Ledge position. A paleosol commonly up to several feet thick and occasionally to 20 or 25 feet thick may be present below the unconformity.

Identification of the Lower Red Ash and Dunmore No. 3 coals in any particular area is often a tedious correlation problem, particularly as there may be one or more coals or coaly zones underlying these key beds. Because there is a tendency to equate "Pottsville" with "conglomerate," there is sometimes an inclination to erroneously place the top of the formation at the first coal or coaly zone above the massive conglomerates, which may exclude a significant section of finer-grained upper Pottsville Formation.

The Pottsville Formation of this area appears to average about 200 feet thick (see Meckel, 1964, Fig. 37). The range is probably from something less that 100 feet to about 300 feet with most between 150 and 250 feet.

## LITHOLOGY

The Pottsville Formation (Sharp Mountain Member) of the Northern Anthracite field is dominantly quartzose sandstones, conglomeratic sandstones, and conglomerates with lesser amounts of siltstone and silt shale and some thin anthracite coalbeds. Conglomeratic sandstones and conglomerates tend to be concentrated in the lower part of the formation.

Meckel (1964) found the conglomerate pebbles to be dominantly vein quartz with minor amounts of chert, sandstone, and other rock fragments. He also indicated (1964, Fig. 44b) that maximum pebble size ranges from 70 to somewhat less than 50 cm, decreasing in a general northward direction. Meckel (p. 65) also found the pebbles to be spherical and well-rounded. Massive bedding, planar bedding, crossbedding and graded bedding all occur commonly. Plant impressions up to trunk size are found frequently.

Meckel (Table 10) found that the main framework component of sandstone and the finer fraction of conglomerates and conglomeratic sandstones is monocrystalline quartz with a large subordinate percentage of polycrystalline quartz and significant small amounts of rock fragments and mixed silt and clay. A few percent of chert, biotite, muscovite, and silica are usually present. Heavy minerals are almost entirely zircon and tourmaline. Grains of most components tend to be obscured by solution and silica overgrowths. Degree of sphericity and roundness is highly variable. Meckel (p. 77) classified most sandstones as protoquartzites and some orthoquartzites.

## DIRECTIONAL INDICATORS

Studies by Meckel (1964, p. 103-112) on azimuth of maximum crossbedding dip direction for the Pottsville (Sharp Mountain) in the Northern Anthracite field, give a mean cross-bedding direction of $341^{O}$ (N19W) with a standard deviation of $66^{O}$. This is somewhat more northerly than the azimuths throughout the entire Anthracite area for the Sharp Mountain ($290^{0}$), Schuylkill ($311^{0}$), and Tumbling Run ($312^{O}$). Similar results for the succeeding Llewellyn Formation are $341^{O}$ in the Southern and Middle Anthracite fields and $012^{O}$ in the Northern field. Meckel (1964, Fig. 44b) also demonstrated that maximum pebble size decreases northward across the entire Anthracite area. The results indicate a southeastern orogenic source area, persisting throughout Pennsylvania time.

A cross-bedding study by Robinson and Prave (1995), based upon measurements on three-dimensional exposures of cross-bed trough axis plunge, infilled channel margins and intersection of bedding plains with infilled troughs, produced general agreement with Meckel's results for the Tumbling Run and Schuylkill Members and the Llewellyn Formation, but strikingly opposed results for the Sharp Mountain Member. Robinson and Prave determined an azimuth for the Sharp Mountain of $238^{O}$ in the

Northern field, 226$^{O}$ in the Middle fields, and 211$^{0}$ in the Southern field. Robinson and Prave infer a northern cratonic source area.

Studies of the age of zircons in the Sharp Mountain vein quartz pebbles by Gray and Zeitler (1994) indicate a maximum age for the original source material between 1200 and 2100 Ma. Source rock this old mitigates against a southeastern orogenic source and suggests a northern cratonic or northeastern New England origin.

## DEPOSITIONAL ENVIRONMENTAL

All workers seem to agree to an alluvial plain depositional environment (most likely proximal alluvial plain). Climate was probably sub-tropical monsoonal with several wet months annually.

## AGE

Based upon paleobotany by C. D. White (1900) and Read and Mamay (1964), the age of the Sharp Mountain is earliest Desmoinesian and, where the Campbells Ledge is present, very latest Atokan (i.e., c. 308 Ma).

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# The Mauch Chunk Formation in the Lackawanna Synclinorium

by
William E. Edmunds

## INTRODUCTION

The maximum thickness and most complete development of the Mauch Chunk Formation occurs in northern Dauphin and Lebanon Counties at the west end of the Southern Anthracite field. In that area, total thickness is estimated to be 4000 to 5000 feet by Trexler and Wood (1968) and Hoskins (1976). Throughout central-eastern Pennsylvania in the area of the Southern and Middle Anthracite fields, both the lower contact of the Mauch Chunk with the underlying Pocono Formation and the upper contact with the overlying Pottsville Formation are conformable and transitional. The lower and upper contacts are generally placed at the bottom of the lowest red bed unit and the top of the highest red unit, respectively.[1] Transitional sequences of interbedded red and non-red clastics are included in both cases in the Mauch Chunk Formation.

Everywhere, outside of central-eastern Pennsylvania, the upper contact of the Mauch Chunk is defined by one of two Pennsylvanian-age regional unconformities. A still earlier, Mississippian-age regional unconformity is present within the Mauch Chunk Formation throughout much and possibly all of central-eastern Pennsylvania as well as in northeastern and north-central Pennsylvania. As long as this unconformity remains internal to the Mauch Chunk, the basal contact of the formation with the underlying Pocono remains conformable. However, once erosion at this unconformity cuts out all of the underlying basal Mauch Chunk and into the top of the Pocono Formation (as is the case throughout most of western Pennsylvania), the unconformity itself becomes the lower contact of the formation. Throughout most of Pennsylvania this lower unconformity is closely overlain by the calcareous sandstones (or arenaceous limestones)of the Loyalhanna Member as its lateral facies equivalent.

The persistent regional thinning and ultimate disappearance of the Mauch Chunk Formation away from its area of maximum development in northern Dauphin and Lebanon Counties is the result of erosional beveling by these unconformities coupled with some greater or lesser degree of depositional thinning of the Mauch Chunk delta distal from the source area (Edmunds, 1993a, 1993b, 1996).

Rogers (1858, p. 145) recognized that the Mauch Chunk Formation (his Umbral Red Shales or Formation XI) was present in the Lackawanna synclinorium of northern Pennsylvania and that it had thinned greatly from its maximum development into the south. I. C. White (1881, 1883) estimated the Mauch Chunk to be between 1000 and 1200 feet thick near Shickshinny at the southwest end of the basin and realized that it thinned steadily to the northeast. Nonetheless, White believe the formation was present throughout the entire basin. White also recognized that the Mauch Chunk tends to lose most of its typical red coloration as it thinned to the northeast and that it was composed mostly of sandstone rather than shale which erroneously was (and, to some degree, still is) thought to make up most of the formation. Although they do not say so specifically, it seems evident that both Rogers and White believed that the loss of Mauch Chunk reflected depositional mass thinning distal from the source area.

C. D. White, in 1904, first recognized the presence of an upper unconformity between the Pottsville and Mauch Chunk Formations in this area based upon paleobotanical correlations which showed that only the upper part (Sharp Mountain Member) of the more complete Pottsville Formation to the south was present. With his interest centered on the Pottsville, White did not comment on the effect of the sub-Sharp Mountain unconformity upon the underlying Mauch Chunk.

Barrell (1907) also believed that the northward thinning of the Mauch Chunk was mainly depositional, but recognized that pre-Pottsville erosion was also a factor.

[1]Inners and Lentz (1988) and Inners and others (1992) show that defining the top of the Mauch Chunk as the highest red unit has led to inconsistent mapping and is, in fact, untenable in several areas—as in the vicinity of Hazleton.

As late as the 1930 Geologic Map of Pennsylvania, the Mauch Chunk was considered to be present throughout the basin. Lohman (1938, p. 49) observed that the Mauch Chunk unconformably was absent in the northern part of the basin. This was later clearly verified by Sevon (1969).

Wells (1973) first demonstrated the presence of the Loyalhanna Member of the Mauch Chunk Formation in the Lackawanna synclinorium at the exposure in the cliffs on the east side of the Susquehanna River near Bellis Island opposite Shickshinny. Edmunds (1993a) showed the Loyalhanna or its facies equivalent is widely present in this area and recognized that the Loyalhanna here as elsewhere is persistently underlain by a major unconformity. This unconformity also extends beyond the limits of recognizable Loyalhanna.

Edmunds also concluded that in the Lackawanna synclinorium the regional thinning and eventual absence of the Mauch Chunk Formation is principally the combined results of erosion at the sub-Sharp Mountain unconformity and erosion and nondepositional at the sub-Loyalhanna unconformity, although the possibility of some degree of depositional thinning could not be discounted entirely.

## STRATIGRAPHIC FRAMEWORK

In the Shickshinny area, where the Mauch Chunk is estimated to be 1000 to 1200 feet thick, the base of the Loyalhanna Member and associated unconformity is approximately 700 feet below the unconformable upper contact with the Pottsville Formation. If correct, this would indicate that 300 to 500 feet of basal Mauch Chunk is present there conformably overlying the Pocono Formation.

Within the Lackawanna synclinorium, scattered control points seem to indicate that the basal Mauch Chunk section is cut out by erosion at the sub-Loyalhanna unconformity in a northwesterly and northerly direction with the zero-isopach line extending diagonally across the basin from the vicinity of West Wyoming on the northwest side to the junction point of Scranton, Dunmore, and Roaring Brook Township on the southeast side. Sub-Sharp Mountain unconformity erosion cuts out the upper part of the Mauch Chunk in a general northeasterly direction with the zero-isopach located across the northern part of Scranton and Dunmore. Since the last of the basal Mauch Chunk is cut out first, the sub-Pottsville zero-isopach represents the northern limit of the formation, beyond which the Pottsville Formation rests unconformably upon the Pocono Formation (see STOP 10) and ultimately the Catskill Formation north of Carbondale. Because the Loyalhanna Member is the bottom unit of the upper part of the Mauch Chunk, it is the last remnant of the formation to be extinguished (see STOP 7B).

On a somewhat more regional scale, the stratigraphic position of the Loyalhanna Member tentatively seems to fall about in the middle of the most complete 4500- to 5000-foot-thick Mauch Chunk sequence of northern Dauphin and Lebanon Counties based upon projection of various lithostratigraphic, and chronostratigraphic data. If this is correct, erosion and nondeposition at the sub-Loyalhanna unconformity coupled with some amount of depositional thinning has eliminated about 2000 to 2500 feet of lower Mauch Chunk Formation between that area and Scranton (see Figure 17). Similarly, across the same distance, later sub-Sharp Mountain unconformity erosion has removed about 1300 feet of the Schuylkill and Tumbling Run Members of the Pottsville Formation and about 2500 feet of upper Mauch Chunk.

## LITHOLOGIES

The lower part of the Mauch Chunk Formation, below the sub-Loyalhanna unconformity, is poorly exposed, especially where thickest at the southwest and of the basin. The basal part of this section represents a conformable transition from the underlying Pocono Formation and is comprised of grayish-red siltstones, claystones, and sandstones alternating with gray or greenish-gray sandstones.

A distinctive paleosol up to 16 feet thick is frequently present at the position of the sub-Loyalhanna regional unconformity. It consists of a variegated, chaotic mixture of poorly graded sand, quartz, and sometimes chert, pebbles up to 4 cm, red shale rip-up clasts, and reworked pedogenic/

biogenic carbonate nodular and irregular clasts all set in a calcium carbonate matrix. Criss-cross desiccation slickensides(?) and vertical desiccation cracks are common. It is discontinuous laterally (see STOP 3 and Pre-Conference Field Trip 2, Appendix A). It may be identified as a calcisol, vaertic calcisol, vaertisol, or calcic vertisol in the classification of Mack and others (1993).

The Loyalhanna Member or a lateral facies thereof overlies the unconformity and associated paleosol. Except where cut by the sub-Sharp Mountain unconformity, the Loyalhanna is 90 to 110 feet thick. Where present in the typical Loyalhanna facies, it is very fine- to medium-grained sandstone, mostly calcareous but with significant non-calcareous sections. It is mostly comprised of high- and low-angle crossbeds with tangential bases and truncated tops in 2- to 8-foot-thick sets (most resemble *pi*- or *omicron*-type crossbeds of Allen, 1963). There are some planar bedded intervals. Color is grayish red to pale red with some light gray. In one instance (STOP 7B) zones of reworked pedogenic calcium carbonate nodules and clasts along with small bivalve fragments are present along the crossbeds. Red shale clasts may be present occasionally. In places, the Loyalhanna displays fluted weathering along the crossbedding reflecting varying calcium carbonate concentrations between adjacent lamina. Zones with a high local concentration of calcium carbonate cement or carbonate nodules and clasts may display pocky, lace-curtain weathering.

Typical Loyalhanna is replaced laterally by light-gray, non-calcareous sandstone with mostly planar bedding or broad low-angle crossbedding, such as seen at Pre-Conference Field Trip 2 and STOP 7B. Although the correlation is less certain, it appears that there is still another Loyalhanna facies consisting of grayish-red, very fine- to fine-grained calcareous or partly calcareous sandstone, mostly planar-bedded or with shallow, low-angle crossbeds.

The remainder of the Mauch Chunk Formation overlying the Loyalhanna Member or equivalent is dominantly sandstones, siltstones, and fining-upward cycles of sandstone grading up to siltstone or silt shale. Most is grayish red to pale red (except the few hundred feet immediately underlying the Pottsville Formation, as discussed below). Except for the fining-upward cycles, it tends to be calcareous to some degree or contains calcareous nodules or clasts.

## THE RED/NON-RED FACIES PROBLEM

I. C. White (1883, p. 44-45) first observed that as the Mauch Chunk Formation thins northward along the Lackawanna synclinorium, its red coloration disappears until north from Pittston the entire remaining unit is gray or greenish gray. White wrote:

> The red shales which characterize the Mauch Chunk Formation over a wide area of the Pennsylvania Carboniferous, thin out toward the north-eastern corner of the district, and disappear entirely along the northern rim of the Lackawanna coal basin before the latter crosses the North Susquehanna River at Pittston, leaving only 150' of greenish shales and flaggy sandstones...to be referred to the Mauch Chunk beds.
>
> So far as the lithological aspect of these beds is concerned, they might with nearly equal propriety be included under the Pocono, for not a trace of red shale could be found in the entire 150'. Other considerations, however, render it certain that the 150' of green beds under the Pottsville conglomerate...should be classed with the Mauch Chunk; for {1} When the red shales begin to make their appearance in the Mauch Chunk a few miles (3-4) south-west from Campbell's Ledge [i.e. Pittston-W.E.E.], they do not come in as a mass on top of these green and greenish-gray beds, but interleave with them as knife edges between layers of the green beds, many of which subsequently change gradually into red rocks, when the Mauch Chunk thickens up toward the south-west. {2} The massive yellowish sandstone which always begins the top of the Pocono in this district, comes in beneath the green beds at Campbell's Ledge [I believe that White's "yellowish sandstone" is actually a facies of the Loyalhanna Member of the Mauch Chunk Formation--W.E.E.].

Unaware of the presence of the sub-Sharp Mountain and sub-Loyalhanna unconformities, White believed that the Mauch Chunk was simply thinning as a depositional wedge and that the loss of red coloration occurred as a lateral facies as the formation thinned. The actual situation, however, seems to be that, as the sub-Sharp Mountain unconformity cuts down section through older and older Mauch Chunk strata northward, the uppermost 100 to 300 feet of remaining Mauch Chunk exhibit the loss or, at least, significant reduction of red coloration, regardless of what stratigraphic level of Mauch Chunk occurs immediately below the unconformable base of the Pottsville. The effect is most pronounced in the case of sandstones which are rarely red in this upper zone, less so with siltstones which usually retain some red, and least with claystones and clayey siltstones which usually remain at least pale red. Where the total remaining Mauch Chunk is less than a few hundred feet thick, the entire formation tends to be non-red.

If this red-non red condition is a primary sedimentary feature, the facies is diachronous upward toward the south and the evident parallelism between the facies transition zone and the unconformable base of the Pottsville is merely an extraordinary coincidence. It seems highly possible, however, that the loss of red coloration and other factors are actually secondary alterations directly related to the proximity of the overlying Pottsville and/or its subjacent unconformable erosion surface. Two possible mechanisms have been suggested involving secondary reduction of the ferric oxide in originally red Mauch Chunk clastics. The first possibility is that reduction of iron oxides was brought about by the action of ground water contemporary with subaerial exposure of the sub-Sharp Mountain erosion surface, possibly enhanced by the introduction of organic acids from peat swamps developed in the subtropical high-rainfall climate prevailing at that time. The second suggested possibility is that ferric oxide reduction was produced by the peripheral effect of hydrothermal solutions coursing through the overlying Pottsville and Llewellyn Formations during the Alleghanian orogeny such as proposed by Daniels and others (1990).

## AGE OF THE MAUCH CHUNK IN THE LACKAWANNA SYNCLINORIUM

There are no known occurrences of specifically identified fossils in the Mauch Chunk of this area to provide direct age control [see STOP 5]. The conformable contact between the Mauch Chunk and the underlying Pocono Formation is placed at approximately middle Osagean Stage based upon the presumed equivalency between that contact and other dateable non-red to red clastic transitions in the central Appalachians, such as that between the Price Formation and Maccrady Shale (see Edmunds, 1993b). The Loyalhanna Member was correlated with the Ste. Genevieve Limestone of Kentucky (now Ste. Genevieve and Warix Run Members of the Slade Formation) by Butts (1924). This correlation has been generally accepted and indicates that the age of the Loyalhanna is latest Meramecian Stage or, possibly, earliest Chesterian Stage.

If these correlations are correct, the remaining basal (sub-Loyalhanna) Mauch Chunk is likely middle to late Osagean and the remaining post-Loyalhanna upper Mauch Chunk is early to, perhaps, middle Chesterian. Late Osagean to latest Meramecian Stage Mauch Chunk section is missing by erosion and non-deposition at the sub-Loyalhanna unconformity. Middle through late Chesterian and earliest Morrowan stage (Pennsylvanian) Mauch Chunk section, as well as Morrowan and Atokan Stage Pottsville section, is missing by erosion in the case of the Mauch Chunk and erosion and non-deposition in the case of the Pottsville at the sub-Sharp Mountain unconformity.

## DEPOSITIONAL HISTORY

The basal Mauch Chunk Formation represents a conformable transition from the coarse gray, alluvial plain clastics of the underlying Pocono Formation. Edmunds (1993a) believed that, although the Mauch Chunk clastics are, on average, distinctly finer than the Pocono and obviously red rather than gray, there was probably no significant change in the nature of the source area to the south nor any great change in the paleogeographic setting. It is concluded that the onset of the Mauch Chunk Formation reflected a climatic change from subtropical monsoonal conditions with several wet months to subtropical semiarid with only a few wet months. This climate change resulted in a decline in weathering and erosion rates, lowered stream competency, and an increase in oxidizing conditions.

Accumulation of Mauch Chunk delta clastics continued during middle Osagean to early Meramecian Ages, possibly depositing as much as 1,000 feet or more in northeastern Pennsylvania. In early Meramecian this area was involved in the general uplift which extended southwestward from here throughout central and western Pennsylvania, eastern Ohio, most of West Virginia and parts of Virginia, Tennessee, and Kentucky (Edmunds 1993a, 1993b). This area remained a positive feature until latest Meramecian Age with erosion removing all but a few hundred of feet of early Mauch Chunk at Shickshinny and all basal Mauch Chunk north of a line running from West Mahoning through south Scranton.

In late Meramecian, the calcareous sandstones and arenaceous limestones of the Loyalhanna Member were deposited across a wide area extending southwestward from northeastern Pennsylvania through much of western and central Pennsylvania, northwestern West Virginia, southern Ohio and northeastern Kentucky, except in Ohio and Kentucky. The Loyalhanna appears to lie unconformably upon a wide, flat expanse of the Meramecian erosion surface and is believed to be essentially isochronic. The highly-crossbedded Loyalhanna is usually interpreted as a shallow marine sandwave complex deposited in a broad, but elongate estuary confined on the northwest by the still-positive, topographically highest remnant of the erosion surface and interfacing on the east with prograding delta margin clastics. To the south in West Virginia, the Loyalhanna is the lateral equivalent of the marine limestones of the Denmar Member of the Greenbrier Formation. In eastern Pennsylvania, other facies equivalents of the typical Loyalhanna are also present and may represent other related marine depositional environments such as barrier island and sandy mud coast. Still farther to the south in the area of the Southern and Western Middle Anthracite fields, the Loyalhanna position appears to be occupied by non-marine alluvial and delta plain clastics.

Following deposition of the Loyalhanna Member, the embayment was overrun by northward-prograding marginal marine and non-marine fluvial clastics. Deposition was presumably continuous throughout, Chesterian Age and into earliest Pennsylvanian. The post-Loyalhanna Mauch Chunk section may have been originally the order of a few thousand feet thick and succeeded by a thousand feet or more of Lower Pennsylvanian (Morrowan Stage) Pottsville Formation (Tumbling Run and Schuylkill Members).

In early Atokan, northeastern Pennsylvania was uplifted and the rocks tilted to the south. Erosional beveling removed all Lower Pennsylvanian Pottsville Formation and all remaining Mauch Chunk Formation north of an east-west line through Scranton.

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# Convulsive Geologic Events and the Origin of Diamictite in the Specthy Kopf Formation in Northeastern Pennsylvania

by
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John B. Richardson, and Moses Attrep, Jr.

## INTRODUCTION

Mapping in the Anthracite area of northeastern Pennsylvania (Figure 18) by Gordon Wood and others in the early 1960's disclosed a distinctive suite of rocks above the redbeds of the Catskill Formation and below the overlying, nonred Pocono Formation. Trexler and others (1962) later referred to this suite of rocks as Spechty Kopf (see below).

Additional mapping and stratigraphic investigation east of the Anthracite area by Sevon in the late 1960's indicated that locally the basal part of the Spechty Kopf contains rock types that are unique in the Devonian and Mississippian rocks of Pennsylvania. Most of the work since 1970 has focused on interpretation of the origin of the basal units with little consideration given to the larger thickness of rocks that lie above the basal sequence and constitute the bulk of the Spechty Kopf Formation.

This paper (1) presents a review of knowledge about the Spechty Kopf in northeastern Pennsylvania with particular emphasis on the unique diamictite, pebbly mudstone, laminite, and quartz sandstone sequence and (2) provides an interpretation of the origin of Spechty Kopf rocks. The Field Conference will see most of the critical components of the basal Spechty Kopf at STOPS 6 and 7A on Day 2.

## STRATIGRAPHY

The Spechty Kopf stratigraphic unit was defined by Trexler and others (1962) to include a sequence of rocks of uppermost Devonian and lowermost Mississippian age adjacent to the western part of the Southern Anthracite field and to most of the Western Middle Anthracite field in eastern Pennsylvania (Figure 18). They considered the rocks to be the uppermost member of the Catskill Formation and separated the Spechty Kopf as a member because of the distinctive nature of the gray and olive-gray sandstone, conglomerate, shale, and siltstone, with interbeds of red sandstone and shale. They did not establish a type section. The unit was discussed in greater detail by Wood and others (1969) and mapped over a large area (Wood, 1968; Wood and Kehn, 1968a, b; Wood and Trexler, 1968; Wood and others, 1968; Trexler and Wood, 1968a, b). The unique lithologies at the base of the Spechty Kopf were never mentioned.

Dyson (1967) mapped Spechty Kopf as a member of the Pocono Formation and noted that the Mississippian-Devonian boundary occurred within the unit. Epstein and others (1974) elevated the Spechty Kopf rank to formation and described in detail the basal sequence.

Today, the Pennsylvania Geological Survey recognizes the Spechty Kopf as a formation (Berg and others, 1980; Berg and others, 1983) that straddles the Mississippian-Devonian time boundary and is lithologically transitional between the underlying Catskill (Devonian) and the overlying Pocono (Mississippian).

The Spechty Kopf is thought to occupy the same stratigraphic position as the Huntley Mountain Formation (Berg and Edmunds, 1979) of north-central Pennsylvania and the Rockwell Formation of south-central Pennsylvania and adjacent Maryland. However, the Spechty Kopf cannot be physically traced into either the Huntley Mountain or the Rockwell because rocks of that stratigraphic position have been eroded from around the Anthracite area (Berg and others, 1980). The Spechty Kopf, particularly the basal sequence, is dissimilar in character to rocks in the Huntley Mountain. Rocks similar to those in

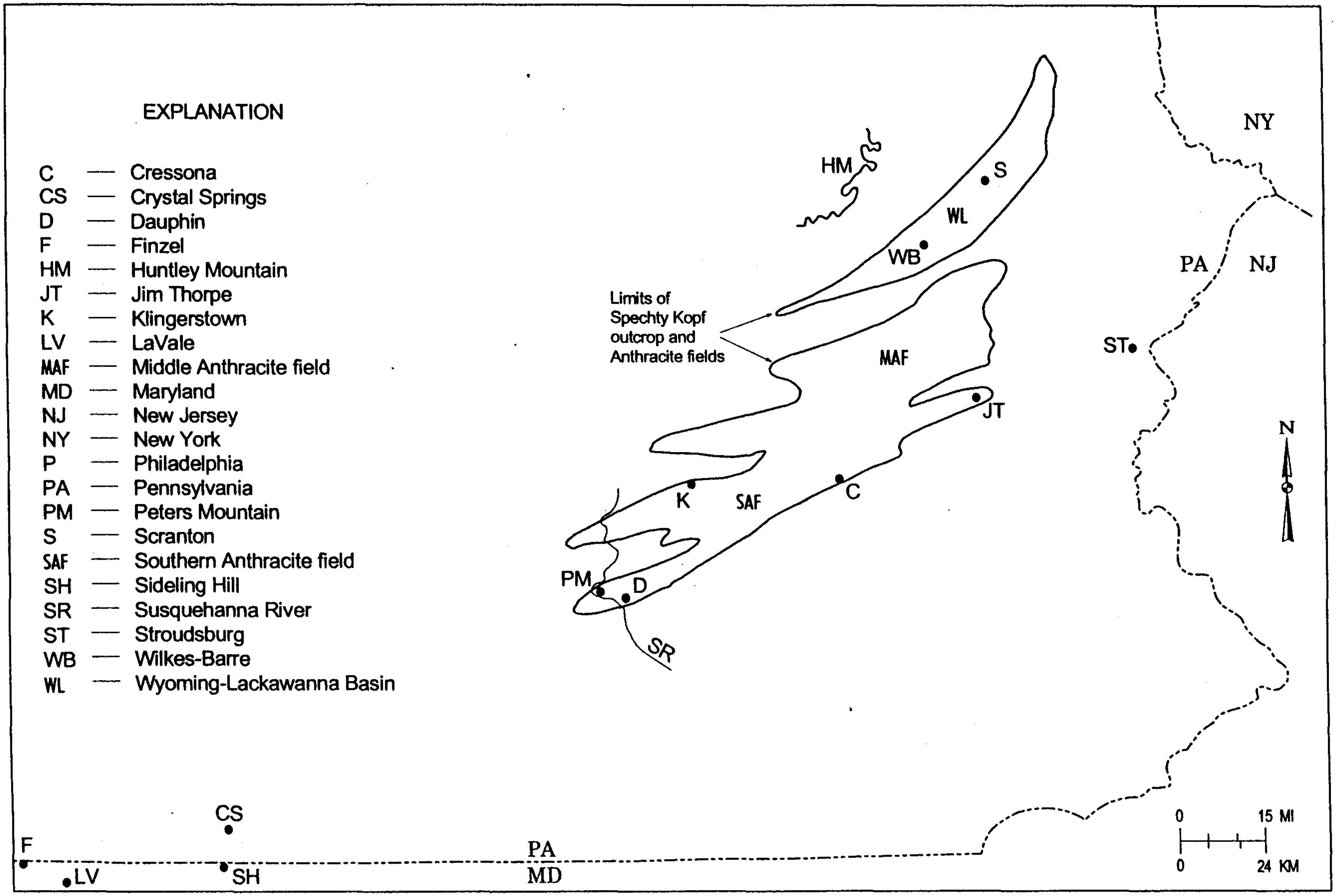



Figure 18. Regional location map.

the basal Spechty Kopf do occur in the lower part of the Rockwell Formation. Rockwell outcrops displaying some of those basal rocks are described briefly by Dennison (1972) and Perry and deWitt (1977) and in detail by Sevon (1979a) and Bjerstedt (1986; Bjerstedt and Kammer, 1988).

## ROCKS UNDERLYING THE SPECHTY KOPF FORMATION

The Spechty Kopf Formation overlies rocks readily identifiable as part of the Upper Devonian Catskill Formation. The Catskill rocks immediately beneath the Spechty Kopf are assigned to the Duncannon Member everywhere except where the Duncannon and one or more lower members have been combined for mapping purposes to form the Buddy's Run Member (Berg and others, 1983). The Duncannon Member was deposited by meandering streams on the Catskill alluvial plain (Sevon, 1985).

## ROCKS OF THE SPECHTY KOPF FORMATION

### Introduction

The rocks of the Spechty Kopf Formation are here divided into two lithologically distinctive parts: (1) a basal sequence of diamictite (base), pebbly mudstone, laminite, and quartz sandstone (top) (Figure 19), a sequence hereafter referred to as DMLS (Diamictite, Mudstone, Laminite, and Sandstone) and (2) the remainder of the formation that is made up of sandstones, siltstones, and shales.

The regional distribution of various parts of the DMLS sequence varies. Within the entire Spechty Kopf outcrop belt, the DMLS sequence occurs only near the eastern limits of Spechty Kopf occurrence. Outside northeastern Pennsylvania, diamictite occurs at several other localities but without the complete DMLS sequence except at Crystal Springs, PA and LaVale, MD (Figure 18) where the diamictite is overlain by quartz sandstone. The lithologies that comprise the DMLS sequence, both in northeastern Pennsylvania and elsewhere, make up only a small part of the Spechty Kopf Formation. As will be noted later, these unique lithologies are restricted to the centers of upper Devonian sediment input systems. As a consequence, most of the area covered by the Spechty Kopf Formation lacks these rocks.

Although this paper deals mainly with the DMLS sequence in northeastern Pennsylvania, attention is given to parts of the sequence, the diamictite and quartz sandstone, as they occur elsewhere in Pennsylvania and adjacent parts of Maryland. This is done because of their relevance to interpretations.

### The DMLS Sequence

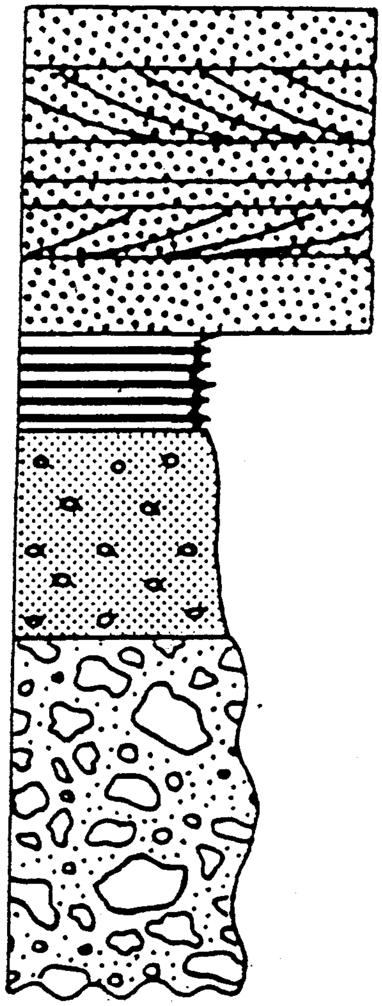
The DMLS sequence is an invariably ordered, vertical sequence composed of polymictic diamictite (base), pebbly mudstone, laminite, and quartz sandstone (top) (Figure 19). Any or all parts of the sequence may be present or absent at any locality within the area where the DMLS sequence occurs in northeastern Pennsylvania.

***Diamictite.*** Diamictite is the basal unit of the DMLS sequence.

General description. The diamictite is a structureless to crudely stratified, unsorted to poorly sorted, dark-colored rock with readily visible scattered clasts of pebble to boulder size (Plate 1, A). Fresh diamictite ranges in color from medium gray to light-olive gray and is often mottled with grayish red. In natural outcrop and some artificial outcrops the diamictite weathers to a distinctive brown color and forms rounded surfaces because of exfoliation of the relatively homogeneous rock (Plate 1, B).

Bedding does occur but may not be obvious in outcrop. In some outcrops, e.g., Jim Thorpe (Figure 20), bedding-parallel parting planes are clearly defined. All of these planes may not separate diamictites of different character as suggested by Suter (1991), but some do. In some outcrops, e.g., Cressona (Figure 18), diamictite is interbedded with well sorted, crossbedded sandstone.

Texture. The bulk of the diamictite is an unsorted to poorly sorted mixture of clay, silt, and sand. The silt and sand grains 'float' in the clay matrix and lack point contacts. Microscopic examination (Epstein and others, 1974) indicates that the clay matrix constitutes 30 to 40 percent of the rock. Suter



**Quartz sandstone**: parallel-sided bedding partings; small- to medium-scale crossbedding; asymmetric and symmetric ripples; rounded to well rounded quartz grains; abrupt basal contact.

**Laminite**: alternating sandstone and claystone laminae; sharp contacts between laminae; some pebbles and cobbles; sandstone laminae thicken upward.

**Pebbly mudstone**: structureless to shaly mudstone or claystone; scattered polymictic pebbles and cobbles; gradational upper and lower contacts.

**Diamictite**: structureless to crudely bedded; unsorted to poorly sorted mixture of sand, silt, and clay with scattered polymictic pebbles, cobbles, and boulders; silt and coarser materials float in clay matrix; sharp basal contact; gradational upper contact.

Figure 19. Generalized DMLS sequence stratigraphic column.

(1991) evaluated 90 thin sections of diamictite and noted matrix variations between 0 and 75 percent of the rock. She classified the diamictite as sublitharenite (0-13% matrix) and lithic wacke (three categories of matrix percentage: 15-40%, 40-60%, and 60-75%).

The sand fraction is dominantly very fine to fine grained at most locations, but all sand sizes occur. In some outcrops, e.g., Lake Scranton (STOP 6), the sand fraction is medium to coarse grained. Studies of grain-size distribution have not been done.

Clasts larger than 1 cm diameter are common, but constitute a relatively small part of the rock as a whole (probably <1%?). A clast-size evaluation at Penn Haven Junction (Figure 20) determined a mean clast size of 2.8 x 2 x 1.5 cm with a range from 1 cm diameter to 12 x 11 x 5 cm (Sevon, 1969). Sixty percent of these clasts were rounded or well rounded. Well rounded clasts 10 to 15 cm in long dimension are usually apparent in a diamictite outcrop. The largest clast known is a rounded, fine-grained, sandstone boulder 50 x 30 x 40+ cm at Jim Thorpe (Figure 20). The second largest clast known is a similar boulder 40 x 30 x 20+ cm at Lake Scranton (Figure 20). Rarely, the surface of a clast is striated, e.g., cobbles collected near Pleasant View Summit (Figure 20).

Composition. The matrix comprises minute flakes of illite-sericite and some microcrystalline silica (Epstein and others, 1974; Suter, 1991). Costolnick (1987) noted chloritized clay. Sand grains are mainly angular and strained, and include monocrystalline and polycrystalline quartz. Quartz may constitute up to 80% of the sand fraction. Costolnick observed at Roaring Brook (Figure 20) that

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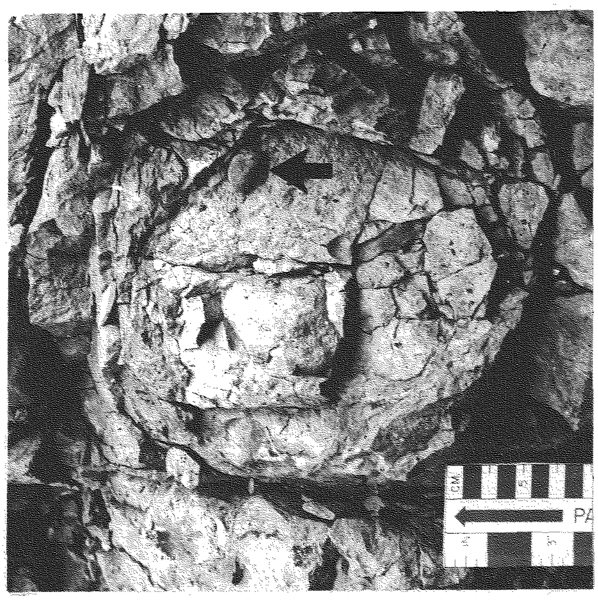

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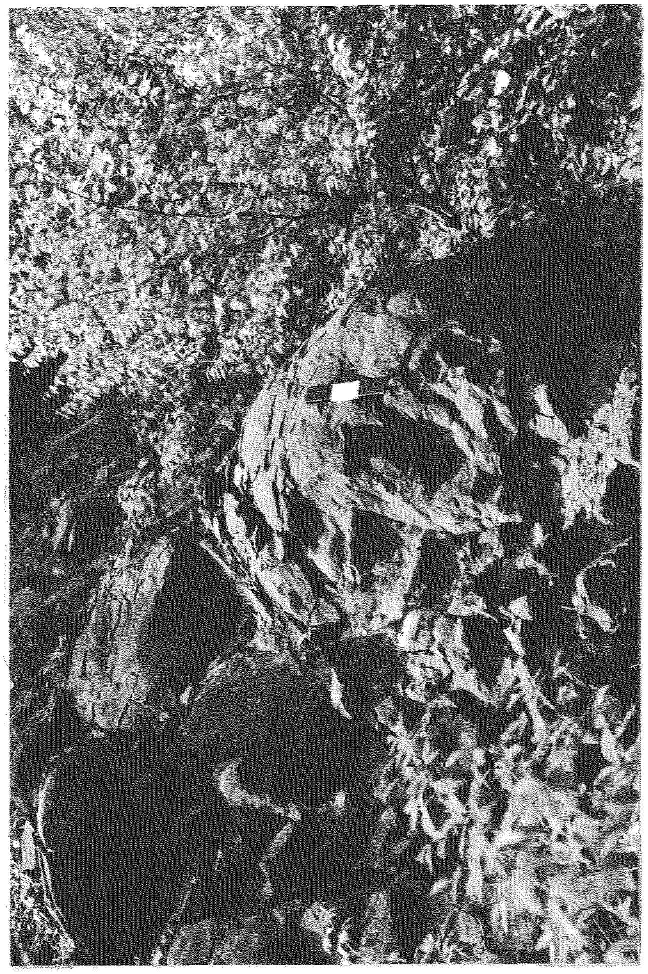

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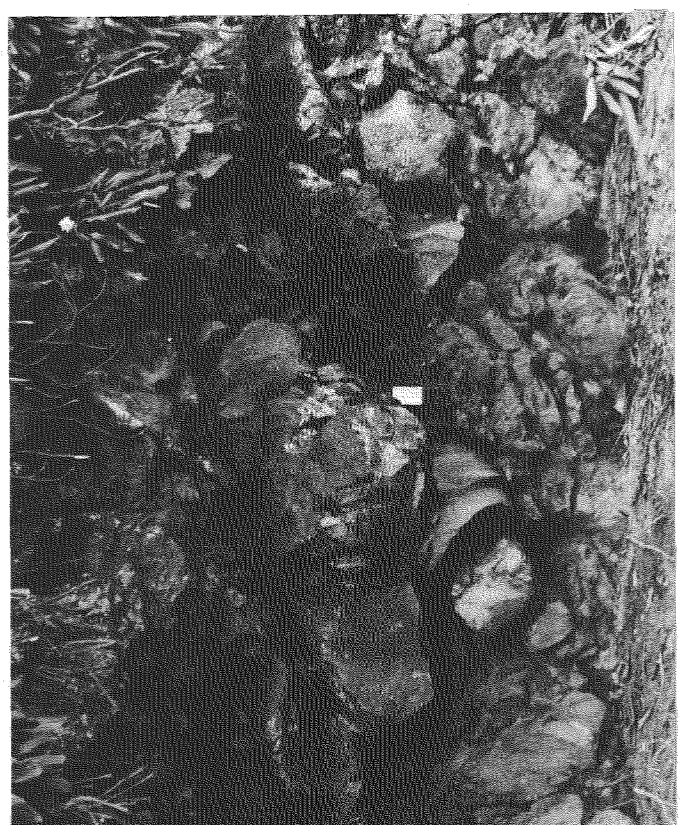

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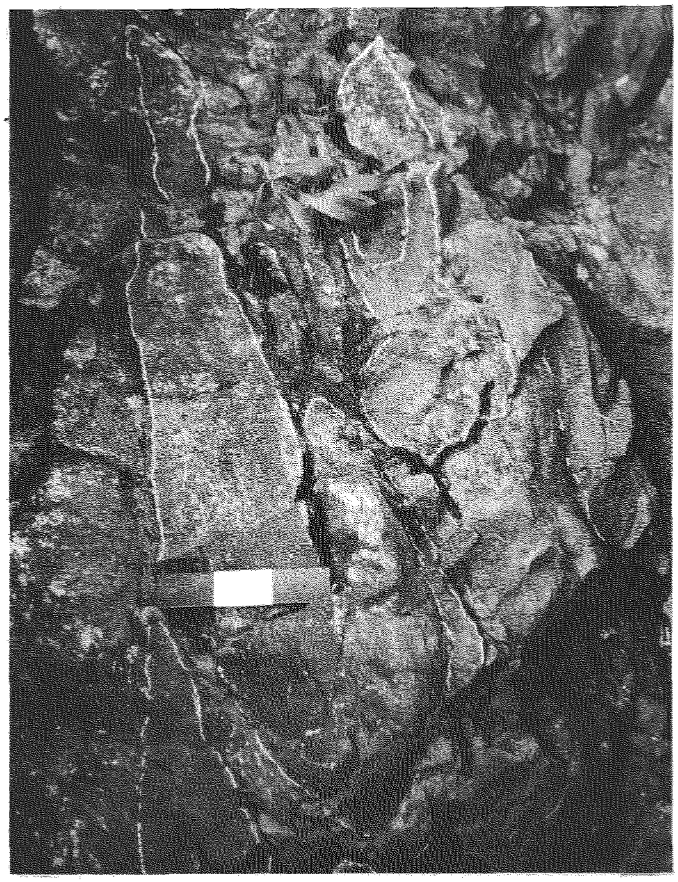


composite and stretched polycrystalline quartz account for more than 60% of the observed quartz with common quartz making up most of the remainder. Sevon (Epstein and others, 1974) noted mainly strained monocrystalline quartz at Jim Thorpe (Figure 20) and Suter noted mainly monocrystalline quartz in her more regional study. Rock fragments observed in thin section include: chert, chloritic phyllite, biotite schist, slate, shale, mudstone, siltstone, sandstone, and limestone (Epstein and others 1974; Costolnick, 1987; Suter, 1991).

Quartz comprises 51% of the large clasts identified by Sevon (1969). Also occurring were decreasingly smaller quantities of red quartzite, siltstone, slate, red shale, sandstone, chert, white quartzite, schist, and conglomerate. Well rounded red (or pink), white, or gray quartzite cobbles are the obvious large clasts observed in most outcrops. Small, white, quartz pebbles are generally the most common clast present. Costolnick noted in the Roaring Brook area that the largest percentage of clasts is well rounded white, gray, and pink quartzite up to 15 cm in longest dimension. He also noted a large number of olive-gray shale clasts as well as phyllite, slate, and schist fragments. Large clasts noted in outcrops along and northeast of the Susquehanna River (Figure 18) are generally metamorphic rocks (quartzite, schist, phyllite, slate). Clasts of granite and metamorphic rocks occur at Crystal Springs (Sevon, 1979a; Suter, 1991) and Sideling Hill (Bjerstedt, 1986) (Figure 18).

Sedimentary structures. Often, the diamictite shows no sedimentary structures, e.g., Jim Thorpe and Dauphin (Figure 18), but that may simply reflect the size of the exposure because at many outcrops, structures are obvious and informative. Examples of sedimentary structures within the diamictite include:

1. Both Costolnick and Suter describe crossbedding in sandier parts of the diamictite at a few localities.

2. Bjerstedt (1986) notes large-scale dewatering and diapiric structures and large ball-and-pillow structures at Sideling Hill (Figure 18).

3. At Roaring Brook, Costolnick noted numerous contorted rock masses that are tapered and tear-drop shaped (Plate 1, C). A similar rock mass occurs at Drakes Creek (Figure 20). Costolnick also noted many, large, ball-and-pillow structures.

4. At Klingerstown (Figure 18), a large sandstone mass, at least 5 m across appears to be "floating" within the diamictite.

5. At Peters Mountain (Figure 18), Baria (1981) identified coherent slumps, contorted pillows, and convoluted beds.

6. At Dauphin (Figure 18), a large, elongate, convoluted, gravel mass occurs within the diamictite.

Contacts. The basal contact of the diamictite is always sharp in that it represents an abrupt change in lithology from the underlying rock. In northeastern Pennsylvania the base of the diamictite rests on an erosional surface of generally unknown magnitude. Costolnick measured relief of 24 m on a vertical contact between sandstone and diamictite at Roaring Brook. The upper contact is gradational when overlain by pebbly mudstone, sharp when overlain by anything else.

Thickness. The thickness of the diamictite often shows great variation over very short distances. An extreme example of thickness variation is seen on the banks of the Lehigh River on the north and

**Plate 1. A**. Photograph of diamictite exposed at Crystal Springs (Figure 18). Arrow points to rounded, quartzite cobble. Scale divided into inch (left) and centimeter intervals. **B**. Photograph of diamictite on the west side of Roaring Brook showing exfoliation weathering. Scale divided into 10 cm intervals. **C**. Photograph of slumped masses of sandstone surrounded by diamictite. Outcrop is along west bank of Roaring Brook. Note large sandstone block in center and tear-drop shaped block beneath. Scale divided into 10 cm intervals. **D**. Photograph of slumped masses of sandstone (outlined with white chalk) surrounded by diamictite. Outcrop is along west bank of Roaring Brook. Scale is divided into 10 cm intervals.

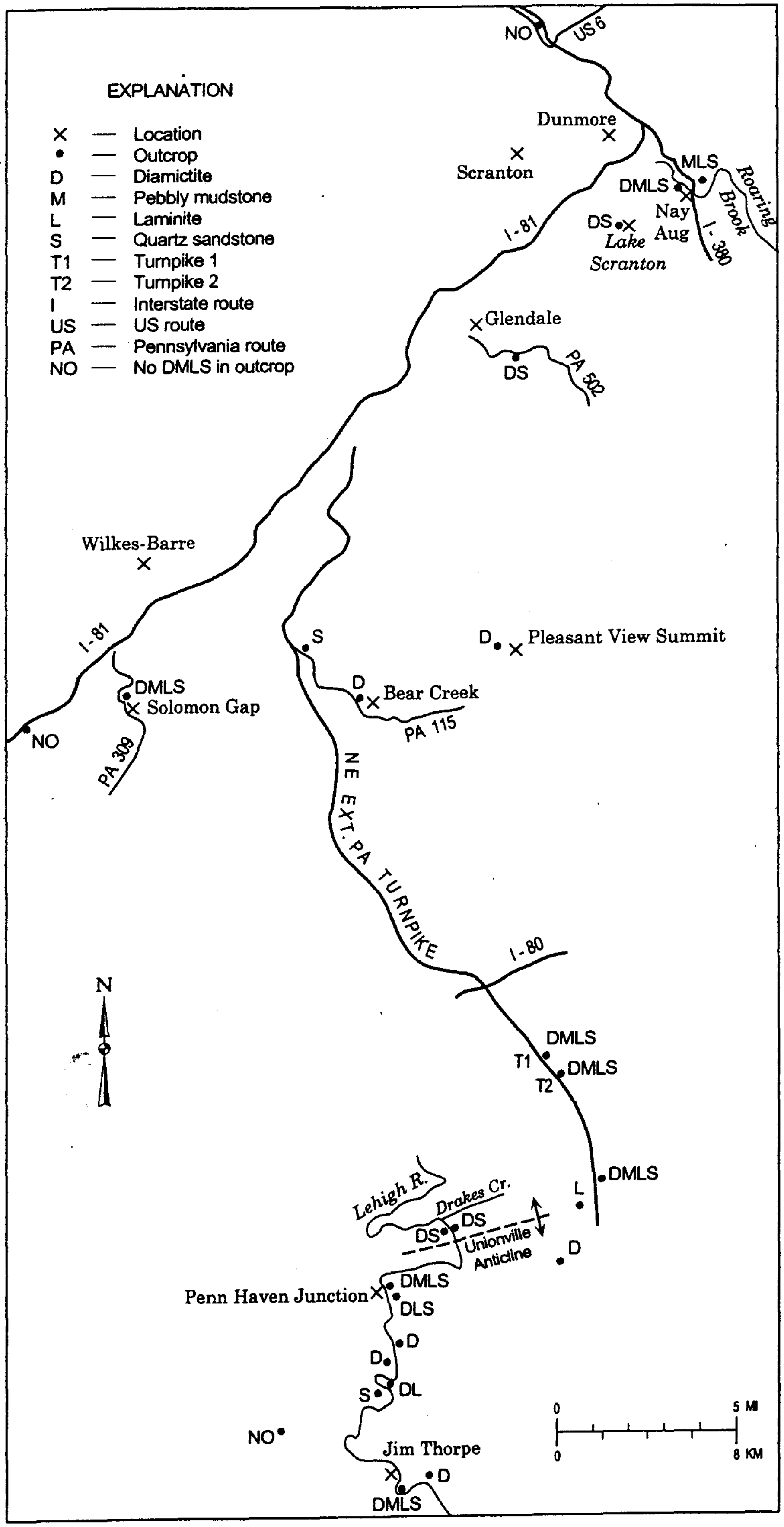



Figure 20. Detailed location map for northeastern Pennsylvania.

south limbs of the Unionville anticline (Figure 20) over a distance of 1 km. On the north limb of the anticline, diamictite and quartz sandstone occur (DS of the DMLS sequence), but on the south limb only the quartz sandstone is present. Maximum known thickness of the diamictite is 34 m at Roaring Brook.

Origin. There is general agreement among the workers who have examined the diamictite that it is the result of some sort of sediment gravity flow, probably debris flow. That is, the diamictite was likely emplaced as a dense slurry. In support of that conclusion are: (1) the poor sorting of the rock mass, (2) its wide range of particle size including some small boulders, (3) its generally structureless appearance and occasional crude bedding, (4) its crude size-grading with the largest clasts near the base, and (5) a limited range of sedimentary structures, some of which suggest rapid dewatering.

Diamictites in Maryland studied by Bjerstedt (1986) are associated with marine deposits and are considered by him to be subaqueous debris-flow deposits. Costolnick considered the diamictite at Roaring Brook to be a subaqueous debris-flow deposit. Baria (1981) considered the deposits to be the result of debris flows on an alluvial fan. Suter identified three different facies within the diamictite based on the work of Wells and Harvey, 1987) and took those as evidence of deposition by debris flow on an alluvial fan. Sevon (1968, 1969, 1973) argued that the DMLS sequence, when viewed as a sedimentological package, requires that the diamictite be the result of a subaqueous mudflow or debris flow.

***Pebbly mudstone.***

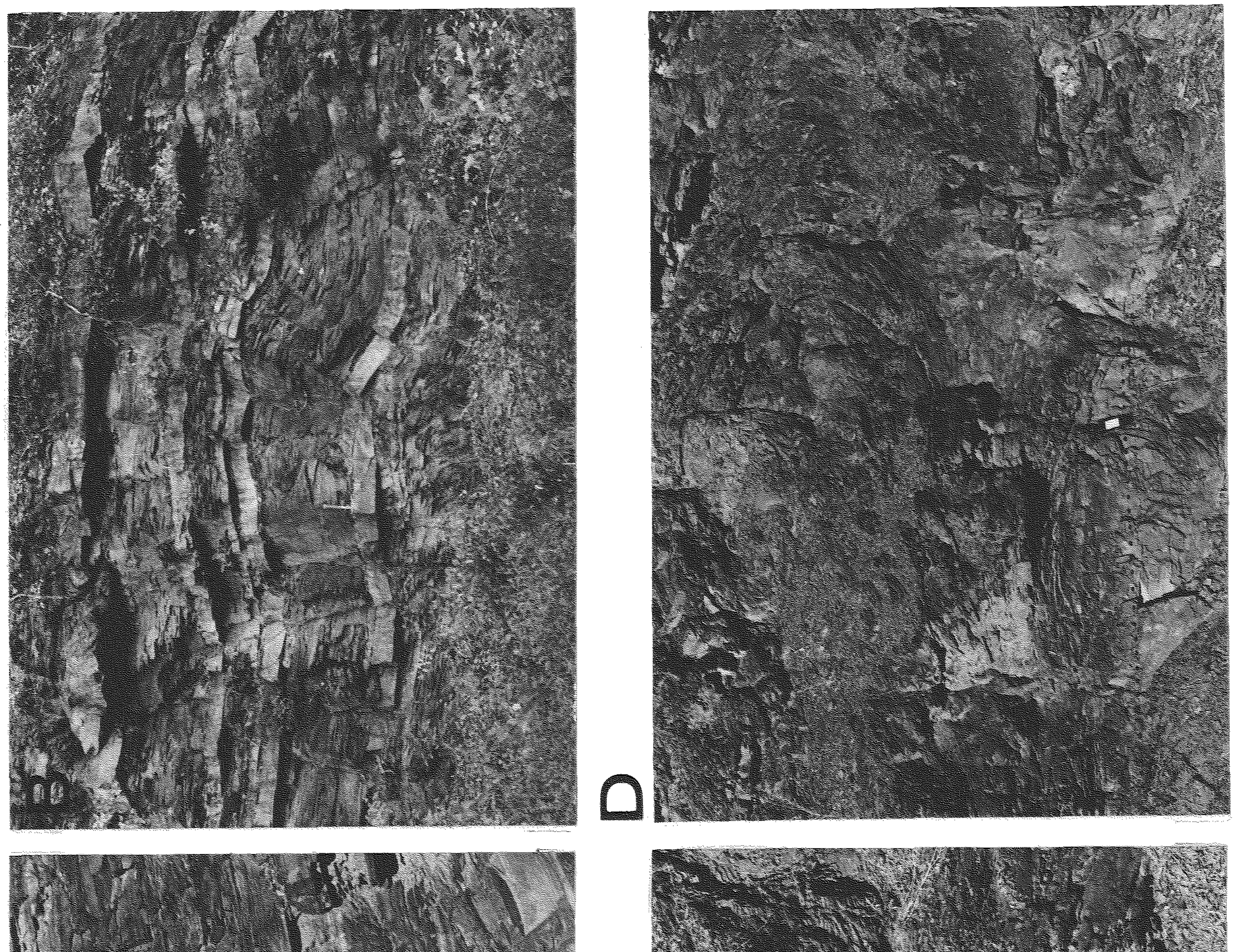
General description. Pebbly mudstone overlies the diamictite and consists primarily of structureless, brownish gray to medium gray, sub-fissile to fissile mudstone or claystone. Bedding is absent to well defined. There is considerable variation in this unit, particularly with regard to bedding and sedimentary structures. The pebbly mudstone sometimes resembles diamictite in outcrop and Suter considers this lithology to be diamictite. The mudstone is more fissile than the diamictite and does not weather to produce rounded rock surfaces. Claystone intervals above pebbly mudstone at Roaring Brook and Turnpike 1 and 2 (Figure 20) are fissile in appearance and produce thin flake-like pieces during weathering.

Texture. Dominant grain size ranges from clay to coarse-grained silt. Sand grains, pebbles, and cobbles are scattered throughout the mudstone, but the coarser sizes are not as abundant as they are in the diamictite. The cobbles are generally very apparent visually because of their contrast to the character of the rest of the rock. At Roaring Brook the pebbly mudstone is mixed with diamictite and the whole is somewhat confusing in terms of relationships. However, the pebbly mudstone at Roaring Brook is overlain by a thick sequence of rhythmically bedded claystone (Plate 2, A) that generally lacks discrete sand grains and coarser clasts. The color of this claystone varies from dark gray to olive green to gray with a reddish hue. The claystone is composed of alternating clay and coarser-grained laminae. The coarser laminae are composed generally of nothing coarser than fine-grained silt, but occasional sandy laminae occur. Similar but less well studied claystone occurs at Turnpike 1 and 2 (Figure 20).

At two outcrops on the west side of Roaring Brook, the claystone contains several interbedded sandstones up to 10 cm thick (Plate 2, B). These laterally persistent sandstone beds often have load casts at the bases of the thicker beds and flute casts at the bases of the thinner beds. In addition, the upper surfaces have asymmetrical ripples. The long axes of the flute casts are oriented N4°W with a north directed flow indicated while the strike of ripple crests varies from N80°W to E-W with a north-flow asymmetry.

Composition. The pebbly mudstone is composed of minute illite-sericite flakes and microcrystalline silica. These components comprise 30-100 percent of the rock (Epstein and others, 1974) (74-100% according to Suter). Limited examination of the pebbles and cobbles of the mudstone indicates that the lithologies are essentially the same as those in the underlying diamictite.

Sedimentary structures. Sedimentary structures are absent in the pebbly mudstone at some outcrops, e.g., Jim Thorpe and Penn Haven Junction (Figure 20). However, some outcrops show large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(multi-meter size) slump structures within the rhythmically-bedded claystone, e.g., Roaring Brook, Turnpike 1 and 2 (Figure 20). These slumps or slump folds have distinct roll-fronts with no apparent disturbance of bedding within the slumped mass (Plate 2, C-D). Bedding above and below the slump is not disturbed but bends around the slump. Limited observation indicates that there may be some chaotically disrupted bedding at the nose of the slump.

Contacts. The basal contact of the pebbly mudstone is gradational over a distance of a few meters wherever observed. The upper contact is gradational over distance of a few or a few 10's of centimeters into laminite or sharp if laminite is absent.

Thickness. Thickness of the pebbly mudstone ranges from zero to about 90 m (this thickness occurs at Roaring Brook and includes the rhythmically bedded claystone). Zero thickness occurs at localities outside of northeastern Pennsylvania and at a few localities in northeastern Pennsylvania, e.g., Glendale, Lake Scranton, and Drakes Creek (Figure 20).

Origin. Sevon (1969) believed that deposition of the pebbly mudstone must have occurred in a subaqueous environment and that the material might be the lateral equivalent of the diamictite. He suggested deposition on a shelf or prodelta. At the Roaring Brook, where there is considerable diversity in the pebbly mudstone interval, Costolnick interpreted the sequence to be mainly the result of turbidity flows with deposition occurring on a slope. He considered the thick, rhythmically bedded claystone with slump structures to be a slope deposit (Rich, 1950). The interbedded sandstones with asymmetric ripples are presumably traction-current deposits. Suter considered the pebbly mudstone to be a diamictite deposited by dilute debris flow (Wells and Harvey, 1987) on an alluvial plain. In reality, the pebbly mudstone was probably deposited by the waning phase of the debris flow that deposited the underlying diamictite. The rhythmically bedded claystone represents later and different deposition, presumably in a pro-delta environment.

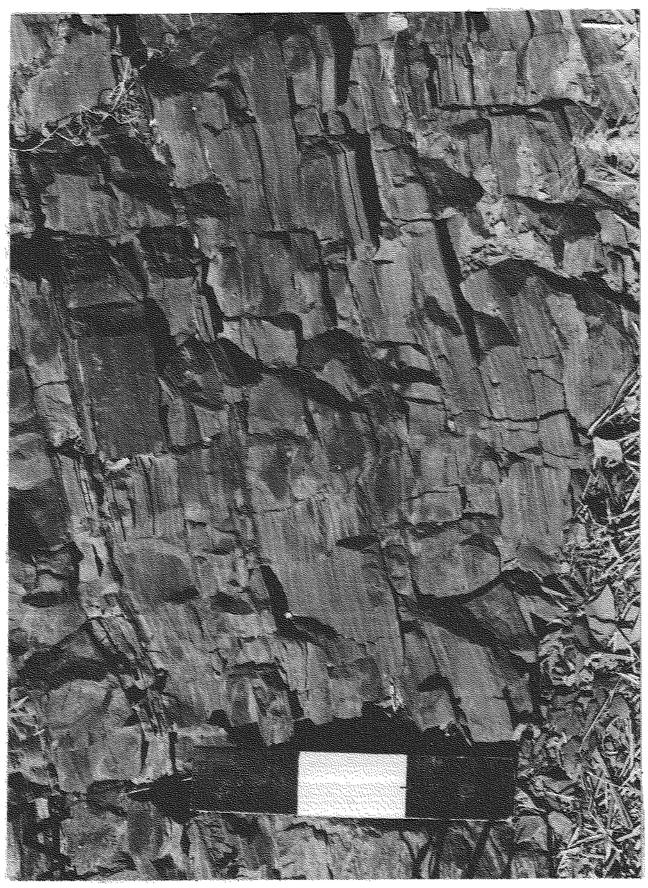
***Laminite.*** Laminite occurs above the pebbly mudstone at most outcrops where the mudstone is present.

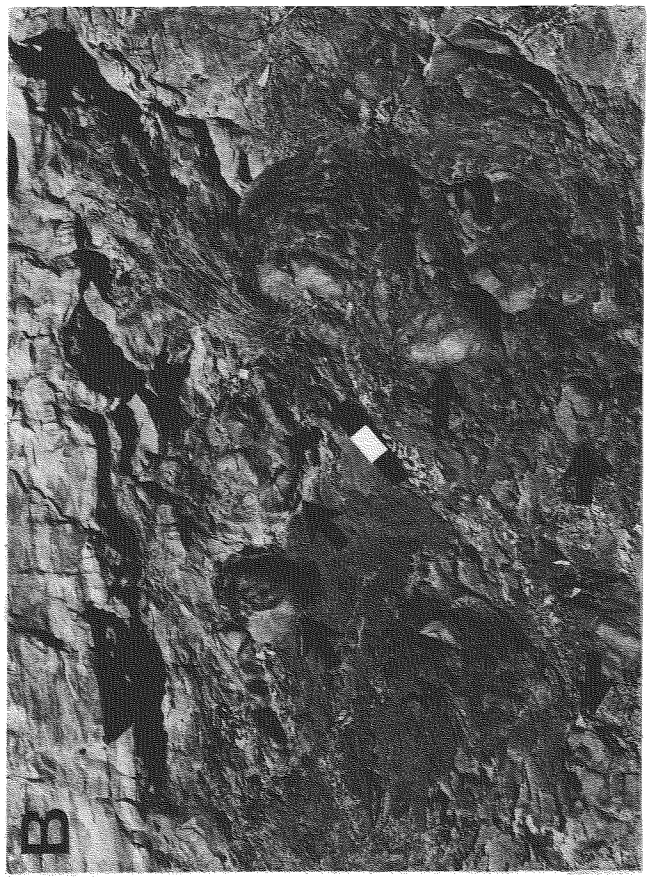
General description. The laminite comprises olive green to light gray, alternating clay and silt or sand laminae that are rhythmically bedded at the millimeter to centimeter scale (Plate 3, A) and have the general appearance of varves. The laminites generally have the appearance of parallel-bedded rock that breaks into 2-5 cm-thick beds in outcrop.

Texture. The laminae are generally fairly distinctive in texture. The clay laminae are almost exclusively clay. The coarser-grained laminae contain a range of grain size from coarse silt to medium-grained sand with some intermixed clay. Coarser sand, granules, and pebbles are sometimes associated with the coarser-grained laminae. Individual laminae generally vary from ½ to 5 mm in thickness, but the coarser-grained laminae increase in thickness towards the upper contact and may be up to several centimeters thick.

Composition. The clay laminae are composed of illite-sericite clay and microcrystalline silica. The coarse-grained laminae are composed mainly of angular, quartz grains. The clay in the coarser laminae is illite-sericite.

**Plate 2.** A. Photograph of rhythmically bedded claystone exposed along I-84/380 at Roaring Brook (Stop 7A). Light colored bands are the coarser laminae. Scale is divided into 10 cm intervals. **B**. Photograph of interbedded sandstones and claystone exposed in the old Nay Aug quarry on the west side of Roaring Brook (Figure 20). Photograph is Fig. 22 in Costolnick (1987). Geologic hammer to left of center is scale. **C**. Photograph of nose of slump structure in claystone exposed along I-84/380 at Roaring Brook (Stop 7A). Dashed line follows trend of bedding. Scale is divided into 10 cm intervals. **D**. Photograph of slump structures in claystone exposed along I-84/380 at Roaring Brook (Stop7A). Dashed line follows trend of bedding. Dotted line shows axis of a slump fold. Scale is divided into 10 cm intervals.

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The coarse-grained laminae are composed mainly of angular, quartz grains. The clay in the coarser laminae is illite-sericite.

Sedimentary structures. A structure noted at some outcrops is the "dropped-in" appearance of some of the coarser particles that occur in the laminite. These do not constitute a large part of the laminite, but are sometimes spectacular in appearance. A few thicker sand laminae at STOP 7A show minute ripple bedding and also some convolute bedding that represents either small-scale slumping or distortion by current flow following deposition of the now-convoluted bed.

At Roaring Brook (STOP 7A) some of the thicker sand laminae are disrupted and parts of these several-centimeter-thick beds have foundered into the underlying claystone. The foundered pieces are now ball-like load casts positioned several centimeters to 2$\pm$ m below and totally isolated from their original bed position (Plate 3, B). The foundered balls range in size from a few to a few tens of centimeters in diameter. Similar structures occur at Turnpike 1 and 2 (Figure 20).

Contacts. The basal contact of the laminite is gradational over distance of a few or a few 10's of centimeters from the pebbly mudstone below. The upper contact is gradational in the sense that, generally, the coarser-grained laminae gradually become thicker before there is a relatively abrupt change from laminite to the overlying sandstone. These upper contact changes take place over intervals that vary at different localities from a few tens of centimeters to a few meters.

Thickness. The laminite ranges in thickness from a few 10's of centimeters to several meters. It is several meters thick at Roaring Brook, but the unit cannot be traced laterally a mile either side of Roaring Brook and does not occur anywhere to the northwest (Figure 20).

Origin. Sevon (1969) suggested deposition of the laminite in the distal bar part of a deltaic plain. Costolnick placed the depositional environment on a slope. Given its stratification alone, deposition of the laminite requires either pelagic deposition, that is, a quiet raining-out of sediment or deposition from pulsed, sheet flows of varying density. We can reject the first alternative because the grain sizes are not compatible with pelagic sedimentation. Instead, the individual coarse-to-fine couplets of sand and silty mud in the laminite look to be the result of many hundreds of micro-turbidites some of which carry sand-size grains or pebbles. Most couplets are sharp-based or, if gradational, they do so over thickness' less than 1/10 of the couplet thickness. In other words, this sediment mass appears to have been deposited very rapidly in a subaqueous environment, possibly the delta front. In some cases the weight of the rapidly-deposited sand caused failure of the underlying muddy mass

***Quartz sandstone***. Quartz sandstone is the uppermost bed of the DMLS sequence.

General description. The quartz sandstone is visually striking in outcrop because of the well developed parallel-sided bedding partings that dominate the unit (Plate 3, C). However, the rock changes character somewhat from south to north. In outcrops at Jim Thorpe and immediately to the north, Penn

**Plate 3. A**. Photograph of laminite exposed along I-84/380 at Roaring Brook (STOP 7A). Lighter colored bands are the coarser laminae. Scale is divided into 10 cm intervals. **B**. Photograph of load cast balls of sandstone that have foundered into underlying claystone. Arrows point to some of the load casts. The sandstone balls came from the discontinuous sandstone layer directly beneath the more massive sandstone at the top of the photograph. Outcrop is along I-84/380 at Roaring Brook (STOP 7A). Scale is divided into 10 cm intervals. **C**. Photograph of outcrop of quartz sandstone exposed along I-84/380 at Roaring Brook (STOP 7A). Top arrow points to a thin shale layer that is persistent throughout the exposure. Middle arrow points to approximate horizon of change from more steeply inclined bedding in lenticular units (below) to parallel sided bedding (above). Lower arrow points to base of the quartz sandstone. The stratigraphic interval from the lower arrow to the middle arrow is approximately 17 m; from the middle arrow to the shale bed at the upper arrow, 7 m. Cab of 18-wheel truck provides additional scale.

Haven Junction, Drakes Creek, and Turnpike 1 and 2 (Figure 20), the sandstone is gray and quartzitic with closely spaced parallel-sided bedding partings. Farther north in the Roaring Brook area, outcrops are white or tan, the sandstone is moderately hard to somewhat friable, and parallel-sided bedding partings are more widely spaced and slightly less regular than to the south. Ripple bedding is common everywhere.

At Roaring Brook (STOP 7A) the lowermost 9 m of this unit comprises thick, lenticular bed sets that dip at an angle greater than underlying and overlying beds (Plate 3, C). Similar beds have not been observed elsewhere.

Texture. The quartz sandstone is generally well sorted and composed of fine- to coarse-grained, rounded to subrounded, quartz grains with only a small amount of silt size material. Pebble layers occur occasionally within the sandstone at Roaring Brook and Lake Scranton (STOP 6).

Composition. The quartz sandstone is made up almost exclusively of strained or unstrained monocrystalline quartz, with only a few polycrystalline grains. Silica forms the cement and the degree of cementation varies. At Jim Thorpe the quartz sandstone is essentially a quartzite because silica cementation is so pervasive. At Roaring Brook the cementation is much less pervasive and the sandstone is not quartzitic. Costolnick noted in the large outcrop at Roaring Brook (STOP 7A) the scattered occurrence of poikilotopic cementation: detrital grains floating or held within single large calcite crystals. The origin of such cementation at STOP 7A is presently unknown, but, in theory, it could represent the alteration of silica cement toward calcite cement or vice versa.

Sedimentary structures. The most obvious and visible sedimentary structure is the prevailing parallel-sided bedding of the quartz sandstone (Plate 3, C). This planarity occurs in all outcrops of the sandstone from Jim Thorpe to Roaring Brook. Spacing of bed partings varies from about one to a few tens of centimeters, but as noted above increases from south to north. The second most obvious sedimentary structure is ripple bedding. Ripple-bedded surfaces (Plate 4, B) occur at all known sandstone outcrops. The ripple bedding is both symmetrical and asymmetrical with variable amplitudes and wave lengths.

A variety of small crossbedding structures occur in the quartz sandstone at Roaring Brook (Plate 4, A). Similar crossbedding may be present in outcrops farther to the south, but has not been noted to date. Costolnick described small-scale, overlapping, trough crossbeds ranging from 2-5 to 5 cm in thickness. These crossbeds generally occur atop medium-scale crossbed sets and are often associated with straight-crested asymmetric ripples (Plate 4, B). Ripple crest orientations are N60°E to E-W with typical wave lengths of 11.4 cm and heights of 1.5 cm. The medium-scale crossbeds are tabular to wedge-shaped ranging from 7 to 30 cm in thickness. The planar-bedded foresets vary widely in inclination and generally curve so as to merge tangentially with their bases. One good candidate for hummocky cross stratification occurs at Solomon Gap (Figure 20).

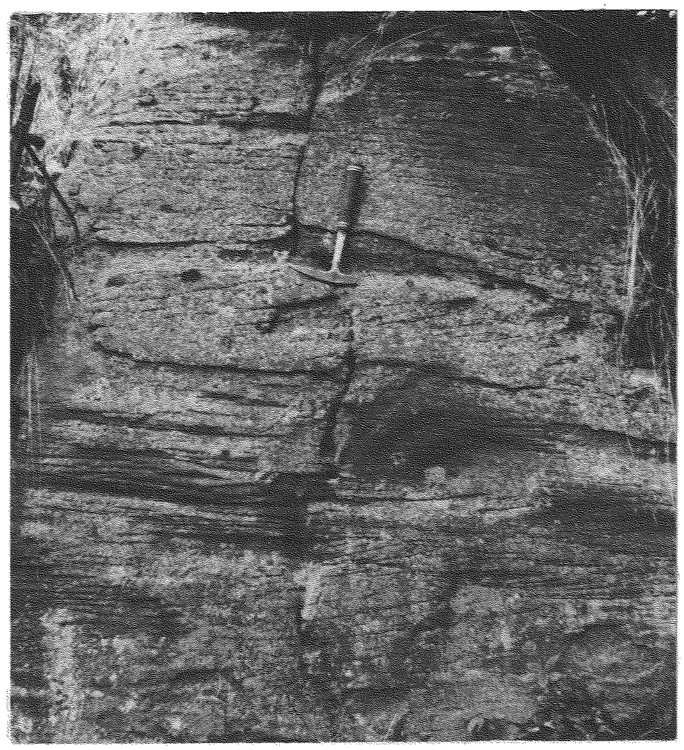
Beds in the lowermost 9 m of sandstone at Roaring Brook (STOP 7A) have large crossbeds that are tangential to the base and may have lengths of 1-2 m. Partings in these beds are curved rather than parallel as in the overlying sandstone and give individual beds a lenticular appearance.

Plate 4. **A**. Photograph of crossbedding in quartz sandstone exposed at Roaring Brook. Dashed lines indicate bedding. Photograph is Fig. 47 in Costolnick (1987). Geologic hammer provides scale. **B**. Photograph of quartz sandstone with parallel sided beds and wave-generated ripples exposed along I-84/380 at Roaring Brook (STOP 7A). Crossbeds in large wave ripples dip to right side of photograph (south). Photograph is Fig. 52 in Costolnick (1987). Geologic hammer provides scale. **C**. Photograph of trough crossbedding in upper part of Spechty Kopf Formation at Roaring Brook. Photograph is Fig. 53 in Costolnick (1987). Geologic hammer provides scale.

A

B

C



Contacts. Contacts of the quartz sandstone are either sharp or gradational. Where the DMLS sequence is complete the lower contact is gradational. Where the underlying laminite is missing the contact is sharp. The upper contact is frequently covered, but where seen it is both sharp and gradational over a relatively few feet.

Thickness. Thickness of the quartz sandstone ranges from zero to about 90 m. At Jim Thorpe it is about 9 m thick. It is generally, but not always, thicker in exposures between Jim Thorpe and Roaring Brook. The 90 m thickness at Roaring Brook is exceptional because the unit thins rapidly laterally and in no other place approaches that thickness.

Origin. Sevon (1969) suggested that the lower sandstones of this unit, those with the steeper bedding inclination at STOP 7A (Plate 3, C), may be distributary mouth bar sediments (Coleman and Gagliano, 1965). In contrast, Costolnick suggests that the lower, more steeply inclined sandstones at Roaring Brook may be lower to upper shoreface sands or beach barrier deposits.

With respect to the bulk of the quartz sandstone unit, Sevon (1969) suggests that the parallel-bedded and ripple-marked sandstone seems most typical of extensive intertidal-flat sands (Evans, 1965; Wright, 1967; Zenovich, 1967). Rocks in a photograph of shelf, transition, and coastal sand deposits in the Upper Cretaceous Mesaverde Group (Reineck and Singh, 1980, Fig. 579, p. 420) appear identical to those at STOP 7A (Plate 3, C). Costolnick agrees that some exposures in the upper part of the sandstone show structures (parallel-sided bedding and asymmetric wave ripples) typical of sheet-like deposits associated with intertidal flats. The latest evaluation is that these sandstones represent sands deposited on the shoreface of a wave-dominated delta (Horne and others, 1980).

**The Remainder of the Spechty Kopf Formation**

General description. The remainder of the Spechty Kopf Formation comprises mixed gray sandstones, siltstones, and some dark gray shales. Some red shales and sandstones occur locally (Wood and others, 1969) but are not common. Thickness of individual beds is variable.

Texture. In the Lehigh River area the Spechty Kopf sandstones are fine to coarse grained with occasional scattered pebbles (Epstein and others, 1974; Sevon, 1975a, b). Wood and others (1969) indicate that, in the Middle Anthracite fields to the west, the Spechty Kopf contains conglomerates as well as fine- to very coarse-grained sandstones. The sandstones make up the majority of the unit. Quartz grains in most of the sandstones are moderately well sorted and angular to subrounded. Interstitial clay ranges from 1 to 25 percent.

Composition. The Spechty Kopf sandstones are dominantly quartz of which about 70 percent is monocrystalline and the rest polycrystalline. Most of the quartz is highly strained. Chert and siltstone grains occur as do muscovite and biotite flakes. Heavy minerals are uncommon. The sandstones and siltstones are cemented with silica. Sorting is moderate to poor.

Sedimentary structures. The main sedimentary structure occurring in the sandstones is crossbedding, generally trough (Plate 4, C), that varies from poorly to well defined. Finer-grained units, siltstones and shales, are generally structureless.

Contacts. Contacts between beds of similar or different texture are either gradational if the overlying bed is finer grained or sharp if the overlying bed is coarser grained. The upper contact of the formation with the overlying Pocono is sharp and presumably unconformable.

Thickness. The upper part of the Spechty Kopf is 100 m thick at Jim Thorpe (Figure 20). Costolnick indicates the upper Spechty Kopf to be between 18 and 38 m thick at Roaring Brook. Wood (1974) shows thickness variations between 30 and 275 m in the Nesquehoning quadrangle immediately west of Jim Thorpe. Wood and others (1969) present an isopach map of Spechty Kopf thickness in seven 7.5-minute quadrangles and show a regional thickness variation from 0 to 730 m. Their thicknesses in excess of 300 m are suspect (Hoskins, 1970, 1976), but the Spechty Kopf apparently is at least 230 m thick over a large area.

Origin. The remainder of the Spechty Kopf Formation is attributed to deposition by braided streams on an alluvial plain (Wood and others, 1969) or unspecified fluvial deposition (Sevon, 1969; Costolnick, 1987)

## ROCKS OVERLYING THE SPECHTY KOPF FORMATION

The Spechty Kopf Formation is everywhere overlain by the Pocono Formation except to the northwest of Roaring Brook (Figure 20) where the Pocono and Mauch Chunk Formations are absent and the Spechty Kopf is overlain by the Pottsville Formation (Berg and others, 1980). Both the Pocono and Pottsville Formations are fluvial in origin.

## AGE OF THE SPECHTY KOPF FORMATION

### Paleontological Dating of the Formation.

Wood and others (1969) report the presence of *Adiantites* ssp., an Early Mississippian species, from a coal bed in an unspecified part of the Spechty Kopf. The Riddlesburg Shale Member of the Price Formation overlies the diamictite at Sideling Hill in Maryland (Figure 18) and contains abundant *Adiantites* plant debris (Bjerstedt and Kammer, 1988). No other identifiable fossils or plant remains have been reported from this rock unit at Sideling Hill.

Rocks of the DMLS sequence have been searched moderately well by a number of people for fossils or trace fossils. To date that search has yielded nothing. Costolnick, in particular, spent a lot of time searching in the Roaring Brook section. He found only some unidentifiable plant fragments.

### Palynological Dating of the Basal Spechty Kopf.

Analysis of the palynological materials referred to here was carried out by John B. Richardson at the British Museum of Natural History, London. He examined samples from Roaring Brook, Penn Haven Junction, Jim Thorpe, Cressona, Peters Mountain, Dauphin, and Crystal Springs, Pennsylvania and Sideling Hill, LaVale, and Finzel, Maryland (Figures 18 and 20). The samples showed miospores in varying degrees of preservation, but all sample locations yielded datable materials.

Richardson's results are reported in an unpublished manuscript (Woodrow and others, 1994) and are quoted, in part, as follows:

"The (miospore) assemblages are typical of the *pusillites-lepidophyta* Miospore Zone, the uppermost spore zone of the Devonian worldwide and are typified by an abundance of *Retispora lepidophyta* and the invariable presence of varieties of *Vallatisporites pusillites* s.l. consistent with the middle or *lepidophyta-explanatus* Subzone. The assemblages associated with the diamictite contain the nominal species of the LE Subzone and also there are two species, *Diducites versabilis* (Kedo) and *Kedospora angulosa* (Naum.), that are found in Oswayo samples (LE Subzone) but not in the overlying Knapp (LN Subzone) in western New York and northwestern Pennsylvania sequences. Further, the presence of *Bascaudaspora mischkinensis* (Kedo), *Convolutispora fromensis*, and *Retispora lepidophyta* var. *minor* indicates in terms of the eastern North American successions that the strata are probably not lower LE Subzone. On the other hand, the absence of *Vallatisporites verrucosus* and *Kedospora angulosa* may indicate that in terms of the spore succession from northwestern Pennsylvania, the diamictite does not fall into the upper part of the LE Subzone. Most probably, therefore, the diamictite belongs within the middle *lepidophyta-explanatus* Subzone (referred to LE Miospore Zone below) and is therefore Strunian and late but not latest Devonian in age."

The number of years spanned by the DMLS sequence is more difficult to determine, but assuming (1) that the middle part of the LE Miospore Zone is roughly equivalent to an upper middle position with the *praesulcata* conodont zone of Ziegler and Sandberg (1990) and (2) that each Late Devonian conodont zone is approximately 1 million years duration, then the DMLS sequence probably spans

500,000 years or less. Its temporal position is very close to the Devonian/Carboniferous boundary (Richardson, 1997, personal communication).

## ORIGIN OF SPECHTY KOPF LITHOLOGIES

### Introduction.

Rocks immediately below the Spechty Kopf are in the Duncannon Member of the Catskill Formation. These rocks represent sediments deposited by meandering streams on an upper Devonian coastal alluvial plain (Sevon, 1985). The source area for the sediments was the Acadian Mountains that lay to the southeast. The mountain front, the boundary between the alluvial plain and the mountains, was on the order of 113 km southeast of Jim Thorpe, i.e., approximately in the position of Philadelphia (Pelletier, 1958; Meckel, 1967; Kirby, 1981; Robinson and Prave, 1995). Sediment was carried onto the alluvial plain by a number of large rivers whose interpreted positions at the present eastern edge of upper Devonian outcrop are coincidental with modern day streams and water gaps (Sevon, 1979b).

During the time of Spechty Kopf deposition, the shoreline of the coastal alluvial plain lay somewhere in Pennsylvania. That position is not known with any certainty in the northern part of the state. In the southern part of the state the shoreline approached the eastern edge of present upper Devonian outcrop and influenced deposition of Spechty Kopf equivalent rocks. The diamictite and quartz sandstone at Sideling Hill and LaVale, Maryland (Figure 18) are attributed to deposition by subaqueous debris flow in a tidal inlet and as sand on a beach, respectively (Bjerstedt and Kammer, 1988). A similar origin is probable for the diamictite and quartz sandstone at Crystal Springs (Figure 18), but has not been proven.

Deposition of basal Spechty Kopf sediments in east central Pennsylvania, at Dauphin, Peters Mountain, Klingerstown, and Cressona (Figure 18), was inland from the shoreline. The diamictite has no associated mudstone, laminite, and quartz sandstone and is in close proximity to or interbedded with sandstones of definite fluvial origin. These diamictites presumably represent deposition on the alluvial plain surface by debris flows as suggested by Baria (1981) and Suter (1991).

### Origin of the DMLS Sequence in Northeastern Pennsylvania.

The origin of the DMLS sequence requires a certain amount of speculation. We will first review the evidence and then try to erect a reasonable story.

1. In northeastern Pennsylvania the areal extent of the DMLS sequence is bounded on the west by an approximate north-south line between Jim Thorpe and Solomon Gap (Figure 20). Its boundary on the east is unknown because of erosion except in the vicinity of Roaring Brook where the sequence does not occur at all two miles northeast of its area of maximum thickness. This loss of rocks may be due either to non-deposition or erosion subsequent to deposition. However, the actual reason is unknown.
2. The sequence is known to be gradational upwards from one lithology to the next at enough localities to indicate that this is the real nature of the sequence.
3. Some of the lithologies require deposition in a standing body of water, therefore, because of the gradational contacts, it appears that all of the lithologies were deposited in a standing body of water.
4. The underlying rocks of the Catskill Formation are meandering stream facies deposited on an alluvial plain.
5. The Spechty Kopf rocks overlying the DMLS sequence are braided stream facies deposited on an alluvial plain.
6. There is considerable variation in the thickness of the Spechty Kopf as a whole.
7. Many of the clasts within the diamictite and pebbly mudstone are exotic lithologies not present in the underlying Catskill rocks and the overlying Mississippian and Pennsylvanian rocks in Pennsylvania. The clasts are interpreted to have been derived directly from the Acadian Mountains. As such they presumably provide an intimate and real representation of the bedrock in the Acadian Mountains.

8. Each unit of the DMLS sequence contains characteristics that appear diagnostic of a particular environment of deposition.

***Creation of the depositional environment.***

From the distribution of DMLS-sequence rocks and thickness variations of the Spechty Kopf, it would appear that some sort of a valley system was eroded into the Catskill alluvial plain in northeastern Pennsylvania prior to Spechty Kopf deposition. The slope, orientation, width, and length of these valleys is not known with certainty, but there were probably two main valleys with positions controlled by the centers of sediment-dispersal systems (Sevon, 1979b). These two valleys probably extended from Roaring Brook to Stroudsburg and from Solomon Gap to Jim Thorpe (Figure 18) and then farther toward the Acadian Mountains (Figure 21A). The valleys were probably not very wide, less than a kilometer?, and may have had moderately steep side slopes.

The reason for the development of the valleys is speculative. During the last part of the Devonian, and possibly on into the early part of the Mississippian, probably between 380 and 360 Ma, compression created north-trending folds and associated domes in southern Connecticut (Osberg and others, 1989). This compression may have caused uplift in the nearby Acadian Mountains adjacent to northeastern Pennsylvania. Such uplift would have created a rain shadow on the west side of the mountains and a consequential decrease in sediment input onto the Catskill Delta (Ettensohn, 1985). As sediment input slowed or halted, valleys could have been eroded into the alluvial plain.

In addition, Johnson and others (1985) indicate that sea level was low during the *praesulcata* conodont zone, the miospore-conodont-correlated time of DMLS sequence deposition (see above). During times of low sea level, streams would have eroded valleys into the Late Devonian alluvial plain. The position of the shoreline with regard to northeastern Pennsylvania at this time is not known. Bjerstedt (1986) indicates that either an interval of non-deposition or one of erosion occurred on the alluvial plain prior to marine incursion and subsequent diamictite deposition at Sideling Hill (Figure 18).

Subsequent to erosional development, the valleys were drowned by a body of water that had its greatest depth in the Roaring Brook area and extended an unknown distance towards the Acadian source area. The reason for drowning of the valleys in northeastern Pennsylvania is even more speculative than formation of the valleys. There is no marine-fauna evidence within the rocks being discussed to suggest that a marine transgression was responsible for the drowning. Rocks interpreted to be Spechty Kopf that are exposed along US 6-11north of Scranton, immediately north of STOP 10, are apparently all fluvial in origin, have no parts of the DMLS sequence, and have no know marine fossils. Nearby time-equivalent rocks in the Huntley Mountain Formation, less than 32 km to the west of Scranton (Figure 18), have not been identified or studied and thus currently add no information.

At Sideling Hill in Maryland (Figure 18), marine transgression into that site occurred prior to deposition of the diamictite. The absence of any fauna in the DMLS sequence in northeastern Pennsylvania is most compatible with a lacustrine environment (Picard and High, 1972), particularly in the Upper Devonian when species were still early in the process of occupying continental environments. However, the lack of faunal evidence does not completely exclude the possibility of drowning by a rapid marine transgression.

Possible reasons for fresh-water drowning of valleys on the alluvial plain in northeastern Pennsylvania are:

1. A peripheral bulge caused by the nearby tectonics developed north of Scranton. This bulge could have blocked fluvial drainage and caused a lake to form. Detailed knowledge of the Upper Devonian geology north of the Roaring Brook area is currently inadequate to provide support or denial for this hypothesis.

2. Woodrow and Fletcher (1967) and Glaeser (1974) suggested that the Wyoming-Lackawanna basin (Figure 18) influenced facies distribution during the Upper Devonian with particular emphasis on excessive accumulations of marine and marginal marine facies in contrast to surrounding areas. The fact

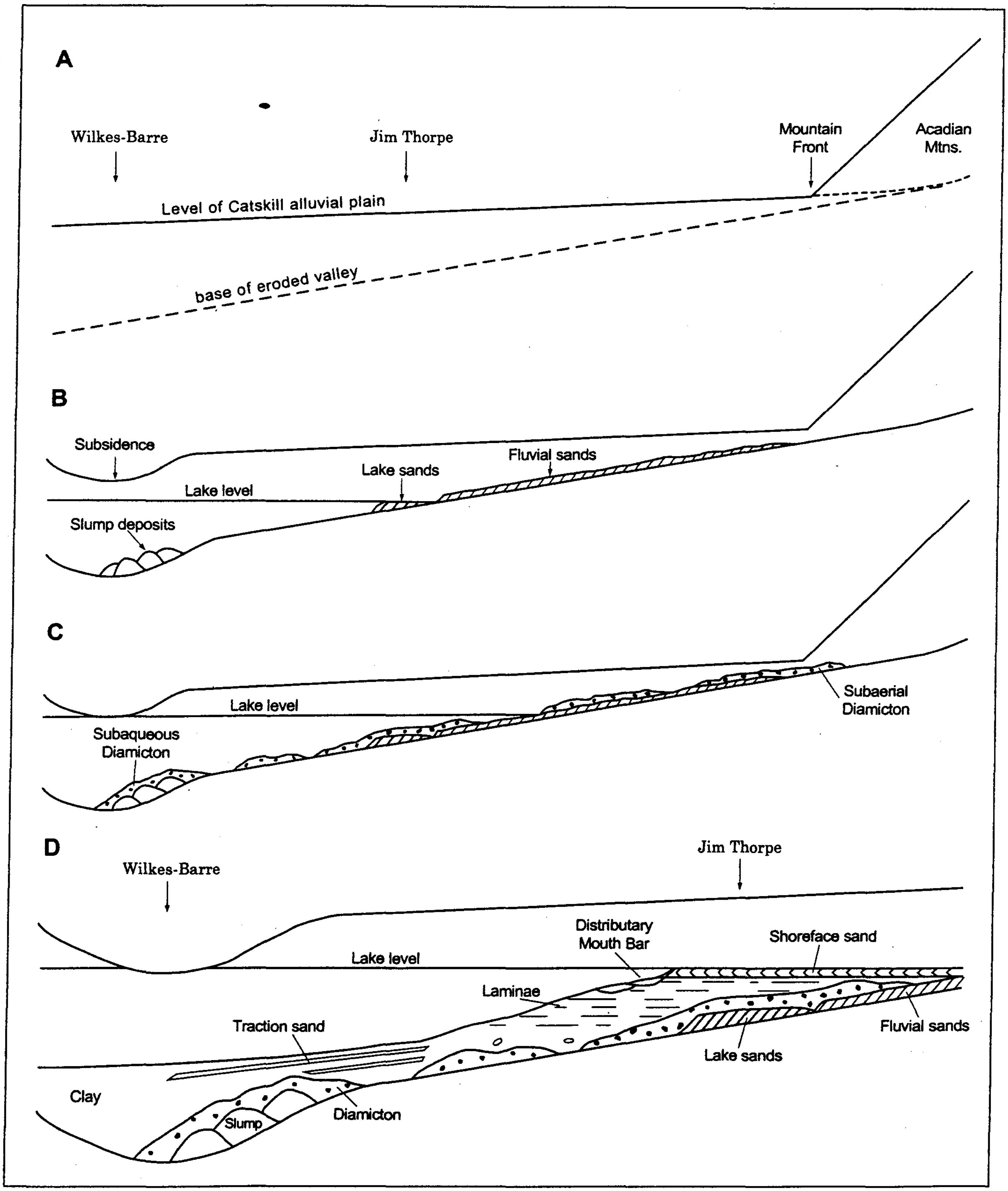



Figure 21. Diagrams illustrating probable geologic history of the DMLS sequence. Horizontal scale is proportional, not exact. Vertical scale is greatly exaggerated. Part D is an enlargèment of part C. A. Erosion of valley into the upper Devonian alluvial plain. B. Development of freshwater (?) lake and initial sedimentation in the lake. C. Lake level at maximum. Deposition of subaerial and subaqueous diamicton. D. Filling of lake with various DMLS sequence facies.

that the Roaring Brook area has several hundred feet of DMLS sequence sediments that are elsewhere much thinner is suggestive of some local subsidence. However, subsidence of such a small area would require faulting and to date no known evidence of such faulting has been found.

3. Tectonic modeling by Beaumont (1981; Quinlan and Beaumont, 1984) indicates that foreland basin response to source-area loading is subsidence. Such tectonic response is generally visualized on the scale of 100's of kilometers rather than the presumed 10's of kilometers involved here. However, if northeastern Pennsylvania were at the southern end of an area tectonically affected by activity in southern Connecticut, then it also could be at the southern end of an area of subsidence that reçeived sediment now lost to erosion.

***Depositional events.***

Prior to deposition of the DMLS sequence, some deposition occurred locally in the valley bottom either before or after they were drowned (Figure 21B). Rocks below the DMLS sequence at Jim Thorpe could be fluvial in origin, but they are not sufficiently diagnostic for a positive determination. Sandstone beneath the diamictite at Roaring Brook was interpreted by Costolnick to be slump deposits caused by slope failure. Water saturation of valley sides during and following drowning could have resulted in failure of parts of the valley walls and movement of pieces of semi-coherent sand onto the lake bottom. Some of these deposits are similar to those described from fan-delta deposits (Ethridge and Wescott, 1984; Kleinspehn and others, 1984).

The diamictite represents a depositional event of enormous magnitude, an event that brought materials directly from the Acadian Mountains to sites of deposition hundreds of kilometers away (Figure 21C). The palynological data indicate that, as closely as such data can pinpoint an event in geological time, diamictite deposition was an instantaneous event everywhere from Roaring Brook to LaVale, Maryland (Figure 18). The trigger for such a widespread simultaneous event must have been something large, probably a convulsive geologic event: an extraordinarily energetic event of regional influence (Clifton, 1988). Woodrow and Sevon (1990) earlier suggested that a bolide impact was the convulsive geologic event that caused transport and deposition of the diamictite.

An impact crater contemporaneous with the basal Spechty Kopf and located relatively close to Pennsylvania is the Charlevoix crater (Rondot, 1970; Grieve and Robertson, 1987) whose center is adjacent to the St. Lawrence River about 110 km northeast of Quebec City in eastern Canada and about 775 km from Roaring Brook (Figure 23). At the time of impact, the crater formed at or near the edge of an epicontinental sea then in retreat from this part of the Laurussian continent (Johnson and others, 1985). The Charlevoix crater is 46 km in diameter and is dated at 360 $\pm$ 25 my old (Grieve and Robertson, 1987).

Exactly what the effects of a bolide impact might have been on the area under consideration are open to speculation. An impact at the Charlevoix crater could have sent tsunamis far onto the Late Devonian alluvial plain and possibly, if wave orientation and alluvial plain gradient were well matched, even into the Acadian Mountains. The backwash from such tsunamis would have carried a lot of debris and deposited it as diamicton. However, tsunamis created by the impact would have been approximately normal to the length of the presumed lakes (Figure 22) and thus would not have been ideal for inland effects. However, the bolide was large enough and close enough to the Acadian Mountains that its seismic effects might have initiated debris flow activity, particularly if an in-water impact also caused a sudden increase in water in the Acadian Mountains. Subaqueous transport of debris from the Acadian Mountains to known sites of deposition in lakes in northeastern Pennsylvania is reasonable because subaqueous debris flows are known to travel across low slopes for hundreds of kilometers (Damuth and Embley, 1981).

Following subaqeous debris-flow deposition of the diamictite and waning-phase deposition of the pebbly mudstone, wave-dominated deltas (Horne and others, 1980) proceeded to fill the lakes from southeast to northwest (Figure 21D). The rhythmically bedded claystones represent prodelta deposition

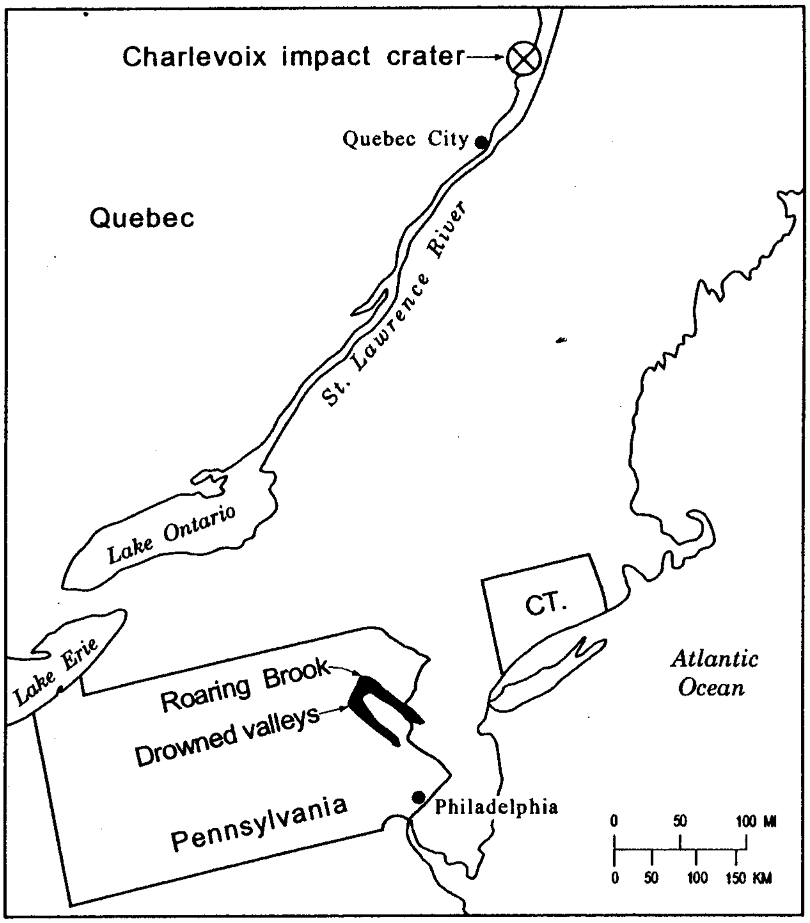



Figure 22. Map showing site of the Charlevoix impact crater and other relevant locations in northeastern United States.

of the finer grained materials swept into deeper water ahead of the advancing delta front. The occasional presence of sand grains and coarser clasts in the claystone indicates that currents were frequently adequate to transport such materials into the deeper water. The thick interbedded sandstones with top and bottom structures at Nay Aug (Plate 2, B) represent coarse grained material brought in by strong bottom traction currents and have similarity to sediments described by Shanmugam and others (1994). The slump structures present in several claystone outcrops suggest that slopes may have been moderate, that the rate of deposition may have been rapid, and that the rate of dewatering was much slower than the rate of deposition. Such conditions would have been conducive to slumping. Many of the features observed in the lower half of the DMLS sequence are similar to those described for fan deltas (DeCelles, 1988), slope, deep sea, and basin-floor fans (Shanmugam and Moiola, 1991; Shanmugam and others, 1994; 1995), and submarine channels (Stanley and Unrug, 1972). The DMLS sequence as a whole has similarities to fan delta deposits described by Ethridge and Wescott (1984).

The laminite at the top of the mudstone interval has gradually increasing amounts of sand and represents the transition from prodelta to shoreface, the delta front. Although these laminites change gradually from mainly clay to mainly sand, the final transition to all sand is fairly abrupt. Large load cast balls of sandstone sometimes occur within the mudstone where rapidly deposited sand foundered into the underlying soft, water-saturated mud.

The laminite usually goes directly upwards into quartz sandstone presumably deposited in a shoreface environment. However, the more steeply inclined, lenticular, basal sandstone beds at STOP 7A may represent distributary mouth bar deposits. In the Roaring Brook area where the water was the deepest, this is a logical progression from delta front to shoreface. Ripple bedding, planar bedding, and small and medium scale trough crossbedding present in the remainder of the quartz sandstone are typical of sediments deposited on a wave-dominated shoreface. The rounded to well rounded sand grains and good sorting indicate reworking by wave action.

Deposition on the shoreface was eventually replaced by fluvial deposition. It is not known whether the valleys were filled at this stage or whether just the lake was filled. Regardless, fluvial deposition continued and, prior to the start of subsequent Pocono deposition, it formed continuous deposits presumably from northeastern Pennsylvania to Maryland.

## POSSIBLE INDICATORS OF A LATEST DEVONIAN IMPACT

A major point of emphasis in a study of the basal part of the Spechty Kopf underway for some years by Woodrow, Sevon, and others, is to test the hypothesis that the diamictite and perhaps all of the DMLS sequence formed as the result of a bolide impact. Whether such a hypothesis seems reasonable or laughable, it is testable. Impact effects can be detected, for example by establishing: (1) the contemporaneity of impactites, various impact-related sediments, and the crater itself, (2) the presence of shock-deformed minerals, especially quartz, and (3) platinum-group element enrichment in impact related sediments.

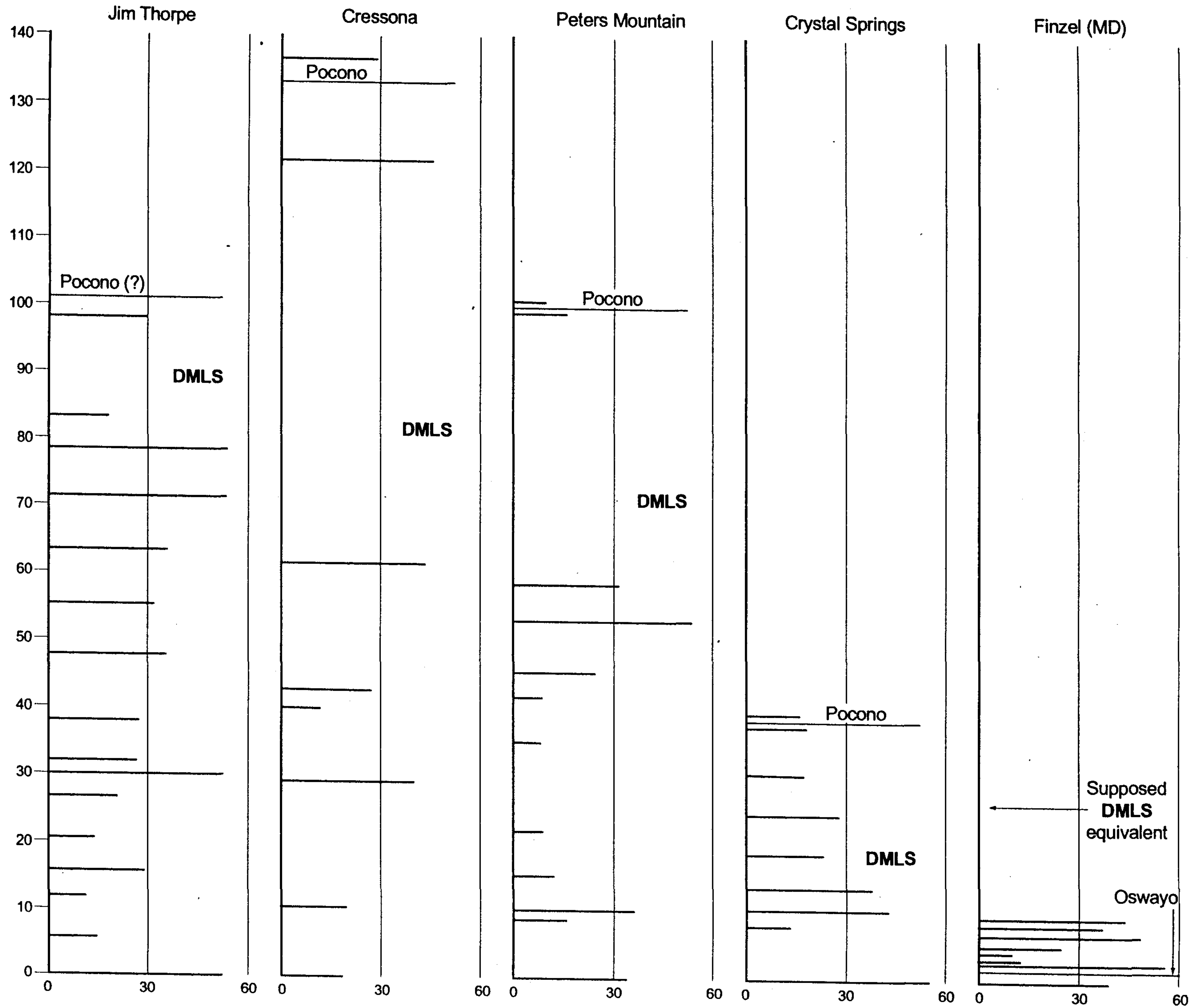
As for contemporaneity, the DMLS sequence and its supposed equivalents over an northeast/southwest outcrop belt spanning 350 km appear to be of the same age to the level of the middle *lepidophyta-explanatus* Subzone discussed above. That is, the basal beds of the Spechty Kopf likely formed within a small part of the half million year span of the miospore zone.

The contemporaneity and other aspects of the Charlevoix impact crater have already been discussed. The crater is of a size likely to have formed once every 10 my (Raup, 1992). Other craters were formed elsewhere in the world at about the same time, the Siljan crater in Sweden being one example (McGhee, 1996).

The search for shocked minerals has been less rewarding. We have examined more than 150 thin sections from the Spechty Kopf and supposedly equivalent units, but have located no unambiguous examples of shocked minerals. The lack of shocked quartz is not surprising considering the character of the diamictite. Most collections of shocked quartz come from centimeter-thick stratigraphic intervals that represent fine-grained sediment accumulated over an extended period of time. Here, we are dealing with 10's of meters of very grain-size-diverse sediment that was deposited in a very short period of time. In addition, some investigations of shocked quartz are accomplished by SEM analysis of very small grains (e.g., Bostwick and Kyte, 1996), an approach we have not tried. However, daunting as it is, the search continues.

Another test is to examine the section in question for anomalous amounts of platinum-group elements. The platinum-group elements, especially Iridium, are relatively common in comets and meteorites and, although enriched locally, they are generally rare on the surface of the earth. A terrestrial rock section suspected as being the result of a bolide (a general term for any object striking the Earth's surface) impact may show enrichment in Iridium. However, there may be no enrichment even if a rock mass was directly or indirectly the result of a bolide impact because not all bolides are enriched in platinum-group elements (e.g., Claeys and others, 1996). Detection of the "Ir anomaly" in rock sections has proved valuable, however, as an indicator of an extraterrestrial contribution to the material in some rock sections, the K/T boundary clay being the most widely known example (Schmitz and others, 1988).

We provided 55 samples from five stratigraphic sections, Jim Thorpe, Cressona, Peters Mountain, Crystal Springs, and Finzel (Figure 20), for Ir analysis to M. Attrep, Jr., of Los Alamos National Laboratory. Data from those analyses are presented in Figure 23. The Spechty Kopf Ir values range from less than 10 parts per trillion (ppt) to nearly 60 ppt. These values are lower than Ir values reported



Jim Thorpe
Cressona
Peters Mountain
Crystal Springs
Finzel (MD)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Pocono (?)
DMLS
Pocono
DMLS
Pocono
DMLS
Pocono
DMLS
Supposed
DMLS
equivalent
Oswayo
0
30
60

for Devonian-Carboniferous boundary sequences in other locations around the world (Wang and others, 1993) and lower yet than the K/T Ir anomalies. However, the other Late Devonian values and most of the K/T values are from marine sediments or highly condensed clay sequences from terrestrial environments. Terrestrial sedimentation rates, in general, are $10^4$ to $10^6$ times greater than those seen on the sea floor and the rate of sedimentation for the debris flow sediments in the Spechty Kopf are probably at the high end of that range. The point is that the Ir values seen in the Spechty Kopf, when viewed in light of the higher sedimentation rates, are comparable with other Ir anomalies reported from the Devonian/Carboniferous boundary and the K/T boundary. Perhaps the Spechty Kopf's prominent Ir anomaly indicates that its geochemistry was influenced by an extraterrestrial source.

In summary, the hypothesis relating the origin of the Spechty Kopf diamictite and perhaps the entire DMLS sequence to a bolide impact cannot be rejected on the basis of the evidence available. The basal Spechty Kopf and its correlatives are contemporaneous to the limit of our techniques. No shocked minerals have been found but we continue to look. Our Iridium data are highly suggestive and we are considering a more detailed analysis of the platinum group geochemistry. In closing, we note that the latest Devonian is a time of mass extinction and widespread black shale deposition. Are impacts, mass extinctions, and deposition of black shales worldwide related?

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Figure 23. Plot of Iridium (Ir) values for samples collected at 3 sites in the Spechty Kopf Formation and 2 sites in the Rockwell Formation. See Figure 1 for location of the sites. Analysis performed by M. Attrep, Jr., at Los Alamos National Laboratory. Pg/g = Pico grams per gram; ppt = parts per trillion.

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# A New Use for an Old Tool

by
Samuel H. Baughman and Robert Gadinski

Carbon monoxide (CO) was recently discovered entering a residence in Dunmore, Pennsylvania. An investigation to determine the source of the CO was conducted by the U.S. Environmental Protection Agency (EPA). During the investigation, when it was found that the deep abandoned mines beneath Dunmore also contained CO, the EPA decided to investigate gases within these mines. These gases were sampled utilizing a straddle packer normally used for groundwater sampling.

Structurally, the area is located on the southeastern side of the Lackawanna synclinorium, a complex, banana-shaped, doubly-plunging structure. Bedrock consists of the Middle to Upper Pennsylvanian-age Llewellyn Formation, an alternating sequence of sandstones, shales, and coalbeds arranged in the cyclothemic sequences that are typical of the "coal measures" throughout Pennsylvania.

There are six mineable coal units beneath the town of Dunmore: the Marcy, Clark, Super Dunmore and the Dunmore 1, 2, and 3, in descending order. In some nearby areas, two of these coalbeds were strip mined—and to the east all of them were exploited in both surface and subsurface workings. Deep mines at Dunmore include those of the No. 1 colliery, Carney and Brown, Spencer Coal Co., and the No. 5 colliery (Figure 29).

During the course of the investigation, maps of the local underground mine workings were reviewed, and several factors that may control the possible movement of the mine gases were identified. These factors are:

- *Barrier pillars beneath Jessup Street in the Dunmore 1, 2, and 3 workings* (Figure 18).
- *Robbing the support pillars east of the barrier pillars in the Dunmore 1, 2, and 3 workings.*
- *Support pillars left intact to the west of the barrier pillars in the Dunmore 1, 2, and 3 workings.*
- *West to east thrust faulting along the western margin of the site.*
- *Pinching out of the Marcy and the Clark seams to the north.*

Field observations confirmed thrust faulting in the area. Drilling and borehole geophysical data further corroborated the geologic interpretations.

The objective of the mine gas sampling was to identify possible CO/mine air movement within the mines, to determine the mode of transport in the coal measures, and to determine the potential risk to local residents. Mine maps were used to assist in placement of test bore holes throughout the town (Figure 24). These bore holes were situated along dip and on either side of the barrier pillars in the Dunmore 1, 2, and 3 workings. Caliper logs were used to identify the mined areas and determine the spacing between the packers.

A straddle packer was modified with a 0.25-inch Teflon tube, and the packers were spaced 10 feet apart. An air pump was used to evacuate the mine gases through the teflon tube after inflation of the packers. Several air monitoring instruments were used to field screen the mine gases prior to sampling. A combustible gas indicator was utilized to determine the oxygen, CO, and lower explosive limit. Carbon dioxide ($CO_2$) levels were measured with a $CO_2$ meter and a landfill gas meter were used to check for methane ($CH_4$) (Table 1). After the field screening data was recorded, a gas sample was collected in a Summa canister and sent for laboratory analysis (Table 1).

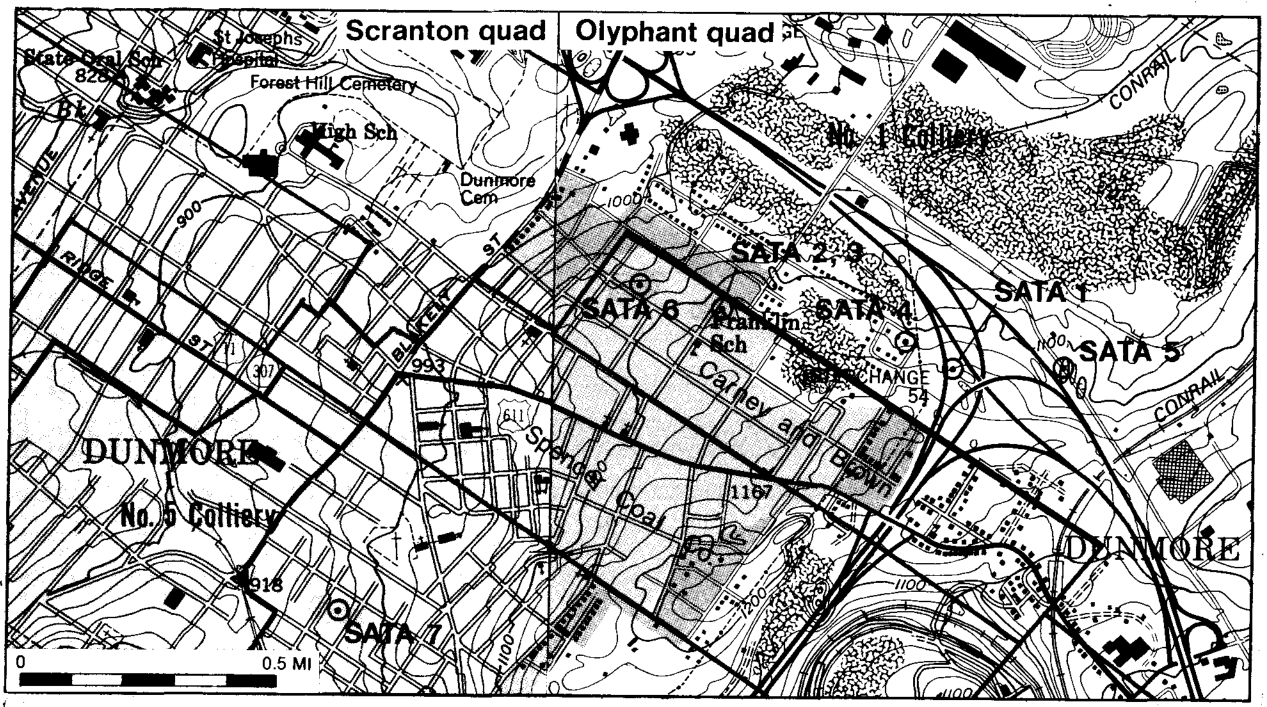



Figure 24. Location of test bore holes SATA 1-7 and relationship to deep-mine workings at Dunmore. The thick black line marks the barrier pillar along Jessup Street (see above).

Table 1. Packer intervals and gases collected.
Analytical units in parts per million.

| Location | Depth (feet) | CO | $O_2$ | $CO_2$ | $CH_4$ |
|---|---|---|---|---|---|
| SATA 1 | 70-80 | 3.9 | 18.5% | 16,500 | 0.85 |
| | 80-90 | 2.8 | 18.3% | 15,500 | 0.86 |
| | 125-135 | 3.4 | 12.5% | 56,300 | 6.1 |
| | 140-150 | 3.6 | 12.0% | 60,700 | 9.3 |
| SATA 2 | 45-55 | 5.1 | 20.7% | 4,910 | 33 |
| | 78-88 | 3.9 | 20.0% | 15,600 | 48 |
| | 88-98 | 3.2 | 20.2% | 20,400 | 4.5 |
| SATA 3 | 30-40 | 2.7 | 19.4% | 4,390 | 5.2 |
| | 55-65 | 2.8 | 16.3% | 17,400 | 73 |
| | 200-210 | 3.9 | 14.9% | 32,800 | 140 |
| | 245-255 | 2.8 | 14.6% | 47,400 | 110 |
| SATA 4 | 60 | 3.8 | 18.1% | 18,800 | 0 |
| SATA 5 | 85-95 | 2.3 | 11.8% | 61,800 | 1.9 |
| | 125 | 2.6 | 9.60% | 78,300 | 3.8 |
| SATA 6 | 106 | | 20.0% | | |

A U-tube manometer was utilized to measure the relative air pressure differences from the mined zone between packers and the ambient atmosphere. Upward and downward flow of air was observed and was apparently related to the barometric pressure and temperature differential.

Sampling mine gases may not be the only use of a packer pump. It may be possible to sample soil gas, depending on the depth to the water table, with a packer pump. Typically soil gas samples are collected to a depth of approximately 2 feet and at discreet zones in the unsaturated zone and/or capillary fringe. With a modified packer pump it may be possible to collect soil gas samples closer to the source. The modified pump has a greater capability than a GeoProbe since sampling can done in areas of larger float and from selected zones in competent strata.

## Scranton's Historic Iron Furnaces

by
Daniel K. Perry
(adapted from *A Fine Substantial Piece of Masonry*, PA Historical and Museum Commission, 1994.)

**Birth of Scranton's Furnaces**

In 1838, self-described "mineralogist" and engineer William Henry was investigating the feasibility of establishing an anthracite-fueled blast furnace along Roaring Brook in the Lackawanna Valley. He was first attracted to the vicinity in 1836 in connection with a speculative project to extend a canal up the Lackawanna River and link it to a railroad which was to run to Port Colden, New Jersey. The project never materialized because one of the key investors, Lord Charles Augustus Murray (Earl of Dunmore) withdrew his financial support. But Henry was intrigued with what he saw along a section of the proposed right-of-way. Well schooled in the process of making iron, he was the first American, in 1835, to experiment successfully with applying a hot blast to the smelting of iron ore, at the Oxford Furnace in New Jersey. Henry believed that the Roaring Brook site contained abundant deposits of anthracite coal and iron ore. Writing some twenty years later, Henry reflected that at the time he had received assurances from "several prominent politicians" that an extension of the North Branch Canal would be constructed to the mouth of Roaring Brook, thus providing a ready source of limestone for flux. Nevertheless, he concluded that these elements, in combination with the fast-flowing and relatively stable waters of Roaring Brook, would provide an ideal location for a furnace.

When William Henry made his initial explorations in "Slocum Hollow" in the late 1830s, the area included a sawmill, gristmill, whiskey still, hotel, cooper shop, and several small dwellings. With the backing of Edward Armstrong, a wealthy Hudson Valley financier who was fond of hunting in the area, Henry negotiated the purchase of the 503 acres known as the "Parsons Lot" in February 1840. Armstrong also had been involved in the aborted railroad/canal endeavor and was particularly interested in exploiting the Valley's coal deposits. The property owners, Zeno Albro, William Ricketson, and William Merrifield, had received title to the land from Ebenezer Slocum's widow. Ebenezer and his brother Benjamin had operated a bloomery on the site from 1800 until 1828, producing small quantities of wrought iron, no doubt utilized by local blacksmiths. By the time Henry toured the area the small furnace had fallen into near total disrepair. Even so, it provided him with evidence that ironmaking in the vicinity had once been feasible.

At first the property owners, sensing perhaps an opportunity to make an exceptional profit, asked $15,000 for the parcel. To this gambit Henry balked, and put them off. In the mean time, unbeknownst to the sellers, he further explored the immediate vicinity and concluded that it was even more promising than he had first surmised. The delay paid off, for by the time William Henry met the owners again they had dropped their price to the more realistic figure of $8,000. At this, Henry made arrangements to purchase the tract pending the arrival of $2,500 from his benefactor as a down payment. Unfortunately, Armstrong died from a horse fall on the day before the draft for the $2,500 arrived. The executor of his estate immediately suspended payment on the property.

On August 5, William Henry notified the property owners of Armstrong's death and his own inability to present a down payment. Securing an extension of thirty days he turned to the proprietors of the Oxford Furnace, his son-in-law Selden Scranton and Selden's brother George. This decision was opportune, for by seeking the Scranton's backing Henry secured both interested investors and technically proficient ironmasters. The Scrantons, in turn, possessed a familial network which together had the knowledge, ability, financial resources, and dedication to establish an ironworks in such an unproven location.

**Scrantons, Grant & Company**

By September 8, 1840, the transaction was completed and William Henry, George and Selden Scranton, and Sanford Grant were in possession of the Slocum property. Grant was a Belvidere, New Jersey businessman who soon became the first manager of the company store. Quickly realizing the need for additional funds, the principles found it necessary to add another partner. Philipp H. Mattes, a German immigrant who was manager and cashier of the Bank of Pennsylvania's Easton branch purchased a one-fourth interest in the firm for $5,000.

Scrantons, Grant, & Company, as the firm named itself, launched into the anthracite iron business on a financial shoestring. Initially their assets included Mattes' $5,000, $5,000 from Grant and a combined total of $10,000 from the Scranton brothers. In addition, George and Selden turned to cousins Joseph and Erastus Scranton of Augusta, Georgia. By 1843, Joseph and Erastus had invested some $13,000. Henry, on the other hand, supplied none of the initial operating capital, but did provide in-kind managerial services to the firm.

Taking up residence in nearby Hyde Park during October 1840, Henry supervised the laying of the blast furnace foundation with the help of local resident Simon Ward and master builder William W. Manness. Reminiscing years later, Ward recalled that no one being present to direct his labor, he borrowed a crowbar from a neighbor and began prying out stone near the site of where the first stack was later built. This simple act amounted to the first day's work at the property. Manness eventually supervised the construction of nearly all of the structures associated with the ironworks, as well as the first shops of the Delaware, Lackawanna & Western Railroad. Beginning in late 1840 and continuing through early 1841, a blast stack and necessary support structures rose on the site. When completed, the furnace stood thirty-five feet high with an eight-foot-wide bosh. During this time local ore was mined, construction materials such as fire bricks arrived from New Jersey, and houses were built nearby. According to J. C. Platt in his Reminiscences of Early History, the workmen boarded at Mr. Samuel Slocum's nearby tavern at a cost of $1.50 per week. This included bathing privileges and meals. Laborers earned about $17 per month and carpenters were paid at a rate of seventy-five cents per day.

**Searching For Ore**

Prior to the completion of the furnace, some 3,750 acres of ore-bearing land "thickly studded with pine, hemlock, and oak timber of original growth," were purchased from the Bank of North America for $11,250. The tract was located approximately three miles southeast of the operation on the southern slope of Moosic Mountain. While Henry had been correct in identifying extensive deposits of coal, he had failed to determine the presence of sufficient quantities of ore in the immediate vicinity. In fact, one of the primary reasons that the Slocums ceased operating their bloomery was the distinct lack of quality ore. The hasty purchase of this additional tract of land was most certainly unexpected and consequently strained the young firm's limited financial resources to the utmost. Construction of the furnace progressed, though, and was completed by Simon Ward and William Manness under Henry's direction in the late spring of 1841. Thomas P. Harper finished construction of the waterwheel shortly thereafter. Unfortunately, the hot-blast equipment did not arrive until early autumn, thus delaying completion of the works. Initially, the new furnace pre-heated the blast by channeling air through "circular" cast iron pipes which surrounded the hearth. Air power for this early stack was derived from "blowing tubs," which resembled large barrels in appearance and contained wood pistons with leather rings. Working alternately, they produced steady, although somewhat seasonal, air pressure, for the system was subject to freezing in winter and insufficient water in summer. The tubs were employed until about 1853, when more commonly used iron blowing cylinders were installed and the blast heating apparatus was relocated to the top of the stack.

**First Attempts**

On September 28, 1841, iron-founder Samuel Templin built a small wood fire in the hearth at the base of the stack. Thus began the preliminary job of drying out the interior of the furnace. It was an intentionally slow process, which prevented the new masonry from shrinking too quickly and pulling apart from the intense heat of a full blast.

On October 9, the first "campaign" was initiated, with the stack filled half way with alternating layers of coal, limestone and iron ore, and the air blast applied. For reasons which are not completely clear, the tuyeres (air nozzles) soon became blocked with semimolten ore and slag that failed to melt completely. In desperation, wood, charcoal, and even brimstone (sulfur) were thrown into the furnace, but to no avail. Within several hours operations were suspended. Workers were then directed to remove a portion of the refractory lining and clear the substantial mass of partially reduced ingredients, called "salamander," which had cooled and solidified within the stack.

A second unsuccessful attempt was made on October 25, 1841. This time the falling water level of Roaring Brook may have been partly to blame. Less water flow meant decreased air pressure in the furnace. Again the tuyeres clogged and operations were terminated. By this point, Henry's competence was being questioned by some of the other partners. These events prompted George Scranton to travel to the "Lackawanna" Works to determine how the furnace could be fired successfully. After numerous modifications, including alterations to the heating stoves, another attempt was made on December 14. In the meantime, a new iron founder named Clarke from Stanhope, New Jersey, had been hired. While this attempt was more encouraging than the others, it too ended in failure. With such a dismal record to show for all of the effort and expense, it must have been painfully obvious why local residents referred to the new operation as the "Jersey Humbug." Amidst this desperate situation, Selden Scranton traveled to Danville, Pennsylvania, and secured the services of John F. Davis, a Welsh ironworker, who was familiar with casting anthracite iron.

**Lighting The Fire**

Davis arrived on January 10, 1842, and immediately proceeded to make alterations. Eight days later the furnace was put into blast and remained so until February 26, when it was "blown out" (shut down) due to equipment problems. During this period approximately seventy-five tons of pig iron had been produced. Although it was an inconsequential amount, even by the standards of the day, the owners and workers struggling at Lackawanna must have hailed it as a rousing victory. Throughout the remainder of 1842, Davis made further modifications to the hearth and blowing equipment, and supervised the construction of two new heating ovens. Between May 1842 and March 1843, two more periods of blast occurred. In all, some 975 tons of pig iron were cast, even though the blowing equipment was still inadequate.

**The First Workers**

Initially, labor was recruited wherever it could be found. During the early 1840's the vicinity was still sparsely inhabited, but workers were soon attracted by the promise of jobs at the furnace. Local residents were joined by an influx of Welsh, Irish, English, and German workers. Contract miners were employed to excavate anthracite and ore and were paid ten cents per ton in 1841. During this early period, experienced miners also were "loaned" from the Scranton brothers' New Jersey operation.

**Ore Mine Road**

A gravity railroad ran between the furnace and the Stafford Meadow Brook ore mines, some five miles distant on the southern slope of Moosic Mountain. James Seymour, from present-day Jessup, surveyed the route, and H. H. Easton from Syracuse, New York, was the builder. Empty cars were pulled uphill by mule while full ones coasted back down, powered only by gravity. It was a circuitous journey which, in its infancy, averaged only two loads per day. The ironworks also utilized ore from a mine located several thousand feet above the furnace along Roaring Brook. The former ore averaged only about 25% iron, while the latter, a carbonate, yielded almost 50%.

**Building A Community**

As a means of attracting labor, the company built housing on the hill opposite the ironworks. In 1841, a gentleman by the name of Captain Stott, of Carbondale, was hired to lay out the village of Harrison, as the immediate vicinity had recently been named, in honor of President William Henry Harrison, who had died earlier that year. Rude dwellings were hewn out of the surrounding forest, lending a particularly ramshackle appearance to an area which was soon dubbed "shanty" hill. In an interview conducted in 1916 by the Scranton Republican, John Hawks related that "I came here in 1840 with my father... [who] had been hired to work at the blast furnaces... . All comers had squatter's rights to build on the South Side near the furnaces. They built shanties in the woods and each shanty had a stone chimney. When a newcomer arrived, the neighbors would get together and build a house by sundown." Lumber with which to construct these small dwellings, as well as the wooden furnace-support shops and structures, was produced at the firm's water-powered sawmill located on Roaring Brook across from the furnace. By 1846, the company had constructed some sixty "good and substantial dwellings for the workmen."

The partners had intended to produce pig iron, which they hoped to ship via mule wagon to canals at Port Barnum (present-day Pittston) and Honesdale, and then on to rolling and puddling mills along the East Coast. Eventually, they planned to move their iron from the furnace to major eastern markets by rail. Despite the furnace "doing first rate," with several successful periods of blast, the young company continued to face difficulties in 1842 and early 1843. On September 7, 1842, George writing to Selden from Lackawanna pleaded that "something must be done speedily for money or we shall be obliged to stop operations." Throughout this period, the price of iron declined steadily. This, combined with the rising cost of transportation, cut deeply into the company's already strained finances. In fact, shippers, like the Delaware & Hudson Canal Company were refusing to deliver any goods at all to the Lackawanna Works without cash in advance. This prompted George to threaten that "we will never give them even a box of chocolates to bring again for us," and that "they have served other merchants worse off than us." The bright spot in this rather bleak picture was Lackawanna's company store which was a busy and profitable operation serving "a store full of customers from morning till evening" and averaging $230 per day "at about 90% profit."

**Making Nails**

With the prospect of almost certain financial ruin staring them in the face, the partners changed their strategy and conceived a plan to make and sell a finished product. They decided to convert a portion of their cast pigs—they were averaging thirty tons per week at the time—into wrought-iron nails. It was estimated that nails would find a better market and be less expensive to ship. After all, the nation was expanding westward at a rapid rate and even in the east, places that were only villages yesterday were fast becoming cities. The construction of a puddling mill and nailworks, however, required a large additional investment.

Selden and George turned once again to their Georgia cousins. On December 15, 1842, Joseph and Erastus loaned an additional $5,000 to the ironworks. Selden traveled to New York City, where he arranged for a $20,000 loan from merchant-financier John Howland of Howland and Co. In May 1843, the nail factory was under construction on the company's property.

Located along Roaring Brook, approximately 500 yards above the furnace, the new facilities included a rolling and puddling mill, 110 by 114 feet, and a building, 50 by 70 feet, designed to house one spike and twenty nail machines. During April 1844 the rolling and puddling mill was put into operation. It housed five reverberatory furnaces and two trains of rolls, driven by a ninety-horsepower water wheel. The nail factory began production during July 1844. It had a forty-horsepower wheel and an estimated capacity of 100 kegs of nails per day.

While the new mills were being readied for production, furnace workers continued to cast and stockpile pig iron in preparation for the day it would be needed to make nail plate. In the meantime, the firm reorganized, and in September 1843 became known as Scrantons & Grant. The active partners were George and Selden Scranton and Sanford Grant. Philipp Mattes, Joseph Scranton, Erastus Scranton, and John Howland were listed as special partners whose liability was limited to the extent of their individual investments. Together the Scrantons controlled a little more than 50% of the company's stock. During that same year, George and Selden's younger brother Charles became supervisor of operations. George, who had served untiringly in that capacity, returned home to Oxford, New Jersey, to be reunited with his family.

During the summer of 1844, the furnace averaged five to seven tons of pig iron per day. The nail factory produced so many nails that the owners had trouble selling them all, but this was not the only problem with this item. Due to the low quality of the local ore, the nails, which the Scrantons were making in such large quantities, were very brittle. In fact, many broke when hammered. Consequently, the company's nails met with almost universal complaint.

**The Switch To "T" Rail**

Steps were taken during 1845 to improve the quality of the iron by mixing ore from Columbia County with local ore. This was successful, and prompted Charles Scranton to describe the new batch of nails as "certainly very fair." The company changed the brand name from Lackawanna to Roaring Brook, no doubt to escape the poor reputation of the former. Unfortunately, by that time the market was again in decline "the nail trade being over done." Even so, the Scrantons put seven new nail-making machines on line by June 1845 in the hope that the market would improve. It did not. Faced with mounting debts and no way to meet them, the company's officers decided to augment the manufacture of nails with "T" rail for the railroads. In a letter dated November 5, 1845, George advised Selden that "we must begin to think about making R. R. Iron rail. I am now satisfied that it's going to be a great business for 15 years with great prices."

During the 1830s and 1840s, America's railroads expanded at an amazing pace. Thousands of miles of new track were being laid annually. Virtually all of this rail, however, was imported from England. It was expensive and sometimes difficult to obtain as Britain's ironmasters enjoyed their monopoly. Consequently, a great opportunity to enter the market was offered to American furnaces. Documentary evidence indicates that the first American T rail was rolled at the Mount Savage Ironworks in Maryland in 1845. With the great boom in railroad construction that was occurring, other American ironmasters quickly followed suit.

In an effort to gain familiarity with this new process, Selden and Charles visited the Montour Works in Danville, Pennsylvania, in early 1846. George traveled to New York City to find financial backers for this latest endeavor. Although he found few investors initially, he did come into contact with Benjamin Loder, president of the New York and Erie Railroad.

**A Railroad Is Saved**

Loder's railroad, under the terms of a relief act passed by the New York legislature in 1845, was required to complete a connection from Piermont on the Hudson River northwest to Binghamton by December 31, 1848, or forfeit a state subvention of $3,000,000. Faced with obtaining an uncertain and expensive supply of English rails, Loder became interested in the planned expansion at Lackawanna. As far as the Scrantons were concerned it was simply a case of being in the right place at the right time.

On September 16, 1846, the Scrantons negotiated a contract with the New York and Erie for the manufacture of 4,000 tons of 58 pound (weight per yard) T rail at $65 per ton. Furthermore, they engineered a loan with the company to expand their works. The railroad sent Loder and board member William E. Dodge to inspect the ironworks on Roaring Brook in October 1846. They and eight of their associates subsequently advanced $90,000 to Scrantons and Grant as well as agreeing to an additional contract for 12,000 tons of rail.

**The Iron Company Reorganizes**

In November 1846, the company reorganized as Scrantons & Platt. Joseph C. Platt, the son-in-law of Joseph Scranton, took the place of Sanford Grant who had tired of the iron business. Platt became manager of the company store and general buyer. He later was appointed real estate agent. The new company listed capital stock at $230,000. By this time, the firm also owned over 5,000 acres of land, 1,200 of which were underlain with coal. In fact, it was the presence of coal that most interested many of Lackawanna's most ardent financial backers. Coupled with the increase in capital and assets the company also realized a substantial growth of prestige. The new investors from the New York and Erie Railroad were some of the wealthiest and most powerful men in the nation. George W., Joseph H., and Selden T. Scranton, and Joseph C. Platt were listed as general partners. Philipp H. Mattes, Edward Mowry, John Howland, William E. Dodge, Anson G. Phelps, Benjamin Loder, Samuel Marsh, Henry Shelden, John I. Blair, James Blair, William B. Skidmore, James Stokes, Philip Dater, Daniel S. Miller, John A. Robinson, William H. Shelden and Frederick Griffing became special partners. By October 2, 1847, the company's capital stood at $250,000. Imbued with a renewed spirit, George Scranton boasted that Lackawanna would soon be the strongest ironworks in America.

The rolling and puddling mill was expanded to meet the new orders for rail. This included a 110-foot addition containing eight more puddling ovens and an eighty-horsepower steam engine "with trains attached sufficient to finish at least twenty five tons of Rail Bar per day." The engine was operational by late July, and on August 9, the company began rolling rail under the auspices of the Rev. John R. Williams, pastor of the First Welsh Calvinistic Church, and his assistant and fellow Welshman Edward Coslett. Williams was described as an expert iron roller. Scrantons & Platt delivered their product at various points along the New York and Erie right-of-way by wagons pulled by oxen and mules. These timely deliveries enabled the railroad company to complete the line to Binghamton with only four days to spare. By striking this singular bargain, both the Erie Railroad and the Lackawanna Ironworks were spared from bankruptcy and placed on the road to financial success. In fact, with the completion of the line as far as Binghamton, the Erie, for a brief period, was the longest railroad in America.

The Lackawanna ironworks continued to prosper and expand. In late 1847, the company received an award from the American Institute for producing the best specimen of T rail in the nation.

By 1847 the company listed over 800 employees. An amazing growth in just seven years! Welsh, Irish, and German immigrants lived just across Roaring Brook on Shanty Hill. In an interview published in The Scranton Republican in 1903, German immigrant John Scheuer recalled walking from New York City to Bucktown (Dunmore) in 1849 where he was introduced to Selden Scranton. "Mr. Scranton made us show him the palms of our hands to prove that we could work... Henry Hess and I got work at the blast furnaces. Men were scarce, and we had to do all kinds of work. My first work was taking out the cinders. Later I hauled props to the ore mines and supplies to the old rolling mill."

In 1850-51 the plan of the city of Scranton was laid out by Joel Amsden, an architect hired by the company. As the success of the ironworks increased, so too did the number of immigrants coming to the area to seek employment. During 1848-49, two more furnaces were constructed; by 1852, more than 3,000 people lived in the immediate vicinity.

The inception of the anthracite iron industry, for the first time in American ironmaking history, reflected the shift from a predominantly rural industry to one that was to become increasingly urbanized as the size of the individual plants and the need for workers expanded dramatically. This was true, not only at Lackawanna, but throughout the Lehigh Valley, at Danville, and Johnstown. Anthracite ironworks served as the corporate model for the massive integrated steel plants which evolved in places such as Pittsburgh and Bethlehem.

**Birth Of The D.L.&W. Railroad**

During the summer of 1850 the company began work on the Leggett's Gap Railroad. This was a major step toward improving the transportation links into and out of the lower Lackawanna Valley. Under the driving force of George Scranton, the road eventually connected the ironworks to the New York & Erie Railroad at Great Bend, a distance of forty-eight miles. By April 14, 1851, the renamed Delaware & Western Railroad Company was hauling iron ore and limestone to the furnaces and bar iron and T rail to market. Soon after, a second right-of-way was constructed which ran in the opposite direction, east through Cobb's Gap. This line offered rail access to markets in New York City and Philadelphia and provided a connection to the rich magnetite ore deposits of northern New Jersey. These two railroads quickly merged to form the Delaware, Lackawanna & Western. With the construction of these roads, the Valley's remaining coal lands were quickly purchased in large parcels and the widespread mining of anthracite in the Valley began. Due to the foresight of Lackawanna's partners, particularly the New Yorkers, these men were to reap immense profits in the coming years from their coal lands and the hauling thereof.

**Lackawanna Iron & Coal Company**

In 1853, Scrantons & Platt reorganized again and became known as the Lackawanna Iron & Coal Company. The company's assets included three furnaces, the rolling and puddling mill, a foundry, two blacksmith shops, a car shop, two carpenter's shops, a sawmill, a gristmill, an office, a company store, 200 houses and dwellings, a boarding house, assorted officers' houses, ore and coal mines, a tavern and a recently completed hotel. Some 8,000 shares of stock were issued and the firm's capital rose from $400,000 to $800,000. Selden Scranton was the first president, Theodore Sturges became the treasurer, Joseph H. Scranton was appointed general superintendent, and Moses W. Scott served as both secretary and assistant treasurer. Joseph C. Platt continued to serve in the capacity of storekeeper. Other directors included Samuel Marsh, Daniel S. Miller, Lothrop L. Sturges, John I. Blair, William E. Dodge, John Howland, and George W. Scranton.

**Harnessing Steam Power**

In 1847, the owners began the conversion from water to steam power. The first engine was installed at the rolling mill and used to power one of two trains of rolls. It was the earliest stationary steam engine to be employed in the lower Lackawanna Valley and was followed by blowing engines at the furnaces in 1853-54. The two double-connected lever-beam engines installed at the furnaces were considered the largest of that type ever used in America. Built by I. P. Morris & Company, of Philadelphia, the flywheels alone weighed 40,000 pounds and were ten feet in diameter. Within three years, two more engines were installed at Lackawanna. By 1879, a total of seven steam engines were in operation at the furnaces producing more than 77,000 cubic feet of air per minute at a pressure of between five and seven pounds per square inch. The engine house was located above and behind the top of the furnaces. Air was pumped via a single large pipe, known as a downcomer, to the furnaces below. A manifold directed smaller branch pipes to the individual tuyeres.

In many ways, Lackawanna Iron & Coal took full advantage of American technological innovation during the mid-nineteenth century. One of the first furnaces in the nation to smelt iron with anthracite, the company's proprietors were constantly modifying the furnaces and mills in an effort to increase production. In 1854, Lackawanna boasted the third largest rail mill in the nation. By 1865, Lackawanna possessed the capacity to manufacture 60,000 tons of iron annually—more than any other furnace complex in the country. Even though the Scranton Furnaces had such awesome potential, they never produced iron at, or even near, capacity. For example, in 1865 the Lehigh Crane Ironworks of Catasauqua possessed a capacity of 50,000 tons annually and in actuality produced nearly 42,000 tons during that same year. Likewise the Thomas Ironworks, also of the Lehigh Valley, had the estimated capacity to manufacture 50,000 tons, and only missed that amount in 1865 by about 1,000 tons! Part of the problem at Lackawanna during this period was that furnace #5, the newest and largest stack, was only in blast for twenty weeks.

**A New Type Of Furnace**

In 1872, the company constructed a blast furnace which was radically different from the others and patterned after furnaces then in use in western Pennsylvania. While the previous furnaces were made of stone and fueled by anthracite, the new one was sheathed with riveted iron plates and used coke for fuel. Coke is a derivative of soft (bituminous) coal and thus had to be shipped in, much to the dismay of local miners who, no doubt, viewed it as a threat to their livelihoods. The company's reasons for building this furnace were several. By this time, coke was well established as an efficient and cost-effective furnace fuel. Although the soft coal had to be transported to Scranton, the new furnace possessed a much greater capacity for producing iron than the earlier stacks. When constructed, it was regarded as the largest furnace in America and by 1879 had achieved an output of 629 tons per week. The use of an alternative fuel made it possible for Lackawanna's ironmasters to continue casting even during prolonged hard-coal strikes.

**Taking Stock**

By 1880, Lackawanna's assets included: five blast furnaces; a rolling mill housing 113 puddling and 35 heating ovens; a steam-powered saw mill; a grist mill; a foundry which averaged 500 tons of castings weekly; machine, car, carpenter, harness and wheelwright shops; a brickyard; and an extensive dry goods store together with company offices. This last structure was completed in 1868 and stood at the corner of Lackawanna and Jefferson avenues. Ore for the stacks, came into Scranton from the company's mines at Mt. Hope, New Jersey; Brewsters, New York; and Dover and Franklin, New Jersey. During 1880, the Scranton operation produced about 125,000 tons of pig iron while an additional 25,000 tons were cast at the company's furnace at Franklin, New Jersey. This total was subsequently converted into 50,000 tons of iron rail, 80,000 tons of steel rail and 5,000 tons of merchant iron.

**Men & Machines**

Like other heavy industry of the period, Lackawanna experienced its share of labor unrest. Concern for the welfare of employees was tempered by a driving desire to produce iron in ever increasing quantities. Skilled employees, such as founders and puddlers, were generally well compensated and given incentives to stay with the company. This, however, was tied directly to the fortunes of the firm and on at least one occasion the board of directors attempted to reduce the salaries of the skilled employees and supervisors by one half in the face of a severe decline in business. Laborers, like guttermen and fillers, endured difficult and dangerous conditions in exchange for low wages and long hours. Interestingly, in 1850 superintendent Joseph Scranton assented to a request by the workmen that on the Sabbath "certain kinds of work which may have been deemed necessary but upon due reflection, we are satisfied is unnecessary..." not be performed. Although it is unclear which employees were given Sundays off, it would certainly not have been those who were directly responsible for maintaining the furnace fires and related machinery.

As with most furnaces, advances in ironmaking technology played an important role at Lackawanna. Information on improving production was gathered from many sources. As early as 1848, Selden Scranton was instructing his brother that "if you meet any iron men I want you to compare notes... ." In 1857, Joseph H. Scranton, still serving in the capacity of superintendent, traveled to the Cambria Ironworks at Johnstown and noted some of the site's more innovative designs. The prominent Welsh ironmaster David Thomas, of the Thomas Iron Works visited the Scranton furnaces in 1856 and made a number of recommendations including altering the bosh dimensions (suggestions that not only were carried out but that ultimately improved output). William W. Scranton, son of Joseph H. Scranton, traveled to Europe in 1872 to study English, French, and German iron and steelmaking techniques. The most significant technological innovation at Scranton, however, was probably the installation of Bessemer converters.

**Making Steel Rail**

The first steel made in America using the Bessemer process took place in 1864 at Wyandotte, Michigan. Nevertheless, by 1871 only five American mills used this process. On June 16, 1874, Lackawanna Iron and Coal laid the foundation for two Bessemer converters—the tenth company in the United States to do so. On December 29, 1875, the firm began rolling steel rails. The new steel mill included a cupola room housing four cupola furnaces, each capable of melting five tons of pig iron in thirty minutes, and two ten-ton ladles mounted on scales which carried the hot metal to the hoisting towers located at each end of the room. The adjacent converter room had a floor that measured 84 by 124 feet and a ceiling 21 feet high, and it contained the two fifteen-foot-tall converters capable of holding seven tons of steel apiece. Air for the converters was provided by two 500 horsepower, independent, horizontal blowing engines manufactured by the Dickson Manufacturing Company, Scranton. Each engine was capable of delivering 9,500 cubic feet of air per minute at a pressure of twenty pounds per square inch.

**Scranton Steel Company**

In 1881, following a disagreement with Lackawanna's board of directors, William Scranton left the firm and with the help of his brother Walter founded the Scranton Steel Company. Charles F. Mattes, son of original partner Philipp Mattes, was appointed in his place. Scranton Steel was located along the Lackawanna River about one mile below the Lackawanna Works. They rolled their first steel rail on May 4, 1883. By 1890, Scranton Steel's two six-ton Bessemer converters were producing 250,000 net tons of ingots per year. These were rolled into some 220,000 net tons of steel rails. This competition ended in 1891 when the two companies merged to form the titan Lackawanna Iron and Steel Company, the third largest steel works in America. The former Scranton Steel plant became known as the "south works." In 1894, the new company manufactured 500,000 net tons of steel rail. This quantity of T rail was one-sixth the total national output and equal to one-third that produced in England at the time.

While the blast furnaces at Scranton produced pig iron at an unprecedented rate, it was still insufficient to satisfy the appetite of the company's steel converters. Although by 1898 only two of the Scranton furnaces were listed as active, the company operated five furnaces in Lebanon County, Pennsylvania, and one at Franklin, New Jersey. These produced Bessemer pig iron, which was shipped to Scranton and converted into steel rail.

**Distant Sources Of Ore**

Ore was also being hauled to Scranton from some distance away. Due to the poor quality of the local ore, David Thomas referred to it as "very lean and hardly worth working," Lackawanna's ironmasters found it necessary, early on, to locate other sources. By the last quarter of the century, thousands of tons of ore were being shipped to the Furnaces by rail from New Jersey's Mount Hope Mines, the Cornwall Ore Banks of Lebanon County, Pennsylvania, and the Foster Tilley Mines of upstate New York. Blended together, these ores were converted into a very high grade of low-phosphorous pig iron. The transport of vast quantities of ore to Scranton, however, played a significant role in the eventual relocation of the Lackawanna Works.

**Beginning Of The End**

During the second half of the nineteenth century, the center of America's iron industry began to shift west following both raw materials and customers. Men such as Andrew Carnegie built huge integrated mills in the Pittsburgh area to take advantage of navigable waterways, abundant sources of soft coal for coke. Others, were looking to capitalize on the newly discovered ore deposits of the Upper Midwest. During the 1890s, Carnegie waged an all-out price war for the T rail trade. By underselling his competitors, including Lackawanna, he tried to force them out of business. Because of the high cost of shipping iron ore into Scranton as well as changing markets, Lackawanna Iron & Steel found it difficult to compete and so in 1899 the board of directors decided to move the plant to Buffalo, New York. By constructing a new plant there, they felt that they would be able to take advantage of the ore boats that plied the Great Lakes. Also, by the late nineteenth century, the Scranton operation had become surrounded by urban development which made future expansion unlikely.

During the last quarter of the nineteenth century the New York City faction on the board of directors gained a majority of the firm's stock. Consequently, the decision to move the plant was made by individuals living elsewhere who based their plans solely on business prospects with very little consideration given to the impact that it would have on the city. Despite a valiant effort by the Scranton Board of Trade to convince the owners not to close, the plant, according to one bitter observer was "deliberately butchered in cold blood." Most of it was shipped to what became Lackawanna, New York, on Lake Erie. The firm's two coal mine shafts, Pine Brook and Briggs, were sold to the Scranton Coal Company. Their other mine, Rolling Mill Slope, had been abandoned long before the decision to move. By 1902, nearly all of the structures which had for so long occupied the banks of Roaring Brook were gone along with more than 2,500 jobs. All that remained were the technologically out-dated stone blast furnaces.

During the sixty years that the Lackawanna Furnaces produced iron, they were the single most significant factor in the economic, social, and industrial life of Scranton. Local historian Frederick L. Hitchcock in his History of Scranton estimates that the "invested" value of Lackawanna at the time of its closing was around $6,000,000. When operating at its maximum the Lackawanna Iron & Steel Company employed from 3,000 to 5,000 men at its furnaces, mills, mines and shops.

Founded in a rugged wilderness, and lacking two of the three essential ingredients for making iron in the immediate vicinity, Lackawanna's founders succeeded where many others would have given up. They did so with vision, energy, and a willingness to gamble in the face of ruin. When they were unable on three occasions to light their new furnace, they found someone who could. When the manufacture of nails proved inadequate they expanded the size of the plant dramatically and pegged their fortunes to T rail—delivering it not by canal or locomotive but by mule wagon! This was followed shortly thereafter with the construction of their own railroad which linked their outpost with both ready markets and much needed resources. In founding an iron furnace the Scrantons founded a city.

Lackawanna helped to make Scranton the largest city in northeastern Pennsylvania. For years the city was recognized nationally as a center of iron and steel production, playing a major role in America's industrialization. The company's development propelled the expansion of the Lackawanna Valley's anthracite industry which in turn prompted growth in railroading and textile manufacture and earned for Scranton a significant place in the history of America's Industrial Revolution.

**FURTHER READING**

**The Scranton Iron Furnaces are discussed in varying degrees of detail in nearly all of the published works dealing with the history of Lackawanna County, Luzerne County, the City of Scranton, or the Lackawanna Valley. Some of the better known of these are John Beck, *Never Before in History: The Story of Scranton* (Northridge, Calif., 1986); Burton**

Folsom, *Urban Capitalists* (Baltimore, 1981); Daniel Hodas, *The Business Career of Moses Taylor* (New York, 1976); H. Hollister, *History of the Lackawanna Valley* (New York, 1869); Thomas Murphy, *Jubilee History of Lackawanna County* (Topeka, 1928), J. A. Clark, *The Wyoming Valley* (Scranton, 1875), and David Craft, *History of Scranton*, Penn. (Dayton, 1891). In addition, W. David Lewis has written a thoroughgoing article about the company's early business dealings titled, "The Early History of the Lackawanna Iron and Coal Company: A Study in Technological Adaptation," Pennsylvania Magazine of History and Biography (October, 1982).

General works on the manufacture of iron and steel in America during the nineteenth century include Frederick Overman, *The Manufacture of Iron* (Philadelphia, 1850), John B. Pearse, *A Concise History of the Manufacture of Iron in the American Colonies up to the Revolution and in Pennsylvania until the Present Time* (Philadelphia, 1876), and James Swank, *History of the Manufacture of Iron in all Ages and Particularly in the United States From Colonial Times to 1891* (Philadelphia, 1892). A more recent work by Lance Metz and Craig Bartholomew titled *Anthracite Iron Industry in the Lehigh Valley* (Easton, 1989), provides a great deal of information about the development and technology of making anthracite iron.

Table 2. Principal Coalbeds in the Northern Anthracite Field.
(Office of Surface Mining, Wilkes-Barre; Bergin, 1976)

| | *Luzerne County* | *Near Scranton* | *North of Scranton* |
|---|---|---|---|
| **LLEWELLYN FORMATION** | | | |
| | **No. 8** | | |
| | **No. 7** | | |
| | **No. 6** | | |
| | **No. 5** | | |
| | **No. 4** | | |
| | **No. 3** | | |
| | **No. 2** | | |
| | **No. 1** | | |
| | **Snake Island,** or George | **Eight-Foot,** or Olyphant | **Olyphant** |
| | **Abbott**, or Rose | **Five-Foot** | **Five-Foot** |
| | **Kidney**, Lance, or Mills | **Four-Foot** | **Four-Foot** |
| | **Hillman** | **Diamond** | **Diamond** |
| | **Checker**, Stanton, or Orchard | **Rock** | **Rock** |
| | **Pittston**, Baltimore, Bennett, Cooper, or Forge | **Big**, Pittston, or Fourteen-Foot | **Grassy Island**, or "G" |
| | **Skidmore,** or Twin | **New County,** or Rider | **Marcy** |
| | **Ross** | **Clark** | **Archbald** |
| | **Top Red Ash,** or Powder Mill | **Dunmore No. 1** | **Top Clifford** |
| | **Middle Red Ash** | **Dunmore No. 2** | **Middle Clifford** |
| | **Bottom Red Ash** | **Dunmore No. 3,** or China Vein | **Bottom Clifford** |
| **POTTSVILLE FORMATION** | | | |
| | **Alpha** | **"A"** | **"A"** |

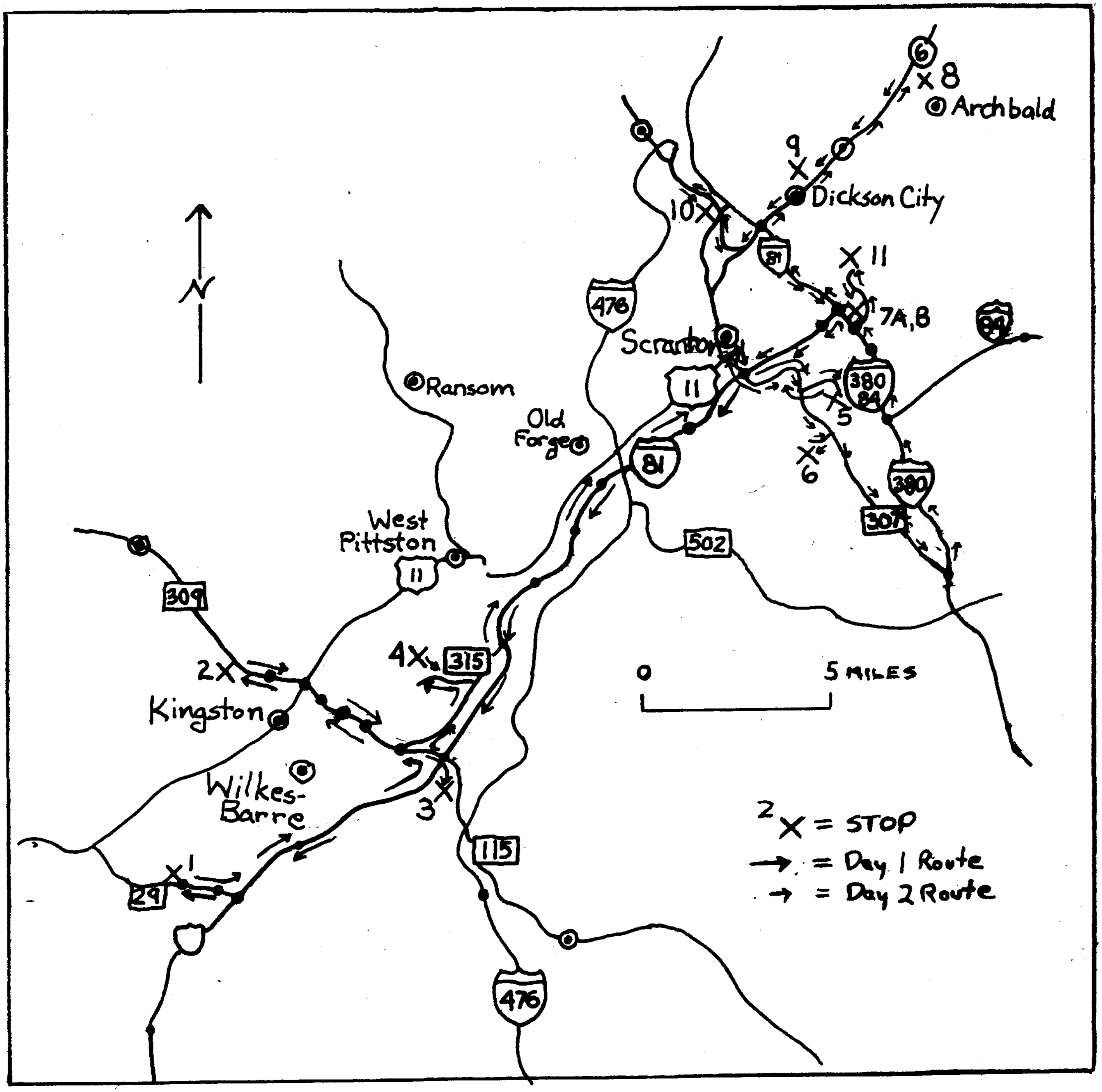



Figure 25. Field trip route and STOP locations.

# ROAD LOG AND STOP DESCRIPTIONS

## DAY 1

| Miles Int. | Miles Cum. | |
|---|---|---|
| 0.0 | 0.0 | Leave parking lot of Radisson Lackawanna Station Hotel. Turn right onto Lackawanna Avenue. |
| 0.1 | 0.1 | Traffic light. Turn right onto US 11-PA 307. |
| 0.2 | 0.3 | Bear right onto US 11S (to I-81). |
| 0.1 | 0.4 | Bear left, following sign for I-81. |
| 0.4 | 0.8 | Gently northwest-dipping, dark-gray sandstone and conglomerate of the upper Pottsville Formation exposed beneath the south abutment of the Harrison Street Bridge to right. The highway here is on the south side of the gorge that is the glacially diverted course of Roaring Brook. The Nay Aug Park Gorge is just upstream to the left (see Appendix A-2). |
| 0.2 | 1.0 | Bear right onto ramp of I-81S to Wilkes-Barre. |
| 0.1 | 1.1 | Entrance ramp cuts through northwest-dipping Pottsville conglomerate. |
| 0.5 | 1.6 | Merge left onto I-81S. |
| 0.4 | 2.0 | Subhorizontal beds of quartzose conglomerate and coarse-grained sandstone of the Pottsville Formation crop on both sides of the highway. Several "log jams" and at least one thin pod of coal are present here. |
| 0.2 | 2.2 | I-81 here crosses and then runs along the right side of the steep-sided valley of Stafford Meadow Brook (Rocky Glen). The valley to the left is an ice marginal, meltwater sluiceway that functioned whenever an ice lobe occupied the center of the Lackawanna valley each time a glacier advance or retreated across the region. For the next two miles I-81 will run along the west flank of the sluice. Several miles upstream of here to the northeast were the original ore mines of the Lackawanna Iron Company. |
| 0.3 | 2.5 | High-benched cut in the Pottsville and Mauch Chunk Formations to right. Though the contact is well exposed, its nature is somewhat conjectural: Pottsville conglomerate (Sharp Mountain Member) is clearly disconformable on the underlying beds. At the north end conglomerate rests on thin olive-gray shaly beds at the top of a thick sequence of locally crossbedded, olive-gray, fine-grained sandstones—with conspicuous stylolites on vertical fractures (Mauch Chunk Formation, "Loyalhanna-equivalent" beds.). But at the south end, where the conglomerate cuts down 8 to 10 feet, a thin package of crossbedded, gray, quartzose sandstones (Campbells Ledge?) is locally present. These beds appear to conformably overlie the Mauch Chunk. Prominent conglomerate ledges along the hillside for a long distance to the south. |
| 0.3 | 2.8 | To the left across Stafford Meadow Brook valley is an old quarry in the Mauch Chunk sandstones exposed at mile 2.5. Operated by the Meadow Brook Crushed Stone Company, this quarry supplied ballast for the Lackawanna and Wyoming Valley Railroad (The Laurel Line), a Scranton to Wilkes-Barre interurban constructed in 1902-1904. The line was active to about 1960 (Henwood and Muncie, 1986). Several large crossbed sets are evident in the quarry face. |
| 0.2 | 3.0 | Old quarry in Pottsville conglomerate to right (at "Exit 51, Lackawanna County Stadium—Montage Ski Area" sign). |
| 0.5 | 3.5 | Cut in lower Llewellyn Formation, exposing the Dunmore No. 1 coalbed to right. |
| 0.1 | 3.6 | Exit 51 (Davis Street-Montage). Continue south. |

| | | |
|---|---|---|
| 0.4 | 4.0 | On hillside in middle distance are extensive excavations in the Mauch Chunk, Pottsville, and Llewellyn Formations around Lackawanna County Stadium, Glenmaura Estates, and Montage Ski area. Lackawanna County Stadium occupies a cutoff incised meander loop in a higher, older phase of the Rocky Glen meltwater spillway. |
| 0.4 | 4.4 | View of Empire Landfill across the Lackawanna Valley to the right (northwest). |
| 0.2 | 4.6 | Cut in subhorizontal, crossbedded and channeled Llewellyn sandstone and conglomerate, containing two thin, discontinuous coalbeds. |
| 0.6 | 5.2 | Cut in contorted, crossbedded Llewellyn sandstone, with a thin discontinuous coalbed exposed at the south end (southbound lane). Bedding is disturbed by subsidence over deep mines. |
| 0.3 | 5.5 | subhorizontal, gray, very coarse-grained Llewellyn sandstone exposed on both sides of road. |
| 0.4 | 5.9 | Exit 50 (Moosic). |
| 0.2 | 6.1 | Good view of Wyoming-Lackawanna Valley ahead to southwest as the roadway crosses the Spring Brook valley and the lower end of the Rocky Glen sluiceway.. |
| 0.3 | 6.4 | Llewellyn sandstone (disturbed by subsidence over deep mines) exposed to right along southbound on-ramp. |
| 0.5 | 6.9 | Enter Luzerne County. |
| 0.6 | 7.5 | Continue south past Exits 49B (Avoca) and 49A (Wilkes-Barre/Scranton Airport). |
| 0.5 | 8.0 | Particularly interesting roadcuts in Llewellyn Formation (mostly crossbedded, medium-dark-gray sandstone) on both sides of highway. Pillars of a three-foot-thick coalbed are exposed along the northbound lane and exit-ramp. Mostly attributable to the mining of this coalbed are the spectacular subsidence structures and effects present here, including open joints, warped rock strata, large rock falls, and free-standing rock stacks. At the south end, a tectonic anticline strikes N60-70E diagonally across the highway. A mine prop sticks out of a collapsed southeast -dipping coal zone near the south end on the northbound lane. |
| 0.4 | 8.4 | To left are runway-approach lights of the Scranton/Wilkes-Barre International Airport. The valley which the light towers crosses carried ice-marginal drainage of an early, higher-level Spring Brook spillway phase. |
| 0.5 | 8.9 | To right are dark-gray, silty shale and rootworked, silty claystone (seatrock) that mark a mined coal horizon. "Structural" disturbance due to removal of the coal is clearly evident. |
| 0.8 | 9.7 | Continue south past Exits 48B (Dupont and Pittston) and 48A (I-476, Northeast Extension of Pennsylvania Turnpike). The name "Dupont" harks back to the period in the middle to late19th and early 20th centuries when the Du Pont Company operated numerous black-powder mills in the northern Anthracite region. Pittston was—until well into the 20$^{th}$ century—the headquarters of the Pennsylvania Coal Company, one of the largest operators in the Northern Anthracite field. Unregulated underground mining by this and other coal companies in the 19th and first half of the 20th centuries left the city with a sad legacy of mine subsidence, culminating on February 8, 1944 with the death of two-year-old Jule Ann Fulmer in a sudden, daylight collapse on Mill Street (Roberts, 1948). Pittston was also the site of the Twin Shaft mine disaster of 1896. A Historical Marker along SR 2006 ("River Road") about 1.1 mile northeast of the US 11 bridge reads as follows:<br>*TWIN SHAFT DISASTER. On June 28, 1896, fifty-eight men were killed in a massive cave-in of rock and coal here, in the Newton Coal Company's Twin Shaft Colliery. An investigative commission appointed by the Governor reported on Sept. 25. Although its safety recommendations would often be ignored, the disaster as a factor that led to a* |

*stronger unionization of this region under John Mitchell after 1900.*

| | | |
|---|---|---|
| 1.0 | 10.7 | Poor cuts in medium-gray sandstone and dark-gray shale of the Llewellyn Formation on both sides of road. |
| 1.3 | 12.0 | Cross Gardner Creek valley. This valley functioned as an ice-marginal, meltwater sluiceway feeding sediment southwestward (to the right) to a delta at the edge of Glacial Lake Wyoming at the village of Ridgewood. |
| 0.3 | 12.3 | Beginning of a deep, nearly continuous, 0.5-mile-long cut in subhorizontal to gently folded Llewellyn sandstone, conglomerate, and shale disturbed by mine subsidence. A 2-foot-thick(±) coalbed is exposed on the northbound lane midway up the cut near the north end. Strata on the southbound lane are largely intact, but those on the northbound lane exhibit considerable disruption due to mine subsidence. |
| 1.0 | 13.3 | Another long, deep cut in the Llewellyn Formation, mostly northwest-dipping sandstones containing carbonized plant remains (stems and trunks) plus a few thin, discontinuous coalbeds. Rocks exposed are moderately disturbed by mine subsidence. |
| 1.4 | 14.7 | Good views of Wilkes-Barre to right as the highway crosses the Mill Creek valley, yet another ice-marginal, meltwater sluiceway. Upstream to the left is a narrow bedrock gorge. Downstream to the right (beyond the racetrack) is a large delta built into Glacial Lake Wyoming at Miners Mills. |
| 0.5 | 15.2 | Continue south past Exits 47B (PA 309N to Wilkes-Barre) and 47A (PA 315S to Bear Creek). |
| 0.6 | 15.8 | Cuts in folded and faulted, gray Llewellyn sandstone and conglomerate just past interchange area. At least two coalbeds were deep-mined here; particularly evident are crushed coal pillars in a dark-gray shale and claystone interval at the south end on the southbound lane. Several thin, discontinuous coalbeds are also interbedded with the thick sandstones and conglomerates. |
| 2.0 | 17.8 | Monarch Fields of Kings College to right. Kings, founded in 1946, is one of two small liberal arts colleges in Wilkes-Barre, the other being Wilkes University which began in 1933 as a two-year junior college associated with Bucknell University of Lewisburg, PA, and became a four-year, independent institution in 1947. |
| 1.2 | 19.0 | View of Wyoming Valley to southwest. |
| 0.4 | 19.4 | Continue past Exit 45 (Business PA 309 to Wilkes-Barre and PA 309S to Mountaintop). |
| 1.2 | 20.6 | Ahead to the right is the Huber Breaker, the last surviving anthracite breaker in the Northern Anthracite field. Erected by the Glen Auden Coal Company in 1938-39, the Huber in its heyday could process 7000 tons of anthracite a day. The adjacent powerhouse was in reality a "cogeneration" plant, providing steam for both electricity and heat. (Many large breakers built in the '20's and '30's were provided with such facilities.) The breaker closed in 1976, amid legal battles surrounding the bankruptcy of the "Blue Coal Company" (Janosov, 1992). |
| 0.4 | 21.0 | At Exit 44 (Nanticoke), bear right onto ramp to PA 29N. |
| 0.4 | 21.4 | Stay to right where exit ramps merge. To the right are abandoned mined-lands of the former Blue Coal Company, now the property of Earth Conservancy. |
| 0.3 | 21.7 | Exit 1 (Main Street, Ashley). Continue north. |
| 0.1 | 22.6 | Directly beneath the highway here is the barrier pillar between the former Huber (right) and Truesdale (left) Collieries. |
| 0.2 | 22.8 | Start of cut in Llewellyn Formation. **Buses pull off onto shoulder of road.** |

**STOP 1.** ***PA 29 ROADCUT NEAR ASHLEY: COALBEDS AND CALCRETE IN THE UPPER LLEWELLYN FORMATION.***

Leaders: Jon D. Inners and Joseph M. Fabiny.

The roadcut on the north side of PA 29 at this point (Figure 26) exposes some of the youngest rocks in the Llewellyn Formation of the Lackawanna synclinorium. Beds here dip northwestward into the Ashley syncline, a branch of the Askam syncline (Bergin, 1976)—the deepest structure in the Northern Anthracite basin (Darton, 1940). The section includes strata from about 17 feet below the No. 7 coalbed to about 110 feet above the No. 8(?) coalbed, a total stratigraphic thickness of about 175 feet. The No. 7 coalbed is approximately 500 feet above the Mill Creek limestone bed (Wood and others, 1986). The No. 8 coalbed, the highest named (or numbered) seam in the Northern field, has its widest distribution in the Askam syncline and is otherwise rarely preserved (see Bergin, 1976). Total thickness of the Llewellyn Formation in the Askam syncline exceeds 1900 feet (Bergin, 1976), and may be as much as 2200 feet (Darton, 1940, Fig. 12).

Aside from the stratigraphic position of these rocks near the top of the Llewellyn Formation, the PA 29 roadcut is significant in exposing several thick "paleosol" calcrete horizons presumably related to the existence of a fairly dry climate during deposition of the upper Llewellyn strata. Occurrences of calcrete in the Llewellyn are known from just below the Snake Island coalbed (mile 34.2 of the Day-1 road log) to at least 60 feet above the No. 8(?) (this outcrop) (Figure 27). Regional geologic, paleoclimatologic and environmental implications of abundant calcrete in the upper Llewellyn will be discussed after description of the rocks exposed in the road cut.

Figure 28 shows the stratigraphic succession at STOP 1, and Appendix B-1 gives a detailed description on the individual rock units

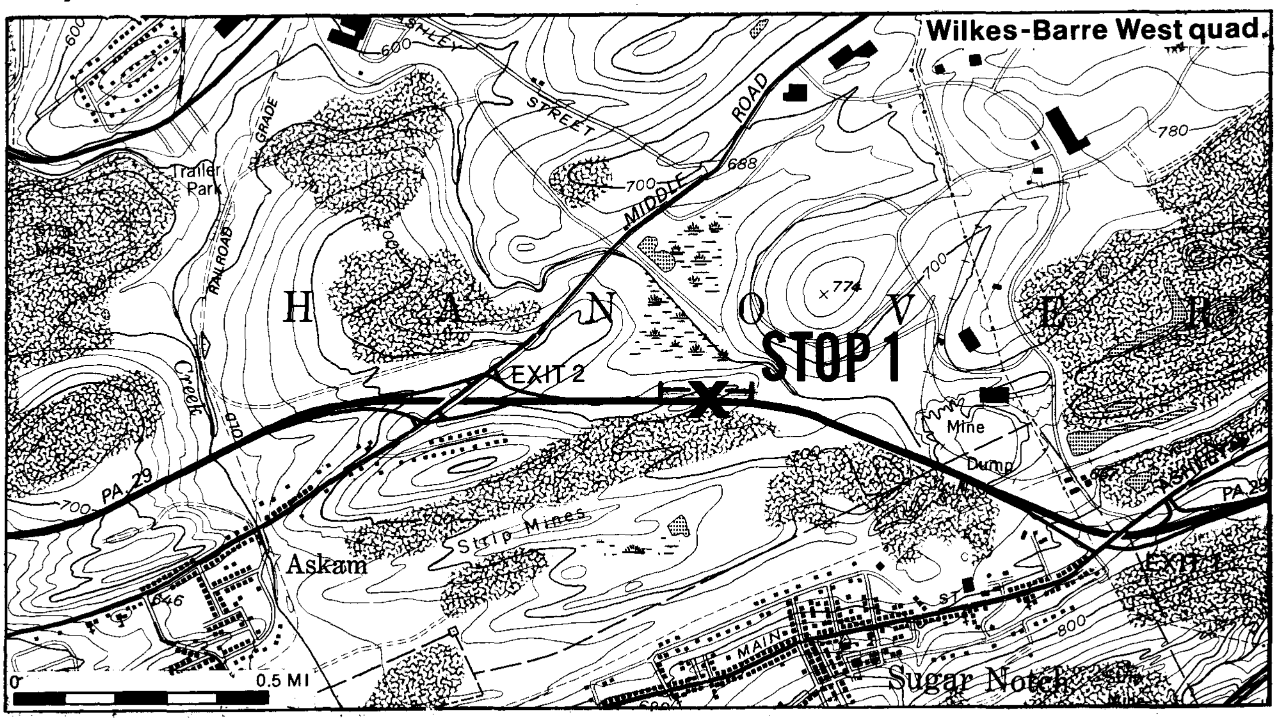



Figure 26. Location map for STOP 1.

## LLEWELLYN FORMATION (part)

### Units 1-8 (0 to 23 feet)

The basal part of the section is predominantly medium-dark-gray, micaceous, fine grained sandstone and sand-silt laminite—lithologies that constitute much of the Llewellyn in the Northern field. Near the top of the interval is the No. 7 coalbed, about a foot-and-a half thick—bright, banded anthracite

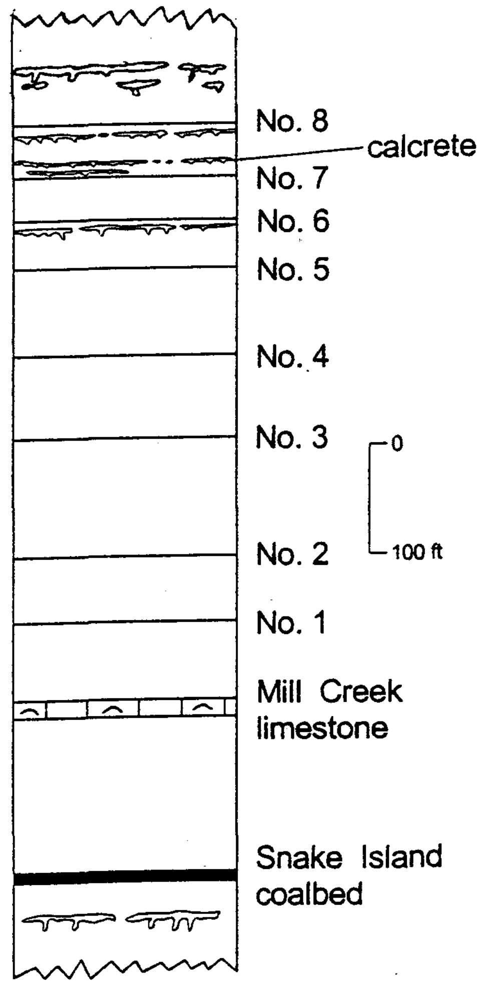



Figure 27. Stratigraphic position of known calcrete occurrences in the upper Llewellyn Formation.

in the upper two-thirds and dull "bony" in the lower third ) (Plate 5, A). The stratigraphy of the coal horizon here is peculiarly reversed, with fissile, carbonaceous clay shale below the coalbed and hackly, rootworked claystone above. It is possible that the No. 7 at this point formed from a mat of rafted peat, the seatrock above representing a succeeding incipient swamp development. A few *Calamites* stems occur on top of the coalbed.

**Units 9-10 (23 to 50 feet)**

This basically fining-upward sequence consists of coarse-grained to conglomeratic quartzose sandstone—with a sharp to slightly erosional base—in the lower 14 feet, abruptly overlain for the most part by a thick unit of poorly bedded silty claystone containing two irregular bedded intervals of large sideritic calcrete masses. Ragged "veins" of calcrete locally extend down one to several feet from the "bedded" masses. Although the claystone is hackly, no root traces or curved, slickensided fractures are evident. The calcrete is, therefore, probably not related to true soil forming processes—and the thick claystone is not a paleosol. Deposition of the calcrete is probably a result of fluctuation of a shallow water table under a seasonally dry climatic regime (see below). The crosscutting "veins" may be deep desiccation-crack fillings.

Note also that the upper 1± foot of the sandstone is calcareous, accounting for its deeply weathered and friable character.

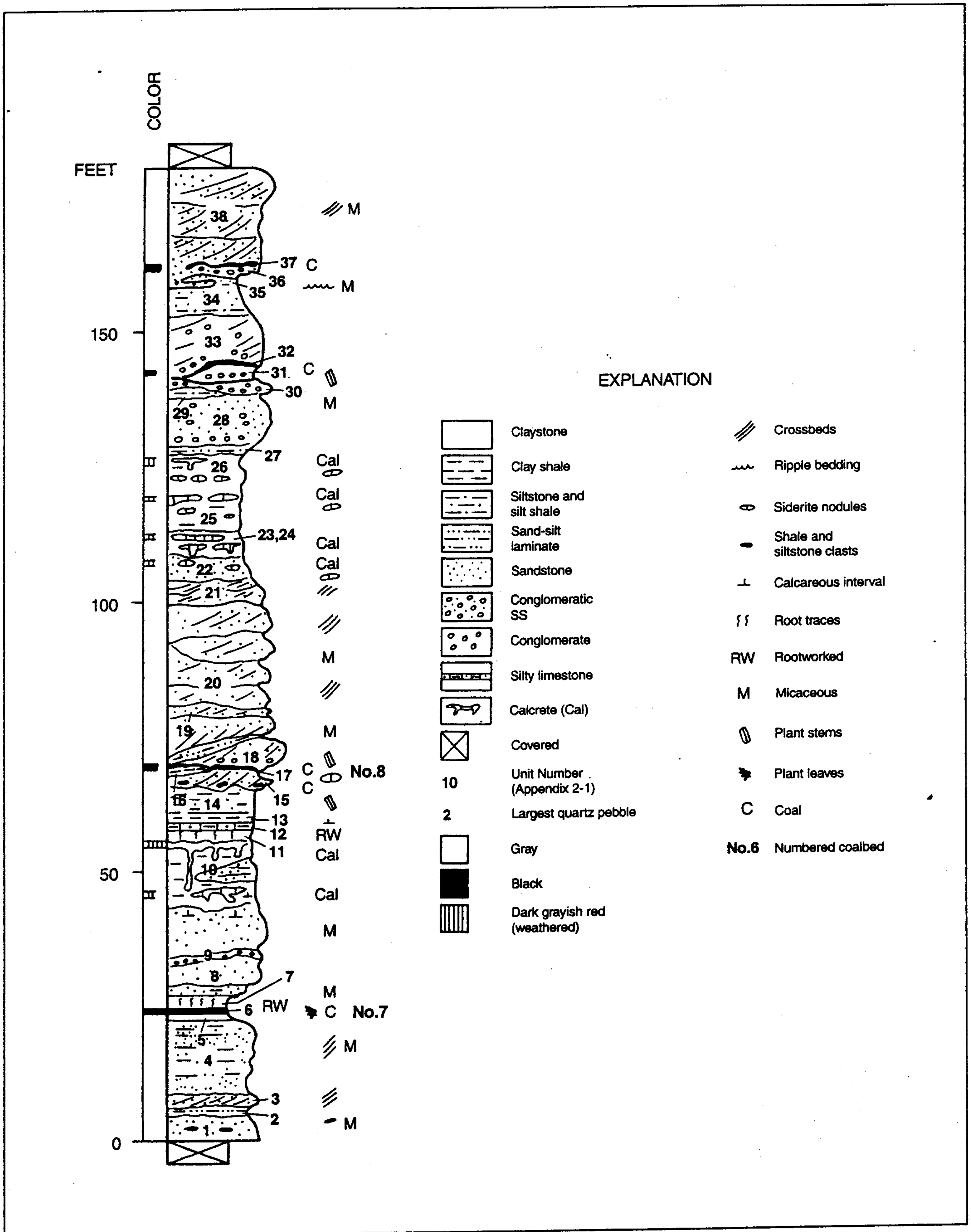



Figure 28. Stratigraphic column of the upper Llewellyn Formation at STOP 1.

**Units 11-14 (50 to 57 feet)**

This interval resembles a typical seatrock-coal-clay shale sequence, with the place of the coalbed being taken by a 0.7-foot-thick, continuous bed of medium-dark-gray calcareous siltstone (unit 12). This siltstone may betoken flooding of an incipient peat-swamp before much development of vegetation had taken place. The clay shales overlying unit 12 contain abundant, but poorly preserved, plant leaves, stems, and fragments, including *Neuropteris*—exactly what you would expect to find above a coalbed.

**Units 15-22 (57 to 102 feet)**

Except for a few relatively thin coaly and sand-silt laminite beds, all of this interval consists of dominantly medium-gray, crossbedded, medium-grained to pebbly, quartzose sandstone. Eight or nine stacked fluvial bodies can be recognized, several with distinctly erosional bases. The most interesting part of the succession, however, is at the base, where at least three very thin "point-bar coals" (see Shaulis and others, 1993) underlie the discontinuous No. 8(?) coalbed (Plate 5, B). The No. 8(?) itself (unit 17) is only 0.2 foot thick where it is not cut or squeezed out by overlying units and probably represents a channel coal formed from the accumulation of rafted plant trunks, peat, etc., in an area protected from erosion and deposition. The thin inclined coalbeds below the No. 8 mark the top of lateral accretion surfaces on a point bar and probably formed from the vegetative cover that formed on the point bar between periods of flood deposition (another argument for marked seasonality in the climate).

Unit 22 at the top of this interval is calcareous throughout its 6-foot thickness and contains many small sideritic calcrete masses in the upper one foot as it grades into overlying calcrete-bearing claystones.

**Units 23-27 (102 to 122 feet)**

This 20-foot-thick interval of dark-gray to medium-light gray, shaly to hackly claystone (with a thin band of sideritic sandstone and sand-silt laminite at the top) contains a profusion of sideritic calcrete masses and nodules. In contrast to unit 10, where the best calcrete development is a the top, the largest masses here are in the lower two feet (unit 23). Irregular "veins" of calcrete crosscut bedding below these masses, as in unit 10. Origin of the calcrete in this interval is believed to be the same as in unit 10, i.e., water-table fluctuations during alternately wet and dry seasons.

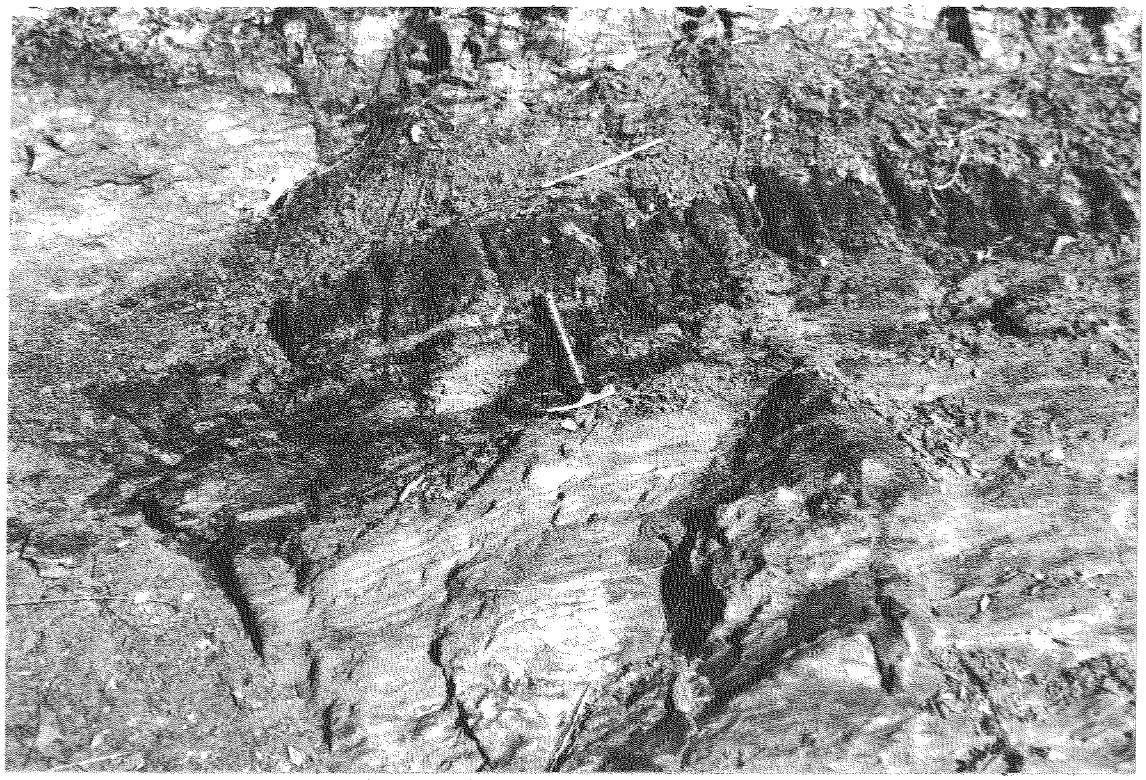
**Units 28-38 (122 to 175 feet)**

This sequence of crossbedded, scoured, and rippled conglomeratic sandstone, sandstone, and sand-silt laminite is similar to units 15-22. The two discontinuous coalbeds (units 32 and 37) are interpreted to be channel-coal developments at an unnumbered horizon. Thin coaly streaks in units 31 and 33 are probably individual carbonized trunks. Perhaps it is this package of conglomeratic rocks which gave rise to the early belief that the high ground extending east-west through Hanover Township from north of Sugar Notch to Nanticoke (the "Hanover hogback") was underlain by Pottsville conglomerate, a notion put to rest by Ashburner (1886a).

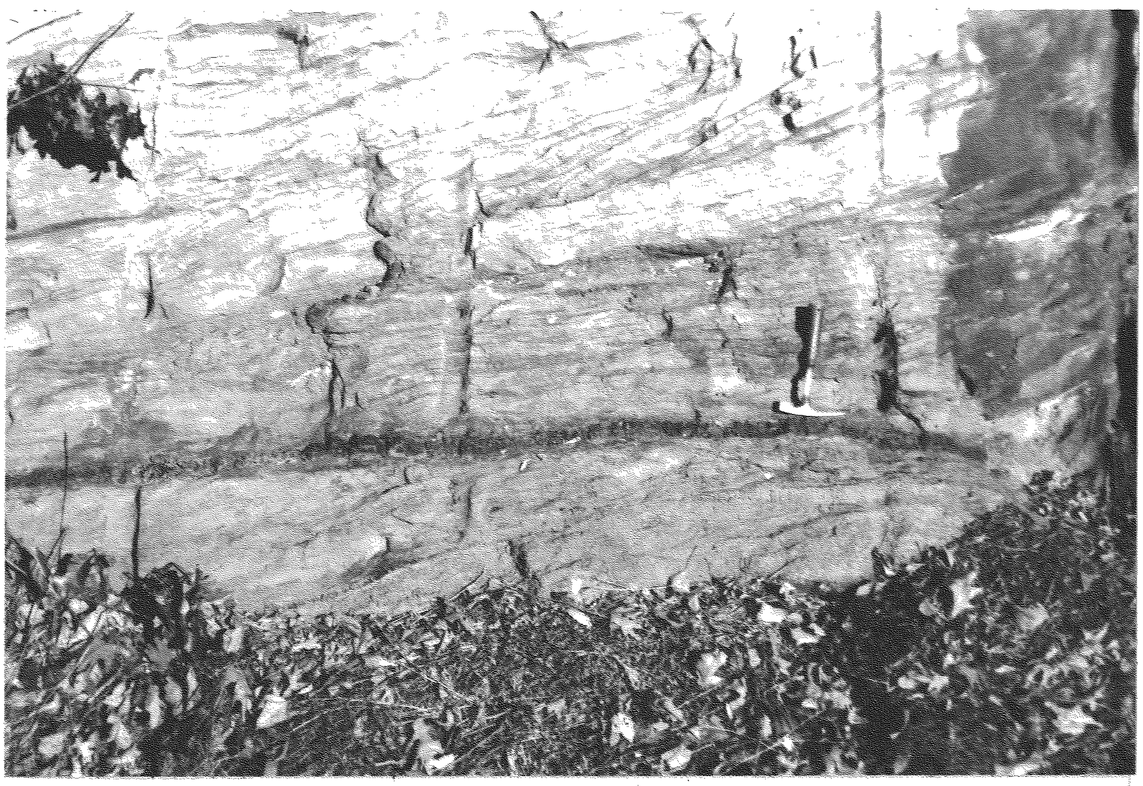
## CORRELATION

Considering that the Mill Creek limestone is probably equivalent to the Ames marine zone of western Pennsylvania (Chow, 1950), the upper Llewellyn rocks exposed at STOP 1 correlate with strata no older than the Casselman Formation of the Conemaugh Group (Figure 29). Eggleston and others (1996) have recently shown that the highest coals of the Llewellyn Formation in the Southern Anthracite field (Schuylkill County) are of upper Stephanian (C?) age (about 302 Ma, according to Edmunds (1996). This makes them equivalent to strata in the Monongehela Group. Since the Llewellyn Formation of the Southern field is more than 1000 feet thicker than in the Wyoming basin, it is unlikely that rocks this

Plate 5



**A**. No 7 coalbed (unit 6) and adjacent beds at STOP 1.



**B**. No. 8(?) coalbed and underlying point-bar coals (units 17 and 15) at STOP 1.

young are preserved here. Based on our current state of knowledge, correlation of these beds with the Casselman seems most reasonable.

The Conemaugh Group (Glenshaw and Casselman Formations) of western Pennsylvania contains numerous calcrete and calcitic paleosol horizons, particularly in strata higher than the Brush Creek marine zone (Shaulis, 1993, and personal communication, 1995). The combination of limited coal development and common pedogenic and "fluctuating-water-table" calcrete in the Conemaugh points to drying of the climate in latest Middle and Late Pennsylvanian time. The occurrence of calcrete in the upper Llewellyn of the Wyoming basin indicates that the change from pluvial to seasonally semiarid conditions so clearly marked in the western Conemaugh rocks also affected deposition and early diagenesis in the northern Anthracite region (Inners and Fabiny, 1996).

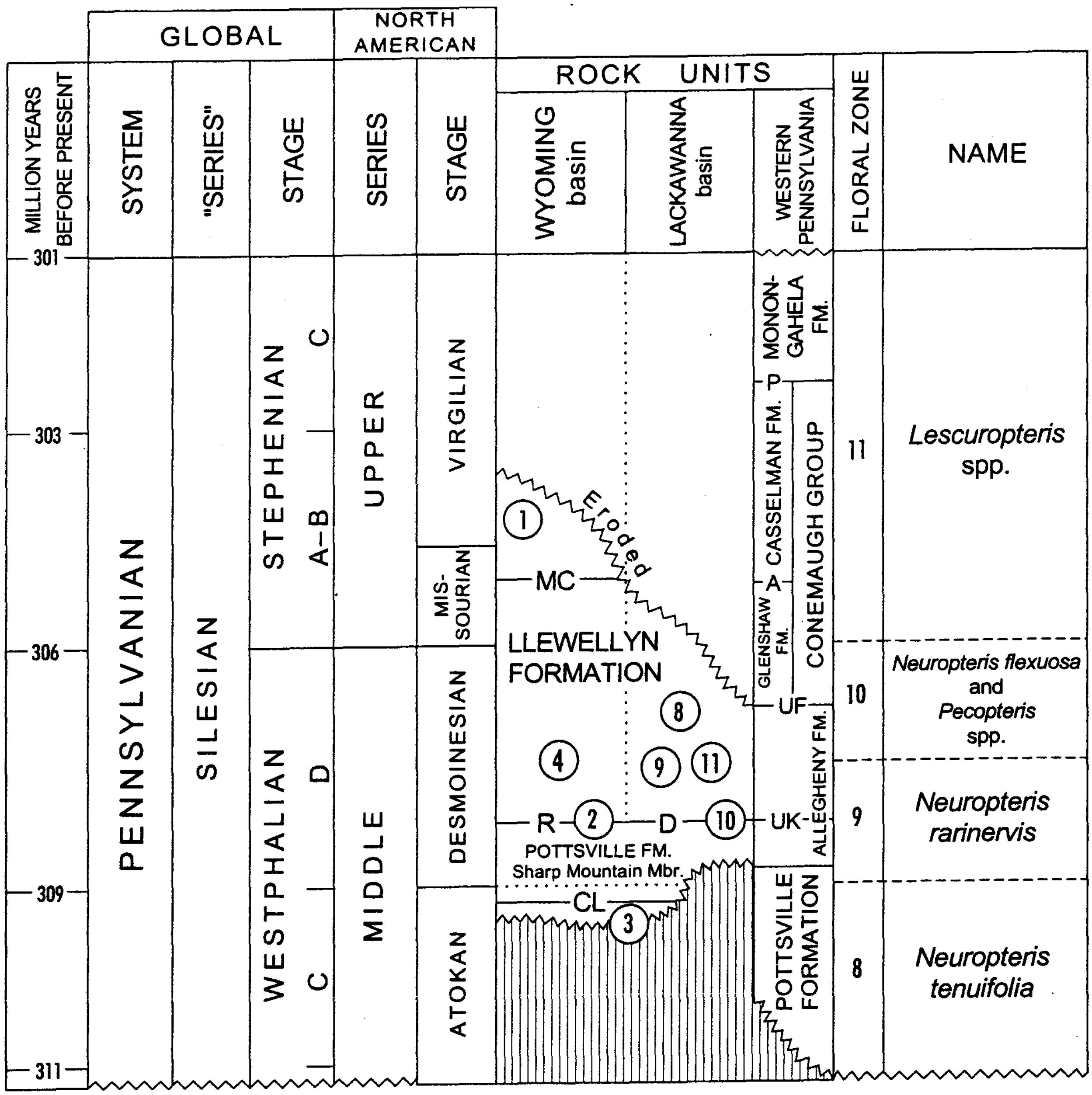



Figure 29. Correlation diagram showing relationship of the Llewellyn Formation to western Pennsylvania rock units, global and North American chronostratigraphic subdivisions, and floral zones. Circled numbers indicate approximate horizons of STOPS.

| | | |
|---|---|---|
| | | Leave STOP 1, continuing on PA 29N. |
| 0.2 | 23.0 | Bear right onto ramp at Exit 2 (Middle Road). |
| 0.3 | 23.3 | Stop sign. Turn left onto Middle Road. |
| 0.1 | 23.4 | Turn left onto ramp for PA 29S. Northwest-dipping Llewellyn carbonaceous shale intermittently exposed to right contains a good variety of plant fossils, including large *Cordaites* leaves, *Calamites* branches and trunks, and *Pecopteris* and *Annularia* leaflets. |
| 0.2 | 23.6 | Merge with PA 29S. |
| 0.7 | 24.3 | Directly ahead to the southeast is Solomon Gap, where PA 309 cuts through Wilkes-Barre and Penobscot Mountains and exposes long sections in the Catskill, Pocono, Mauch Chunk, and Pottsville Formations. Between 1850 and 1947, anthracite from the Northern field was transported through this gap to the Lehigh Valley on the Ashley Planes, a system of inclined planes and stationary steam engines originally engineered by Josiah White. |
| 0.2 | 24.5 | Continue past Exit 1. |
| 0.7 | 25.2 | Get into left lane, following signs to I-81N to Wilkes-Barre. |
| 0.5 | 25.7 | Cut in northwest-dipping upper Pottsville conglomerate and sandstone (southern part) and lower Llewellyn sandstone, shale, and coal (northern part). Horizon of Lower Red Ash coalbed occurs at mile 25.9. About 250 feet farther north the split Upper Red Ash coalbed is beautifully exposed. |
| 0.3 | 26.0 | Merge with I-81N. |
| 0.3 | 26.3 | Cut in lower Llewellyn Formation to right. |
| 0.4 | 26.7 | Northwest-dipping bottom rock of Lower (?) Red Ash coalbed exposed in strip mine to right. |
| 1.0 | 27.7 | To right are old strippings in lower Llewellyn coalbeds on the northwest flank of Wilkes-Barre Mountain. |
| 2.8 | 30.5 | Cut in northwest-dipping Llewellyn sandstone and shale, with an 8" coalbed on the right side of the highway. |
| 0.6 | 31.1 | Cut in Llewellyn Formation (see mile 15.8). The prominent exposed bedding plane of black, carbonaceous shale at the north end of the medial cut has an attitude of N84W/24SW, reflecting one of the *en echelon* "valley" folds that are transverse to the main axis of the Lackawanna synclinorium. This bedding plane contains the carbonized impression of large *Sigillaria* (?) trunk. |
| 0.3 | 31.4 | Bear right onto ramp at Exit 47B (PA 309N to Wilkes-Barre). |
| 0.4 | 31.8 | At stop sign, merge with PA 309N. |
| 0.4 | 32.2 | Long cut in Llewellyn Formation, extending on left to southbound on-ramp at Exit 1. Three unmined coalbeds are well exposed in the southern part of the cut, each about 12" thick. (The lower two coalbeds are also exposed on the right side of the road.) The thick, laterally extensive sandstone units are beautifully crossbedded and channeled. The coalbeds are very low in the section and presumably are the Red Ashes. |
| 0.8 | 33.0 | View of Wilkes-Barre and several surviving refuse banks to right. |
| 0.4 | 33.4 | Exit 2 (Wilkes-Barre Center City). Continue straight. |
| 0.6 | 34.0 | Cross valley of Mill Creek. Less than a mile downstream from here, near the confluence of Mill Creek with the North Branch, is the "type section" and best exposure of the Mill Creek limestone bed of the Llewellyn Formation—probable equivalent of the Ames marine zone at the top of the Glenshaw Formation (Conemaugh Group) in western Pennsylvania. |
| 0.1 | 34.1 | Refuse bank from the former Prospect Colliery is ahead on right. |
| 0.1 | 34.2 | To right is a road cut through Llewellyn strata just below the Mill Creek limestone, including calcrete, siderite nodules, and the Snake Island coalbed. |
| 0.4 | 34.6 | Cross North Branch Susquehanna River. |

| | | |
|---|---|---|
| 0.4 | 35.0 | For the next mile the trip will be crossing broad outwash terraces constructed from material transported from northern Pennsylvania and southern New York. This material filled in the last remnants of Glacial Lake Wyoming. Under a few tens of feet of gravel are tens of feet of clayey sediments that are probably glacial-lake varves. |
| 1.1 | 36.1 | Continue northwest past Exit 6 (Luzerne boro). |
| 0.1 | 36.2 | At approximately this point is the axis of the great "buried valley of the Susquehanna," which extends from the Lackawanna-Luzerne countyline near Duryea southwestward to Glen Lyon (a distance of about 17 miles). The elevation of the bottom of the valley here is approximately 330 feet above datum (the datum being -6.67 feet below mean sea level)—about 210 feet below the ground surface, or 170 feet below the bottom of the present North Branch Susquehanna River (Ash, 1950, Section 14). The "buried valley" was scoured out by the successive Pleistocene glaciers which moved southwestward between the mountains that surround the Northern field (see Braun, this guidebook). |
| 0.2 | 36.4 | Directly ahead is Toby Creek gap through Shickshinny and Larksville Mountains. Here, in the late 1870's, I. C. White of the 2nd Pennsylvania Geological Survey measured a section in the Catskill to Pottsville Formations (see White, 1883, p.167-168). |
| 0.8 | 37.2 | To left is a prominent cut in the Pottsville and Mauch Chunk Formations (STOP 2). |
| 0.3 | 37.5 | Deep cut through southeast-dipping, strongly cross bedded Pocono sandstone. Another cut occurs along the old railroad grade parallel to Toby Creek just east (right) of the highway. Bouldery and cobbly late Wisconsinan kame gravel is poorly exposed at the south end of the cut on the right side. |
| 0.5 | 38.0 | Long cut to right exposes thick, basal Pocono conglomerate (the "Griswold Gap conglomerate" of I. C. White [1883]) at south end; underlain by a relatively thin interval of Spechty Kopf (?) sandstone and olive shale; underlain in turn by fining-upward, gray-and-red alluvial cycles of the Duncannon Member of the Catskill Formation (mile 38.3). What appears to be the top of the Duncannon is marked by a thick, hackly, olive-gray claystone paleosol. |
| 0.6 | 38.6 | Get into left lane of highway. |
| 0.2 | 38.8 | Turn left onto Hillside Road. Watch out for on-coming traffic! |
| 0.3 | 39.1 | Turn around in semi-circular dirt roadway to right and proceed back on Hillside Road. |
| 0.3 | 39.4 | Stop sign. Turn right onto PA 309S. |
| 0.1 | 39.5 | Toby Creek on right. |
| 1.0 | 40.5 | Bear right onto Exit 6 (Luzerne boro). |
| 0.2 | 40.7 | Rock cut to right. **Buses pull off onto shoulder of ramp.** |

## STOP 2. *PA 309 ROADCUT AT LUZERNE: MAUCH CHUNK-POTTSVILLE STRATIGRAPHY AND STRUCTURE.*

Leaders: William E. Edmunds and Norman W. Gillmeister.

The roadcut along the ramp at southbound Exit 6 of PA 309 (Figure 30) exposes the upper 150 feet of the Mauch Chunk Formation, the entire thickness of the Pottsville Formation, and the basal coal and seatrock of the Llewellyn Formation (Figure 31) on the northwest limb of the Lackawanna synclinorium. The medial part of the Pottsville Formation is complexly faulted.

## STRATIGRAPHY (Edmunds)

### Mauch Chunk Formation

The 50-foot siltstone at the base of this exposure represents the uppermost part of the remaining Mauch Chunk Formation. I. C. White (1883. p 167-168) measured the following rough section of the

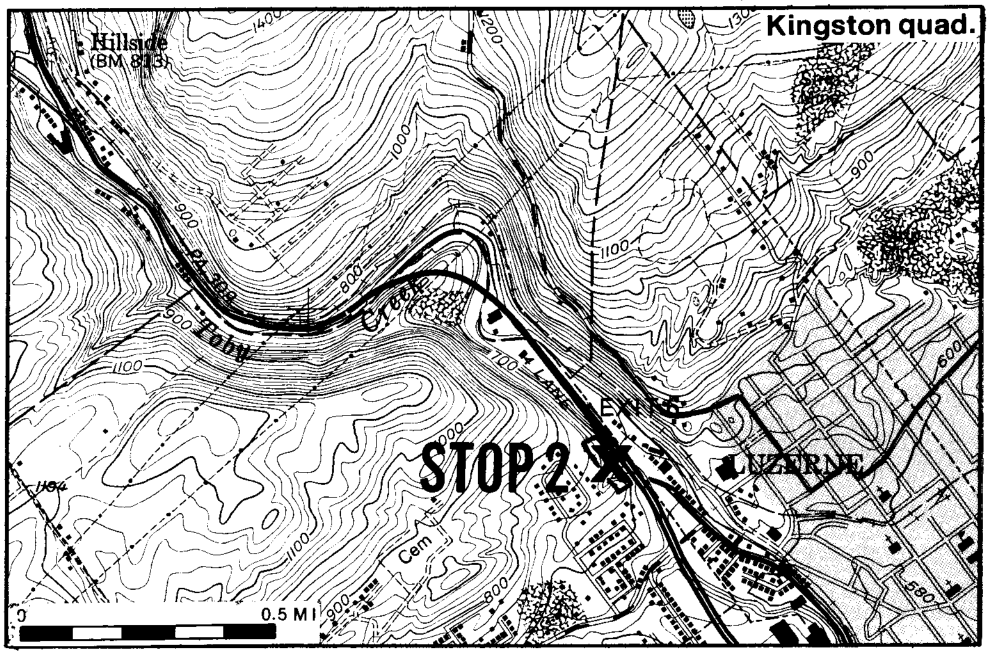



Figure 30. Location map for STOP 2.

Mauch Chunk Formation along the opposite side of Toby Creek (units 2-8 ):

1. Pottsville conglomerate, base visible......................30'
2. Concealed 1000' [paced], dip 20°...................say 342'
3. Sandstone, gray current bedded.. ..........................40'
4. Sandstone, gray with streaks of red and some thin bands of calcareous material ................................ 35'
5. Sandstone, gray current bedded.............................25'
6. Sandstone massive, some pebbles.........................25'
7. Red shale.........................................................20'
8. Sandstone, reddish ..................................................5'
9. Sandstone, gray, massive (Pocono Formation, part).....75'

White's section indicates that the Mauch Chunk is about 490 feet thick. Recent examination of the sandstones of units 3, 4 and 5, have led to the conclusion that they are a weakly calcareous facies of the Loyalhanna Member of the Mauch Chunk Formation. The Loyalhanna is here, as everywhere, underlain by a major unconformity. Using White's figures, the upper part of the Mauch Chunk between the sub-Loyalhanna and sub-Sharp Mountain unconformities is about 440 feet thick. The lower part of the Mauch Chunk between the conformable contact with the Pocono Formation and the sub-Loyalhanna unconformity is about 50 feet thick. If White's measurements are anywhere near correct, erosion at the sub-Sharp Mountain unconformity has removed about 200 feet of upper Mauch Chunk in the 16 miles from Shickshinny to Forty-Fort. In the same distance erosion at the sub-Loyalhanna unconformity has removed at least 200 feet from the lower part of the formation. The combined effect of these two unconformities eliminates all remaining Mauch Chunk Formation in the 17 miles between Forty Fort and north Scranton (STOPS 7B and 10).

The three-foot-thick, yellowish-gray claystone at the top of the Mauch Chunk siltstone is interpreted as the paleosol of the sub-Sharp Mountain unconformity , possibly a (protosol as defined by Mack and others, 1993)

Notice the uncharacteristically small amount of pale-red coloration in the Mauch Chunk siltstone. This is related to the question of why the sandstones and, to lesser degree, siltstones in the uppermost few hundred feet of the Mauch Chunk underlying the Pottsville in the Northern field display little or no

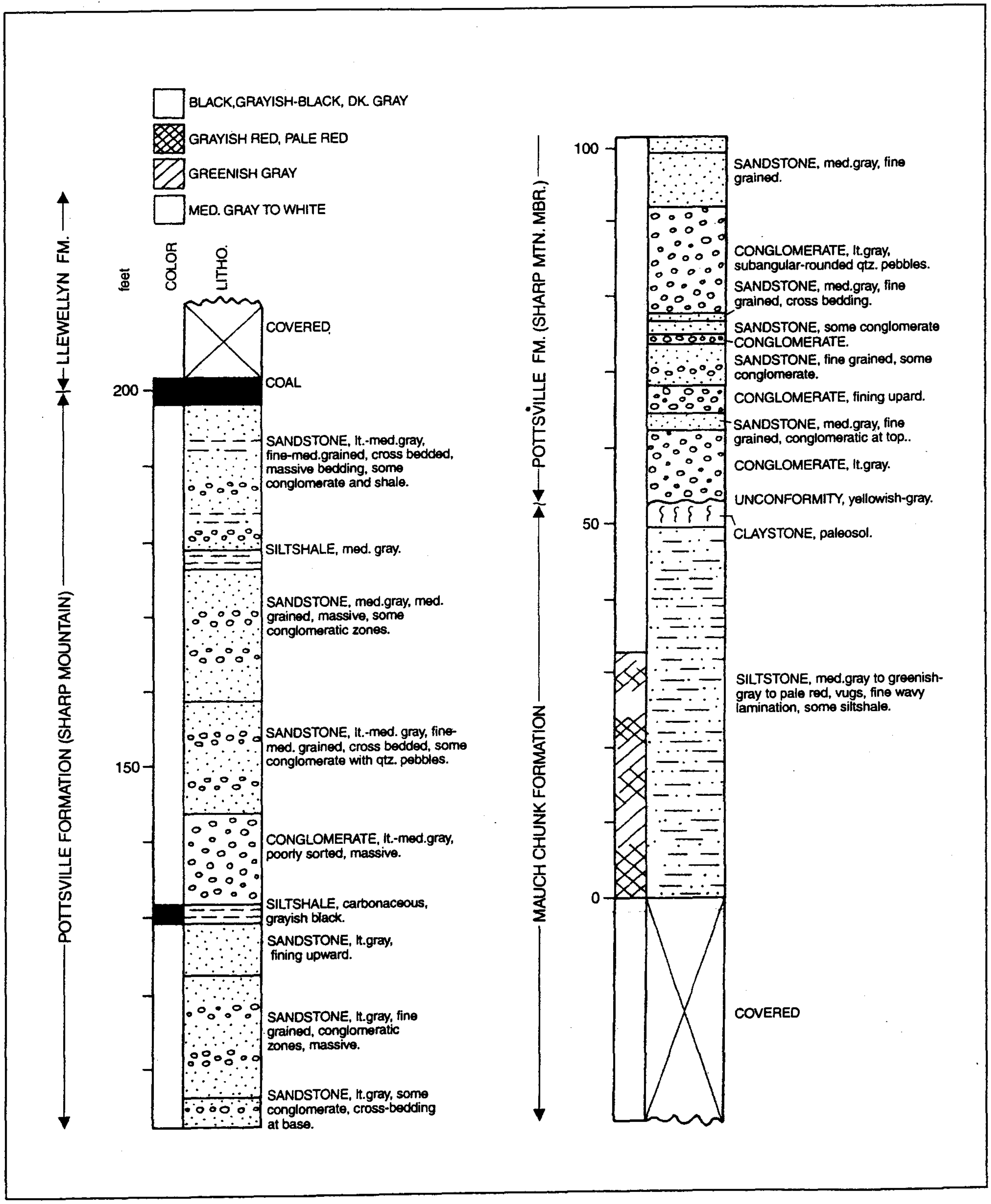



Figure 31. Stratigraphic column of exposure at STOP 2 (adapted from Edmunds and Eggleston, 1989, Fig. 2).

red color. This condition seems to occur in most places regardless of what stratigraphic level within the Mauch Chunk directly underlies the Pottsville. Where these same laterally equivalent Mauch Chunk strata lie more than 100 to 200 feet below the Pottsville, they usually exhibit distinct coloration. Some possible explanations include:

1) The red-nonred facies is a primary sedimentary feature which is strongly diachronous up section in a southerly direction, and its apparent parallelism to the unconformable base of the Pottsville Formation is only an extraordinary coincidence;
2) Reduction of ferric oxide in originally red sediments by action of ground water contemporary with subaerial exposure of the sub-Sharp Mountain erosion surface the Atokan Stage.
3) Reduction of ferric oxide in originally red sediments by action of peripheral infusion of hydrothermal solutions passing mainly through the overlying Llewellyn and Pottsville Formations, at the time of the Alleghanian orogeny as proposed by Daniels and others (1990).

**Pottsville Formation (Sharp Mountain Member)**

Except for two one-foot-thick silt shale beds, the Pottsville Formation is composed entirely of quartz-pebble conglomerates, conglomeratic sandstones, and sandstones. Sediments are arranged in a series of somewhat vague, variously proportioned fining-upward cycles. It is interpreted as an anastomosing alluvial-plain sequence. Assuming that the coalbed at the top of the sequence is correctly identified as Lower Red Ash (see below) the entire Pottsville is exposed here. Thickness is 144 feet, which is distinctly toward the thinner end of its range.

The Pottsville of the Northern Anthracite field consists only of the Sharp Mountain Member and rests unconformably upon the underlying Mauch Chunk Formation (C. D. White, 1904, p. 274). Between here and the southern Anthracite field, 40 miles to the south, erosion at the sub-Sharp Mountain unconformity has removed the underlying Tumbling Run and Schuylkill Members of the Pottsville Formation (1300 feet) and something on order of 2000 feet of uppermost Mauch Chunk Formation. The unconformity reflects erosional beveling of rock uplifted and tilted to the south in northeastern Pennsylvania during Atoken time.

**Llewellyn Formation (Red Ash coalbed)**

The partially exposed anthracite bed at the top of the section is identified as the Red Ash coalbed based upon mapping by Ashburner (1884, Plates 5 and 8). Ashburner indicates that it, and the overlying Ross coalbed, were mined in the Waddell and Walters Company's Mill Hollow drifts, located on the opposite side of Toby Creek valley. The Red Ash and Ross were later the object of shallow stripping operation on both sides of the valley.

More commonly in the Wyoming sub-basin of the Northern Anthracite field , two or three Red Ash coalbeds are recognized and designated “Lower”, “Middle”, and “Upper.” Why there is only one here is unknown. In any case, it is treated as a key bed marking the base of the Llewellyn Formation.

**STRUCTURE** (Gillmeister)

The major structural features at this stop are shown on the sketch (Figure 32). The most prominent feature is bedding, which increases in dip from about 20 degrees to the south in rocks of the Mauch Chunk Formation to 35 degrees to the south at the base of the Llewellyn Formation. Higher degrees of dip occur near faults. The attitude of bedding, as measured near road level, is summarized in Figure 33A.

A number of more and less prominent, south-dipping (i.e., out-of-basin) thrust faults are also present (letters A to D, Figure 32). Net slip ranges from a few feet, for faults that are nearly parallel to bedding (B and C, Figure 32), to possibly a few tens of feet for the two larger faults that have footwall cut-off angles of 22 to 30 degrees. The large fault at the north end of the outcrop (A, Figure 32) should root in the upper part of the Mauch Chunk, not too far below the level of the exit ramp. Orientation data for all measured faults, including one oblique-slip fault, is shown in Figure 33B.

The reason for specifying "road level" for the bedding measurements shown on Figure 33A can be seen at point E in Figure 32. At this spot is a nearly isoclinal, overturned syncline that is complexly faulted (Figure

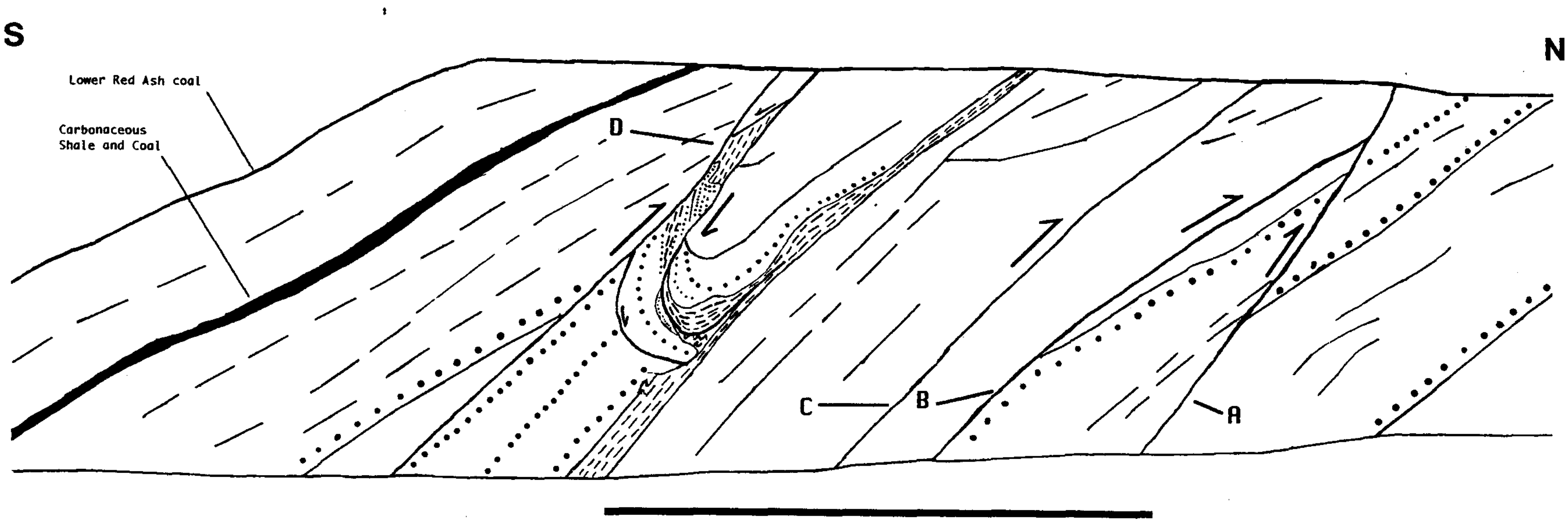



Figure 32. Sketch of rock exposure at STOP 2 from level of exit ramp to top of the steep cut, looking west. The scale bar is approximately 50 feet long. Bedding is indicated by thin lines and by filled circles. Letters A to D mark thrust faults, with arrows indicating relative motion. An overturned, faulted syncline is present between letters C and D.

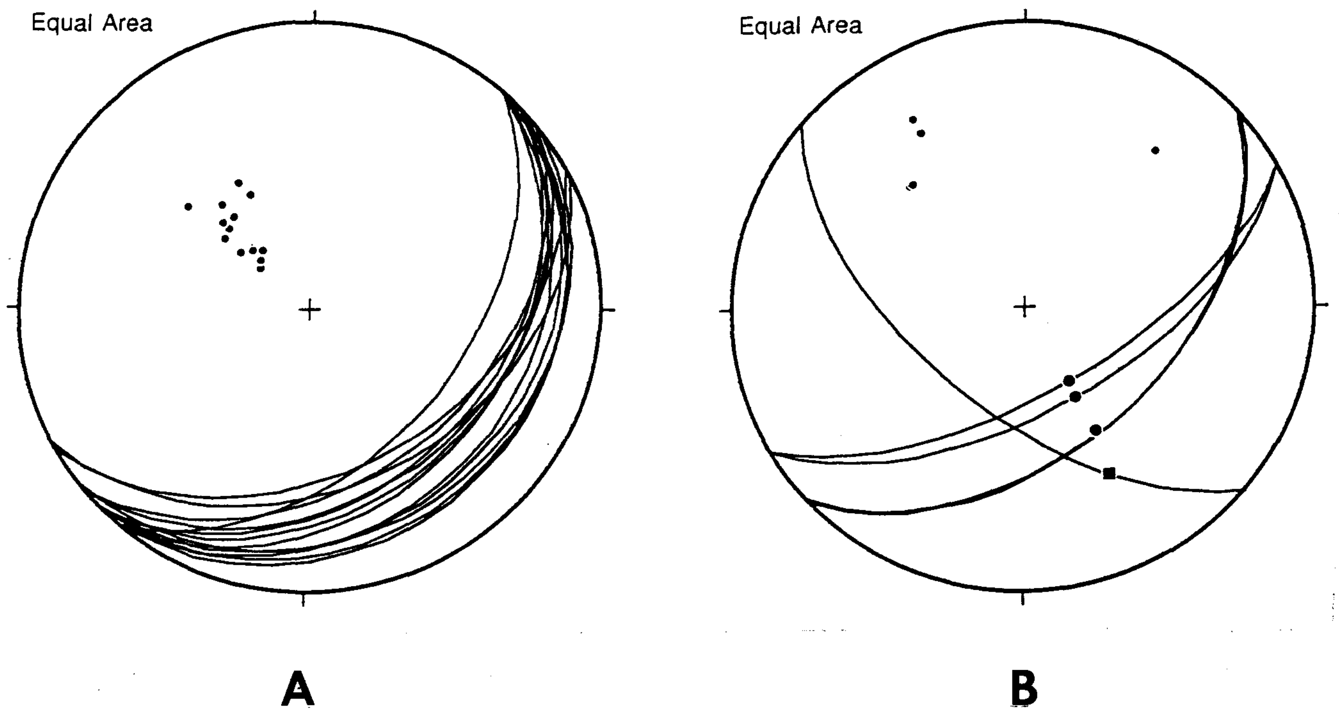



Figure 33. Stereograms (Schmidt net, lower hemisphere projection) of structural elements at STOP 2. A. Attitude of bedding, shown as great circles and poles (dots). B. Attitude of faults, shown as great circles and poles (small dots). The large dots indicate the orientation of fault plane lineations on thrust faults; the square indicates the orientation of fault plane lineation on an oblique-slip fault.

34. It is bounded to the north (lower, upright limb) by a dark gray carbonaceous shale and to the south by prominent thrust fault D in Figure 32. The upper part of the shale layer wraps around the fold hinge to form part of the upper, overturned limb, whereas the lower part of the shale unit continues relatively undisturbed to road level. The low-strength shale clearly provides the locus for a detachment surface within the surrounding higher strength sandstone and conglomerate sequence. The upper limb of the fold actually consists of tectonically mixed chunks of sandstone and shale bounded above and below by thrust faults. In the hinge area, the fold is bounded by a curved fault surface that juxtaposes folded conglomerate and sandstone with south-dipping massive conglomerate, forming a nearly orthogonal relationship of bedding to either side of the fault (Figure 34).

STOP 2 has provided an opportunity to see the contact relationships between the coal-bearing rocks of the Wyoming Valley and the underlying rocks. These relationships appear to be generally structurally uncomplicated during the course of field mapping, when most of the outcrops encountered are parallel to strike. As shown here, occasional hints of greater complexity in the form of sudden changes in the thickness of the Pottsville Formation (both increases and decreases), sudden variations in the dip of the beds, and the presence of exposed fault surfaces do take place. The infrequently encountered types of cross sections that can be seen at STOP 2—and STOP 3 ("in spades")—show that the hints of structural complexity are quite real.

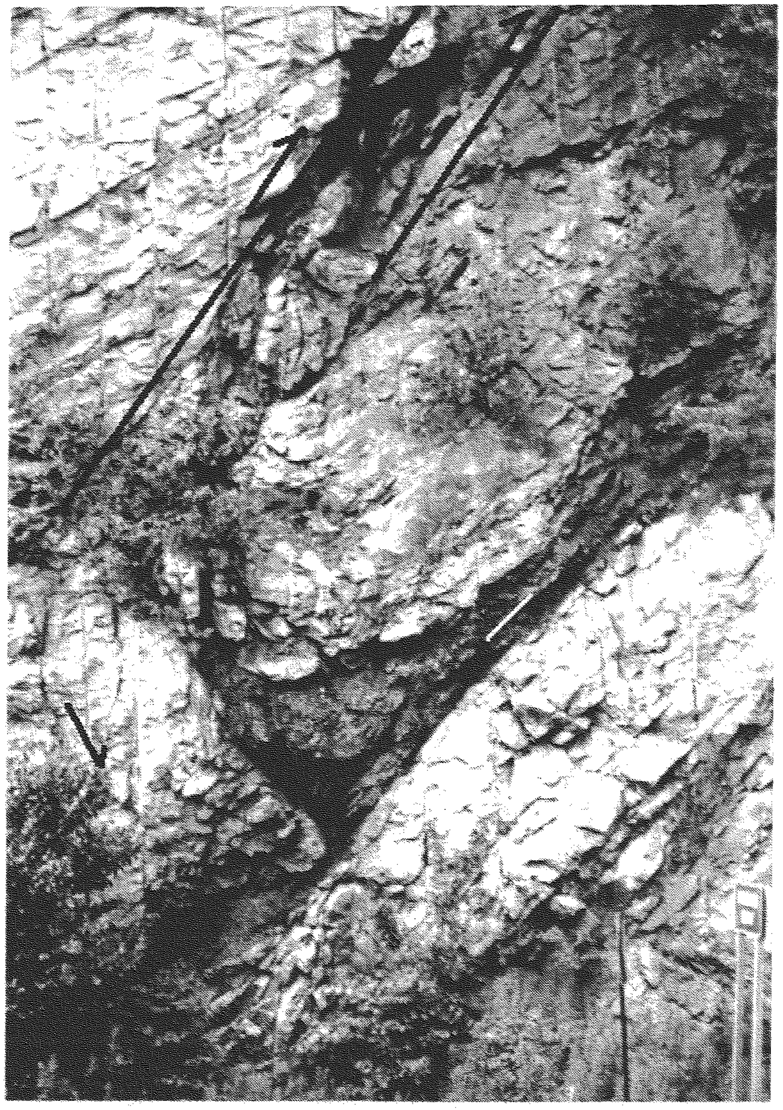


Figure 34. Photograph of overturned syncline within the Pottsville Formation that is outlined by a dark-appearing layer of coal and carbonaceous shale. Heavy lines with arrows indicate thrust faults on the upper, overturned, limb. Note the disrupted and rotated blocks of sandstone and conglomerate between the two faults. The heavy arrow indicates relative motion on a curved fault just below the arrow. The thin white line is drawn on part of a surface of intense deformation that separates the lower, relatively undeformed, part of the coaly sequence from the upper part that is involved in the folding.

| | | |
|---|---|---|
| | | Leave STOP 2, continuing ahead on exit ramp. |
| 0.1 | 40.8 | Enter borough of Luzerne. |
| 0.2 | 41.0 | Traffic light. Continue straight ahead at this and succeeding three lights. |
| 0.7 | 41.7 | Bear left onto entrance ramp to PA 309S. |
| 0.3 | 42.0 | Merge with PA 309S, then proceed south past Exits 5, 3, and 1. |
| 1.4 | 43.4 | Cross North Branch Susquehanna River. |
| 2.3 | 45.7 | Long cut in Llewellyn Formation (see mile 32.2). |
| 0.4 | 46.1 | Follow sign for PA 115S, staying in middle lane. |
| 0.3 | 46.4 | Cross over I-81. |
| 0.3 | 46.7 | Late Wisconsinan kame gravel entrance to Best Western East Mountain Inn to left. |
| 0.2 | 46.9 | Traffic light. Continue ahead on PA 115S. |

0.2 47.1 Start of long cut in gently northwest-dipping Pottsville conglomerate and sandstone.

0.2 47.3 Pottsville/Mauch Chunk contact well exposed to left. The contact zone here is unfaulted, contrary to what we will see at STOP 3.

0.1 47.4 High cut in interbedded gray and red Mauch Chunk sandstone and shale to left. To right is the Laurel Run gap through Wilkes-Barre Mountain.

0.5 47.9 Turn right at entrance to Seven Tubs Natural Area. **Continue down park access-road about 0.3 mi to parking lot in old quarry on left.**

**STOP 3 AND LUNCH.** ***THE SEVEN TUBS NATURAL AREA AND ITS ENVIRONS: GEOMORPHIC DEVELOPMENT OF "THE TUBS"; STRATIGRAPHY OF THE MAUCH CHUNK AND POTTSVILLE FORMATIONS; AND STRUCTURE AT THE MAUCH CHUNK/POTTSVILLE CONTACT.***

Leaders: Duane D. Braun, William E. Edmunds, and Norman W. Gillmeister.

The Seven Tubs Natural Area is situated in Plains Township, Luzerne County, on the southeast side of Laurel Run (Figure 35). Spectacular erosional potholes are developed along the lower 1200 feet of a tributary stream that heads near the old Oliver School on PA 115 about a mile and a half to the southeast. These "Seven Tubs" are carved into northwest-dipping sandstones of the Lower Mississippian Pocono Formation—the same unit that crops out in the former quarry where the STOP begins. To the north and northwest, on the abandoned grade of the Lehigh and Susquehanna Division of the Central Railroad of New Jersey, nearly continuous rock cuts expose most of the Upper Mississippian Mauch Chunk Formation, as well as the lower part of the Lower to Middle Pennsylvanian Pottsville Formation. We will first examine The Tubs, then eat lunch, and finally "walk off" lunch with a long hike along the old railroad grade to study the rocks exposed there.

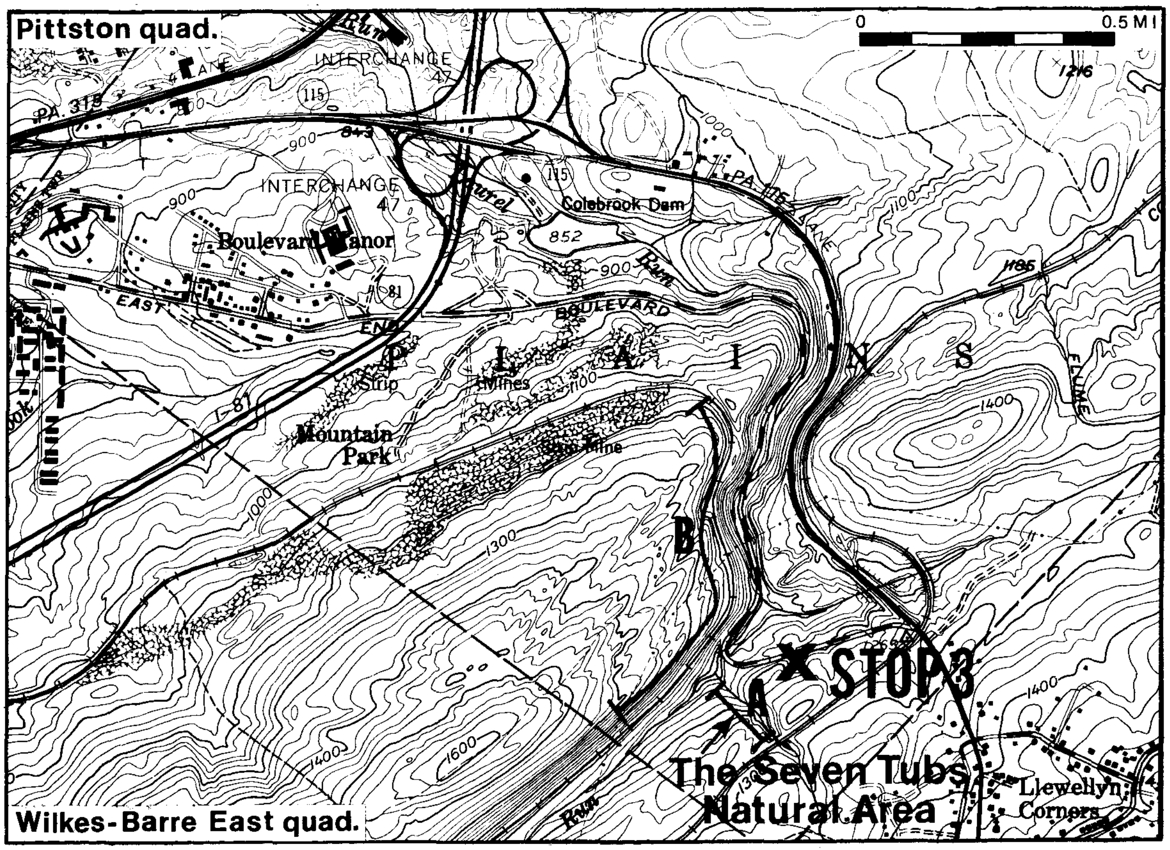



Figure 35. Location map for STOP 3. (A = The Tubs; B = Railroad cut.)

**Part 1. The Origin of the Tubs (or Whirlpool Canyon)** (Braun)

Circular potholes cut out of bedrock are observed where turbulent water flows across a bedrock surface that is resistant to erosion (usually sandstone or crystalline rock). Such situations typically occur in steep, narrow bedrock gorges—like the lower Susquehanna gorge (Sevon and Thompson,1987; Thompson, 1988) where the turbulent flow has an exceptionally high velocity (supercritical or upper regime flow). Potholes also form in coastal surf zones along the ocean and large lakes (such as the Great Lakes) where high velocity flow is episodic and bidirectional. Pothole erosion has been attributed to vertical axis vortices in the turbulent flow moving sand and larger clasts in a circular path to grind out the pothole (Baker, 1973; Baker and others, 1978; Thompson and Sevon, 1987; Thompson, 1988; Sevon, 1989, 1993). The pothole is initiated at some point of weakness and once initiated, is deepened and enlarged by each high-velocity event capable of generating a vortex at that site (Baker, 1973; Baker and others, 1978; Thompson and Sevon, 1987; Thompson, 1988; Sevon, 1989). The rate at which a pothole forms, enlarges, and deepens has never been directly measured. General observations by various lay people and geologists suggest that supposedly active potholes have changed little in their lifetimes. It is reasonable to assume that in order to erode out such forms, particularly to depths of 10 or more feet such as at The Tubs, it should take a large number of high-velocity vortex events over a considerable period of time. A time scale of pothole development on the order of hundreds to thousands of years seems more likely for such well developed forms as The Tubs, rather than just years to tens of years.

Since the discovery of the Archbald Potholes on a hillside above any present stream (STOP 8) it has been realized that glacial meltwater could also be responsible for the cutting of such forms. Moreover, since The Tubs are also within the glaciated region and far better developed than potholes on any other stream flowing down the dipslope of the south flank of the Lackawanna synclinorium (verified by walking all such streams as part of ongoing mapping) there has been a tendency to assume that The Tubs have been formed by glacial meltwater. This also implies that the present stream is not be capable of cutting such large potholes.

Ongoing glacial deposit mapping of the area, however, indicates that glacial meltwater never or at most, for only a few meltwater seasons, flowed down the dipslope at The Tubs. The critical difference between The Tubs and the Archbald Potholes is their respective orientation relative to glacial ice and meltwater flow. The Tubs are oriented transversely towards the ice and meltwater flow (Figure 36), while the Archbald Potholes lie in a valley oriented parallel to and sloping in the same direction as ice and meltwater flow (STOP 8). Ice flow direction is shown by glacial striations and the edge or margin of the glacier is transverse to that direction. At The Tubs the glacial striations show that the ice flowed obliquely across the Pottsville conglomerate strike- ridge, through the Laurel Run water gap, and obliquely up the dipslope at The Tubs (Figure 36).

During ice recession, a series of ice margins would have existed that should have impounded a short-lived proglacial lake in the northeast draining Laurel Run valley. Its outlet would have been at an elevation of 1400 feet at Oliver Mills (Figure 30). Sand and gravel deposits south of The Tubs, at 1480 to 1360 ft. elevation (labeled G on Fig. 36), may mark a kame delta (ice marginal delta) built into that lake when the ice front was immediately south of The Tubs. The proglacial lake would have flooded The Tubs area (The Tubs are from 1190 to 1110 feet in elevation) until ice retreated north of The Tubs and opened the Laurel Run water gap. At that point, only some stagnant ice would have remained in the Laurel Run valley to provide any downslope meltwater drainage to cut The Tubs.

It is conceivable that Glacial Lake Laurel Run may have drained subglacially through the water gap when the ice margin was right at The Tubs and permitted a period of downslope drainage to cut The Tubs. However, this period of meltwater drainage would have been for only a few years as the ice continued its recession from the area. Even this short period of drainage is doubtful. The only

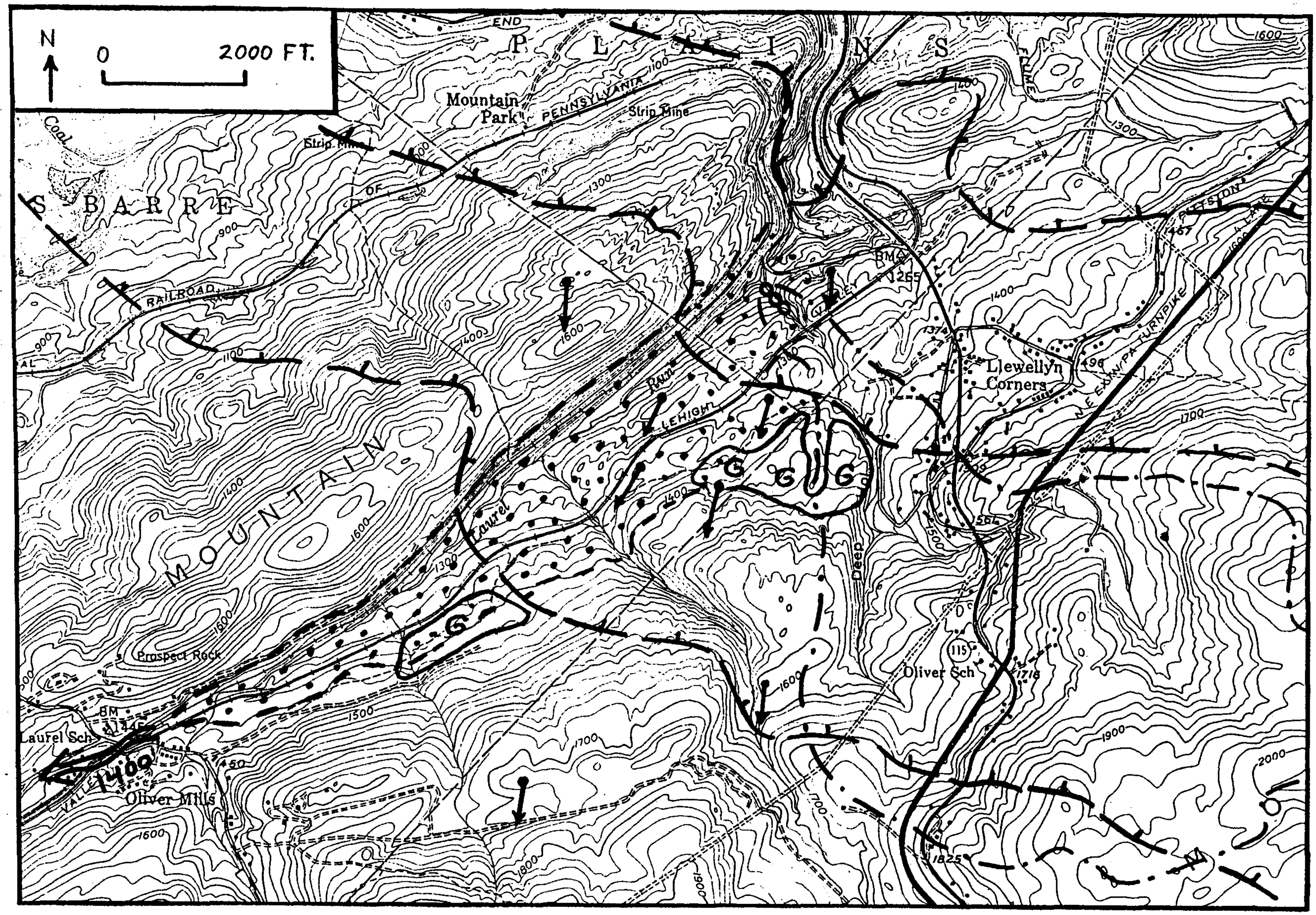



Figure 36. Topographic map (Wilkes-Barre East 7.5' quad.) showing The Tubs (3 linked circles), glacial striation directions (arrows), Glacial Lake Laurel Run (dotted area inside dashed lines), the 1400' elevation lake outlet (double arrow), gravel deposits (G), recessional ice margin positions (dashes with tick marks facing up ice), and the drainage basin boundary of The Tubs stream (dot-dash line).

significant thickness of glacial deposits in the Laurel Run valley that would indicate short-lived stability of the ice margin is not at The Tubs but at the sand and gravel deposits south and upslope of The Tubs.

Since it is difficult to get a significant duration of meltwater drainage downslope at The Tubs, one is left with only one other alternative, that the present stream has cut the potholes over the 17,000 years or so since deglaciation. The question then is: What is special about the situation at the Tubs that permits the development of the largest, deepest series of potholes of any stream on the south flank of the Lackawanna synclinorium? The answer appears to lie in a unique combination of rock resistance, joint prominence, channel (dipslope) steepness, and drainage basin size. The Tubs site is cut in some of the most resistant and well jointed sandstone and conglomerate layers of the Pocono Formation. The Tubs can be described as a joint-slot gorge that has a zig-zag pattern down the dipslope following at least three different joint directions. In such a joint-slot gorge, the entire stream flow is directed into the pothole. There are also exceptional increases in water depth as discharge increases, thereby greatly increasing the "depth-slope product" or erosional force of the water. The best potholes form where the channel has an abrupt turn, going from following one joint direction to another.

In only a few short segments of other streams in the region are there similar joint-slot gorges in the very resistant sandstone or conglomerate of either the Pocono or Pottsville Formations. The best developed potholes for each of those other streams are in those segments. The other joint-slot gorge streams are much smaller than the stream at The Tubs. Where the bedrock is less resistant, thinner-bedded sandstone and finer-grained clastic rocks, the channels on the dipslopes tend to widen and strip off individual beds of rock rather than drill vertical potholes.

The Tubs are so large because the stream that has cut them has the largest combination of drainage area (1.6 $mi^2$), channel width (5 to 10 feet above The Tubs), and slope steepness (0.2 ft/ft) of any stream draining through a joint-slot gorge on the south flank of the Lackawanna synclinorium. The slope is especially steep and permits even relatively small flood events to move tools around the potholes. (Note that the boulders in the bottom of some of the potholes are lags that do not move significantly—and if enough boulders accumulate, they can "choke off" the pothole development.) All these factors together give The Tubs stream the greatest amount of energy to put into scouring out the largest potholes in the area.

## Part 2. Geology of the Mauch Chunk and Pottsville Formations (Edmunds)

### INTRODUCTION

At this STOP we will examine the 595-foot-thick Mauch Chunk Formation, including the remnant of the basal part of the formation, the intraformational sub-Loyalhanna regional unconformity, the Loyalhanna Member, and the remaining supra-Loyalhanna Mauch Chunk. We will also see the multiply-faulted contact between the Mauch Chunk and Pottsville Formations and the lower part of the Pottsville Formation.

In addition to being spectacularly exposed bedrock gorge and plunge pools at "The Tubs," gray, fluvial sandstones of the upper part of the Pocono Formation underlying the Mauch Chunk Formation are exposed along the access road and in the abandoned quarry at the parking lot.

Exposures of the Mauch Chunk and Pottsville Formation will be examined along the abandoned narrow-gauge railroad on the side of Wilkes-Barre Mountain on the northwest side of Laurel Run (Figure 35). Access to the railroad grade requires a 75-foot climb up the steep dirt trail just beyond the point where the paved road crosses Laurel Run.

Wilkes-Barre Mountain forms the southeast rim of the Northern Anthracite basin in the center of the Lackawanna synclinorium. Dip here is 15 to 20 degrees northwest. In contrast to the area of the Southern and Middle fields, where the Mauch Chunk Formation is mainly a valley-former, Wilkes-Barre Mountain is a hogback with the southeast-facing scarp slope and principal crest supported by Mauch Chunk sandstones and siltstones. The Pottsville Formation forms a secondary bench partway down the northwest dip slope side of the mountain. The contact between the Mauch Chunk and underlying Pocono closely matches the course of Laurel Run along the foot of the scarp slope.

The Mauch Chunk-Pottsville stratigraphic succession along the railroad south of Laurel Run is shown in Figure 37 and described in detail in Appendix B-2. The section can be conveniently divided into six distinct segments: basal Mauch Chunk transition, sub-Loyalhanna-unconformity, Loyalhanna Member, post-Loyalhanna Mauch Chunk, faulted contact section, and basal Sharp Mountain Member.

## STRATIGRAPHIC DESCRIPTION

### Basal Mauch Chunk transition (units 2-9)

The contact between the Pocono and Mauch Chunk Formations is placed at the base of the pale-red claystone and clay shale of unit 2 which is the lowest red bed above the gray Pocono. The contact is believed to be conformable. The overlying 72 feet between that contact and the sub-Loyalhanna unconformity is a sequence of interbedded red claystones and shales and gray or greenish-gray sandstones which represent the transition between the non-red Pocono and the dominantly red main body of the Mauch Chunk.

The transition is believed to reflect the climatic change from sub-tropical humid-monsoonal conditions with several wet months per year to subtropical semiarid conditions with only a few wet months per year. This change occurred throughout the central Appalachian depositional basin at about middle Osagean time (c. 345 Ma).

This 72-foot-thick section is all that remains of the early Mauch Chunk fluvial sequence deposited in the four million years or so prior to the onset of erosion associated with the sub-Loyalhanna unconformity. Original thickness cannot be accurately reconstructed, but was, perhaps, something on the order of 600 to 1000 feet.

### Sub-Loyalhanna unconformity (unit 10)

The chaotic mixture of quartz sand and pebbles, pedogenic carbonate clasts, and red shale clasts set in a calcareous matrix (unit 10) is identified as the paleosol associated with the unconformity underlying the Loyalhanna Member or equivalent in this area. Notice also the curved, crisscross desiccation cracks which are typical of a vertic calcisol or calcic vertisol in the classification of Mack and others (1993).

The unconformity itself is part of the regional unconformity associated with the positive erosion surface of the vast structural uplift which developed throughout the central Appalachians in early Meramecian time (c. 340 Ma) (Edmunds, 1993a, 1993b). At this point and throughout much (but not all) of Pennsylvania, the unconformity is overlain by the latest Meramecian-age Loyalhanna Member or its lateral equivalent. In this situation, the lacuna (erosion and non-deposition) extends from middle Osagean to latest Meramecian. Elsewhere, the unconformity may be overlain by older rocks (as is clearly the case in southern West Virginia and probably the case in parts of the Southern and Middle Anthracite fields) or by younger rocks (as in eastern Ohio).

### Loyalhanna Member (units 11-18)

The Loyalhanna Member of the Mauch Chunk Formation is a unique unit recognizable by (1) its sandy limestone to calcareous sandstone composition; (2) the general presence of strong crossbedding in lensoidal and tabular sets 2 to 8 feet thick, composed of high-angle crossbed subsets with tangential bases and truncated tops (pi- or omicron-type crossbeds of Allen, 1963); and (3) a tendency to produce fluted and pock-marked weathering surfaces reflecting contrasting calcium carbonate concentrations between crossbed subset layers.

All of the above characteristics are present at this site. The Loyalhanna here is a fine- to medium-

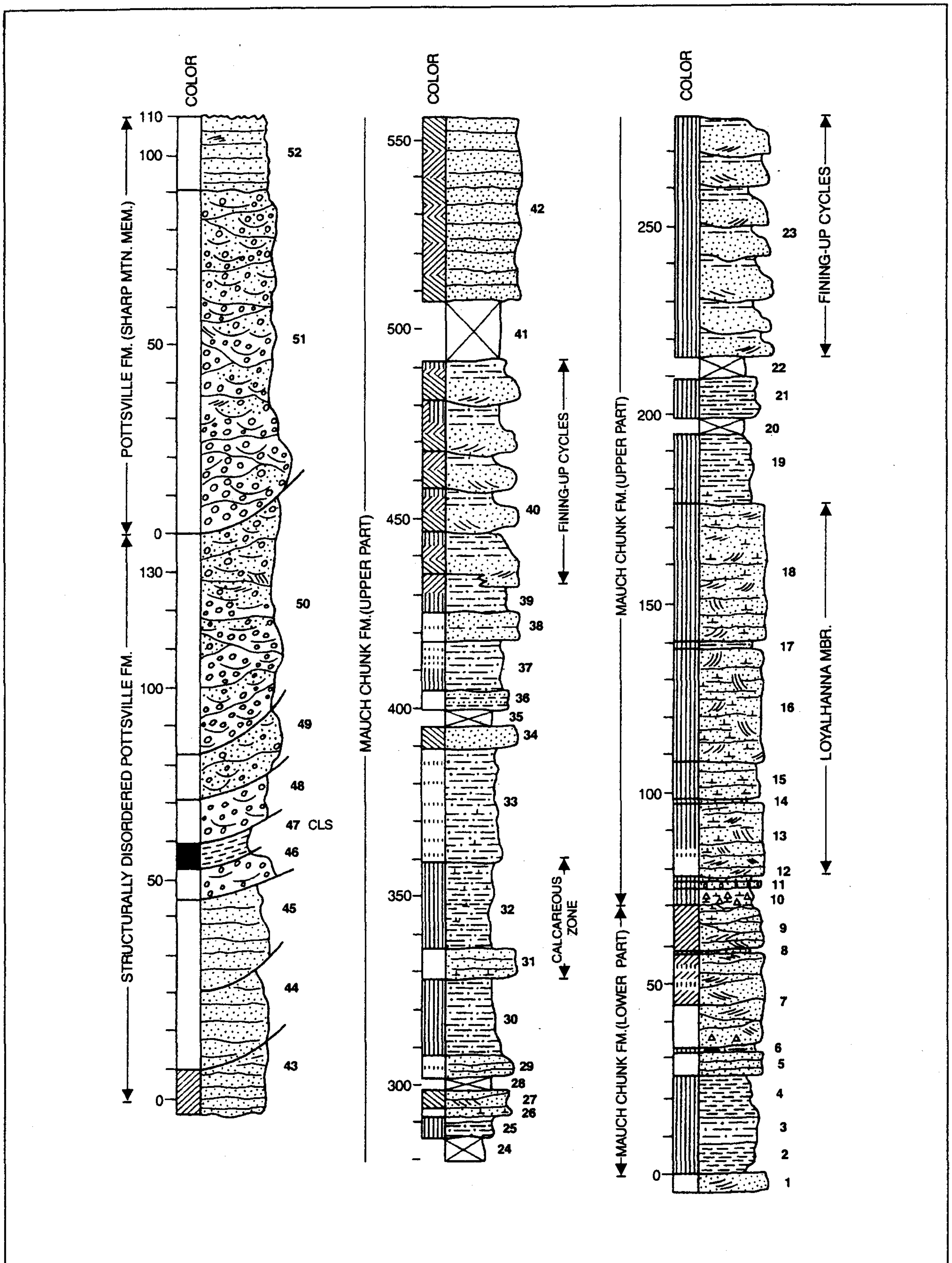



Figure 37. Stratigraphic column of Mauch Chunk and Pottsville Formations along the abandoned railroad at STOP 3. The rock symbols are standard (see also other figures in this guidebook. Color bar symbols: vertical lines = grayish red and pale red; slanted left = greenish gray; slanted right = bluish gray; blank = gray (N4-N7); solid = dark gray (N2-N3).

grained quartz sandstone with carbonate cement generally present, except in the lower part of unit 13 and scattered zones in units 16 and 18. Petrographic examination may show the presence of pelletal carbonate grains as well, which would be typical of the Loyalhanna. The quartz sand-carbonate ratio is expected to be at the high end of the range for the Loyalhanna. High-angle crossbedding is common throughout, except in unit 15, which is massive, and in parts of unit 18, where low-angle crossbeds prevail. Fluted and pocked weathering occurs, but is less common than is usual, probably reflecting the relatively low carbonate fraction. The Loyalhanna here is grayish red to pale red, except for the lower part of unit 13 which is light gray. Red coloration is not typical of the Loyalhanna overall, but it is also present in Somerset County and the Broad Top synclinorium, reflecting the introduction of red clay from the nearby edge of prograding Mauch Chunk lower delta plain clastics. The Loyalhanna contains two 1-2-foot-thick hackly siltstones, the lower of which is calcareous (units 14 and 17). At 99 feet thick, the Loyalhanna is at the upper end of its known thickness range.

No invertebrate fossils were observed here. This is typical of the Loyalhanna megascopically, but elsewhere microscopic examination has shown the presence of finely ground marine invertebrate material and macroscopic shell fragments occur at STOP 7B.

The Loyalhanna Member represents a near-isochonic, late Meramecian-age (c. 330 Ma) marine transgression extending from northeastern Kentucky and southern Ohio to northeastern Pennsylvania. It correlates with at least the upper part of the marine limestones of the Denmar Member of the Greenbrier Formation of West Virginia and the Warix Run Member of the Slade Formation of Kentucky (Butts, 1924; de Witt and McCarew, 1979; Brezinski, 1989). It physically resembles the Warix Run, which was originally the upper part of the now-restricted Ste. Genevieve Limestone.

The depositional environment of the Loyalhanna is interpreted by several workers to be predominantly shallow marine, current-dominated sand waves. A minority have proposed an eolian dune origin, presumably subsequently drowned. In eastern Pennsylvania, other facies of the Loyalhanna are present, representing other contemporary shallow-marine and littoral conditions.

**Post-Loyalhanna Mauch Chunk (units 19-43)**

The Loyalhanna is sharply overlain by 33 feet (partially covered) of grayish-red, locally calcareous siltstone (units 10-21). This is succeeded by a series of grayish-red, non-calcareous, fining-upward cycles consisting of very fine- to fine-grained sandstones with low-angle crossbedding and scoured bases which grade up to thin siltstones or silt shales (unit 23 and possibly also units 24 [covered] and 25). These are interpreted as stacked shallow fluvial distributaries of the northward prograding edge of the Mauch Chunk lower delta plain.

Overlying the siltstone of unit 25 is 16 feet of medium- to very coarse-grained sandstone (units 26-29, including 3-foot covered unit 28). The basal 2.5 feet (unit 26) is a very calcareous, light-gray, coarse- to very coarse-grained sandstone with a large fraction of red shale and pedogenic carbonate clasts. This may represent a basal scour or lag deposit. The remainder of the sandstone and the overlying 20-foot-thick pale grayish-red siltstone and silt shale (unit 30) is non-calcareous. Units 26-30 are presumed to be some aspect of the lower delta plain distributary system. **(Notice: The outcrop of unit 30 is covered with poison ivy!)**

Next higher is an 8-foot-thick gray sandstone, which is calcareous in the lower two feet, overlain by 23 feet of calcareous, grayish-red siltstone and silt shale (units 31 and 32). The calcite occurs as cement rather than pedogenic nodules or caliche zones. Unit 32 is the most distinctly calcareous, long sequence other than the Loyalhanna. It is interesting to note that it occurs at about the expected position of the widespread marine invasion of the Alderson-Wymps Gap limestone bed in southwestern and south-central Pennsylvania.

Unit 32 is a continuation of siltstone and silt shale, but only a few places in the lower part are calcareous and red coloration is confined to part of the shalier beds. This unit also contains rare possible plant fragments.

Units 34-39 constitute a 40- to 45-foot-thick sequence of gray and bluish-gray sandstone and sand-silt laminite and grayish-red and mottled gray and red siltstone and silt shale arranged into to broadly fining-upward cycles. The are probably fluvial deposits.

Unit 40 is a 61-foot-thick sequence of fining-upward fluvial cycles. Each cycle is 10 to 12 feet thick and consists of medium-light-bluish-gray, fine- to medium-grained sandstone, with low-angle crossbedding and incised base, which grades up into medium-light-bluish-gray, greenish-gray, and reddish-gray siltstone and silt shale.

After 15 feet of cover (unit 41), the uppermost remaining Mauch Chunk Formation consists of 49 feet of medium-bluish-gray to greenish-gray, very fine- to fine-grained sandstone (unit 42) overlain by approximately 12 feet of greenish-gray, fine- to medium-grained sandstone (unit 43). Both are siliceous, hard, and dense, and superficially appear to have been partially recrystallized, based on observations of grains and bedding.

Where complete, the post-Loyalhanna Mauch Chunk Formation is essentially identical to the Chesterian Stage. What remains here is probably early to middle Chesterian. Original thickness of the post-Loyalhanna Mauch Chunk was likely in the 2000-2500-foot range.

The red to non-red facies transition problem is readily observable in this series of exposures. All Loyalhanna and post-Loyalhanna rocks up through unit 32 are dominantly grayish-red. In units 33 through 43 only the fine-grained fraction retains any red coloration with greenish-gray and the peculiar bluish-gray as the dominant colors. The sandstones of units 42 and 43 appear to be recrystallized and are very hard and dense. X-ray examination of a sample from unit 42 by R. C. Smith II of the Pennsylvania Geological Survey indicated the presence of a large chlorite fraction. The high density of the unit-42 rock suggests that it might be an iron chlorite. The non-red (or minor red) facies encompasses the uppermost 235 feet of the remaining Mauch Chunk at this point, which is not untypical regardless of what part of the Mauch Chunk Formation underlies the sub-Sharp Mountain unconformity. It is difficult to resist the speculation that this loss of red coloration and other factors is the result of secondary alteration caused by groundwater activity associated with the overlying erosion surface or by peripheral action of hydrothermal solutions passing through the overlying Sharp Mountain.

The exceptional hardness of sandstone in this altered non-red zone may explain in part the resistant ridge forming character of the Mauch Chunk in the Lackawanna synclinorium.

**Faulted contact section (units 44-50)**

This sequence provides an unusually good exposure of the effect of thrust faulting in the Pennsylvania Anthracite fields (see also Part 3 of this STOP). At least seven individual fault slices create an almost indecipherable disorder. Units 44 and 45 seem to be slices of unit 52 which is the finer-grained part of the Pottsville Formation normally overlying the basal conglomerates of unit 51. It is possible, however, that they might be detached sandstones of the Mauch Chunk Formation. Units 46 and 48-50 are detached slides of the Pottsville basal conglomerate (unit 50).

Unit 47 is a slice of grayish-black clay shale with abundant plant fragments, mostly rooting structures. While it is possible that this is shale from relatively higher in the Pottsville, it is more like a piece of the Campbells Ledge shale bed which occurs frequently at or near the base of the Pottsville conglomerates but above the sub-Sharp Mountain unconformity. Although apparently not the case here, the Campbells Ledge shale elsewhere may contain recognizable flora and insects. Read (1944, p. 680) identified the flora of the Campbells Ledge as "Mercer age" (i.e., late Atokan age [ c. 310 Ma]) which would place it in the upper part of Read and Mamay's (1964) floral zone 8. The source and depositional nature of the Campbells Ledge shale is obscure. In some cases, such as here, it seems to be more of a paleosol; in others, it is a thin carbonaceous shale deposited on the sub-Sharp Mountain erosion surface prior to the arrival of the first Pottsville (Sharp Mountain) conglomerates—or it may be interbedded with the very earliest conglomerates. On northbound I-81 at road-log mile 64.5 (Day 1) a discontinuous 8-inch coalbed occurs at this horizon.

**Pottsville Formation—Sharp Mountain Member (units 51-52)**

In the Northern Anthracite field only the Sharp Mountain Member of the Pottsville Formation remains. The lower two members are cut out by erosion at the sub-Sharp Mountain unconformity.

The Sharp Mountain is not completely exposed at this STOP, and the thickness of what is exposed is uncertain because of structural complications. The basal Sharp Mountain here consists of about 90 feet of light- to medium-gray conglomerate and conglomeratic sandstone (unit 51). Grain size is mostly from coarse sand to one-inch pebbles. Clasts are dominantly clear or white quartz. Bedding is lenticular or wedge-shaped with common trough crossbedding. Fossil trunk, branch, and other plant fragments occur commonly. All features indicate a high-energy, braided alluvial deposit.

The basal conglomerate is overlain by medium-gray, medium-grained sandstone, largely in planar beds with some plant fragments (unit 52). These beds represent a transition to a lower-energy fluvial system.

## Part 3. Structure (Gillmeister)

Rocks of the upper part of the Mauch Chunk Formation are exposed along the railroad grade that lead north to the contact with the Pottsville Formation. The rocks dip gently to the north and gradually change from red-beds to greenish-gray lithologies closer to the contact. A relatively widely spaced pressure solution cleavage that is nearly perpendicular to bedding also becomes prominent close to the contact.

Figure 38 is a sketch of the contact relationships on the west side of a cut that extends from the Mauch Chunk to the Llewellyn Formation. The relationships are not simple and appear to change, along strike, from one side of the cut to the other.

The contact, as shown on Figure 38, occurs at what appears to be an asymmetric kink fold with a steep limb that dips to the north. Minor thrust faults occur in both the Mauch Chunk and the adjacent Pottsville conglomerate. On the east side of the cut, the contact is along a nearly vertical fault with the Mauch Chunk side displaced up with respect to the Pottsville. Note that the widely spaced cleavage is folded, and that a more closely spaced cleavage, nearly parallel to the axial plane of the fold, is present in the lower part of the outcrop on the west side of the cut.

A unit of carbonaceous shale and sandstone overlies the first conglomerate beds. Small conjugate thrust faults, what appear to be small drag folds ( along northern contact), and a well-developed closely spaced pressure solution cleavage characterize the shales. The contact with the conglomerates to the north appears to be conformable on the west side of the cut, but looks like a fault, with cataclastic features in the conglomerate, on the east side.

Another important feature to be seen here is that the nearly vertical shales are overlain by nearly horizontal conglomerate. One interpretation is that we are looking at a strange variety of fault duplex with a roof thrust that has been "lubricated" by carbonaceous shale. Remnants of a striated fault plane are visible at point B (Figure 38). The striations trend nearly north-south, but the polarity of slip is not obvious. Numerous vugs, partially filled with quartz crystals, are present in rocks immediately below, but not above, the fault, indicating cataclasis of the underlying rocks and the probable presence of high fluid pressures during faulting.

Other structures that can be examined include pre-folding, north-striking, strike-slip faults at points A and A1 on Figure 38. Lineations on the faults plunge gently north, but at A1 the fault surface has been folded to give steeply plunging lineations. A small, tightly folded, thrust fault is present in the lowest conglomerate unit on the east side of the cut, as is a large north-striking joint surface that is encrusted with quartz crystals.

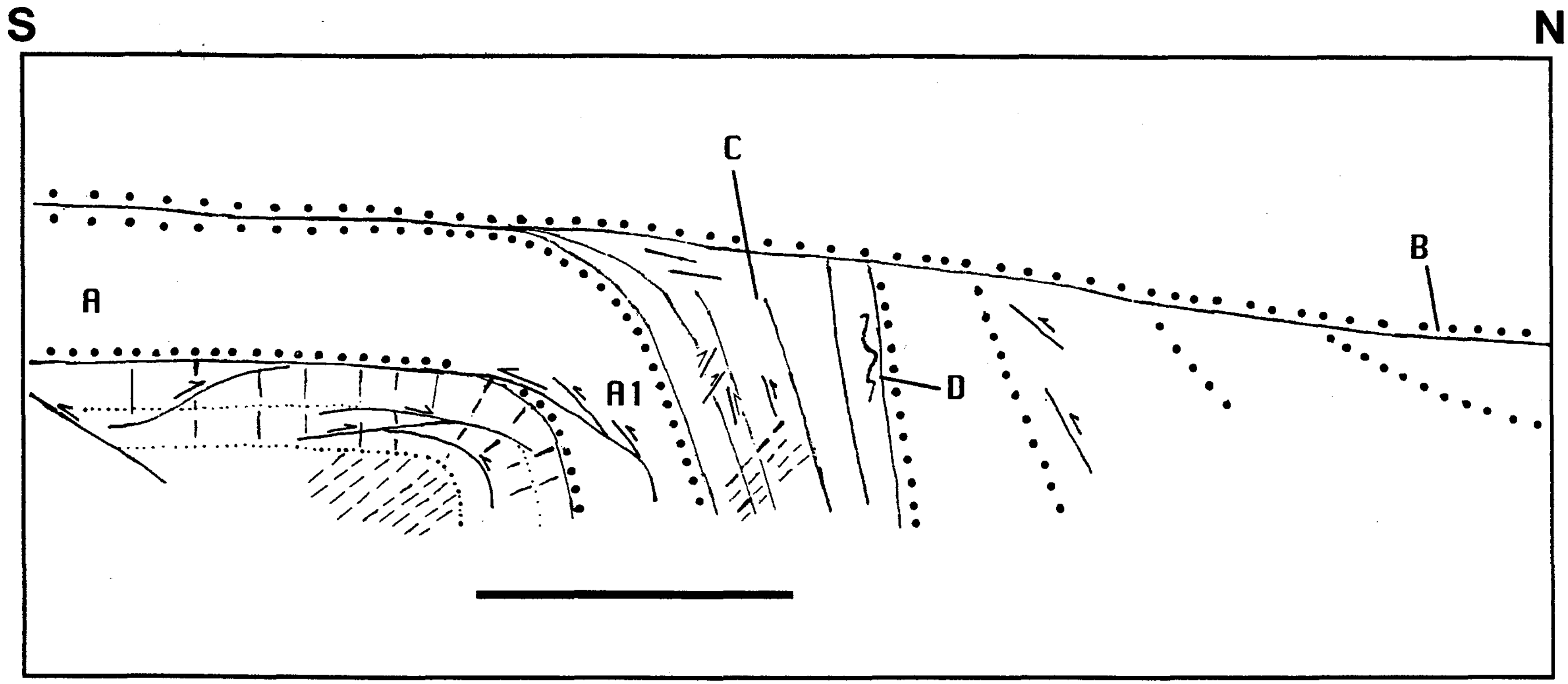



Figure 38. Sketch of important structural features in cut on old railroad grade, as seen looking to the west. The scale bar is about 20 feet long. Bedding in the Mauch Chunk is outlined schematically by a pattern of small dots. Bedding in conglomerates of the Pottsville Formation is shown by a pattern of filled circles. Letter C marks a unit of carbonaceous shale and sandstone, where bedding is schematically indicated by solid lines. Short, dashed lines indicate cleavage; the spacing of the lines reflects the spacing of the cleavage. Solid lines with arrows indicate small thrust faults. Pre-folding, strike-slip faults are present at A and A1. D marks the location of small drag folds along the shale-conglomerate contact. B locates an exposure of a striated fault surface and fault gouge that separates a continuous layer of conglomerate from a variety of lithologies below.

The quartz-filled joint surfaces are also consistent with high fluid pressures in the rock, that allowed the tensional fractures to form.

Orientation data for the faults, including the bearing and plunge of striations, is shown on Figure 39A. The orientation of bedding for the rock-cut and adjacent area is shown on Figure 39B.

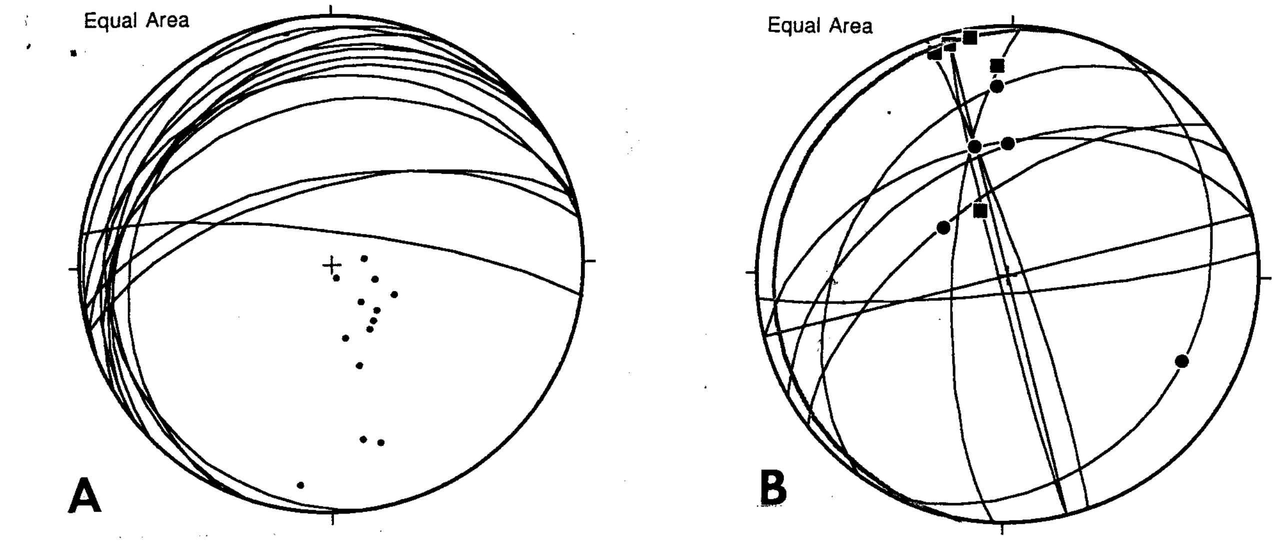



Figure 39. Stereograms (Schmidt net), lower hemisphere projections, of structural elements at STOP 3. A. Bedding, shown as great circles and poles. B. Faults, shown as great circles. The orientation of striations on fault surfaces is also shown, where data are available. Filled circles indicate the lineations on thrust faults, squares indicate strike-slip faults. The orientation of the large fault at B on Figure 38is shown by the gray great circle with the square showing orientation of the gently north-plunging lineation.

| | | |
|---|---|---|
| | | Leave STOP 3, returning to PA 115 via park access-road. Turn left on PA 115, going north toward Wilkes-Barre. |
| 1.1 | 49.0 | Traffic light. Continue straight ahead on PA 115N. |
| 0.5 | 49.5 | Cross I-81. |
| 0.6 | 50.1 | Bear right onto Exit 1 (PA 315N). |
| 0.3 | 50.4 | Ahead in distance to north can be seen the "315 Quarry" of the American Asphalt Paving Company (STOP 4). |
| 0.2 | 50.6 | Bear left at fork in exit ramp. |
| 0.2 | 50.8 | Traffic light. Turn left onto PA 315N. |
| 0.2 | 51.0 | Cuts in sandstone and conglomerate of the Llewellyn Formation to right (containing large plant trunks at the entrance to the Hampton Inn). |
| 0.2 | 51.2 | Cross Laurel Run, to which "The Tubs" stream is tributary. Laurel Run was yet another ice-marginal sluiceway that fed a delta in Glacial Lake Wyoming, this one at Parsons downstream to the left. |
| 0.1 | 51.3 | Woodlands Inn to right is the place to "party" in the Wilkes-Barre area. It has one of the largest alcoholic beverage budgets among such establishments in the Commonwealth. |
| 0.1 | 51.4 | Cuts in Llewellyn Formation adjacent to and across from Plaza 315. Disruption of bedding in dark-gray sandstones and occurrence of two thick rootworked seatrocks suggest the former presence of mined-out coalbeds here (though no coal is now evident). |
| 0.5 | 51.9 | Traffic light in Fox Hill. Continue straight on PA 315N. |
| 0.2 | 52.1 | Entrance to Pocono Downs racetrack on left. |

| | | |
|---|---|---|
| 0.1 | 52.2 | Cross Mill Creek valley (glacial sluiceway) a second time today. |
| 0.3 | 52.5 | To right, behind Hanover Homes, is a 20- to 30-foot-high cut in till and kame gravels. |
| 0.5 | 53.0 | Traffic light. Continue straight ahead. |
| 0.5 | 53.5 | Turn left onto Ridgewood Road at sign for American Asphalt Paving Co., passing through village of Keystone. |
| 0.6 | 54.1 | Bear right into quarry entrance. **Buses continue about 0.5 mi, past crushing and processing plant to upper level of quarry.** |

**STOP 4.** ***STRATIGRAPHY AND ECONOMIC GEOLOGY OF THE LLEWELLYN FORMATION IN THE "315 QUARRY" OF THE AMERICAN ASPHALT PAVING CO.***
Leader: William Edmunds.

The American Asphalt Paving Company's "315 Quarry" (Figure 40) produces crushed stone from sandstones associated with the Red Ash and Ross coalbeds near the bottom of the Llewellyn Formation (Figures 41and 42; see Appendix B-3 for detailed stratigraphic description). Current production is from units 10 and 15. In the recent past, unit 6 was also quarried from a pit in the center of the operation, now mostly buried and covered by stockpiles. Other sandstones have provided minor amounts.

Approximately 130 feet of Llewellyn-Formation strata are exposed in the quarry, including the Middle and Upper Red Ash and Lower and Upper Ross coalbeds. Air drill hole records show the presence of the Lower Red Ash coalbed, marking the base of the Llewellyn, 60 to 66 feet below the Middle Red Ash. Below that are 150 to 203 feet of the Sharp Mountain Member, which constitutes the entire Pottsville Formation in the Northern Anthracite Field, and the upper 257 feet of the Mauch Chunk Formation.

All three Red Ash coalbeds were originally mined underground in this area, mostly as part of the operations of the old Packer colliery of the Lehigh and Wilkes-Barre Coal Company. The present quarry was probably developed as an extension of the earlier open-pit coal mines.

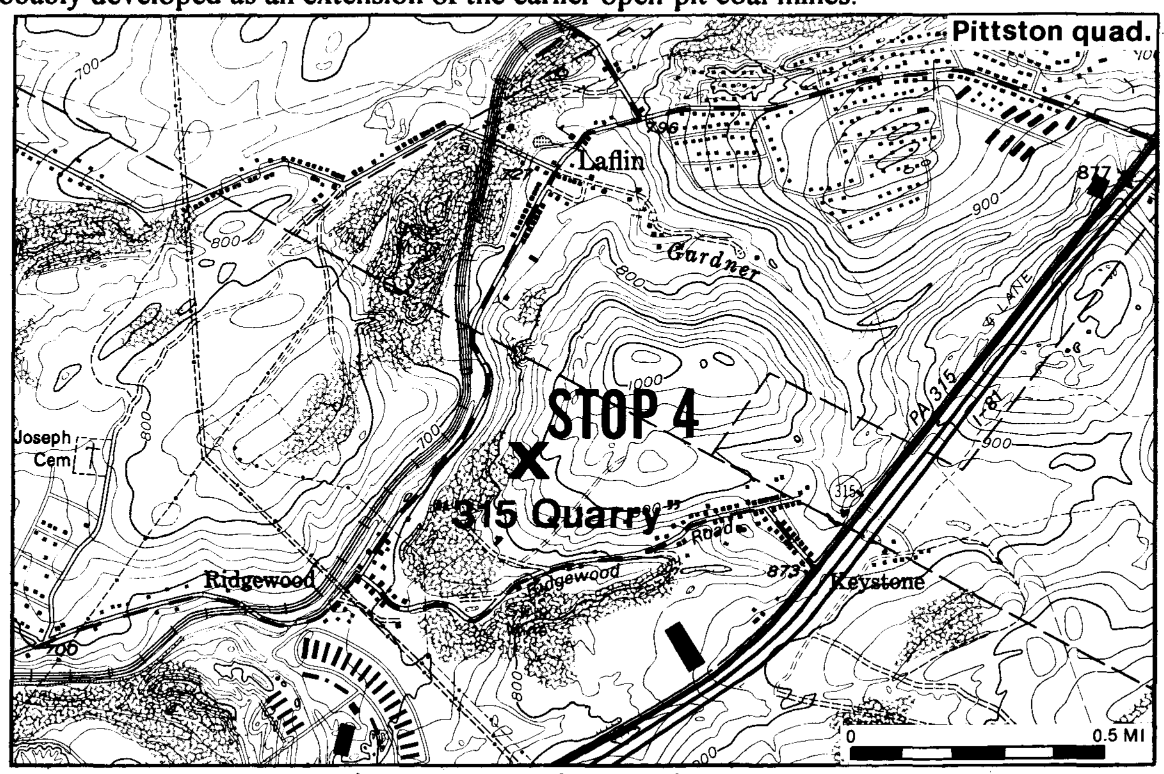


Figure 40. Location map for STOP 4.

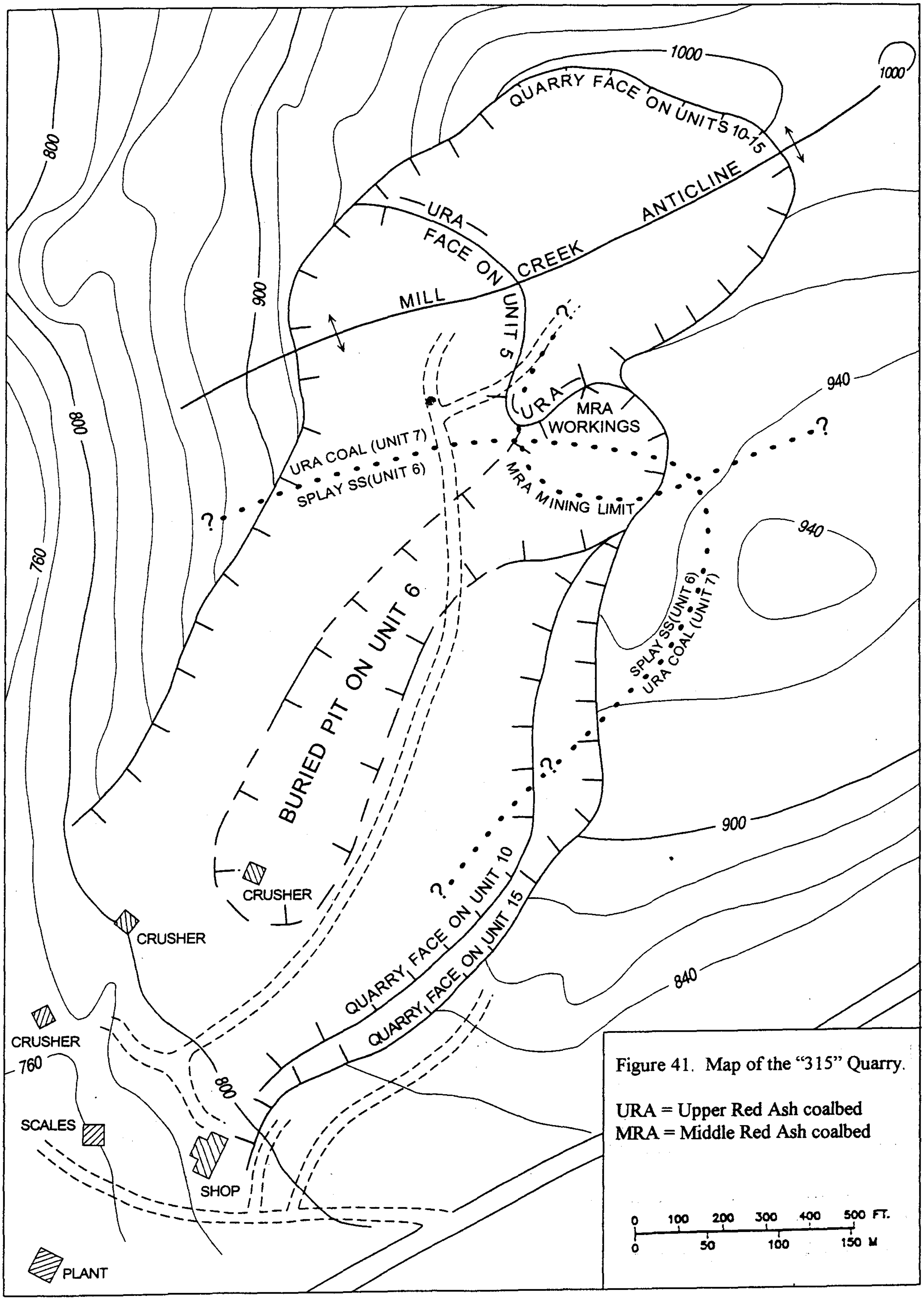



Figure 41. Map of the "315" Quarry.

URA = Upper Red Ash coalbed
MRA = Middle Red Ash coalbed

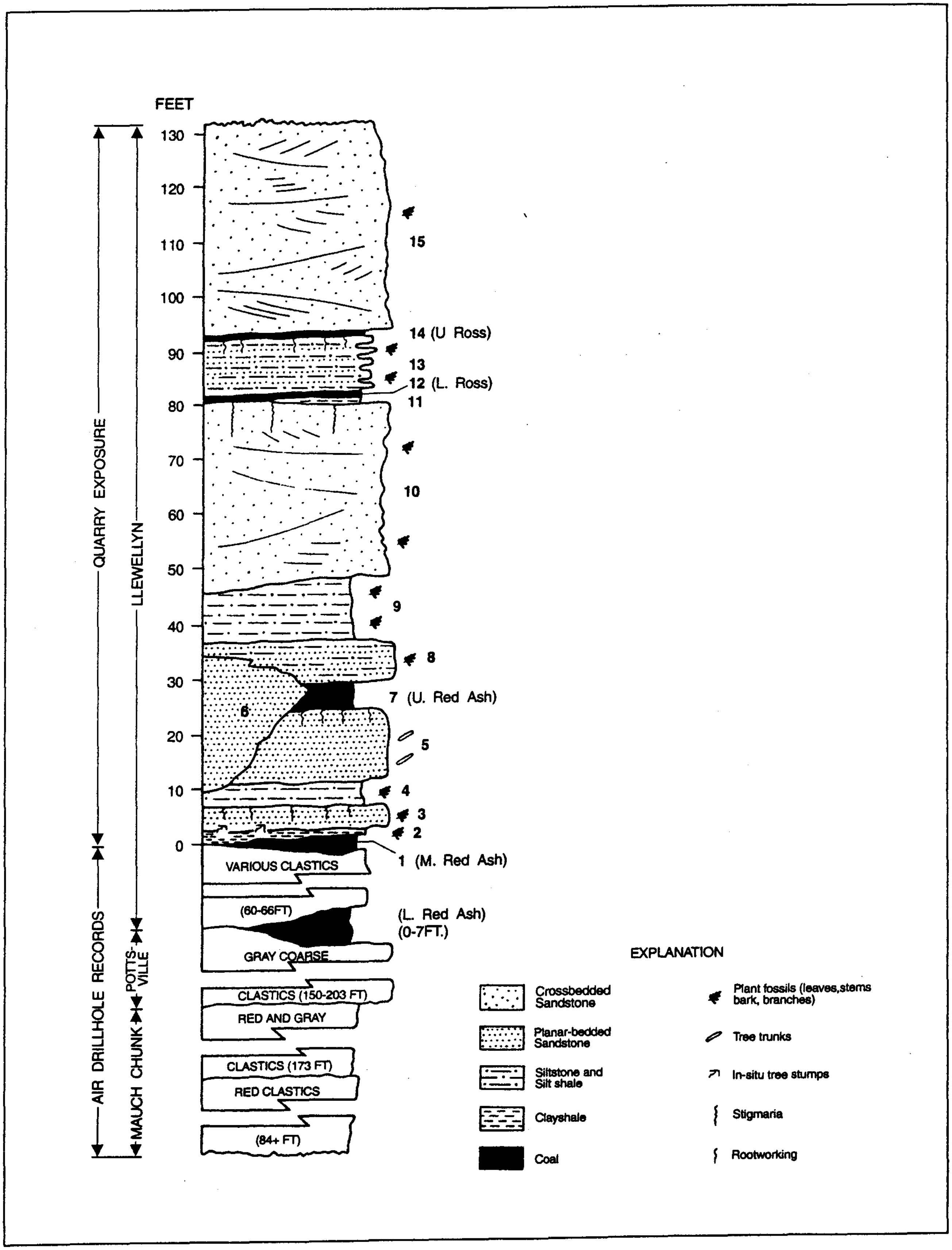



Figure 42. Stratigraphic column of the Llewellyn Formation exposed at STOP 4, the “315 Quarry.”

Operations have encountered past deep mining on the Upper Red Ash coalbed in the northern part of the quarry and mine timbers and rails were exposed along the southwest edge of the north quarry level. Mine openings on the Middle Red Ash are exposed in the northeast end of the abandoned lower quarry level (Figure 41).

Drilling indicates that none of the Red Ash coalbeds are completely continuous across the property. The nature of the loss of the Lower and Middle Red Ash seams is not known, but the Upper Red Ash (unit 7) is laterally displaced and/or cut out by an incised splay sandstone (unit 6). The Upper and Lower Ross coalbeds are too thin to mine.

The exposure in the "315 Quarry" is typical of the lower part of the Llewellyn Formation (Figure 42). Low-energy peat swamps alternated with blankets of high-energy fluvial sand. Lithologic transition tend to be fairly abrupt. Most sandstones overlie coal beds, either directly, such as units 8 and 15 above the Upper and Lower Red Ash seams, or with only a thin fine-clastic interval, such as unit 2 (shale) overlying the Middle Red Ash seam. Similarly peat swamps succeed fluvial sands with little or no fining-upward shale or underclay/paleosol. Sub-coal *Stigmaria* and root-working penetrate directly into underlying sand substrate.

Most sandstones appear to be laterally persistent and, at least on a local scale, do not occupy channels cut into previous sediments. Planar bedding, wedge-shaped foreset bedding, and large-scale trough crossbedding are all common. The depositional environment of the unit 6 sandstone—which laterally displaces the Upper Red Ash coalbed (unit 7) and is incised into underlying units 5 and 4—is exceptional. It appears to have originally formed as a crevasse splay which, after breaking the previously established Upper Red Ash peat swamp and developing a high-energy fluvial channel, cut out the Upper Red Ash peat and the underlying unit 5 sand over a substantial area (Figure 42). The Upper Red Ash swamp seems to have persisted laterally to the fluvial channel for a time before being buried by the sandstones and siltstones of unit 8—which is in itself, in part, a lateral facies of the upper part of the unit 6 sandstone.

Various plant fossils occur throughout the section. The carbonaceous clay shale (unit 2) overlying the Middle Red Ash coalbed contains abundant, well preserved leaves and other plant parts, as well as *in situ* stumps up to three feet high. (The stump casts themselves seem to have disappeared over the last few years, but the mold impressions are still present near the Middle Red Ash openings at the northeast end of the lower quarry level.) Another carbonaceous shale (unit 4), three feet higher, also contains good plant impressions and represents an incipient coal bed as indicated by the root-working present in the underlying sandstone (unit 3). In places, the overlying unit 5 sandstone contains large tree trunks and other plant debris. Well preserved plants are also present in the unit 9 siltstone, several feet above the Upper Red Ash coalbed. Extraordinary *Stigmaria* up to several feet long occur commonly in the upper part of the sandstone underlying the Lower Ross seam.

Although the Pennsylvanian paleobotany of the Northern Anthracite field was examined by C. D. White almost a century ago and, no doubt, a number of others since, published results are fragmentary. Logically, it should be reasonable to assume that the lower coal beds of the Llewellyn Formation and associated paleobotany here should be equivalent to the lower seams of the Llewellyn in the Southern and Middle fields. That is to say that they should be assignable to Read and Mamay's (1964) floral zone 10 (zone of *Neuropteris flexuosa* and *Pecopteris* spp.). However, C. D. White (1904, p. 269, and 1912, p. 441) states that the Red Ash (White's Dunmore) coalbeds are older than the basal-Llewellyn Buck Mountain coalbed to the south, and therefore, are "Pottsville." By inference then, the Red Ash coals should fall in Read and Mamay's floral zone 9 (zone of *Neuropteris rarinervis*) and the Pottsville-Llewellyn contact is miscorrelated in the Northern field. This problem has never been adequately pursued.

The main structural axis of the Northern Anthracite field (Lackawanna synclinorium) lies about 1.25 miles northwest of the "315 Quarry." The southward dip of the beds here is a reflection of the east-west Mill Creek anticline, the axis of which lies across the north end of the quarry (Figure 41). The Mill Creek anticline is one of many such subordinate structures which strike between east-west and N45E through the length of the Northern field. Since the main axis of the Lackawanna syncline changes direction by about 70 degrees from ENE-WSW to N-S along the length of the Northern field, these subordinate axes are about parallel to the main axis at the southwest end, but almost perpendicular to the main axis at the north end (see Figure 10).

| | | |
|---|---|---|
| | | Leave STOP 4, proceeding back to quarry entrance and turning left onto Ridgewood Road toward Keystone. |
| 0.6 | 54.7 | Stop sign. Turn left onto PA 315N. |
| 0.4 | 55.1 | Several cuts in subhorizontal Llewellyn sandstone to right. The northernmost cut at the crest of the hill contains abundant large plant trunks and branches (casts). |
| 0.3 | 55.4 | To right is a long cut in subhorizontal to southeast-dipping Llewellyn sandstone and conglomerate, containing a possible mined-coal horizon (rootworked seatrock overlain by fractured sandstone). A discontinuous, dark-gray shaly bed contains a profusion of carbonized plant remains, including many *Calamites* trunks. |
| 0.3 | 55.7 | At traffic light, cross Gardner Creek valley (glacial sluiceway) a second time. Continue straight ahead. |
| 0.2 | 55.9 | Cuts in strongly crossbedded Llewellyn sandstone and conglomerate on both sides of road. |
| 0.1 | 56.0 | Subhorizontal, crossbedded, platy Llewellyn to left at crest of hill. |
| 0.3 | 56.3 | Traffic light at Dunkin' Donuts. Continue straight ahead. |
| 0.1 | 56.4 | To right is a cut in kame gravels. |
| 0.4 | 56.8 | Cut through anticline in Llewellyn sandstone, axis trending about N60E. |
| 0.3 | 57.1 | Continue straight ahead through two traffic lights near Abraham Chevrolet. |
| 0.5 | 57.6 | Bear right onto I-81 ramp. |
| 0.3 | 57.9 | Merge left onto I-81N. |
| 0.3 | 59.2 | To right are the approach lights and large embankment fill for the Wilkes-Barre/Scranton Airport. |
| 0.4 | 59.6 | Cuts in Llewellyn Formation on both sides of highway (see mile 8.0). |
| 0.2 | 59.8 | Continue past Exits 49A and 49B. |
| 0.8 | 60.6 | To right are outcrops of gently northwest-dipping, cross-bedded, platy Llewellyn sandstone with a pillar of a 2-foot-thick coalbed (Dunmore No. 3?) near the north end. (Several timber props stick out of the collapsed mine passages adjacent to the pillar.) Another collapsed coal horizon lies several tens of feet farther north. The entire exposure shows marked evidence mine subsidence. |
| 0.3 | 60.9 | Enter Lackawanna County. Just beyond the county line are scattered outcrops of gently southeast-dipping, medium-dark-gray, granule to small-pebble quartz conglomerate that may be upper Pottsville. (Then again, it may be Llewellyn!) |
| 0.4 | 61.3 | Cross broad valley of Spring Brook again. To right is the Rocky Glen sluiceway. |
| 0.2 | 61.5 | Exit 50 (Moosic). Continue straight ahead. |
| 0.5 | 62.0 | Cross Pennsylvania Turnpike (I-476). |
| 0.1 | 62.1 | Cut through gently west-dipping, crossbedded Llewellyn sandstone. |
| 0.5 | 62.6 | Subhorizontal, crossbedded Llewellyn sandstone, containing a discontinuous coalbed halfway up on the left side of cut. |
| 0.4 | 63.0 | Splendid cut through Llewellyn Formation, containing two exposed coalbeds (probably the Dunmore Nos. 1 and 2) the lower and thicker one (8-22") underlain by a thick, sandy rootworked seatrock in which several upright tree trunks (probably *Sigillaria*) occur |

(Figure 43). A still lower third coalbed (Dunmore No. 3?) was apparently mined out at about road level. (A pillar of this bed [or a thickened phase of the middle bed], 30" thick, is present at the north end of the cut on the right side.)

| | | |
|---|---|---|
| 0.3 | 63.3 | View to right of incised meanders (one occupied by the Lackawanna County Stadium) of the Rocky Glen glacial sluiceway. |
| 0.4 | 63.7 | Exit 51 (Davis Street-Montage). Continue straight. |
| 0.4 | 64.1 | Cut in lower Llewellyn Formation exposing three coal beds, probably the Clark and Dunmore Nos. 1 and 2. |
| 0.4 | 64.5 | Pottsville Formation (with Campbell's Ledge coalbed at base) and underlying Mauch Chunk sandstone exposed to left. |
| 0.5 | 65.0 | Old quarry in Mauch Chunk Formation across Stafford Meadow Brook to right. |
| 0.3 | 65.3 | Cut in olive-gray Mauch Chunk sandstone to left. |
| 0.8 | 66.1 | Bear right at Exit 52 (River Street). |
| 0.2 | 66.3 | Stop sign. Turn left following signs for PA 307. The two-story concrete building directly opposite the stop sign is built on top of the slag dump of the Lackawanna Iron Furnaces. A cut though the slag dump on the northbound lane of I-81 is visible to the right from the bridge over the interstate. |
| 0.1 | 66.4 | Stop sign. Turn right onto Meadow Avenue. |
| 0.2 | 66.6 | Traffic light. Turn right onto Moosic Street (PA 307S). |
| 0.2 | 66.8 | Cross I-81. |
| 0.1 | 66.9 | Deep cut in crossbedded Pottsville conglomerate exposing a low anticlinal fold at the south end. |
| 0.3 | 67.2 | Pottsville conglomerate in a low anticlinal fold to right. |

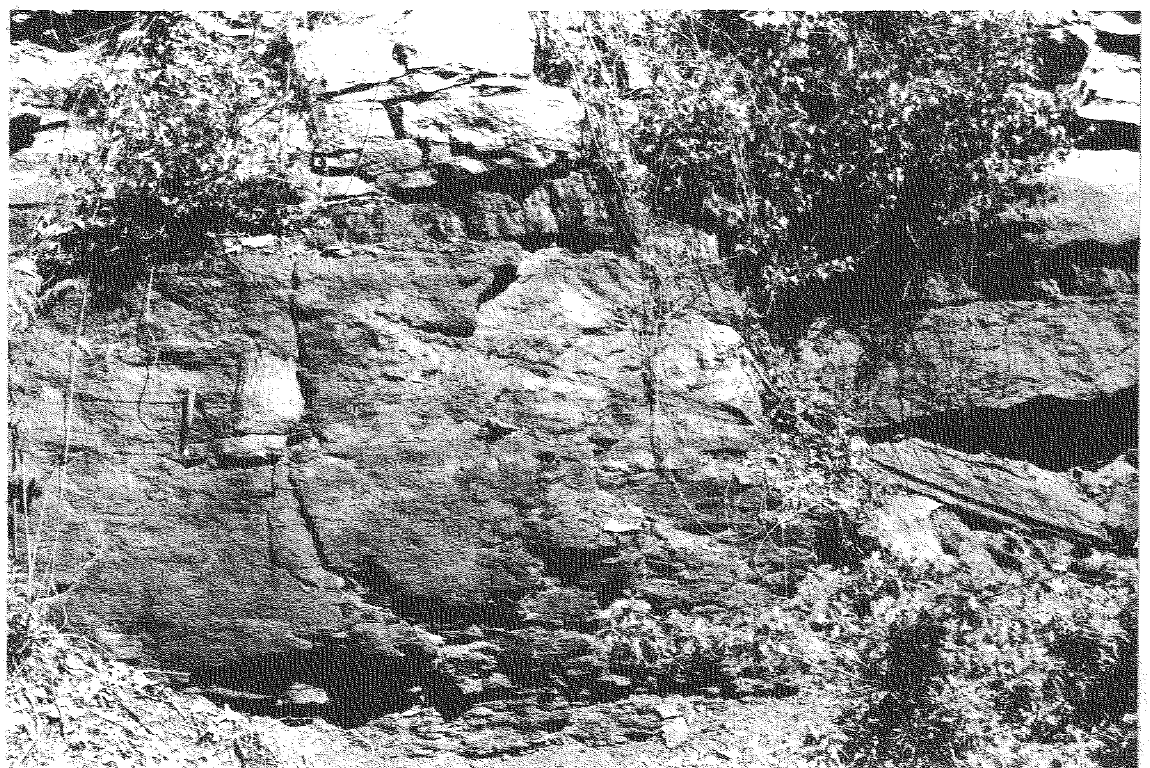


Figure 43. *Sigillaria* (?) stump in seatrock beneath the Dunmore No. 2(?) coalbed on I-81 at mile 63.0. Note the long *Stigmaria* slanting down to the right. Hammer to left gives scale.

| | | |
|---|---|---|
| 0.7 | 67.9 | Pottsville conglomerate ledges exposed at crest of hill. |
| 0.1 | 68.0 | Traffic light. Turn left opposite Lake Scranton. Uppermost Pottsville strata are exposed to the right and basal Mauch Chunk in roadcut directly ahead |
| 0.1 | 68.1 | Stone structure to right of road. |
| 0.4 | 68.5 | Stop sign. Turn right. |
| 0.5 | 69.0 | Low north-dipping ledges of Mauch Chunk sandstone to right. |
| 0.1 | 69.1 | Turn right into old quarry area. **Park buses on roadway between two shallow run-off pits.** |

**STOP 5.** ***THE ELMHURST BOULEVARD PIT AND "THE STUMPS": FOSSIL PLANTS AND THE REMAINS OF A MISSISSIPPIAN PALEOFOREST IN THE MAUCH CHUNK FORMATION.***
Leader: William Kochanov.

## INTRODUCTION

During the spring of 1996, plant fossils were found in an inactive aggregate quarry located in the southwest corner of the Olyphant 7.5-minute quadrangle just south of Elmhurst Boulevard (Figure 44). Since the site was mapped as part of the Mauch Chunk Formation (Berg and Dodge, 1981, p. 438), the presence of a well-preserved floral zone made the site significant. Detailed descriptions of plant fossil assemblages from the Upper Mississippian are rare in Pennsylvania. This was not the first time that fossil plants have been observed at this locality. Sevon (1997, personal communication) noted their presence in July of 1976 as part of field work associated with the compilation of the 1980 state geologic map.

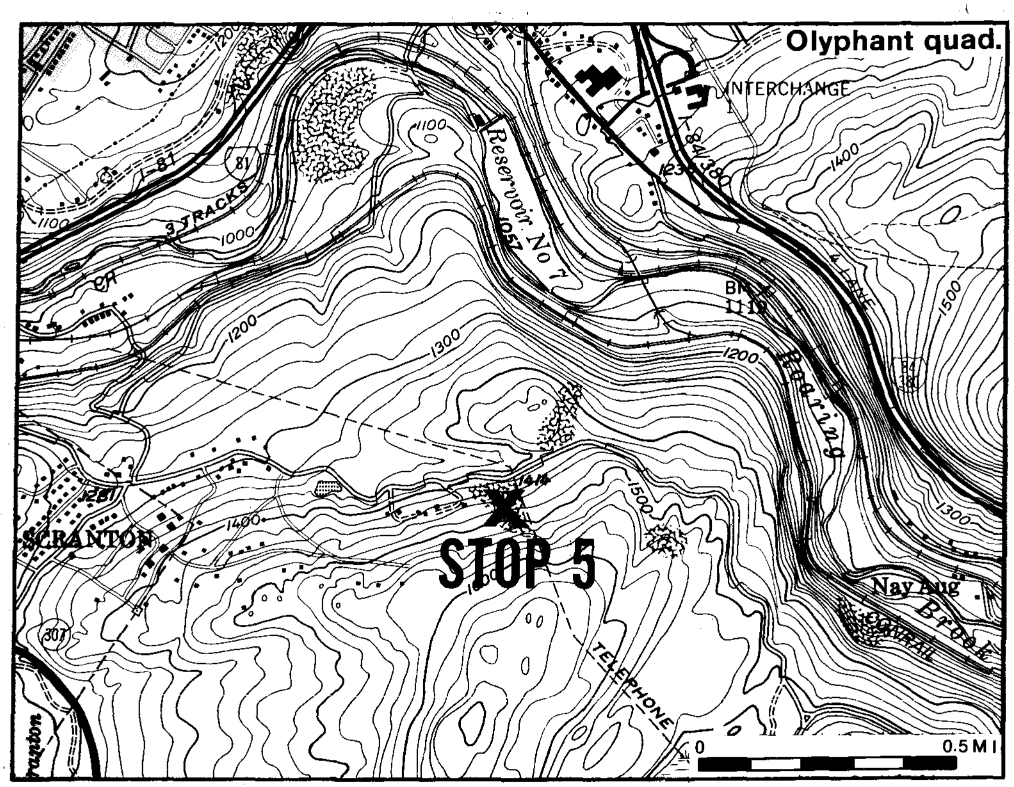



Figure 44. Location map for STOP 5.

The "rediscovery" of the plant fossils resulted in much speculation as to the relative age of the rock unit and its stratigraphic relationship with nearby sections. Most notably the I- 84/380 roadcut (STOP

7B). It was suggested at an early stage of the investigation by Edmunds (1996, personal communication) that the flora may not be Mississippian in age but correlative with the Pennsylvanian Campbells Ledge, an areally discontinuous, carbonaceous shale unit that occurs stratigraphically below the Sharp Mountain Member of the Pottsville Formation. The Campbells Ledge shale was first noted by White (1883) at its type locality near Coxton, Lackawanna County, and was included as part of his Susquehanna Gap Section. Underlying the Pottsville conglomerate (i. e., Sharp Mountain Member) is a five-foot-thick *bituminous slate* described as having abundant plant and insect fossils underlain by a three-foot-thick sandstone. Plant fossils identified by Lesquereux (1884) gave an early Pottsville age to the shale.

In spring of 1996, the type section of the Campbells Ledge shale was visited by Bill Kochanov of the Pennsylvania Geological Survey and intern Mike Cypcar in order to sample the fossil-bearing shale and make comparisons with the Elmhurst Boulevard flora. The collection consisted of numerous seed casts, molds, and compressions and rare, poorly preserved ferns. One possible specimen of a conchostracan was also found. Concurrent with the collection of the Campbells Ledge flora, a similar search was made at the Elmhurst Boulevard site with an emphasis on locating diagnostic Mississippian plant genera such as "*Triphyllopteris*" or *Rhodea*. This would confirm the relative age of the flora at the new site as being either Mississippian or Pennsylvanian.

Specimens from both sites were tentatively identified and taken to Dr. Hermann W. Pfefferkorn at the Department of Geology of the University of Pennsylvania for confirmation of the identification and possible age determination. Pfefferkorn (1996, personal communication) stated that Lesquereux's (1884) identification of the Campbells Ledge flora was suspect (some of the listed species names were of post-Pottsville time). Regarding the recent collection of Campbells Ledge flora, he stated that although many of the seed fossils were well preserved, they were not useful as biostratigraphic markers due to their lack of distinguishing characteristics. The poor preservation and limited samples of the ferns prevented their specific identification and were not a helpful tool in solving the stratigraphic problem.

The plant fossils from the Elmhurst Boulevard site are primarily lycopods occurring in the bottom six feet above the pit floor. Identification of the lycopod *Lepidodendropsis* suggested a Mississippian age. The Mississippian age was further supported by the finding of a few specimens of a fossil fern compression identified as "*Triphyllopteris*" *lescuriana* c.f. and "*Triphyllopteris*" *biloba* c.f. (The nomenclature of the genus "*Triphyllopteris*" has recently undergone revision. For this reason it is shown in quotes).

Although the discovery of the "*Triphyllopteris*" specimens did help resolve the problem of the general age of the Elmhurst Boulevard section, it also brought a new problem to light. According to Read (1955), the distribution of the "*Triphyllopteris*" flora in Pennsylvania is restricted to the upper part of the Pocono Formation. If the rocks present at the Elmhurst Boulevard site are indeed part of the Mauch Chunk Formation, then the stratigraphic range of "*Triphyllopteris*" should be extended. However, if Read's interpretation is correct then the rocks exposed in the shale pit are part of the Pocono Formation.

## LITHOLOGIC EVALUATION OF THE ELMHURST BOULEVARD SITE

In general, the Elmhurst Boulevard pit can be broken down into the following main areas (Figure 45):

1. the blocks—an area at the south end of the pit (uphill) where large slabs of sandstone are lying about;
2. the benches—an area adjacent to the blocks (west);
3. the stumps--an outcrop in the larger storm water basin at the north end of the pit.

**The blocks.** At the south end of the pit (uphill), one is standing on a pavement of fine- to medium-grained, medium-light-gray, micaceous, sandstone. About half the pavement has been disturbed by

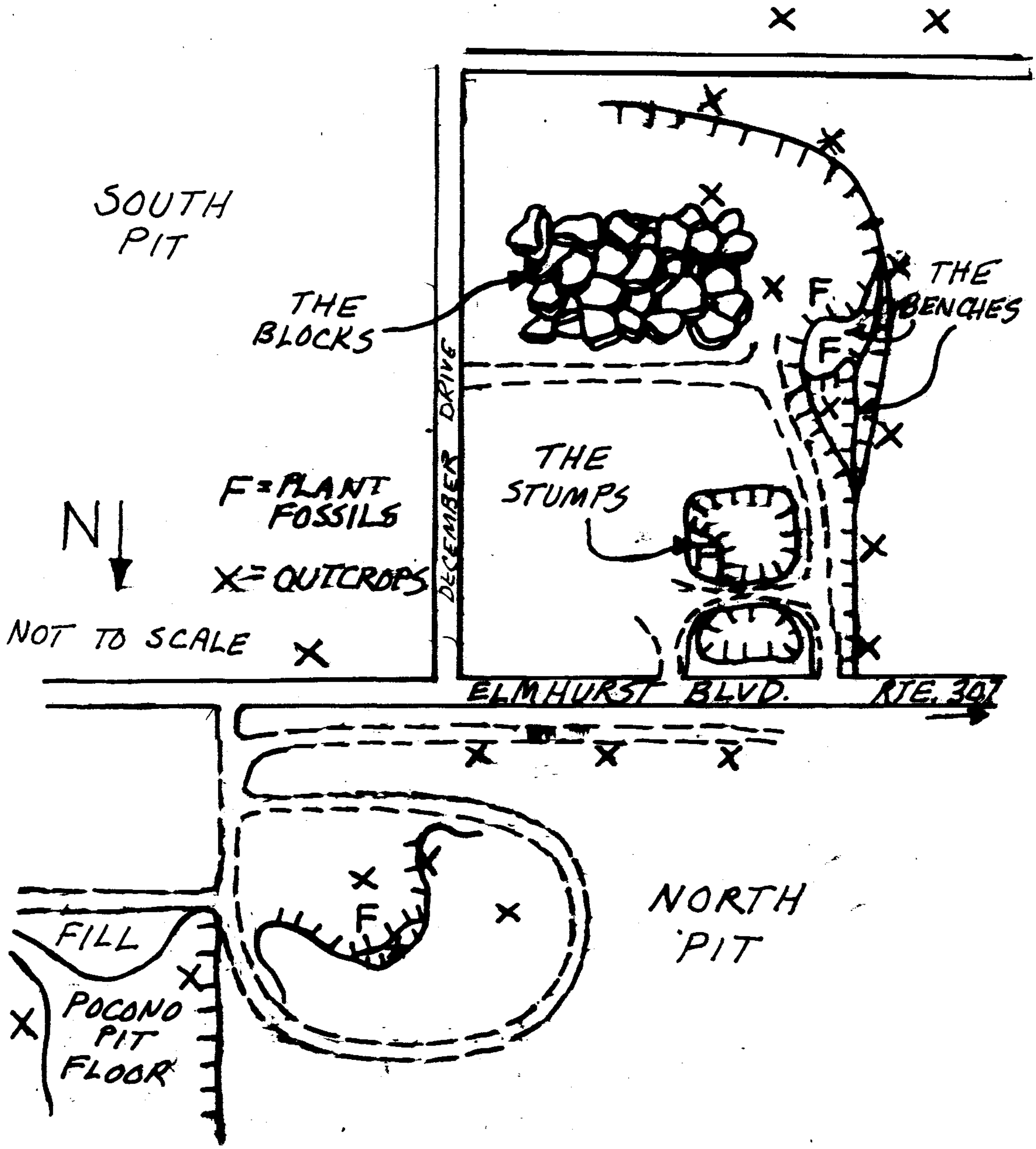



Figure 45. Generalized map of the area around STOP 5, showing sites named in the text. Not to scale.

blasting and subsequent uprooting by heavy machinery. A six-foot thickness was obtained by measuring down an open fracture.

Close examination of the scattered sandstone blocks reveals that the laminae are crossbedded (planar). Another observation is the change in the color of the sandstone from a medium-light-gray (fresh) to more brown-gray (weathered). The change in color coincides with the presence of calcite.

Not all the sandstone will react with hydrochloric acid, however. It appears to be restricted to certain individual beds or portions of those beds within the sandstone unit. This is interesting since one would expect the entire sandstone body to be reactive throughout. As a criteria for regional correlation the calcareous nature of the sandstone could be missed if one was not thorough in testing a greater number of bedding exposures.

Since this exposure is mapped as Mauch Chunk, the presence of a crossbedded, partly calcareous, fine- to medium-grained sandstone did bring to mind the Loyalhanna limestone. Loyalhanna equivalent strata has been interpreted in nearby Nay Aug Park Gorge by Edmunds (1996, personal communication) approximately one and one-half miles to the west (Pre-Conference Field Trip 2, Appendix A-2). It would not be unusual to find a Loyalhanna equivalent unit at the Elmhurst Boulevard site that is comparable with the Nay Aug section.

**The benches.** Immediately west of "the blocks," one is able to examine the overlying strata in detail. In contact with the undulating (rippled?) surface of the basal sandstone, the strata is noticeably carbonaceous in part. This is particularly true in the shallow troughs of the sandstone surface. Plant fossils—primarily roots, molds, casts and compressions of lycopods—begin to appear at this point and, going upsection, are common over the next three feet. Little or no carbonaceous material is present on the peaks of the ripples(?), where the sandstone appears gradational to a light-olive-gray micaceous siltstone.

Continuing up section, the unit grades into a dark greenish-gray, very silty to sandy claystone. It weathers a characteristic yellow to moderate brown with various blends of red, yellow, and orange particularly along bedding partings and joint surfaces.

At the first bench (Figure 45), many carbonized plant fossils are scattered about the base primarily along the south side. Limited compressions of "*Triphyllopteris*" were discovered in the greenish-gray claystone approximately 6 feet from the top of the basal sandstone (pit floor). The "*Triphyllopteris*" impressions match the matrix in color and are difficult to locate.

Bedding becomes better developed as one approaches the second bench. Here, a 20-inch-thick bed of calcareous, very fine- to fine-grained sandstone occurs. This bed possesses a weathered rind that gives it a porous appearance and is traceable along the length of the pit highwall. Small nodules are also present within the sandstone.

Thin calcareous sandstone beds can also be found along the upper highwall and along the cut on the road just above the pit to the south. The calcareous zones appear to be confined to the base of small, shallow trough crossbeds. This observation has proven to be useful in mapping sandstone bodies in the Pennsylvanian Llewellyn Formation. Calcareous sandstones have been identified for the first time in the Llewellyn by testing those that exhibit trough crossbedded structures.

Along the road immediately above the pit (south), the siltstone/claystone lithology is capped by a medium-gray, medium-grained to fining-upward, cross-laminated sandstone. The laminae are plain to see on weathered surfaces. A total thickness for this sandstone at this locality is approximately 4 feet.

**The Stumps.** Although not as critical in resolving the biostratigraphic problem at the Elmhurst Boulevard site, the presence of the stumps is significant from a paleobotanical and perhaps paleoecological perspective.

As part of the search for "*Triphyllopteris*" a number of broken sections of fossil "trees" were identified within the larger storm-water drainage basin at the north end of the pit (bottom of the hill). The sections were circular in shape, ranging from 1-2 feet in diameter, with some having a faint "sigillarian" type of pattern on their surface (Figure 46). Some specimens were found intact within the bedrock (hard, silty, olive-gray claystone) and in a vertical orientation. The stumps in place were of no appreciable height, 1-2 feet on average. It is not known if they were any taller due to the disturbed nature of the storm-water basin.

Figure 46. Fossilized tree stump in the Elmhurst Boulevard shale pit at STOP 5. Note the mold of another stump to the right.

In addition, thick tapering root casts were also discovered. Petrographic analysis of one of the roots showed mineral replacement within the core of the root cast that mimics the external shape. This appears to be preservation of the internal structure of the root.

**ACROSS THE ROAD TO THE NORTH**

To the north of the Elmhurst Boulevard pit described above is another exposure of "the stumps" strata (Figure 45). It differs in that it continues the stratigraphic section below the basal sandstone that comprises the floor of the south pit.

The sandstone unit is actually two distinct sandstone beds, an upper sandstone 6 feet thick and a lower sandstone averaging 4 feet in thickness. The upper bed, which corresponds to the basal sandstone exposed on the floor of the south pit, exhibits planar crossbedding much more clearly. The underlying light- to medium-gray, medium-grained sandstone bed appears weakly crossbedded, nearly horizontal, and is in an erosional contact with the underlying strata. The base of this sandstone is highly weathered in places, resembling the calcareous bed noted at the second bench at the south pit. The lower sandstone is also pockmarked and pitted in places where it is weathered. The pits range from approximately one-quarter to one-half inch in length. Shaly, lumpy nodules have also been observed 15 inches from the base of the sandstone.

Below the two sandstone beds, the olive-gray, silty claystone lithology, similar to that described at the south pit, returns. The thin, calcareous beds that are present, verge on being limestone. Thin-sections have not been studied to make this determination. The lower claystone section wraps around a nearby hill to the northeast allowing one to obtain a total thickness of approximately 23 feet. At its base, the unit is in sharp contact with a light-gray to light-olive-gray, medium grained, non-calcareous, crossbedded sandstone interpreted to be the top of the Pocono Formation.

Recent mining activity has also exposed the sandstone (the 4 foot[+]-thick-unit noted at the top of the south pit section) capping the upper claystone/siltstone sequence. This can be examined in the northwest corner of the north pit. In the north pit, the entire thickness of the sandstone is exposed with a total thickness of 16.5 feet.

At the top of this sandstone is a thin, bony coal (approximately 3 inches thick), followed by a brown-gray, medium-grained sandstone approximately 1.5 feet in thickness. Faint laminations can be seen on weathered surfaces. It is carbonaceous in part and micaceous. The thin coal is considered to be the base of the Pottsville Formation at this site.

The Pottsville Sharp Mountain conglomerate is visible just at the crest of the hill and is estimated to be separated from the uppermost sandstone in the north pit by 1-5 feet. The conglomerate has an approximate thickness of 23 feet.

**DISCUSSION**

Composite sections pieced together from outcrops within a one mile radius of the Elmhurst site helps put the section into somewhat of a clearer perspective (Figures 47 and 48.). They bring to light the stratigraphic changes in this part of the Mississippian section over a relatively short distance.

Tracing the PA 307 section towards the south pit, the Mauch Chunk red beds disappear and are pinched out by the underlying Pocono Formation. Tracing of the red beds and adjacent strata though the woods shows that the red beds *underlie* the non-red strata exposed in the Elmhurst Boulevard (south) pit. The siltstone/claystone sequence is present at the PA 307 outcrop and continues to the north and south pits. The calcareous sandstone capping the red beds thickens, as noted at the foundation site, but by the time it reaches the north and south pits, it is split by the siltstone/claystone sequence.

The fossiliferous facies change is unique to this part of the section. The stumps and the abundant occurrence of lycopods have not been found elsewhere in the Dunmore area. "*Triphyllopteris*" however, has been identified from the I-84/380 section.

The scant paleobotanical evidence occurring in the south pit does suggest that the section there may be correlative with rocks elsewhere within the upper part of the Pocono Formation, as inferred from Read (1955). However, Read does make some clarifications on characterizing the Mauch Chunk flora. He states that the lithology of the Mauch Chunk is not well-suited for the preservation of identifiable plant material and that correlatives of the Mauch Chunk in the northern and central Appalachians rarely show many well preserved plant fossils. Due to the limited number of plant species, he concludes that there is insufficient data to fully characterize the Mauch Chunk flora and make it distinct from the Pocono flora. This leaves the door open to the possibility that the stratigraphic range of the "*Triphyllopteris*" flora is longer than what is documented.

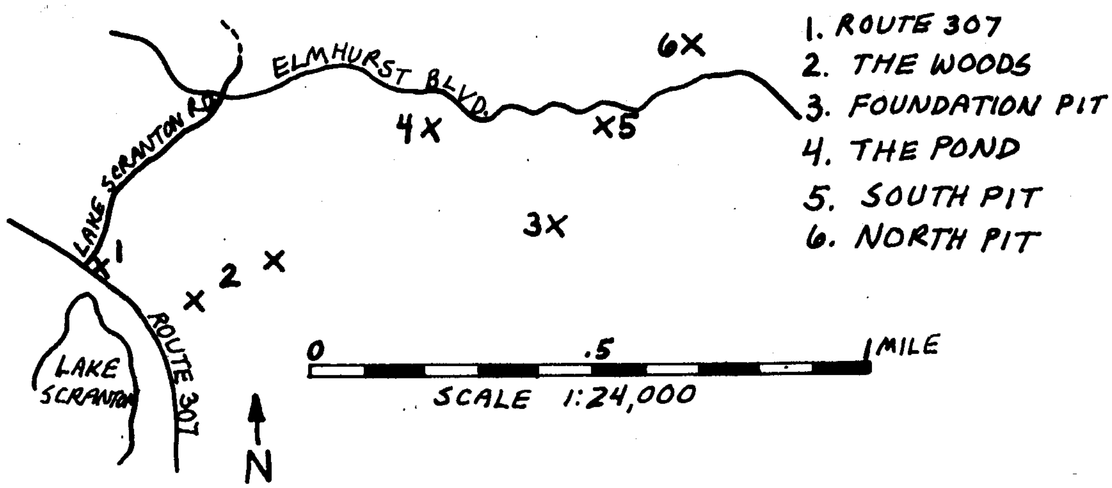



Figure 47. Map showing locations of outcrop sections used in Figure 48.

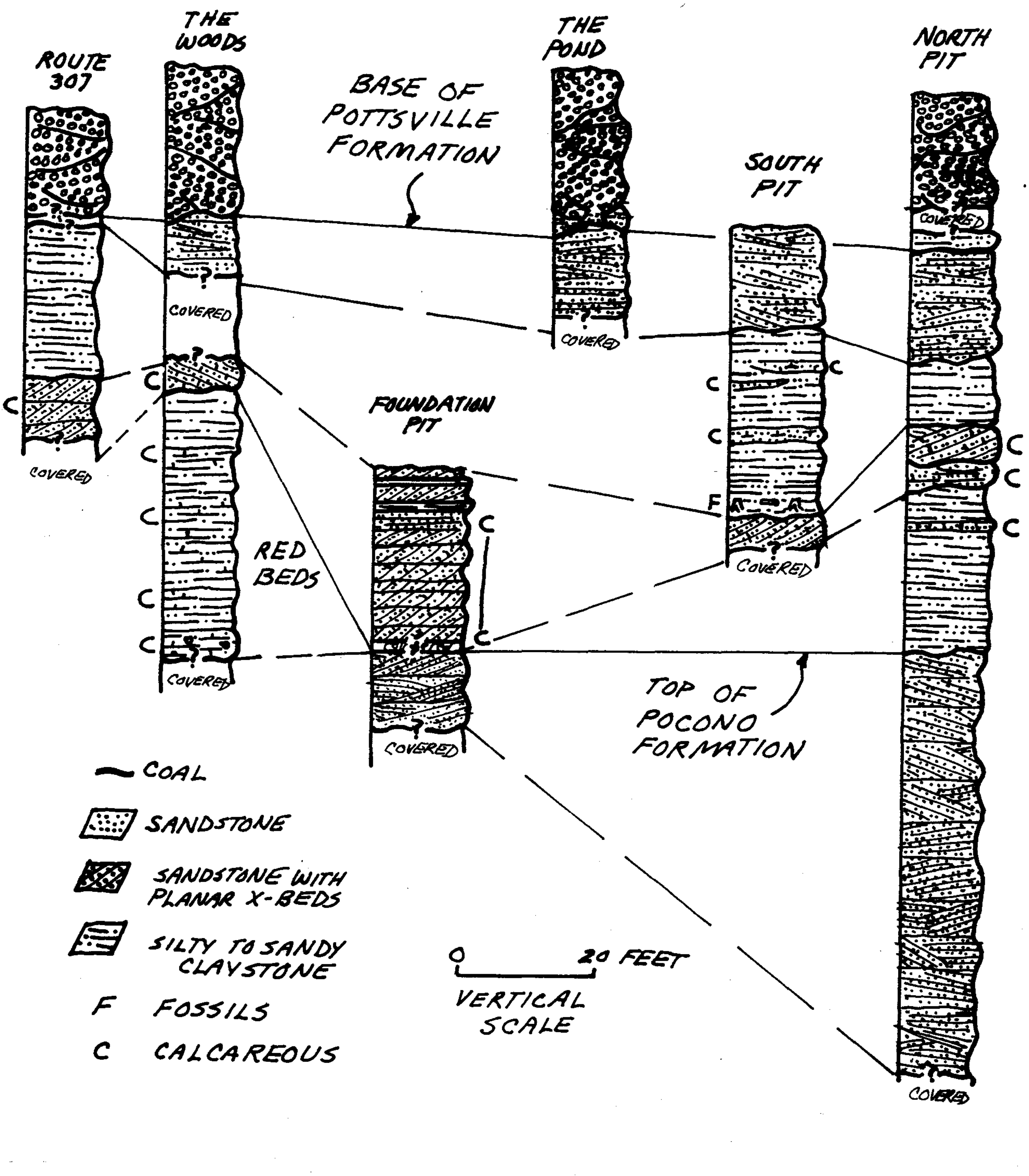



Figure 48. Outlying outcrop sections correlated to the north and south (Elmhurst Boulevard) pits.

Aside from the occurrence of red beds beneath the rocks of the Elmhurst Boulevard pit just to the west, the main lithologic characteristic bearing on their correlation revolves around the presence of calcareous beds in the Pocono. The north and south pits both contain calcareous siltstone/silty claystone and sandstone beds. Although calcareous beds were included in the Pocono in some earlier investigations (Kehn and others, 1966; Sevon, 1969), such beds are now generally recognized as belonging to other formations—particularly the Mauch Chunk. The Pocono, in the strict sense, has come to be recognized as a light-gray to light-olive-gray, medium-grained, crossbedded sandstone and minor siltstone with conglomerate beds that mark the basal contact with the underlying Spechty Kopf Formation (Berg and others, 1980; Sevon, 1975, 1997 personal communication). Calcareous beds are not considered part of the Pocono Formation.

The non-calcareous character of the Pocono sandstone lends itself useful as a field mapping tool. The challenge is properly interpreting the problematic calcareous beds that occur above the Pocono proper (i.e., the crossbedded, non-calcareous sandstones and siltstones). Are the calcareous beds part of the Pocono? Are they transitional with the overlying Mauch Chunk Formation and contain elements of both formations? Are they strictly part of the Mauch Chunk Formation and comparable to a Loyalhanna equivalent?

Are the calcareous sandstones marine in origin? No macroinvertebrate fossils have been identified from these beds. This does not preclude the possibility of finding grain-sized shell fragments at a microscopic level. Preliminary petrographic analysis has not been successful in recognizing microfossils or shell fragments at this time. Ichnofossils, aside from those associated with the plant fossils, are also not present. The homogeneity and general lack of distinct bedding in portions of the siltstone/claystone lithologies may suggest that burrowers were active but that is speculative.

Why are the sandstones calcareous? Petrographic viewing of the sandstone that comprises the south pit floor shows that the interstitial cement is the calcareous component. This leans the interpretation towards post-depositional diagenesis. To get the pore spaces at least partially filled with a carbonate cement, the carbonate minerals would have to be mobile, moving through the pore spaces by changes in hydrostatic pressure and/or through the process of evapotranspiration. The carbonate minerals concentrate and subsequently precipitate in the more porous and permeable sand bodies. As the carbonate minerals precipitate in the interstices of the sands, they may block the intergranular pathways and prevent a more complete and thorough filling of the pore spaces with carbonate minerals (the partially calcareous sandstone). Relatively larger grain sizes at the base of the sandstone beds would permit easier movement of mineral laden groundwater enhancing the occurrence of calcareous zones at the base of sandstone bodies.

The relatively, rapid thinning of the crossbedded, calcareous sandstones from the foundation pit to the north and south pits suggests that the foundation pit may have been located in a more active area of sediment deposition, perhaps part of a shallow fluvial system (ephemeral stream?). The thinner sandstones observed at the north and south pits can possibly be interpreted as sheetflood deposits.

Sheetfloods are defined as, "A broad expanse of moving, storm-borne water that spreads as a thin, continuous relatively uniform film over a large area in an arid region and that is not concentrated into well-defined channels; its distance of flow is short and is of short duration (AGI Glossary)." McKee and others (1967) described the basal sand layer of flood deposits of Bijou Creek, Colorado, as being composed of horizontal or largely horizontal layers that extended one-quarter to one-half mile from beyond the stream bank. The average thickness of the deposits ranged from 2-3 feet but reached a maximum of 12 feet in one location. The second most common structure was overlying tabular planar cross-bedding that was attributed to a reduction in current strength along the sediment front.

Reading (1978) states that sheetflood deposits deteriorate into patterns of braided channels and bars which cut into the upper surface of the sediment sheet. The result being a layer of fairly well sorted sediment accompanied by some minor small-scale scouring. He adds that cross-bedding and cross-lamination may occur.

With some degree of author circumvolutioning, a compilation of these deposits would show a basal, horizontal to largely horizontal layered sandstone with an erosional contact at the base overlain by a planar, crossbedded sandstone. In general, this is the thin medial sandstones exposed in the north pit.

After flood deposition ceased, the opportunistic lycopod flora responded by colonizing the site. The preservation of the stumps in an upright position and the presence of preserved root casts suggests that the plants were in growth position before burial and that the land surface was exposed long enough for the plants to grow. The irregular surface of the south pit floor shows areas of more carbonaceous sedimentation. The stumps flora may have exploited a low-lying area that was subsequently buried (at least partially) by finer-grained sediment during the course of more-normal deposition. The burial resulted in the death of the trees with the upper branches and stems disarticulating and possibly providing the material that is preserved throughout the pit.

In general one can say that the strata in the vicinity of the Elmhurst Boulevard pit were in a state of flux during the transition from Pocono to Mauch Chunk time. Erosional processes coupled with varying topographic relief, a fluvial environment, and a semi-arid(?) climate during the later Mississippian may have worked together producing complex, lateral facies changes over a relatively short distance.

| | | |
|---|---|---|
| | | Leave STOP 5. Turn left and retrace route to Moosic Street (PA 307). |
| 0.6 | 69.7 | Stop sign. Turn left. |
| 0.4 | 70.1 | Traffic light. Turn right onto PA 307N. Lake Scranton directly ahead is the largest of numerous reservoirs constructed by the Scranton Gas and Water Company (President, William Warren Scranton) in the 1880's and '90's. |
| 0.7 | 70.8 | Scenic Overlook to right provides a splendid view of the city of Scranton, the Lackawanna Valley, and the mountains to the northwest. |
| 0.4 | 71.2 | Cross I-81. |
| 0.2 | 71.4 | Traffic light. Continue straight ahead through this and succeeding light. |
| 0.7 | 72.1 | Traffic light. Bear right, following US11-PA 307 signs. Ahead to the right is the campus of the University of Scranton. Founded by Jesuits in 1888 as the College of St. Thomas, the institution was chartered as the University of Scranton in 1938 |
| 0.1 | 72.2 | Get into left lane (to Lackawanna-Jefferson Avenues). |
| 0.2 | 72.4 | Traffic light. Turn left onto Jefferson Avenue. |
| 0.1 | 72.5 | Turn left into parking lot of Radisson Lackawanna Station Hotel. End of Day-1 field trip. |

## DAY 2

| **Miles** | | |
|---|---|---|
| Int. | Cum. | |
| 0.0 | 0.0 | Leave parking lot of Radisson Lackawanna Station Hotel. Turn right onto Lackawanna Avenue. |
| 0.1 | 0.1 | Traffic light. Turn right onto US 11-PA 307, staying to left. |
| 0.2 | 0.3 | Bear left, following signs for PA 307 (Moosic Street). |
| 0.1 | 0.4 | Traffic light. Turn left onto PA 307S (Moosic Street). |
| 0.7 | 1.1 | Traffic light at Meadow Street. Continue straight ahead. |
| 0.3 | 1.4 | Deep cut in Pottsville conglomerate just after passing over I-81. |
| 1.0 | 2.4 | Traffic light opposite Lake Scranton. Continue straight ahead on PA 307S. |
| 0.1 | 2.5 | Gently southeast-dipping, lower Mauch Chunk sandstone and shale on both sides of road. |
| 0.3 | 2.8 | To left are low cuts in crossbedded Pocono sandstone. |
| 1.0 | 3.8 | Turn right at entrance to Lake Scranton Water Treatment Plant (Pennsylvania-American Water Company). **Proceed 0.4 mi to emergency spillway cut of Dam No. 2. Park buses and debark.** |

**STOP 6.** ***EMERGENCY SPILLWAY CUT OF DAM NO. 2: DIAMICTITE AND QUARTZ SANDSTONE OF THE SPECHTY KOPF FORMATION.***

Leaders: William D. Sevon. Donald L. Woodrow, and David E. Costolnick.

This stop at a small reservoir just east of Lake Scranton (Figure 49) provides an excellent opportunity for easy viewing of the diamictite and overlying quartz sandstone, the lowermost and uppermost units of the DMLS sequence of the Spechty Kopf Formation. Because of time constraints, the Field Conference will examine only the rocks exposed in the emergency spillway. In addition to the man-made exposures of the spillway, natural exposures of the quartz sandstone at the west end of the dam show weathering-etched bedding surfaces that emphasize both parallel-sided bedding and crossbedding at the top of the sandstone. An outcrop in the woods 100m (300 feet ) or so farther west shows diamictite in vertical contact with sandstone and a 40 x 30 x 20+ cm clast of sandstone.

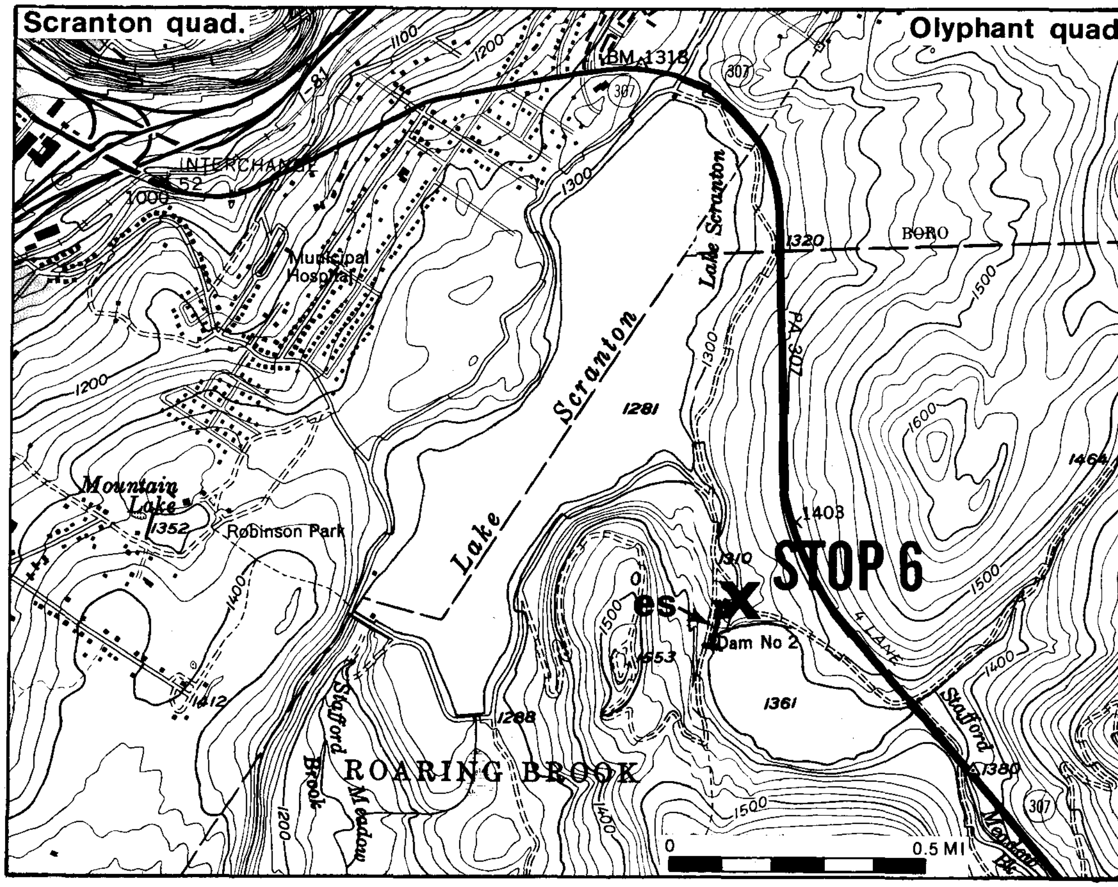



Figure 49. Location map for STOP 6. (es = emergency spillway.)

A generalized stratigraphic section for STOP 6 is shown in Figure 50. The spillway exposure is divided into 3 parts: the upper spillway adjacent to the dam, the sloping spillway between the upper and lower parts, and the spillway trench east of the sloping spillway. The diamictite is exposed along both sides of the spillway trench and the sloping spillway and may or may not form the floor of the upper spillway. The diamictite is mainly structureless in the lower part, but locally shows some crude bedding. It contains scattered clasts of quartz, quartzite, and metamorphic rocks. The largest clast noted in the trench is a mass of red shale 2.1 x 0.75 x ? m exposed on the north side of the trench near the sloping

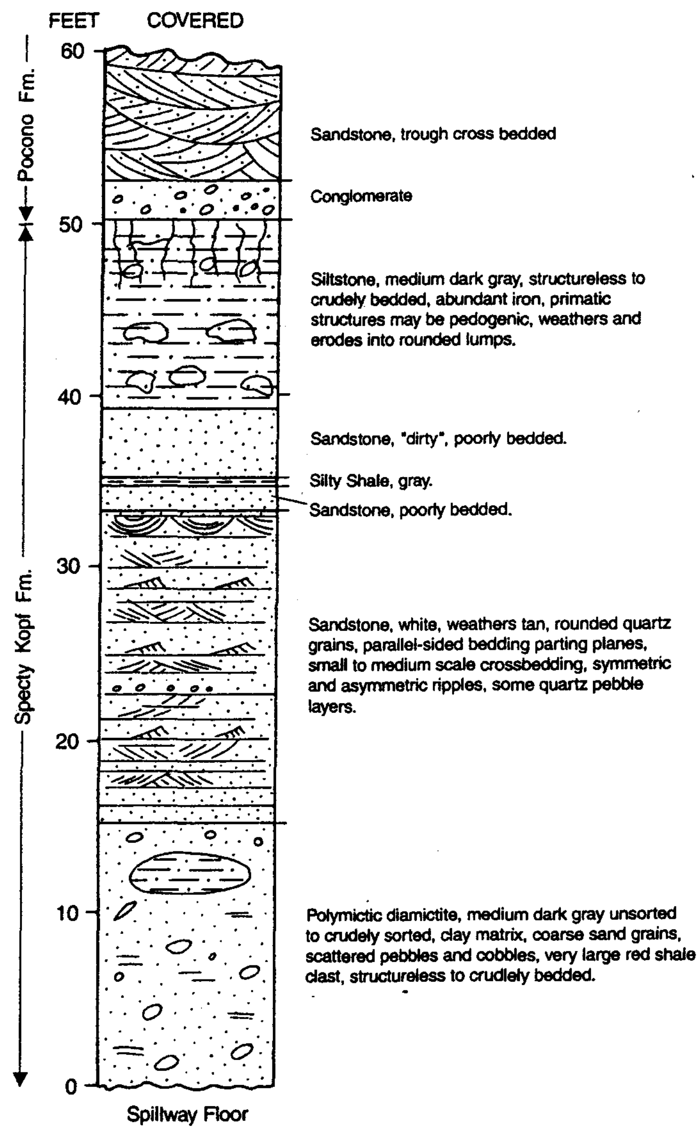



Figure 50. Stratigraphic section of the rocks exposed in the emergency spillway at STOP 6.

spillway. A rounded, white-quartzite boulder exposed near the spillway floor on the dam side in the sloping spillway is 13 x 15 x 5+ cm. The upper part of the diamictite in the trench has some bedded conglomeratic sandstone that is not a diamictite. However, discriminating individual continuous beds is difficult in the outcrop and the whole is lumped as diamictite for convenience.

A large, wedge-shaped sandstone forming the floor of the upper part of the sloping spillway has asymmetric ripples on the surface whose crests are oriented 285°-290° azimuth with a flow direction of 20° azimuth. This sandstone is controversial among several persons who have viewed this outcrop. Some view the sandstone as a large slab that is dislocated from its original position and has been incorporated into the diamictite as a very large clast. Another view is that the sandstone is the channel floor upon which the diamictite was deposited. Interpretation hinges on whether or not the diamictite along the upper edge of the mass abuts or goes under the sandstone. Also undetermined is whether the rock flooring the upper spillway is diamictite or another sandstone. If it is the latter, then the diamictite pinches out between the east end of the trench and the upper spillway.

The quartz sandstone has parallel-sided bedding parting typical of the unit. It also has an abundance of small to medium scale crossbedding that is best seen along the rock face of the upper spillway. A bedding surface above the sloping spillway at the east end of the concrete dam on the south side of the spillway shows parallel troughs with 280° azimuth for orientation of the troughs and dip of crossbedding. Note that the quartz grains are rounded. Note also the thickness of the sandstone (5.5 m) and keep it in mind when viewing the same sandstone at STOP 7A where the sandstone is 55 m thick. STOP 7A is 4 km (2.4 mi) distant.

The 3.3-m-thick, medium dark gray siltstone above the sandstone contains a moderate amount of iron and some prismatic structures that may be pedogenic in origin. This part of the section has received no study and is not known to occur anywhere else. The top of the sequence is exposed in the woods above the spillway where at least 10 m of Pocono sandstones and conglomerates occur.

Items to be considered here are:

1. What is the depositional environment of the diamictite? Is it possible to tell from this single outcrop? Do you know of any rocks from other stratigraphic positions in Pennsylvania that have the physical character of this rock?

2. What is the depositional environment of the quartz sandstone? Is a shoreface environment of deposition a real possibility or is some other environment required? Keep in mind that this unit will be seen again at STOP 7A where the context is much different.

| | | |
|---|---|---|
| | | Leave STOP 6. Return to PA 307 and turn right (south) at stop sign. |
| 1.1 | 4.9 | To right are scattered exposures of gently northwest-dipping, crossbedded, gray sandstone and hackly red mudstone (fining-upward alluvial cycles) of the Duncannon Member of the Catskill Formation. For the next mile thick till deposits mantle the area to either side of the road. Along PA 307 from here to the junction with I-380 bedrock crops out at hilltops, but the remainder of the area is covered by till mantle 6 to 30 feet deep. In buried valley areas, the till can be as thick as 300 feet. |
| 1.4 | 6.3 | At lip of the hill to right are northwest-dipping ledges of gray and red, calcitic sandstone and siltstone of the Packerton-Poplar Gap Members of the Catskill Formation. In the woods just downslope from these outcrops are several large boulders of calcitic breccia, one of which is from a bed more than 3 feet thick. |
| 0.9 | 7.2 | Gently southeast-dipping beds of flaggy, crossbedded sandstone and red, shaly mudstone (Packerton-Poplar Gap) well exposed to left just south of Old Brook Inn in Tooley Corners. |
| 0.5 | 7.7 | Outcrop of subhorizontal, crossbedded, flaggy and calcitic Packerton-Poplar Gap sandstone to left. |
| 0.7 | 8.4 | Blinking traffic light at intersection with PA 690 in Quinlan Corners. Continue straight ahead on PA 307S. |
| 1.3 | 9.7 | Get into left lane and cross over I-380.. |
| 0.1 | 9.8 | Turn left across traffic onto ramp for I-380W (Scranton). |
| 0.3 | 10.1 | Merge left with I-380W. |
| 0.9 | 11.0 | High cut in gently southeast-dipping, alternating gray-and-red sandstone and shale of the Catskill Formation (Packerton-Poplar Gap Members). Sandstones are characterized by channeling and numerous calcitic breccia lenses, some of which contain red-shale clasts of small cobble size. A particularly good channel can be seen at the south end of the cut on the right. |
| 1.9 | 12.9 | Another splendid cut in the Packerton-Poplar Gap, this one exposing sandstone- |

dominated, fining-upward cycles with beds dipping gently northwest. The sandstone beds are crossbedded and channeled and contain numerous calcitic breccia lenses.

| | | |
|---|---|---|
| 0.9 | 13.8 | I-380/84 interchange area. Continue following I-380W (now combined with I-84) toward Scranton. |
| 1.8 | 15.6 | Good view of Spechty Kopf sandstone cliffs near southwest end of Moosic Mountains ahead to right. |
| 0.2 | 15.8 | Cross deep valley of Roaring Brook, which function as a major glacial sluiceway for meltwater from Glacial Lake Wallenpaupack. That lake covered a much large area than the present man-made version. |
| 0.1 | 15.9 | On the west side of Roaring Brook gap (Cobbs Gap) to the left are the "scars" of several abandoned quarries in various facies of the Spechty Kopf Formation. The southernmost and smallest is in the basal diamictite. The middle quarry is that of the former Nay Aug Brick Company in the medial "disrupted shale." The highest and northernmost is in the upper sandstone. |
| 0.6 | 16.5 | Slow down and pull off onto right shoulder of road just entrance ramp at high sandstone and shale roadcut. **Watch for traffic on ramp.** |

## STOP 7A. *I-84/380 ROADCUT AT COBBS GAP (PART A): STRATIGRAPHY AND POST-DEPOSITIONAL DEFORMATION IN THE SPECHTY KOPF FORMATION.*

Leaders: William D. Sevon, Donald L. Woodrow, and David E. Costolnick.

This is the first of a two-part stop in cuts along I-84/380 in Cobbs Gap at the west end of the Moosic Mountains (Figure 51). STOP 7A provides an opportunity to view in detail the claystone (part of the pebbly mudstone), laminite, and quartz sandstone parts of the DMLS sequence. Because of the traffic, this is a very noisy and dangerous site for large numbers of people. **Please: Stay on the wide berm. Do not get close to the roadway!** The Field Conference has special permission to visit this site. Remember that you are not legally allowed to stop and examine rocks along an interstate highway without special permission. Keep that in mind should you wish to return here to study these rocks.

The complete Roaring Brook stratigraphic section is shown in Figure 52. The exposure at STOP 7A starts in the upper 20 m of Unit 3 and proceeds upward to the top of Unit 6. Unit 7 is in the covered interval at the top of the exposed rock section. A number of features in the section have been marked with red flagging. Note particularly:

1. Large slump structures occur in the claystone (Unit 3, Figure 52) near the south end of the exposure. The axis of the southernmost slump (Plate 2D—p. 42) is 325° azimuth with presumed direction of slump of 55° azimuth. Bedding at the nose of the next slump to the north (Plate 2,C—p. 42) is 16° azimuth with a direction of movement of 285° azimuth. The nature of these slumps indicates that they are penecontemporaneous with deposition. What is their significance?

2. North of the southern slumps is a very large slump whose orientation is not clear. One measurement of a slumped bedding surface is 53° azimuth with presumed direction of slump of 317° azimuth.

3. Look at the rhythmic lamination of the claystone (Plate 2A—p. 42). Some of the laminae appear to be almost nothing more than color changes; others result from definite grain size differences. Careful search should yield some laminae composed of very coarse-grained silt and very fine-grained sand. Some of these coarse-grained laminae have micro slump structures.

4. Near the top of the claystone are numerous load cast balls of sandstone that foundered into the underlying claystone (Plate 3, B—p. 44). These balls seem to be good evidence that deposition of the sand was rapid and that the underlying clay was not dewatered. The balls came from a disrupted bed of sandstone in the laminite.

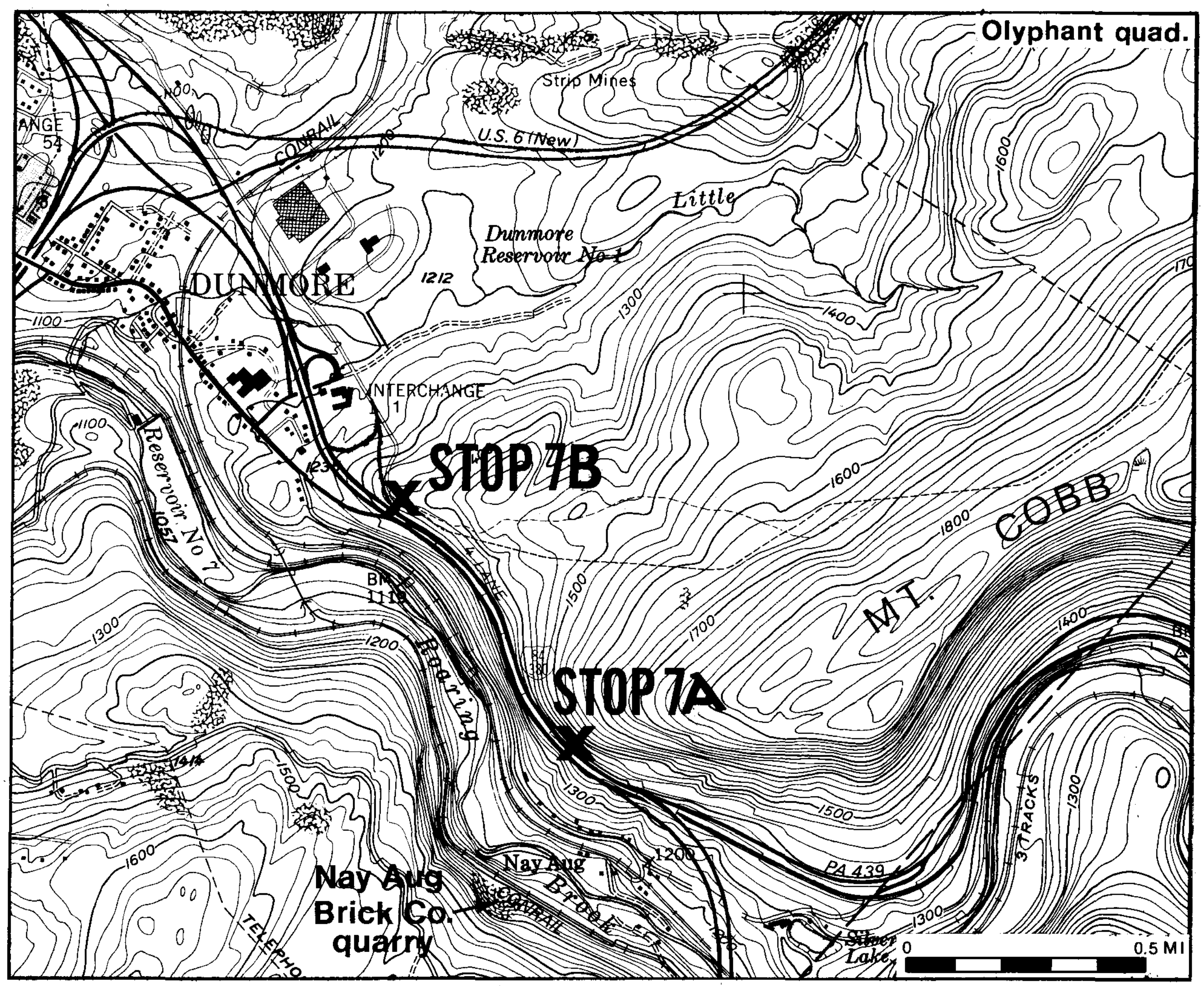



Figure 5l. Location map for STOPS 7A and 7B on I-84/380.

5. The laminite (Unit 4, Figure 52) (Plate 3A—p. 44) shows nicely the fairly rapid change from dominantly clay sediment to dominantly sand. Presumably the laminite represents a transitional environment of deposition.

6. The quartz sandstone (Plate 3, C—p. 44)) makes up the remainder of this exposure and is divided into two parts, Units 5 and 6 (Figure 52). Look for crossbedding in the first 17 m. This lower part of the sandstone (Unit 5) presumably has a different depositional environment (distributary mouth bar?) than the upper part (wave-dominated shoreface?). One measurement of bedding in Unit 5 was 90° azimuth with 33° north dip. Bedding in the overlying Unit 6 measured 82° azimuth with 18° north dip. Costolnick notes that Unit 5 is submature in composition and contains some interstitial clay along with small, angular grains of rock fragments. Exposures of this unit on a dead-end road below the level of I-380 show even better definition of lenticularity of individual beds defined by parting planes. These beds have long sweeping crossbeds with tangential bases and north dips.

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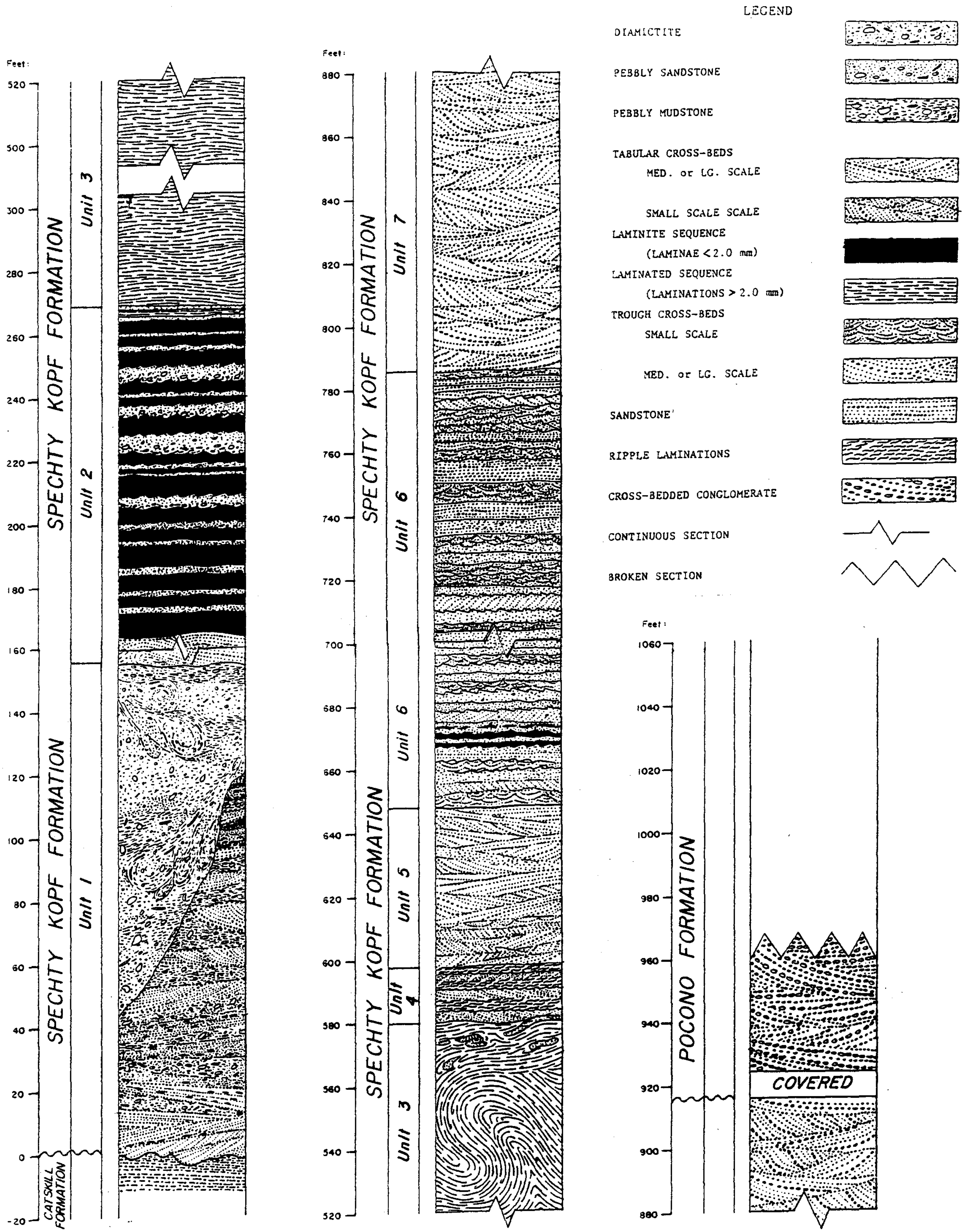
Figure 52. Stratigraphic section of the rocks exposed in the Roaring Brook area. This stratigraphic section was prepared by Costolnick (1987) and is a composite of observations and measurements made at 28 localities in the Roaring Brook valley. Detailed information related to the various units is presented in the text article.



LEGEND
DIAMICTITE
PEBBLY SANDSTONE
PEBBLY MUDSTONE
TABULAR CROSS-BEDS
MED. or LG. SCALE
SMALL SCALE SCALE
LAMINITE SEQUENCE
(LAMINAE < 2.0 mm)
LAMINATED SEQUENCE
(LAMINATIONS > 2.0 mm)
TROUGH CROSS-BEDS
SMALL SCALE
MED. or LG. SCALE
SANDSTONE
RIPPLE LAMINATIONS
CROSS-BEDDED CONGLOMERATE
CONTINUOUS SECTION
BROKEN SECTION
Feet:
SPECHTY KOPF FORMATION
Unit 1
Unit 2
Unit 3
CATSKILL FORMATION
Unit 4
Unit 5
Unit 6
Unit 7
POCONO FORMATION
COVERED

Unit 6 is mature to supermature with nothing but rounded quartz grains. Look for symmetric and asymmetric ripples. Costolnick measured crest orientations between 60° and 90° azimuth with indications of current flow to the southeast. Be sure to look at the purplish-colored surface about 6 m south of the sign for "Exit 1, Tigue St." This surface (Plate 4, B—p. 47) shows cross sections of wave ripples with south dipping crossbeds. Costolnick notes that these purplish zones have poikilotopic cementation. About 33 m north of the Exit 1 sign is a 40-cm-thick zone with 4 thin shales interbedded with sandstone (Plate 3, C—p. 44)). These shales are persistent throughout the visible extent of the outcrop and must represent a significant change in depositional events. What? Above the shale beds the sandstone is dominated by parallel-sided partings that presumably reflect bedding. Other indications of bedding and crossbedding are obscure. Do not be fooled by Liesagang banding that resembles crossbedding.

Not occurring in this outcrop but exposed along the dead-end road below the level of I-84/380 is a normal fault with at least 4 m of displacement. Unit 5 on the north side of the near vertical fault is brought into contact with the Unit 4 and the upper part of Unit 3 on the south side. The fault has an 80° azimuth and an 87° north dip. Slickensides on the sandstone verify downward movement of the sandstone. The fault is lost in cover up slope from the dead-end road and is not present in the I-84/380 exposure.

During examination of the rocks exposed at this site, give serious consideration to some of the ideas put forth in the earlier discussion of the Spechty Kopf (p. 34-60). Do the proposed environments of deposition seem reasonable for the rocks exposed here? Does filling of a lake seem reasonable? What are the implications of the large slump structures in the claystone? Could they have been caused by local tectonic activity such as movement along a growth fault or are there other probable causes?

| | | |
|---|---|---|
| | | Leave STOP 7A. Proceed straight ahead on I-84/380, staying to right. |
| 0.3 | 16.8 | Outcropping ledges of Pocono sandstone to right. |
| 0.2 | 17.0 | Pull off onto right shoulder of road just before it narrows at Exit 1 (Tigue Street). Debark from buses. (Buses go 0.4 mi to stop sign at end of ramp, turn left, and proceed 0.2 mi to abandoned gas station just beyond entrance to Holiday Inn. Participants will walk through road cuts along ramps and board buses at that point.) |

## STOP 7B. *I-84/380 ROADCUT AT COBBS GAP (PART B): "LOYALHANNA" AND POTTSVILLE DISCONFORMITIES AND THEIR STRATIGRAPHIC RELATIONS.*

Leader: William E. Edmunds.

### INTRODUCTION

This stop begins at the east end of the highway cut on the westbound lane of I-84/380 and continues along the new exit ramp, which when complete, will connect to the new Lackawanna Valley Industrial Highway (new US 6) (see Figure 51). As shown in Figure 53, the exposure is interpreted as displaying the uppermost 142 feet of the Pocono Formation (including a 16-foot-thick paleosol below the sub-Loyalhanna regional unconformity), the remaining 19 feet of the Mauch Chunk Formation (all Loyalhanna Member or equivalent) below the regional sub-Sharp Mountain unconformity, and the lower 121 feet of the Pottsville Formation (Sharp Mountain Member).

In earlier stops to the west and southwest (Pre-Conference Field Trip 2 [Appendix A-2] and STOP 3), the basal Mauch Chunk below the sub-Loyalhanna unconformity is at least 37 feet thick at Nay Aug Park Gorge and 72 feet at "The Tubs." At this stop, all of the basal Mauch Chunk has been removed and the sub-Loyalhanna unconformity is incised an undetermined distance into the top of the underlying Pocono Formation. The upper most 16 feet of the remaining Pocono has been weathered into a complex soil profile.

At "The Tubs" (STOP 3), ninety-nine feet of Loyalhanna and an additional 495 feet of later

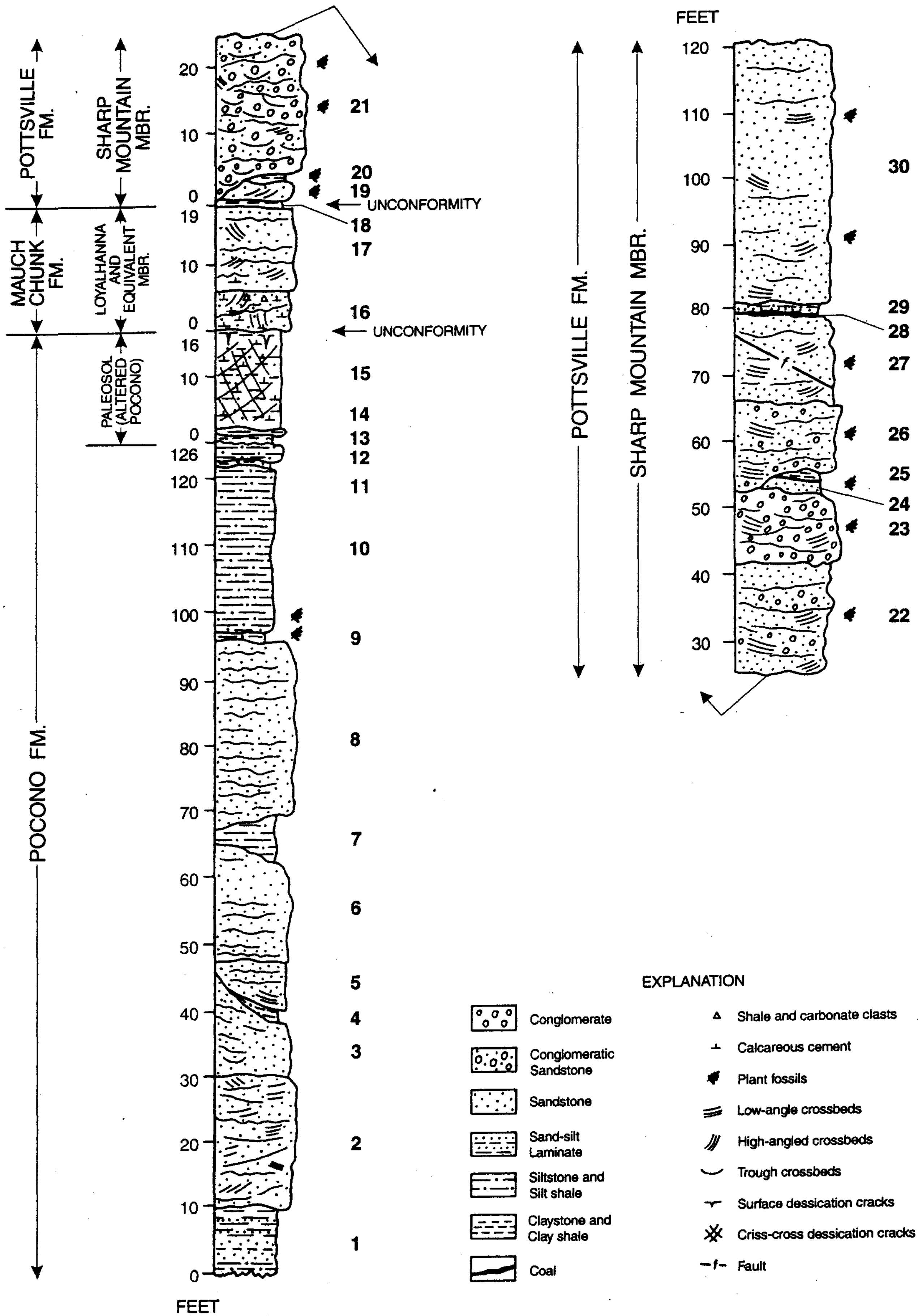



Figure 53. Stratigraphic column of Pocono, Mauch Chunk, and Pottsville Formations at STOP 7B.

Mauch Chunk are present between the sub-Loyalhanna and sub-Sharp Mountain unconformities. At Nay Aug Park Gorge only about 65 feet of Loyalhanna Member and lateral equivalent remains between the two unconformities. This is reduced to 19 feet here.

The perplexing sequence exposed here was studied first by Sevon (1969), who correctly identified the Pocono and Pottsville Formations and surmised that certain intervening rocks (probably units 13 through 17 of Figure 53) were part of the Mauch Chunk Formation. Wells (1973) recognized that unit 16 strongly resembles typical Loyalhanna. Sevon (Stop 5, in Edmunds and Eggleston, 1989) again correctly identified the Pocono and Pottsville Formations and considered that units 13 through 17 were part of the Mauch Chunk Formation with distinct affinities for the Loyalhanna Member.

The description and identification of the Pocono Formation, paleosol, Mauch Chunk Formation (Loyalhanna Member), and lower part of the Pottsville Formation presented here is that of Edmunds and Eggleston (1993), with minor modifications. In 1995 and 1996, excavation of the new access and entrance ramps connecting I-84/380 to the Lackawanna Valley Industrial Highway enlarged cut to display units 1 through 21 and also exposed an additional 95 feet of Pottsville Formation (units 22-30). At the same time, these fresh cuts have lost or suppressed most of those physical characteristics which are enhanced by some degree of weathering. This has particularly affected the Loyalhanna (unit 16), the paleosol zone (units 13-15), and the hematite-siderite zones in the Pocono (units 5, 6, 8, and 10). The best remaining weathered exposures of the paleosol and Loyalhanna are found in a remnant of the older cut along I-84/380 between the new exit and access ramps.

## STRATIGRAPHIC DESCRIPTION

In northeastern Pennsylvania, the Pocono Formation is dominantly fine- to coarse grained, medium-light-gray to light-gray or greenish-gray quartzose sandstone with at least one notable interval of conglomeratic sandstone. Units 2, 3, 5, 6, and 8 are typical Pocono sandstones. They are interpreted as fluvial deposits which form the main body of the Pocono alluvial plain. Sandstone sequences often terminate by grading upward into a short interval of thin-bedded siltstones or hackly silt shale which is usually medium gray to grayish black (units 4, 7, and 9). These finer-grained clastics probably represent lowered fluvial competency or stream diversion and, in some cases, brief weathering surfaces. Plant carbonizations and impressions occur in some cases, such as unit 9. The 28-foot-thick siltstone-and-shale-sequence of units 10, 11, and 12 is finer than usual for the Pocono, but not unique.

Weathered surfaces of the sandstones and siltstones of units 5 through 10 are covered with small-grayish-red spots up to 1 mm which are so abundant in places that they appear as bands or zones of reddish coloration. Based on microscopic examination, R. C. Smith II of the Pennsylvania Geological Survey has determined that the "red spots" are oxidized occurrences of iron-carbonate (probably siderite). Where exposed on a fresh surface, the iron carbonate is present as secondary mineralization in the clastic matrix and appears as translucent, pale-brownish-yellow blade-like crystals. The implacement of the iron carbonate may be related to groundwater activity associated with the overlying sub-Loyalhanna unconformity erosion surface, or alternatively, to hydrothermal activity as discussed previously (see p. 31 and STOPS 2 and 3).

### Paleosol and the lower unconformity (units 13-15)

The sub-Loyalhanna regional unconformity is present between units 15 and 16. Units 13 through 15 are a paleosol developed on the eroded upper surface of the Pocono Formation and formed around a matrix of weathered siltstone which was originally a continuation of the siltstones of units 10 through 12.

The base of the paleosol is a 0- to 0.7-foot-thick zone that superficially appears to be a pale-red limestone, but is actually a disaggregated siltstone impregnated almost completely with secondary calcium carbonate (unit 13). This zone appears to be similar to a carbonate hardpan.

Unit 14 is a 0- to 1.2-foot-thick zone of altered silty claystone containing numerous small red pedogenic limestone nodules. Weathering removes the nodules, leaving the bed heavily pockmarked.

Unit 15 is a calcareous siltstone which grades upward into what is virtually a silty limestone. The top contains abundant pedogenic carbonate nodules and vertical sand-filled desiccation cracks. The unusual, curved, criss-crossed and slickensided desiccation fracturing is typical of a highly calcareous paleosol. Unit 14 is formed by the massive infusion of secondary calcium carbonate into the weathered upper surface of the Pocono siltstone. Using the paleosol classification of Mack and others (1993), this sequence shows the distinguishing characteristics of both a calcisol and a vertisol. Designation as a vertic calcisol seems most appropriate.

The erosional and non-depositional hiatus at the unconformity extends from early or middle Osagean to latest Meramecian time (c. 345-330 Ma).

**Loyalhanna Member (units 16-17)**

Only 15 to 19 feet of the Mauch Chunk Formation remains at this site, all Loyalhanna Member, or equivalent. In a strict sense, only the lower part (unit 16) retains the distinctive characteristics of the Loyalhanna calcareous fine-to medium-grained sandstone with high-angle crossbedding that exhibits truncated tops and tangential bases. The six feet of typical Loyalhanna found here consists of two crossbed sets. The lower set displays fluted weathering. The upper crossbed set contains masses of carbonate nodules, iron minerals, and some small, but recognizable, invertebrate shell fragments cascaded along the crossbed surfaces.

The overlying sandstone (unit 17) appears to have little resemblance to typical Loyalhanna. It is non-calcareous, except slight in the lower few feet, and its bedding and crossbedding style is different. Only 9 to 13 feet of unit-17 sandstone remains below the sub-Sharp Mountain unconformity here, while the same sandstone along Roaring Brook at Nay Aug Park (see Pre-Conference Field Trip 2, Appendix A-2, unit 9 of section) is 55 to 60 feet thick. This sandstone is believed here to be a lateral facies of the typical marine Loyalhanna.

**Pottsville Formation (Sharp Mountain Member)**
**and the sub-Sharp Mountain unconformity (units 18-30)**

At this site the sub-Sharp Mountain unconformity is placed at the intensely weathered zone of clay and shale of unit 18, which is interpreted as a paleosol (probably a protosol in the classification of Mack and others, 1993). The erosional and non-depositional hiatus at the unconformity extends from latest Meramecian (Late Mississippian, c. 330 Ma) to latest Atokan or earliest Desmoinesian (Middle Pennsylvanian, c. 310 Ma).

The 0- to 0.5-foot-thick grayish-black, carbonaceous shale with abundant plant fragments and coaly stringers of unit 20, directly below the conglomerate of unit 21, is identified as the Campbells Ledge shale bed, which is only slightly older than the conglomerate. Although the Campbells Ledge has been treated as a separate member of the Pottsville Formation (Kehn and others, 1966), it seems more practical to include it as a bed within the Sharp Mountain Member.

The 0- to 3-foot-thick sandstone of unit 19 is also part of the Campbells Ledge sequence. Although less well known, this thin sandstone frequently underlies the Campbells Ledge shale. The sandstone is light gray, fine to medium grained and displays lensoidal crossbed-sets with evenly spaced 1-cm-thick, upward-convex crossbeds with truncated tops and bottoms. Large plant carbonizations and impressions occur commonly.

Unit 21 is the typical basal or near-basal, high-energy, braided-alluvial conglomerate and conglomeratic sandstones of the Sharp Mountain Member, followed by the somewhat lower-energy sandstones and conglomerates of unit 22. Units 23 through 26 represent a second conglomerate-to-sandstone, fining-upward sequence. The carbonaceous clay shale of unit 25 probably reflects a brief "attempt" to establish a local peat marsh.

The sandstones of units 27, 29, and 30 are typical of the upper part of the Sharp Mountain Member, as well as the overlying Llewellyn Formation. They represent a general decline in stream energy and, probably, a more regular organization of the fluvial systems. The thin shaly coal of unit 28 indicates an interruption of coarse clastic sedimentation and brief development of a small peat marsh.

| | | |
|---|---|---|
| 0.6 | 17.6 | Leave STOP 7B. Turn right onto access road and proceed to entrance ramp for I-84/380N. |
| 0.2 | 17.8 | Stop sign. Turn right onto entrance ramp, following signs for I-81. |
| 0.1 | 17.9 | Cuts in Pottsville and Mauch Chunk at STOP 7B. |
| 0.3 | 18.2 | Merge with interstate (I-84/380), staying in right lane. |
| 0.5 | 18.7 | Bear right at Y intersection, following signs for I-81N (Binghamton). |
| 0.5 | 19.2 | Merge with I-81N. |
| 0.4 | 19.6 | Exit 55 (Blakely Street-Throop). Continue straight ahead. |
| 1.5 | 21.1 | To the right, formerly underlying much of the community of Throop, were the deep mines of the Pancoast Colliery, site of one of the worse disasters in anthracite-mining history. A Historical Marker at the corner of Charles and Sanderson Streets reads: *ANTHRACITE MINE DISASTER. On the morning of April 7, 1911, the nearby Pancoast mine here in Throop was the scene of a disastrous fire. Seventy-two miners died by suffocation, and a government rescue worker also was killed. This tragedy soon led to the enactment, on June 15, of State legislation requiring that all interior buildings at coal mines be constructed of incombustible materials..* |
| 0.3 | 21.4 | Cross Lackawanna River. |
| 0.1 | 21.5 | Exit 56 (Dickson City). Continue straight ahead. |
| 1.0 | 22.5 | Bear right onto ramp at Exit 57A (US 6E). |
| 0.4 | 22.9 | Merge left with US 6E. |
| 0.4 | 23.3 | From here at MacDonald's to STOP 8, US 6 runs along the side of the dipslope of the homoclinal ridge that marks the northwest limb of the Lackawanna synclinorium. The slope is covered by thick till deposits, typically 30 to 100 feet thick. The ice flowed from the north, across the ridge and deposited the material as a "till shadow" in the lee of the homoclinal ridge. |
| 0.8 | 24.1 | Traffic light (second MacDonald's to left). |
| 0.3 | 24.4 | "Wal-Mart cut" on hillside to left (STOP 9). |
| 0.3 | 24.7 | Traffic light at intersection with Scott Road. Continue straight ahead. |
| 0.2 | 24.9 | Good view of Lackawanna Valley to right. Moosic Mountains form the skyline. |
| 0.1 | 25.0 | Traffic light (Office-Max to left). |
| 0.1 | 25.1 | Late Wisconsinan cobbly till exposed to left. |
| 0.2 | 25.3 | Intersection with PA 347. Continue straight. To left is a till cut. |
| 0.1 | 25.4 | Cross Hull Creek. To right is "Blakely Falls," a picturesque post-glacial gorge cut largely through southeast-dipping, crossbedded sandstones in the lower Llewellyn Formation. Mining on at least three coalbeds is evident along the stream, most likely including (from lowest to highest) the Dunmore No. 1, Clark, and New County. These workings were part of the Miles Slope of the Olyphant Mine. (Two more seams, the 14-Foot and Rock, were mined farther to the southeast). The buried preglacial course of Hull Creek lies just north of the present valley (see Braun, *Quaternary geology*, this guidebook). |
| 1.7 | 27.1 | Enter Archbald borough. Archbald was named after James Archbald (1793-1870), a contractor on the Erie Canal (1817), first mayor of the city of Carbondale (1851), and chief engineer of the Delaware & Hudson Railroad (1858-1870) (Folsom, 1981). |
| 0.1 | 27.2 | To left are several excavations in the "till shadow." Some cuts are 30 feet high. |
| 0.2 | 27.4 | Traffic light at intersection with PA 247. Continue through this and next three lights. |

1.1 28.5 Cut in gently southeast-dipping Llewellyn strata to left. Exposed are two 1-foot-thick coalbeds separated by several feet of rootworked silty seatrock.

0.2 28.7 Turn right at entrance to Archbald Pothole State Park. Debark from buses.

**STOP 8 AND LUNCH.** ***ARCHBALD POTHOLE(S): BEDROCK GEOLOGY, DISCOVERY, AND ORIGIN—PLUNGE POOL(S) OR SUBGLACIAL POTHOLE(S) OR....?***

Leaders: Duane D. Braun, Gary M. Fleeger, and Jon D. Inners.

The Archbald Pothole is one of the geologic marvels of Pennsylvania—ranking with the Hickory Run Boulder Field in terms of uniqueness. Yet, unlike Hickory Run, its origin has sparked limited controversy. This can possibly be traced back to the fact that not long after it was discovered, J. Peter Lesley, State Geologist of the 2nd Survey, pronounced—without even seeing it—that the pothole had been formed "by water falling through a crevasse in the glacier" (as paraphrased by Charles A. Ashburner in the Annual Report of 1885). Although Ashburner, who also apparently did not visit the site, did offer two other explanations (see below), most others seem to have either accepted Lesley's pronouncement—or, after having gone over the ground themselves, come to a similar conclusion. But not everyone.

As we will see, one's interpretation of the Pothole (actually there are two of them, but one was never cleared out) have an important bearing on one's interpretation of the deglaciation history of the Wyoming-Lackawanna Valley. For many years, it was generally believed that a large mass of stagnant ice occupied much of the valley in late Pleistocene time (Itter, 1938; Peltier, 1949), but recent work by Braun (p. 1-15) suggests this may not have been the case. If a large mass of stagnant ice did not exist, how could a crevasse (or moulin) have stayed open for a long enough time to allow a relatively stationary waterfall to drill the Archbald Pothole (or "plunge pool," in this case)? Could the Pothole, and its companion, have been formed by subglacial meltwater as the continental glacier gradually retreated from the valley?

Both the "plunge pool" and "subglacial" hypotheses will get an airing at this STOP. A Pennsylvania Survey geologist (true heir of J. Peter Lesley that he is) will defend the old idea, while Duane Braun will offer his well thought out alternative.

We will first take a look at the bedrock geology of the park and the history of the pothole's discovery, after which we will wade into the question of the origin of the two potholes at Archbald.

**BEDROCK GEOLOGY**

Archbald Pothole State Park lies on the northwest side of the Lackawanna basin, 0.5 mile north of the village of Eynon (Figure 54) and about 2 miles west-northwest of Archbald. The park is underlain by bedrock strata assigned to the lower part of the Llewellyn Formation. Naturally outcropping rocks consist of gray, medium to coarse grained, crossbedded sandstones that exhibit considerable evidence of stream abrasion "upstream" (north) of the exposed pothole (Pothole No 1). Pothole No. 1cuts down through sandstone, shale, and coal (in descending order) (McGlade, [1969]), the coal being the Archbald (=Clark) bed. The coalbed is reported to be about 8 feet thick.

A better sense of the stratigraphy of the pothole can be gained from examining the elongate stripping on the Archbald coalbed north of parking lot (Figure 55). Azimuth of the stripping is about N8W—a good approximation of the bedding strike in the area, and the strata exposed in the highwall dip gently east-southeastward at 5-10 degrees. Although the coalbed is concealed, the intensity of fracturing and subsidence and the numerous fallen sandstone blocks point to its former presence. Probable remnants of one mine chamber can be seen about 350 feet north of the parking lot.

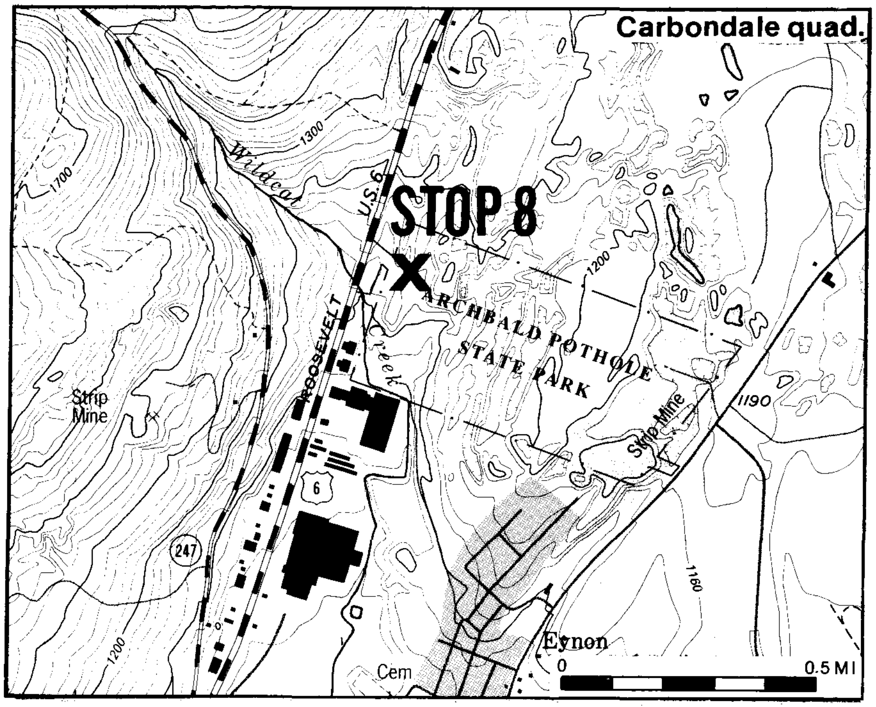



Figure 54. Location map for STOP 8 (Archbald Pothole).

The sandy to silty claystone which presumably immediately overlies the coalbed is intensely rootworked and contains numerous well preserved *Stigmaria*. Clay shale with *Calamites* and *Neuropteris* overlies the silty claystone at the north end of the stripping but is cut out by the capping channel sandstone to the south (Figure 55). Examination of nearby mine maps suggests that the coal stripping was done in the 1940's. The deep mining goes back to the 19th century, and that is when the recorded history of the Archbald Pothole(s) begins.


Figure 55. Generalized stratigraphic section exposed in strip mine northeast of Archbald Pothole.

## THE DISCOVERY OF THE ARCHBALD POTHOLES

Rather than paraphrase the very informative description of the discovery of the two potholes written by Edward S. Jones, managing head of Jones, Simpson and Company, the firm which ran the local Ridge mines of the Eaton colliery, his account is given verbatim here (Weyburn, 1929):

> In [February of ] 1884 a miner by the name of Patrick Mahon, of Archbald, in the employ of Jones, Simpson and Company, was drilling a heading in what was known as the drift mine of the company [on the Clark or Archbald seam]. The heading was on the first lift of the inclined plane. The miner fired a blast, and when the outpouring of stones and water from the hole came rushing through, the miners in that vicinity of the mine called out a cry of alarm and ran from the mine for the safety of their lives, imagining that the mountain was coming in upon them.
>
> [I] was summoned and directed that an examination be made and gave instructions to have the excavation completed. About three hundred mine carloads of smooth, round and oval stones were taken out, or approximately 800 to 1,000 tons of matter, all the material showing the action of the water and continuous grinding, until many of the stones had become smooth and rounded surfaces, as though they had undergone a course of polishing. These stones varied from the size of a hen's egg to larger stones 15 to 20 pounds in weight.
>
> The discovery of this glacial pot-hole was reported...to Colonel Hackley, the land-owner, and he appropriated the sum of $500 to have a retaining wall and fence built around this geological wonder. About 1,000 feet farther north another hole of similar character was encountered [Pothole No. 2], and when this was tapped and the surface settled down some 12 or 15 feet, it was decided not to do the necessary excavation, as it was deemed to be a larger hole than the one first discovered, and the expense involved was to be considered.

Pothole No. 1, 38 feet deep, was subsequently used as an air-shaft to ventilate the Ridge mines (Ashburner, 1886). Pothole No. 2 was discovered in 1885.

Soon after its discovery the exposed pothole became a local tourist mecca, and in 1886, the Lackawanna Historical Society conducted a "Summer School of Geology" under Prof. John C. Branner, who as a Survey geologist, had made the original on-site studies of the pothole two years before. (Branner also believed the pothole was a plunge pool at the base of a crevasse-waterfall.) The site continued to excite curiosity through the succeeding decades, and in 1961 Archbald Pothole State Park was established.

Let us now consider how the "potholes" may have formed, first looking at the traditional explanation (as set forth by the Survey's Gary Fleeger) and than at Braun's alternative hypothesis.

## HYPOTHESIS NO. 1: MOULIN-WATERFALL PLUNGE POOLS

The origin of the Archbald Potholes has excited speculation since their discovery, as have similar ones found around the world (Fairbridge, 1968; Alexander, 1932). The valley in which they are found is on a side slope, semi-parallel to the ridge to the west. It has no stream flowing in it, and the Dundaff 15-minute topographic map (Figure 56) indicates no stream within the valley prior to disruption by surface mining. The lack of a stream in the valley indicates that the potholes, and the valley containing them, must have been scoured by glacial meltwater. John C. Brannerr (Weyburn, 1929) proposed in 1884 that Pothole No. 1 was drilled by water in a plunge pool at the bottom of a moulin in the continental glacier. Ashburner (1886) believed that water falling through a vertical moulin would not drill an inclined pothole, such as Pothole No. 1, but that the flow of water would have to be inclined in the direction of the axis of the hole. He thought that the potholes formed either by water flowing beneath the ice, or by water flowing over the edge of the retreating ice. Other glacial potholes have had similar proposed origins (Sugden and John, 1976). But Branner's waterfall theory has become the generally accepted one for the "Archbald Pothole" for over 100 years.

The Pothole No. 2 was mapped by Itter (1938) at the head of a small valley. This valley position is such that there probably was insufficient water flowing at the base of the glacier upstream of this point to cut a subglacial channel, but there was sufficient flow below the upper pothole. Possibly, a large amount of water was introduced to the base of the glacier at the point of the upper pothole. Most likely, the water introduced at the first pothole moved down from higher in the glacier

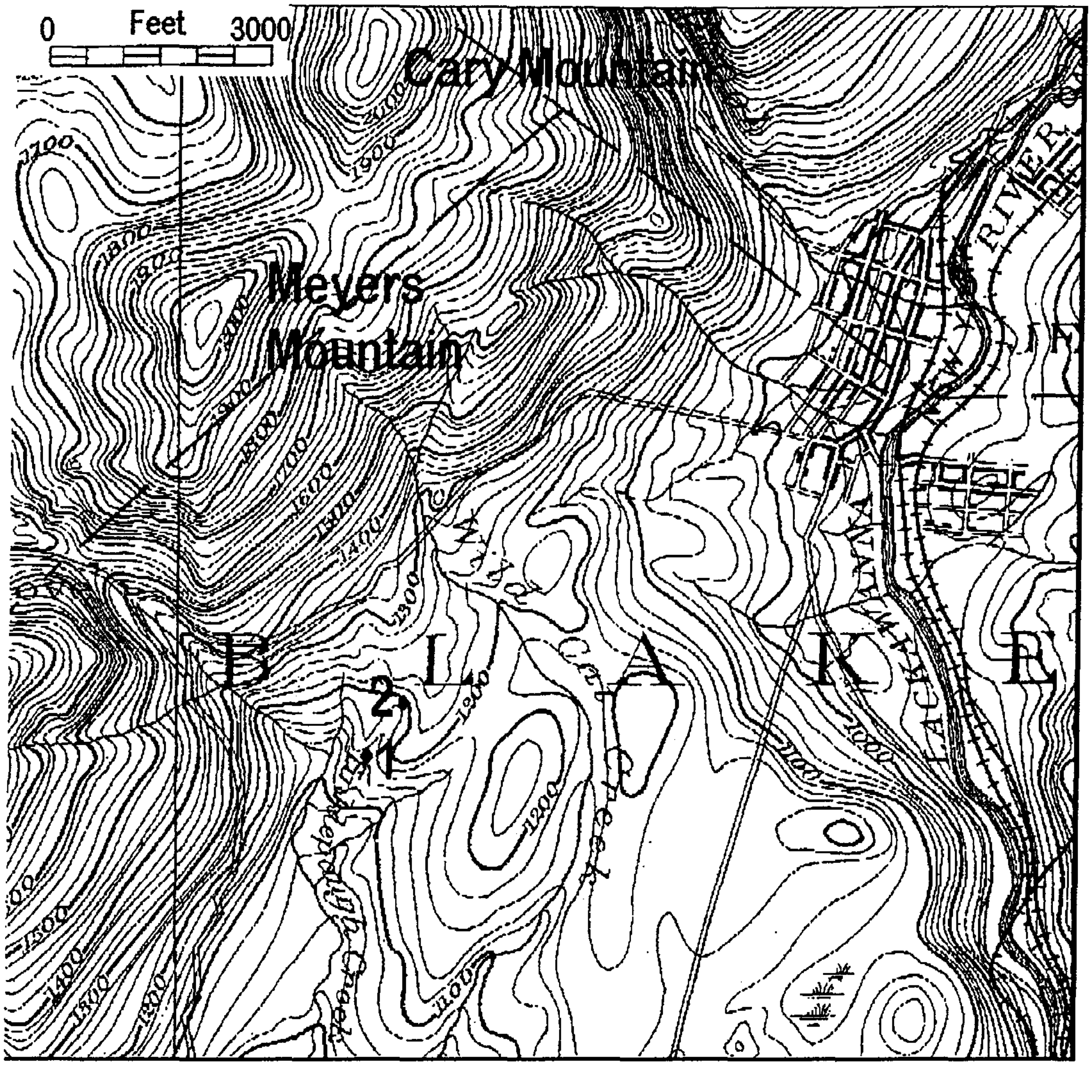



Figure 56. Portion of the Dundaff 15' topographic map (1892). 1 = Pothole No. 1 (Archbald Pothole); 2 = Pothole No. 2. Note that Wildcat Creek is not the same stream on the 7.5' and 15' maps. Wildcat Creek on the Carbondale 7.5' map is Tinklepaugh Creek on the Dundaff 15' map.

through a hole in the ice. Because of the location of the Pothole No. 2 suggests no subglacial flow upstream from that point, it was probably not formed as a true pothole, but as a plunge pool.

The location of the Archbald Pothole (i.e., No. 1) does not suggest an unusual weakness that would cause it to be drilled by a subglacial stream at this site. Jointing parallel to the non-systematic joints measured in the valley occurs within the pothole. Jointing occurs throughout the small valley, yet only the two potholes are known to occur. Most potholed stream beds seem to have numerous potholes within them (Sevon, 1989; personal observations). Potholes drilled at the base of waterfalls through moulins would require no such weaknesses in the underlying rock, and would be less numerous.

Perhaps the shape of the Archbald Pothole provides clues to its origin. It is elliptical in shape, measuring 42 feet by 24 feet at the surface. It narrows to 17 by 14 feet at the bottom (Figure 57).

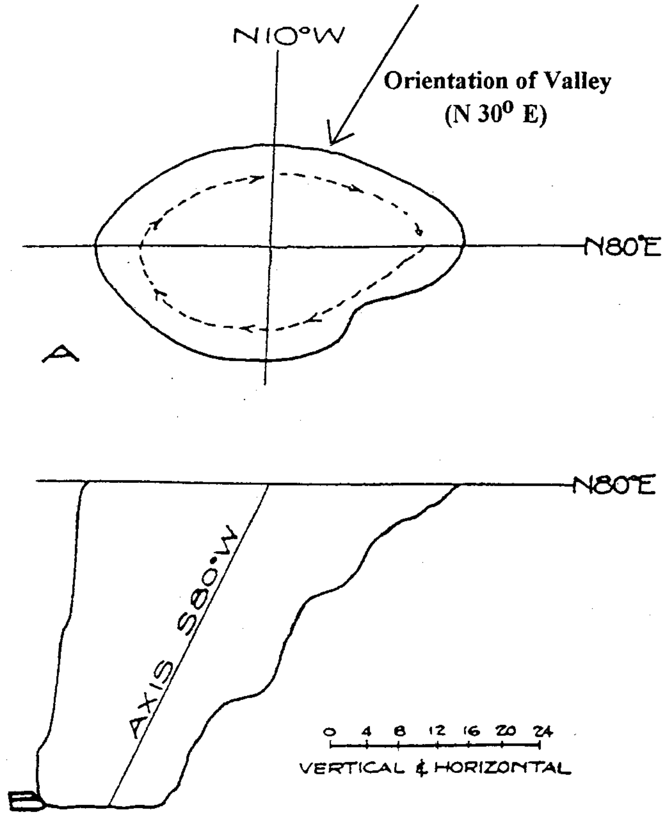



Figure 57. The Archbald Pothole. A. Surface outline. B. Cross section of the pothole along the plane of elongation. Modified from Itter (1938).

Crevasses through which surface meltwater could flow would be likely along the valley sides due to drag between the glacier and the valley sides while the ice was active. A dead ice mass in the Lackawanna Valley would melt faster along the valley margins, particularly the south-facing margin as in the case here. This would result in an ice mass higher in the center of the valley than along the margins. Meltwater would flow on the glacier surface toward the valley sides, where it would encounter crevasses and descend into the ice. If the meltwater reached the base of the ice, it would likely drill a plunge pool in the underlying bedrock. Multiple meltwater streams would flow across the surface of the glacier and descend through moulins developed at valley-side crevasses. The flow at Archbald would have been west, toward the mountain, descending through an inclined moulin to the base. Melting of the ice within the moulin by the meltwater flow would extend the moulin back towards the center of the valley, resulting in a plunge pool that is elongate toward the east. That explains why the Archbald Pothole is extended to the east along the non-systematic joints, but not to the west. It also explains the 5-foot overhang along the west wall of the pothole. These features are not consistent with a stream flowing down the small valley, which is at a 50-degree angle to the directions of pothole elongation and the inclination of the axis of the pothole.

Would sufficient time be available to drill at plunge pool of this size? Alexander (1932) expressed concern that a moulin would not exist long enough in the same spot to drill a pothole of such magnitude while the glacier was moving. It is true that moulins are ephemeral features in active ice. However, there is no reason to require active ice during the time of plunge pool formation. As the continental glacier melted, Meyers and Cary Mountains would have eventually been exposed. At that point, the ice to the east of the mountain would likely have become stagnant, dead ice. The mountains are over 800 feet above the potholes, leaving the possibility that more than 800 feet of dead ice may have existed at the location of the potholes.

Alexander (1932) also felt that a stagnant ice mass would not be able to supply sediment to drill a pothole, and that water alone would have to account for the erosion. At Archbald, there must have been a sub-ice stream that would have continually supplied sediment to the pothole. McGlade [1969] and Itter (1938) both suggest that subglacial stream erosion was partially responsible. Rocks exposed immediately upstream from the Pothole No. 1 are streamlined either by fluvial or glacial erosion. It is possible that plunge pools existed at both pothole sites, and that a sub-ice meltwater stream originated at the Pothole No. 2 and flowed to and beyond the Archbald Pothole. Certainly the plunge pool water had to exit somewhere, and something transported the cobbles that filled Pothole No. 1 after it was drilled. (But where did the material filling Pothole No. 2 come from? How "dirty" was the ice?)

Harper (1995) calculated a 3.2 inch per year drilling rate of potholes in Pine Creek, Allegheny County, Pennsylvania. At this rate, it would require about 140 years to drill the Archbald Pothole, although the rate of deepening would probably decrease with depth. Assuming that the glacial meltwater flow was considerably greater than present Pine Creek and that Pine Creek probably does not have a sediment content comparable to that of glacial meltwater, the Archbald Pothole could easily have been drilled as either a true pothole or a plunge pool. The nearly vertical flow of a waterfall would erode faster than lateral flow, requiring even less time, and could have been accomplished during the time dead ice existed at the site. In addition, the potholes in Pine Creek are drilled into sandstone. The Archbald Pothole is drilled into several lithologies, about half sandstone and the other half claystone and coal.

Consideration must be given to both the moulin and subglacial stream hypotheses. Evidence suggests that each may have been partially responsible. Moulin-waterfalls may have drilled the initial potholes. Subsequently, a high-volume stream, subglacial or ice-marginal, could then have continued the work after elimination of the moulin.

**HYPOTHESIS NO. 2: SUBGLACIAL POTHOLES** (Braun)

When the Archbald Pothole was discovered in 1884, the miners encountered rounded cobble gravel extending to within a foot of the bottom of the coal seam they were following (i.e., the Clark or Archbald). The gravel-filled pothole was excavated upward 38 feet to the ground surface to form an air shaft for the underground mine. The clasts, examined by geologists of the Second Pennsylvania Geological Survey, were all thought to have come from the Pocono, Pottsville, and (what we now call ) Llewellyn Formations. Some of the rounded clasts were coal.

As noted above, the pothole is a somewhat elliptical-shape hole 42 by 24 feet at the surface, narrowing downward to 17 by 14 feet (Figure 57). The south and west sides are nearly vertical and appear to be joint bounded. Besides narrowing downward as it developed, the pothole migrated slightly to the southwest so that its axis is inclined steeply to the southwest (Itter, 1938). The northeast part of the pothole becomes a broad V-form that continues upslope to other ice and water sculptured rock ledges on the floor of a shallow valley. Up that valley about a 1000 feet to the northeast a second infilled pothole was encountered in 1885 (Pothole No. 2). That infilled pothole was cut 50 feet into bedrock, was covered by about 15 feet of glacial deposits, and was purported to be slightly greater in diameter than the first one encountered. Pothole No. 2 was never excavated and may have been destroyed by later strip mining. The potholes were cut into the moderately resistant Llewellyn Formation, starting at the surface in micaceous, thin bedded sandstone, then passing through carbonaceous shale and into the underlying coal seam.

The Archbald Potholes are unique in that they are not in a present stream channel, but rather they are "high and dry" in a shallow, small scale valley cut into a hillside (Figure 58). Prior to coal

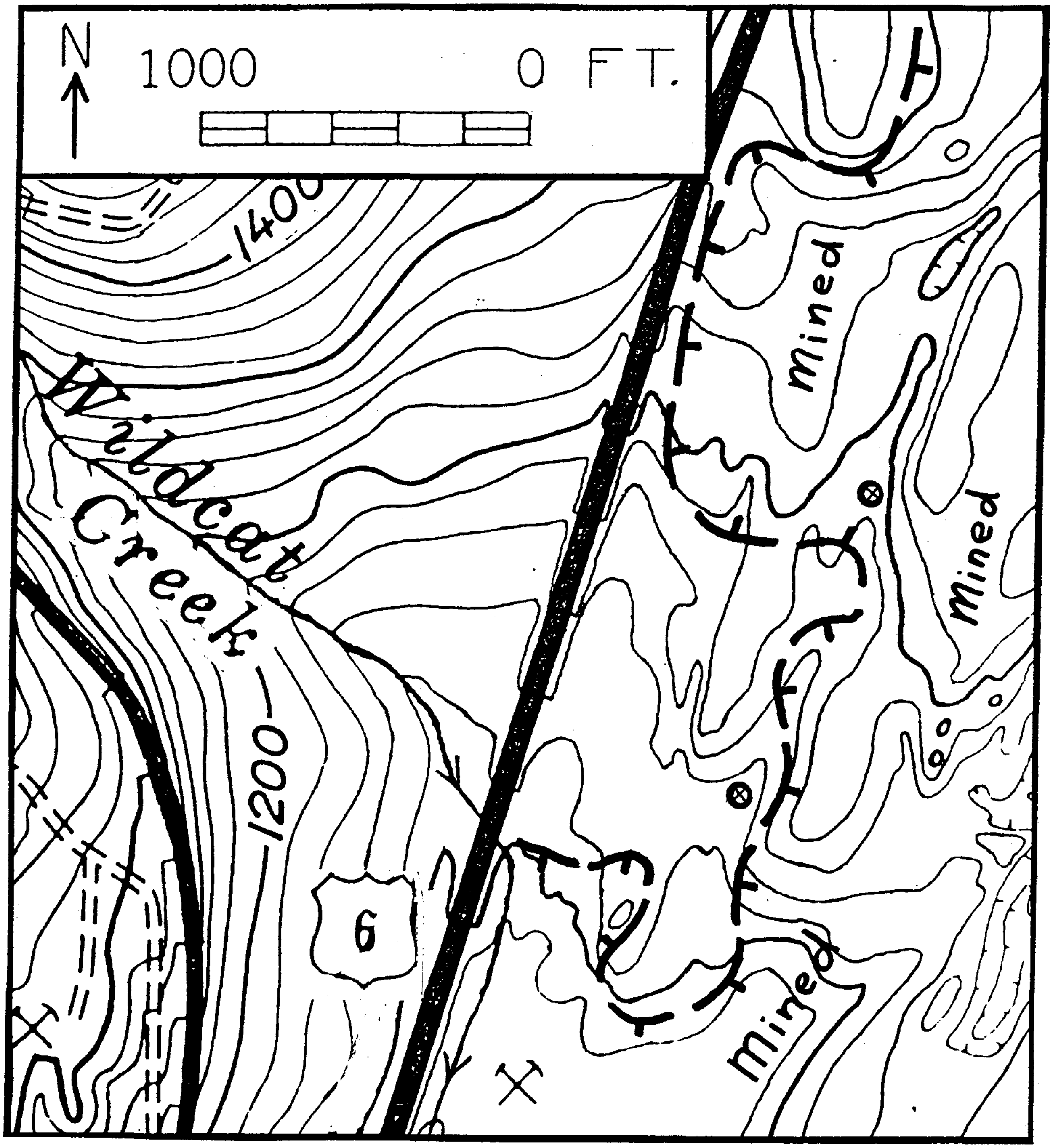



Figure 58. Topographic map (Carbondale 7.5' quadrangle) of the area around the Archbald Potholes showing that the potholes are in a shallow, northeast trending hollow in the hillside on the north side of the Wildcat Creek valley. Heavy dashed line marks edge of coal mining disturbance with the tick marks pointing towards the disturbed area.

mining disrupting the upslope drainage, only a small ephemeral flow would have crossed the site of the now excavated pothole from the 2000 foot long and 500 foot wide valley lying upslope of the site. The lack of a present day stream indicates that another source of water is necessary to cut the potholes, namely glacial meltwater. McGlade [1969] followed earlier suggestions (see above) that the potholes were developed as waterfall plunge pools as glacial meltwater on or in the glacier fell to the base of the glacier. Itter (1938) also suggested that subglacial meltwater met the waterfall at an angle and helped to accelerate the pothole-cutting process (Figure 57).

While the water fall hypothesis is enticingly simple, such vertical shafts (moulins) through a glacier move with the flowing ice and do not stay in the same place for more than part of a single meltwater season. This means that either the potholes formed in a few weeks or a series of moulins paused at the same spots during the time the glacier covered the area. Another option would have the ice stagnate so a single moulin could remain stationary over the site. The problem in such stagnant ice masses is that the drainage rapidly becomes localized, thereby minimizing the duration and quantity of waterfall flow. All of these options are highly unlikely and unnecessary to explain the potholes.

All that is necessary to explain the source of the glacial meltwater that cut the potholes is an understanding of how the glacial ice and meltwater interacted with the topography of the north flank of the Lackawanna Synclinorium. The site is located in a valley that is parallel to and sloping in a down-ice direction, the optimal orientation for subglacial meltwater to follow (Figure 59). The regional ice flow, about S20W, obliquely crossed the N40E to S40W trending ridge on the north flank of the Lackawanna Synclinorium such that a significant amount of ice and subglacial meltwater were funneled through the wind and watergaps (Figure 59). This explains why there are so many deeply incised windgaps in the mountain crest on the north flank of the syncline. While the regional flow is S20W, the ice wrapped around (becomes lobate around) the ridge partly obstructing its flow such that on the southeast side (Archbald side) of the ridge the ice flow was close to parallel to the orientation of the ridge (Figure 59). What this reorientation of the ice did at the Archbald potholes site was to direct subglacial meltwater flow moving through the deep windgap between Meyers Mountain and Cary Mountain down along the base of the ridge and through the potholes site (Figure 59). The subglacial meltwater flow through the site could have been maintained for hundreds of years as the glacier advanced into and retreated from the region. This would have occurred in each glaciation so as much as several thousands of years of meltwater flow may have occurred throughout the later part of the Pleistocene. This scenario permits sufficient time to grind out such deep and large potholes as those at the Archbald site.

If long term subglacial flow was capable of carving deep potholes at this site, it should have been capable of doing the same elsewhere on the floor of the Lackawanna Synclinorium. That this was the case regionally is suggested by several of the mine flooding disasters in the deeply scoured Wyoming Valley area. In at least three of the mine flooding events (out of 17 disasters) boreholes around the failure site showed 30 to 50 feet of firm rock over the coal seam. At the failure site the rock thickness abruptly declined to 15 ft or less, suggesting a narrow gorge or pothole very locally cut into the bedrock (Ash, 1950).

| | | |
|---|---|---|
| | | Leave STOP 8. Turn left onto US 6W. |
| 4.1 | 32.8 | Traffic light at Scott Road. Turn right onto access road, following signs for Wal-Mart. The roadcut is entirely in till that is at least 50 feet thick. |
| 0.1 | 32.9 | Continue straight ahead in front of Wegmans. A large till slide is evident on the steep slope behind this store. |
| 0.1 | 33.0 | Turn right into parking lot. |
| 0.1 | 33.1 | Stop buses at west end of lot adjacent to access road. Debark. |

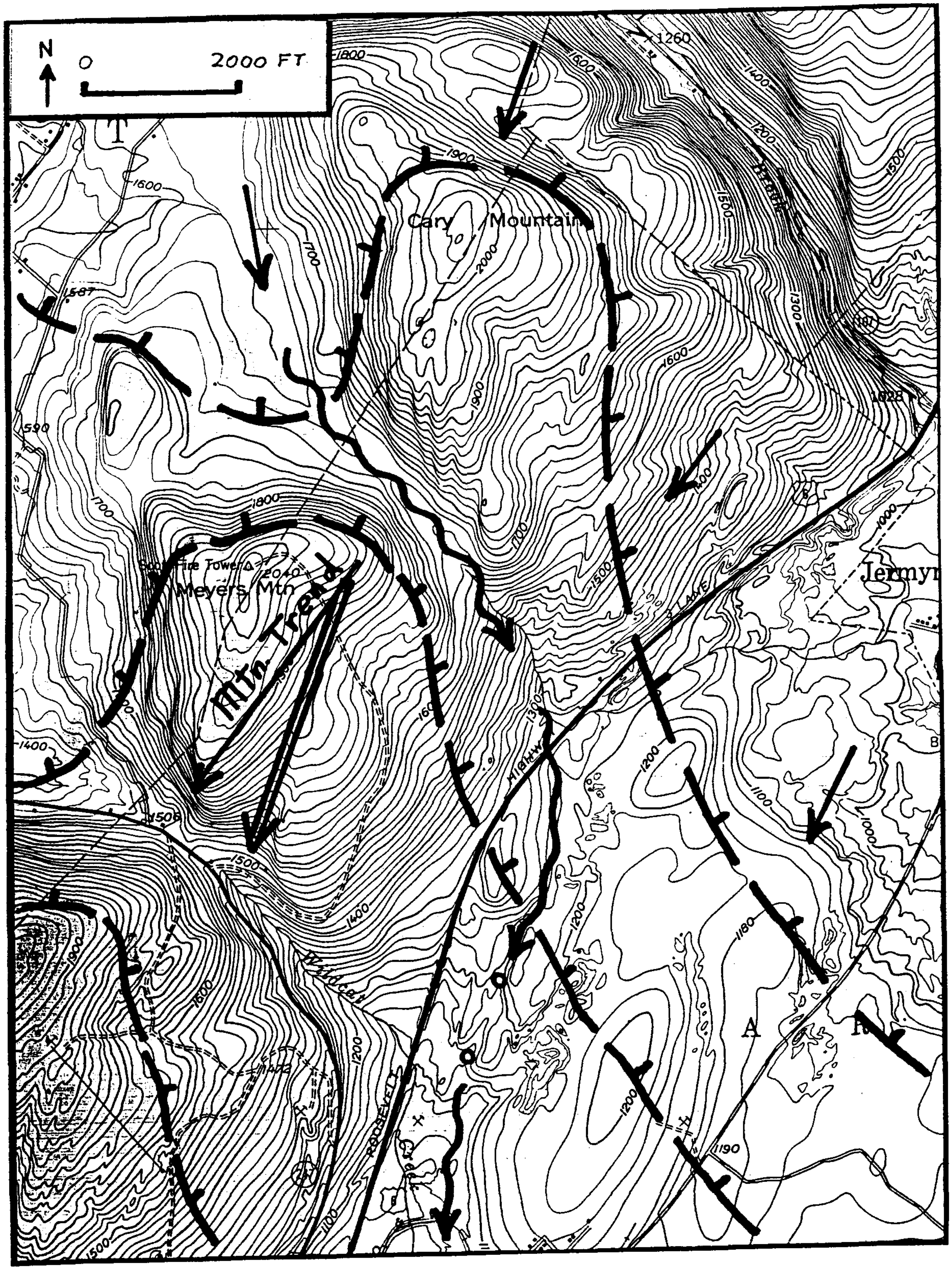



Figure 59. Topographic map (Carbondale 7.5' quadrangle) of the area around the Archbald potholes (two circles) showing regional ice flow direction (double line arrow), inferred local ice flow direction (short arrows), inferred subglacial meltwater flow across site (wavy line arrows), and inferred ice margins around the knobs on the north side of the Lackawanna Valley.

**STOP 9.** ***WAL-MART ROCKSLIDE AT DICKSON CITY: A SLOPE FAILURE IN DIPPING, JOINTED, AND COLLAPSED LLEWELLYN STRATA.***

Leaders: P. Richard Scheller, Nathan Houtz, Gerald Ahnell, and William E. Kochanov.

The rock slide behind the WAL-MART Department Store in Dickson City northwest of US 6 (Figure 60) is a prime example of why geological and geotechnical studies should be done before any major construction project—particularly, in this case, one involving deep cuts into a hillside. At least three geological and historical facts are at play here: bedding dips roughly parallel to the hill slope and was "daylighted" by the cut; rock forming the slope is thick-bedded, well jointed sandstone; and the slope overlies coalbeds that have been deep mined. Since the WAL-MART slope failure is in litigation, it is best not to say more here. Just take at look—"[S]ome circumstantial evidence is very strong, as when you find a trout in the milk," as Thoreau said.

**BACKGROUND**

On January 3, 1996 a very large sandstone bolder broke loose from the steep embankment wall behind the Dickson City WAL-MART. The boulder sheared off a tall, high-mast light post in the store's rear parking lot. That particular boulder came to rest a few feet from the wall of the building. In April and again in September of the same year, additional boulders broke loose and slammed into the building wall causing some structural damage. On December 16, 1996 at the height of the Christmas shopping season, evidence of the potential for more serious damage to the building and possibly its occupants resulted in the closure of the store and a relocation of its inventory. Today, the store remains closed as geotechnical engineers and store owners workout what will sure to be a costly remedial strategy for the unstable rock slope.

The WAL-MART building is located at the toe of a 200-feet-high cut made in the slopes to accommodate several structures at this new mall (Plate 6, A-B)). The rock cut runs parallel to the back

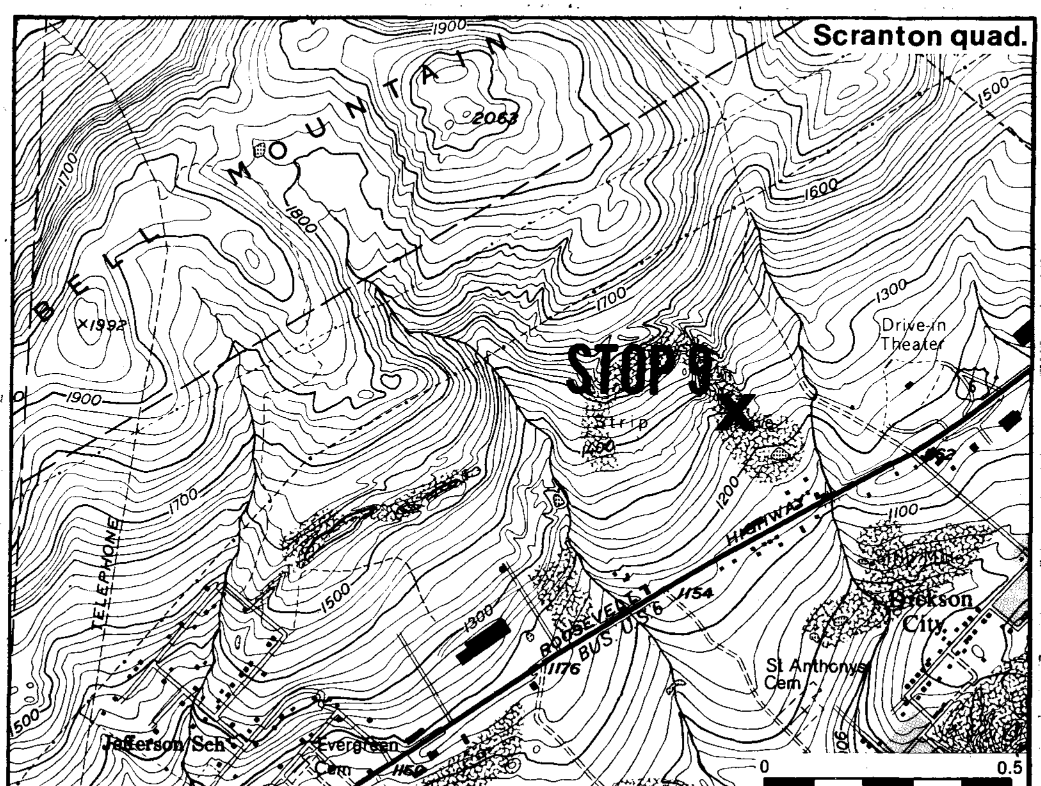



Figure 60. Location map for STOP 9 (WAL-MART rockslide).

Plate 6


**A.** Distant view of the WAL-MART rockslide (STOP 9). Even from across the parking lot the intensely disturbed nature of the rock strata is evident.

**B.** Close-up view of southeast-dipping, highly fractured sandstone of the Llewellyn Formation behind the WAL-MART Department Store (STOP 9).

of the building and extends 150 feet beyond the building. A 35 feet-wide access road at the toe of the cut extends beyond the building and provides access to the loading docks for the store. The building is approximately 500 feet long (parallel to the cut) and 300 feet wide (perpendicular to the cut). The cut was made in 1990-91.

The natural slope of the ground beyond the rock cut is approximately 15 degrees. A partially completed intermediate bench excavation was cut about 60 feet from the top of the cut but was never fully completed behind the southern end of the WAL-MART building and the area near the loading docks. Jagged rocks protruded out from the uncompleted intermediate bench. Analysis of the slope behind the building indicates an overall cut angle of inclination of about 42 degrees. However, in certain areas, above and below the intermediate bench, inclinations of 60 degrees to near vertical are evident.

**IN-SITU CONDITIONS OF THE ROCK MATERIALS IN THE CUT AREAS**

Rock materials that make up most of the upper two-thirds of the cut consist of light-yellow sandstone beds (lower Llewellyn Formation) of varying thickness (1-6 feet thick) striking in a direction semi-parallel to the cut face. In general, the bedding has a dip of about 15 to 20 degrees out of the cut face. However, the presence of several steeply inclined shear zones striking semi-perpendicular to the cut face results in some variation of the dip of the sandstone layers along the cut. A series of relatively flat, thinly bedded sandstones (less than 1 ft.) and interbedded shale layers are present near the top of the cut above the thick, light-yellow sandstone layers. The total thickness of the thin layer sequence is about 10 to 15 feet. The inclination of the cut through the thinly bedded layers is almost vertical.

The in-situ rock materials in the lower one-third of the cut has been covered with a fill consisting of large boulders along most of the cut. The lower in-situ rock exposed beyond the left corner of the building consists of dark, thinly bedded (2-12 inch thick) sandstone and interbedded shale layers. It is obvious from Plate 1 and more apparent standing below the slopes, that a very large number of loose boulders and large rock blocks present in the slope constitute an extremely serious safety and building damage hazard.

In addition to the joints along the bedding, two main rock mass discontinuities are present in the rock cuts. These discontinuities include:

a) Shear zones—A series of shear zones striking in a direction almost perpendicular to the cut face, and dipping steeply (> 60 degrees) to the north can be observed in the exposed walls. Shear zones are present throughout the entire length of the cut at a spacing of about 40 to 60 feet and about 15 feet wide. They contain heavily broken rock and continuous zones of soil-like materials 6 to 14 inches wide. The joints within the shear zone are wide open and the soil-like materials near the surface is partially eroded by water flows, leaving isolated, loose rock boulders in the face of the cut.

a) Joint sets—Two main sets of continuous joints can be observed all along the cut. One set of joints strikes semi-parallel to the cut and dips about 50 degrees southeast towards the building. The spacing between joints varies from 1 foot to several feet. The second set of continuous joints strikes in a direction semi-perpendicular to the cut face and dips steeply $60 \pm 10$ towards the northeast and/or southwest direction. The spacing between these joints also varies from 1 foot to several feet.

In the course of field mapping of the Olyphant and Scranton quadrangles, Kochanov measured a stratigraphic section of the rock cut behind the store (Figure 61). He observed three thick coalbeds and their underlying rootworked seatrocks in the WAL-MART cut. The lowest coalbed is too disturbed for accurate measurement; it is overlain by dark-gray clay shale containing *Lepidodendron* and *Lepidophylloides*. The middle seam (probably exposed in a pillar) is at least 39 inches thick. Extremely fossiliferous claystone and clay shale (*Calamites, Asterophyllites, Neuropteris, Alethopteris, Pecopteris, Sphenophyllum*, and *Bowmanites*) occur not far above this

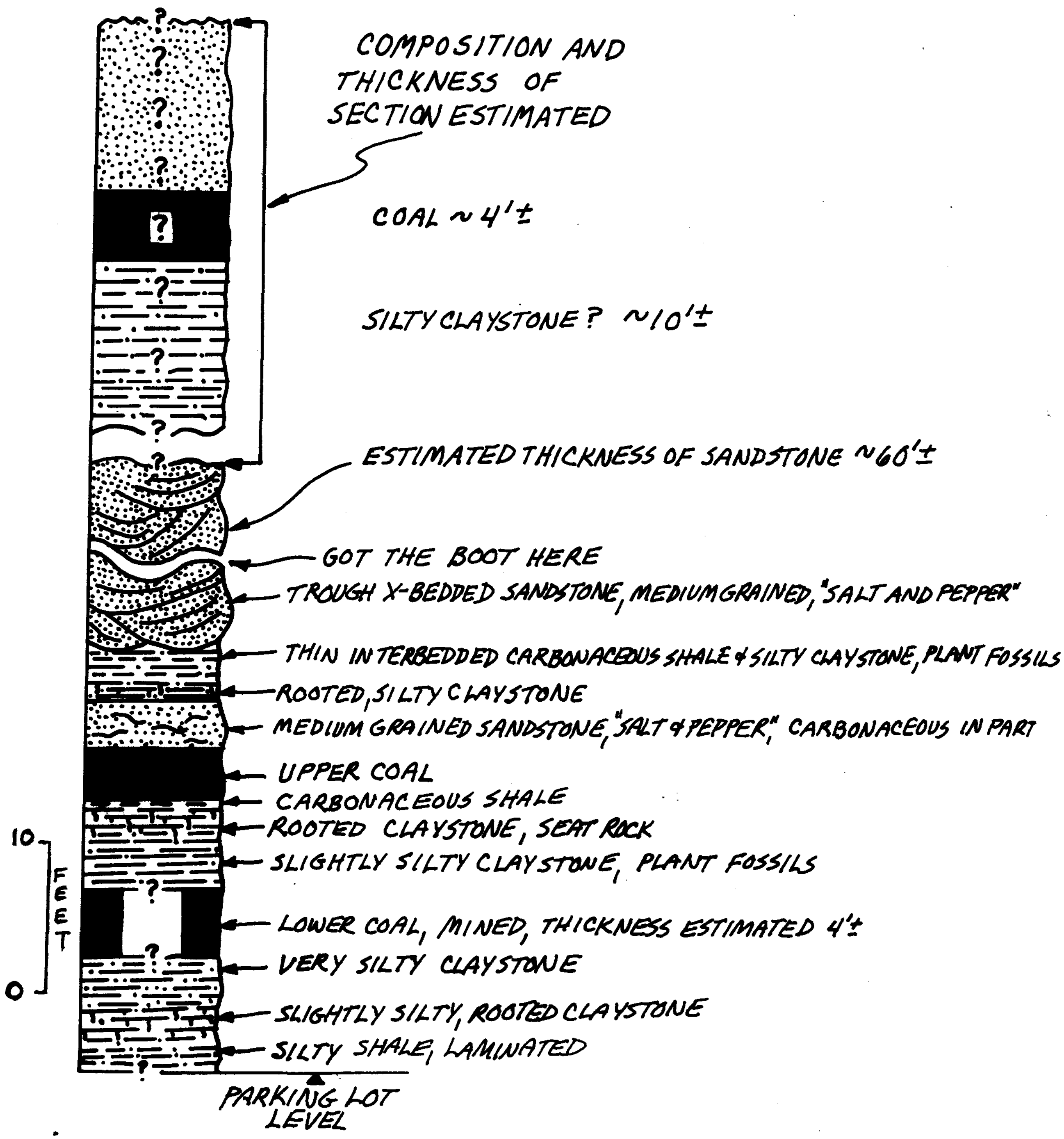



Figure 61. Stratigraphic section exposed in the rock cut behind the WAL-MART Department Store (STOP 10). Some thicknesses are estimated

seam. Higher in the cut another coalbed was estimated to be about 48 inches thick. These coalbeds are probably within the Dunmore-Clark (Archbald)-New County (Marcy) interval, but their exact identification is uncertain at this time.

**POTENTIAL MODES OF FAILURE**

Based on the geometry of the cut and the in-situ conditions of the rock materials, the main mode of failure that can and has already occurred at this site, consist of loosening, detachment and falling of large rock boulders. The fall of these boulders can be triggered by hydraulic pressures that build up in the joints beneath and/or behind the boulders during periods of snow and freeze/thaw or during periods of heavy rainfall. Erosion of soils within the shear zones would also reduce confinement and lead to boulder falls.

Another source of large, unstable boulders is the fill materials that were spread out on the two benches present in the rock cut. Large boulders were pushed to the edges of the upper benches immediately above the building. The stability of these large boulders is precarious and presents a clear danger to the building and to the traffic in the access road below.

Because of the high elevation and close proximity of loose boulders (in-situ and fill) to the back of the building, there continues to be a high probability of impact to the structure during rock falls. The boulder that sheared off a light post fell within 20 feet of the back of the building.

**REMEDIAL MEASURES**

The main remedial measures planned to improve slope stability and reduce potential hazards are:

a) Flattening the present rock cut geometry by reducing the inclination of the slopes between benches to a minimum of 50 degrees and by increasing the width of all benches to a minimum of 40 feet. In addition, the benches should have a slight inclination (about 10 degrees) towards the slope to minimize downward rolling of loose boulders that might fall on the bench. The inclination of the bench would also divert rainfall toward lined drainage ditches to be installed at the toe of the slopes between berms.
b) Remove all loose fill from the benches of the rock cut and all non-essential fill materials.
c) Provide drain holes inclined at 10 degrees above the horizontal on all slopes between benches to reduce pore pressure build-up within the joints behind the slope face.

Behind Wegmans a short distance to the northeast, glacial till is sliding on the underlying bedrock surface. The situation will only worsen as material is removed at the toe of the slope, as was done in the summer of 1997.

| | | |
|---|---|---|
| | | Leave STOP 9. Turn right onto access road to US 6W. |
| 0.3 | 33.4 | Traffic light. Turn right onto US 6W. |
| 0.1 | 33.5 | Behind Pep Boys to right is an excellent exposure of lower Llewellyn strata, including a thin coalbed. Bedrock is capped by Late Wisconsinan kame gravels. |
| 1.0 | 34.5 | Traffic light at Fashion Mall. Lower Llewellyn sandstone and shale exposed behind mall buildings to right. |
| 0.3 | 34.8 | Complicated interchange between US 6, I-81, and US 11. Follow signs for US 6W/11N (Clarks Summit). |
| 0.2 | 35.0 | Bear right onto entrance ramp for US 6W/11N. |
| 0.2 | 35.2 | Merge with US 6W/11N, keeping to right. |
| 0.1 | 35.3 | Pull off onto right shoulder at large rock cut. Debark from buses. |

**STOP 10.** ***US 6W-11N ROADCUT IN LEGGETTS GAP: POCONO, POTTSVILLE, AND LLEWELLYN STRATIGRAPHY..***
Leader: William E. Edmunds.

## INTRODUCTION

Unlike previous stops exposing this part of the section (STOPS 2, 3, and 7B), no part of the Mauch Chunk Formation remains here at the US 6-11 cut in Leggetts Gap (Figure 62). Erosion at the sub-Sharp Mountain unconformity below unit 3 (Figure 63) has cut below the older sub-Loyalhanna unconformity and into the underlying Pocono Formation. Between here and the southwest end of the Northern Anthracite field at Shickshinny, approximately 1000 to 1200 feet of Mauch Chunk Formation has been unconformably lost. Of this, about 700 feet was removed by erosion at the sub-Sharp Mountain unconformity and between 200 and 400 feet at the earlier sub-Loyalhanna unconformity. Northward from Scranton, the sub-Sharp Mountain unconformity erosion continues to cut down section. The last of the Pocono and Spechty Kopf is lost near Jermyn, beyond which the Sharp Mountain rests upon the upper Devonian Catskill Formation (see Sevon, 1969).

Another excellent exposure of this part of the section extending down into the underlying Catskill Formation is found a short distance higher on the ridge directly above this site in a roadcut along I-81.

**Pocono Formation (units 1 and 2)**

The sandstone of unit 1 is typical fluvial Pocono as discussed at STOP 7B. This may be the same sandstone as unit 6 or 8 at STOP 7B and displays the same dark-red hematite (?) pinhead pitting.

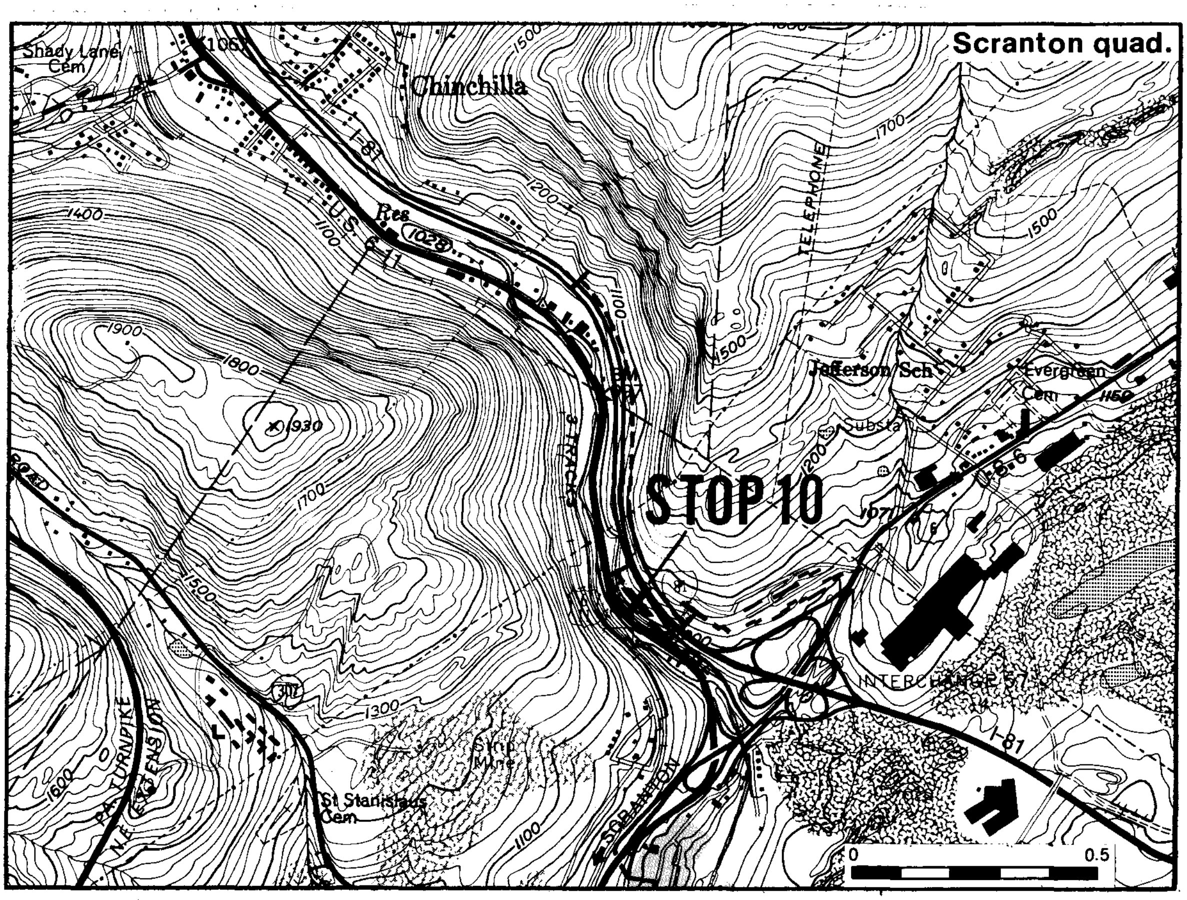



Figure 62. Location map for STOP 10.

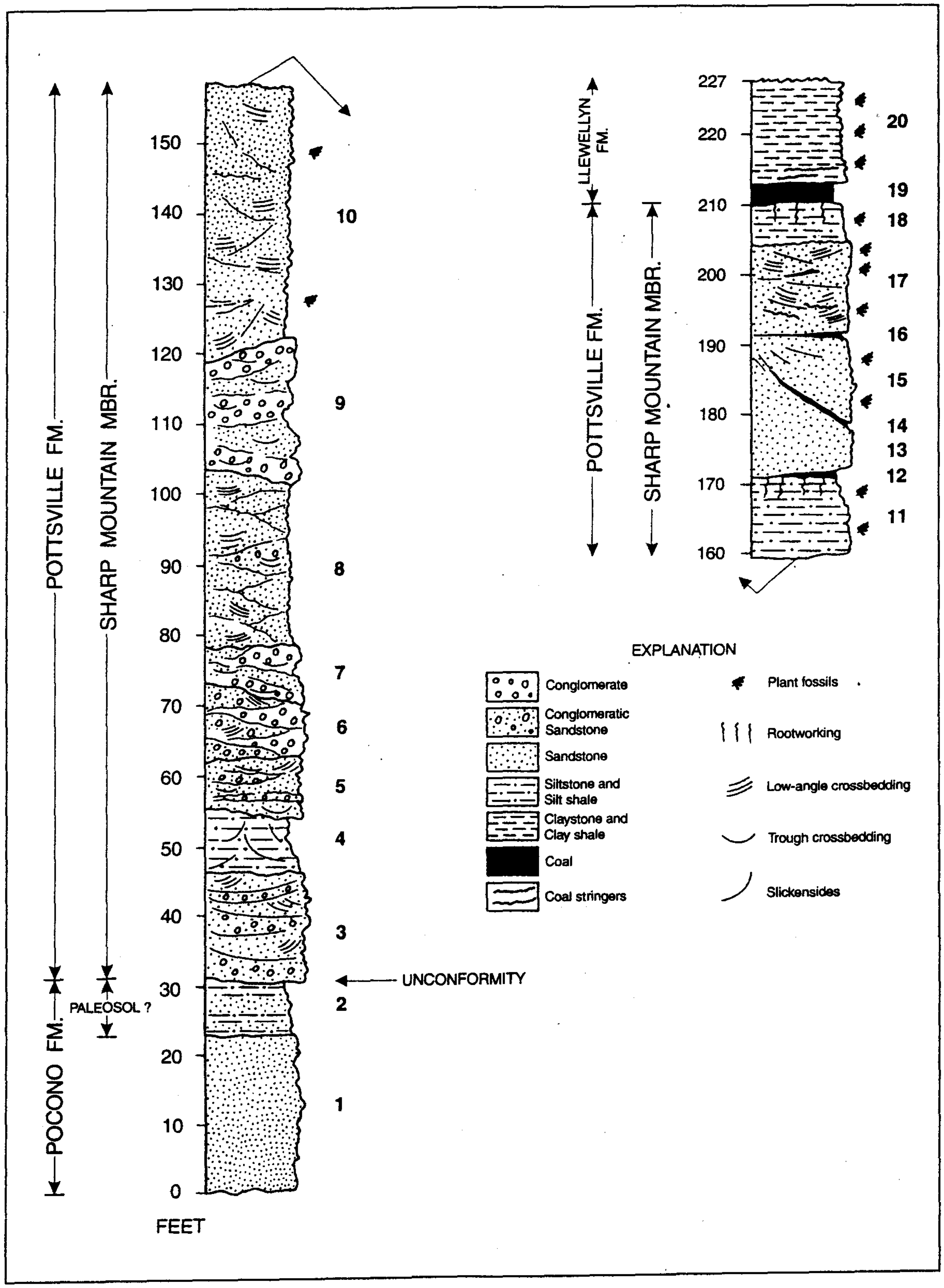



Figure 63. Stratigraphic column of the upper Pocono, Pottsville, and lowermost Llewellyn Formations exposed on US 6W-11N in Leggetts Gap (STOP 10).

The siltstone to very fine-grained sandstone of unit 2 is speculatively identified as a paleosol formed on the weathered upper surface of the Pocono below the sub-Sharp Mountain unconformity. Superficially, it resembles the sub-Loyalhanna paleosol of STOP 7B (unit 15 of Figure 63), but is non-calcareous and lacks the prominent curved crisscross desiccation cracks. It would most likely be identified as a simple vertisol in the classification of Mack and others (1993). The genetic difference between unit 2 and the vertic calcisol at STOP 7B may be a matter of climate. Vertic calcisols tend to form under semiarid conditions, such as would be associated with Late Mississippian sub-Loyalhanna erosion. Unit 2 at this stop would be expected to be associated with the semi-tropical wet climate of the middle Pennsylvanian.

**Pottsville Formation (units 3 through 18)**

The complete Pottsville Formation (Sharp Mountain Member) is exposed at this stop. Unit 4 is interpreted as the Campbells Ledge shale bed and unit 3 as the conglomeratic sandstone which often underlies the Campbells Ledge. As seen in previous stops, the Pottsville (Sharp Mountain) is divided into an alluvial high-energy conglomeratic lower part and a lower-energy, finer-grained upper part with some ephemeral local peat-swamps.

**Llewellyn Formation (units 19 and 20)**

The 2.9-foot-thick mined coalbed near the top of the exposure (unit 19) is interpreted as the Dunmore No. 3 seam, which marks the base of the Llewellyn Formation in the Lackawanna subbasin of the Northern Anthracite field. As mentioned previously at STOP 4, C. D. White (1904, p. 269; 1912, p. 441) questioned the correlation of the Dunmore No. 3 with the Buck Mountain coalbed, which marks the base of the Llewellyn in the Southern and Middle fields and believed that the Dunmore coalbeds were older than the Buck Mountain and should be included in the Pottsville. The abundant plant fossils above and below the coal at this site may shed some light on this problem.

| | | |
|---|---|---|
| | | Leave STOP 10. Proceed ahead on US 6W-11N. |
| 0.1 | 35.4 | Cut in southeast-dipping Pocono sandstone to right. |
| 0.2 | 35.6 | Long cut in southeast-dipping Spechty Kopf sandstone to right |
| 0.4 | 36.0 | Clarks Summit-South Abington Joint Sewer Authority plant to right. |
| 0.7 | 36.7 | 2nd traffic light in Chinchilla. Turn left and then almost immediately left again on side street in front of Rave Garden Center. |
| 0.1 | 36.8 | Stop sign. Continue south on US 6-11. |
| 0.8 | 37.6 | Stone ruins to right. |
| 0.1 | 37.7 | Historical Marker to right reads: *SCRANTON. Ebenezer Slocum built the first house and made the first iron here prior to 1800. Its founding, naming, and growth as a city were due to George W. Scranton and associates. Leader in iron and steel for 60 years after its founding, 1840.* |
| 0.2 | 37.9 | Wooden flume to right. |
| 0.7 | 38.6 | Bear right around traffic circle. To left about halfway around perimeter is a coal monument commemorating this as the "Gateway to Scranton" and the first traffic circle in Pennsylvania (dedicated in July of 1941). |
| 0.2 | 39.8 | Yield sign. Merge right and cross two-lanes of traffic to get on entrance ramp to I-81S. |
| 0.2 | 39.0 | Merge left onto I-81S. |

| | | |
|---|---|---|
| 1.1 | 40.1 | Exit 56 (Dickson City). Continue straight ahead. |
| 0.1 | 40.2 | Cross Lackawanna River. |
| 0.1 | 40.3 | Coal-refuse banks to right mark the former location of the Marvine Colliery. |
| 0.2 | 40.5 | Note large, stone-lined drainage channel to right carries runoff and seepage from large interchange area under construction to south. |
| 1.2 | 41.7 | Exit 55B (Blakely Street-Throop). Continue straight ahead. |
| 0.7 | 42.4 | Get into left lane, following signs for I-84/380. Just to the right behind the sound barriers is the part of Dunmore affected by carbon monoxide leakage from underlying deep mines (see p. 61-63). |
| 0.2 | 42.6 | At Y-intersection, bear left toward I-84/380. |
| 0.6 | 43.2 | Get into right lane, following signs for Exit 1. |
| 0.3 | 43.5 | Bear right onto ramp at Exit 1 (Tigue Street). |
| 0.2 | 43.7 | Stop sign. Bear right. |
| 0.1 | 43.8 | Turn right, passing under I-84/380 and in front of Holiday Inn. |
| 0.2 | 44.0 | Stop sign. Turn left opposite entrance ramp to interstate. |
| 1.1 | 45.1 | Turn right at entrance to Keystone Landfill. **Proceed through security gate to aggregate quarry on hillside beyond landfill.** |

## STOP 11. *KEYSTONE SANITARY LANDFILL AND QUARRY COMPLEX: LLEWELLYN STRATIGRAPHY, GEOHYDROLOGY, AND ENVIRONMENTAL GEOLOGY.*

Leaders: Gerry Ahnell, P. Richard Scheller, and Albert J. Magnotta.

### INTRODUCTION

The Keystone Sanitary Landfill and Quarry Complex (Keystone Complex) offers a unique vista into the depositional environments of the Pottsville and lower Llewellyn Formations, as well as insights into the overlying Pleistocene deposits. The site's coal mining history and current landfilling, methane recovery and quarrying activities present not only geotechnical and environmental monitoring challenges but also provide the basis of favorable land-use and resource recovery potential well into the next century.

### GEOLOGIC SETTING AND MINING HISTORY

The Keystone Complex occupies approximately 1,000 acres of ground straddling the Boroughs of Troop and Dunmore between Marshwood Road and the new Lackawanna Valley Industrial Highway (LVIH– currently under construction). Figure 64 shows the approximate site boundaries in relation to the area's mapped geologic contacts and its various cultural and drainage features. The site is situated on the southeast limb of the Lackawanna basin which has been described as a doubly-plunging synclinorium containing numerous smaller anticline-syncline pairs (Figure 10). Bedrock beneath the site generally dips to the west-northwest, although some local reversals can be seen. The anthracite-bearing Llewellyn Formation underlies nearly the entire site with some shales, sandstones, and conglomerates of the Pottsville Formation outcropping in the extreme southern reaches of the property near the LVIH and Keystone Quarry. At present, glacial till deposits ranging from a few feet to over 100 feet in thickness can be seen in an exposed borrow pit located between the "Tabor Site" and Phase II Development Areas (Figure 65).

Beginning in the late 1800's and extending into the 1970's, the Keystone Complex and much of the surrounding area was subjected to extensive coal mining activities by the Pennsylvania Coal Company. Initially, underground room and pillar mining methods were employed to remove the coal from three (3) principal seams across the site. In descending stratigraphic order, these coals were identified as the Dunmore No. 1, Dunmore No. 2 and Dunmore No. 3 seams. The Dunmore No. 3 seam

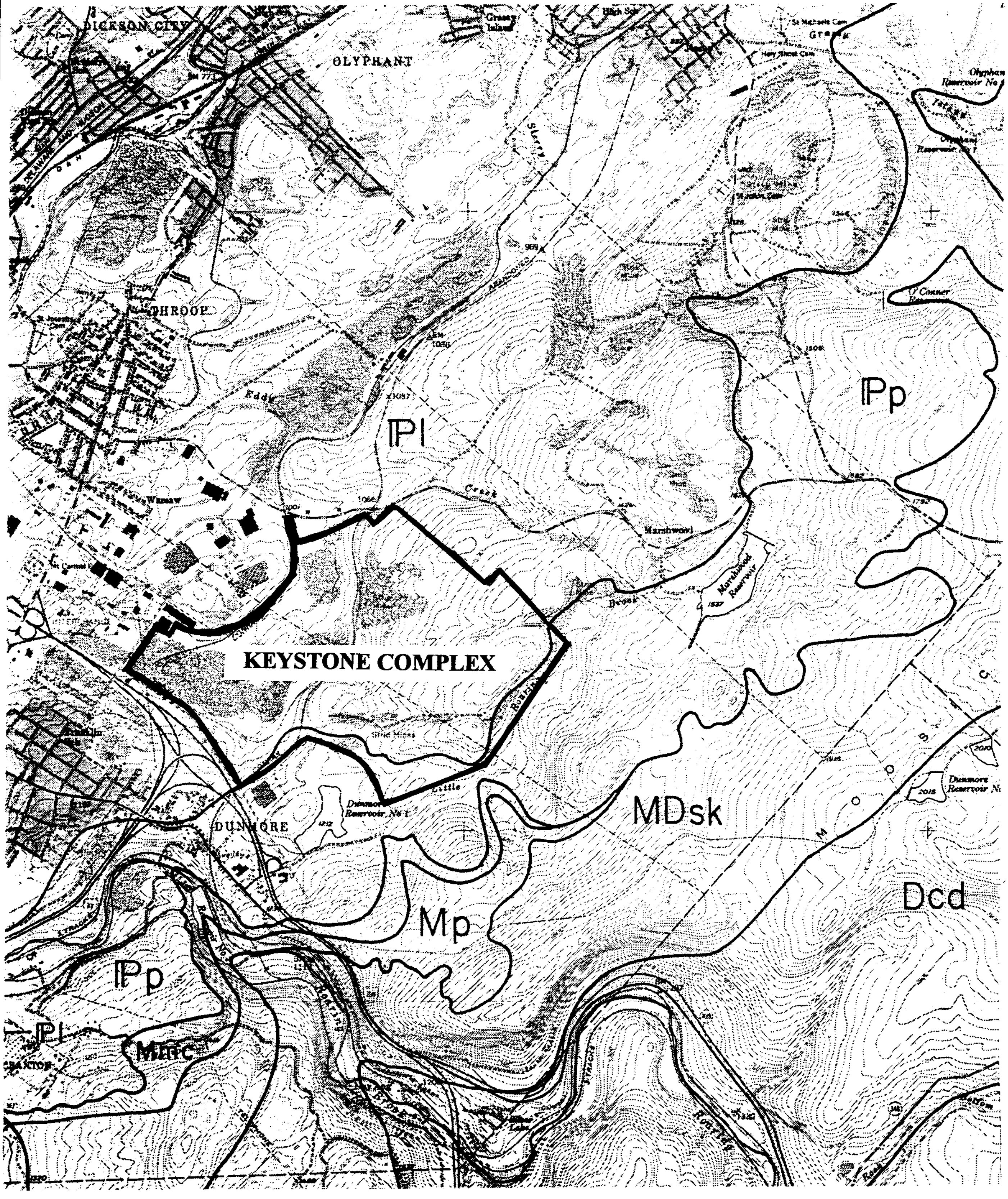



Figure 64. **Map Derived From Olyphant, Pa. - Atlas of Preliminary Geologic Quadrangle Maps of Pa.**

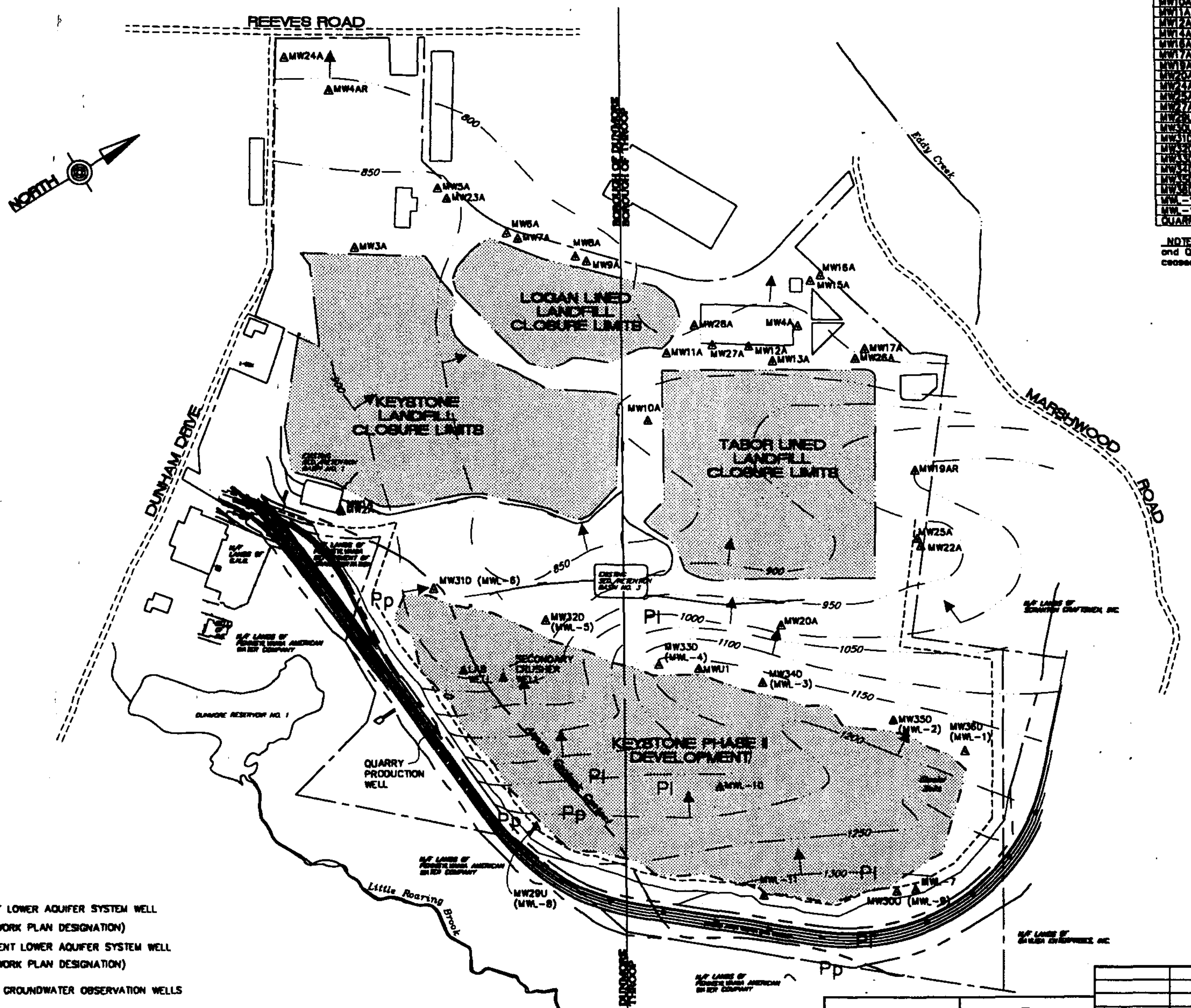
N

| | |
|---|---|
| **HYDRO-GEO SERVICES, INC.**<br>428 Bridge Street<br>New Cumberland, Pa. 17070<br>(717) 774-2138 Fax (717) 774-2125 | **SITE LOCATION**<br>KEYSTONE COMPLEX<br>Lackawanna County Olyphant, Pennsylvania |
| PROJECT NO \| DATE: 08/27/97 | SCALE: 1 inch = 3,600 feet \| FIGURE NO: 1 |

STATIC WATER LEVELS
LOWER AQUIFER SYSTEM WELLS
SEPTEMBER 23, 1996

| WELL ID (TOC ELEVATION) | DEPTH TO WATER | W.L. ELEVATION |
|---|---|---|
| MW2A (1102.65) | 174.00 | 928.65 |
| MW3A (1037.15) | 173.10 | 864.05 |
| MW5A (1030.23) | 170.55 | 859.68 |
| MW6A (1027.84) | 188.30 | 839.54 |
| MW9A (1021.09) | 176.90 | 844.19 |
| MW10A (1026.58) | 159.85 | 866.73 |
| MW11A (1012.72) | 200.93 | 811.79 |
| MW12A (1005.92) | 192.15 | 813.77 |
| MW14A (1005.69) | 203.25 | 802.44 |
| MW16A (992.43) | 200.15 | 792.28 |
| MW17A (1053.72) | 258.25 | 795.47 |
| MW19AR (1185.66) | 179.55 | 1006.11 |
| MW20A (1259.89) | 295.45 | 964.44 |
| MW24A (1045.21) | 253.35 | 791.86 |
| MW25A (1228.04) | 292.60 | 935.44 |
| MW27A (1006.17) | 194.35 | 811.82 |
| MW29U(MWL-8) (1371.03) | 141.10 * | 1229.93 |
| MW30U(MWL-9) (1455.80) | 139.30 | 1316.60 |
| MW31D(MWL-6) (1231.13) | 373.60 | 857.53 |
| MW32D(MWL-5) (1233.42) | 373.55 | 859.87 |
| MW33D(MWL-4) (1280.23) | 125.20 | 1155.03 |
| MW34D(MWL-3) (1301.64) | 146.30 | 1155.34 |
| MW35D(MWL-2) (1354.91) | 176.30 | 1178.61 |
| MW36D(MWL-1) (1399.89) | 217.70 | 1182.19 |
| MWL-10 (1392.79) | 227.15 | 1165.64 |
| MWL-11 (1459.59) | 146.60 | 1312.99 |
| QUARRY LAB WELL (1244.66) | 356.70 * | 887.96 |

NOTE: Water level data obtained after Quarry Lab Well and Quarry Production Well (on same fracture trace as MW29U) ceased pumping for approximately 18-20 hours.




150

LEGEND

| | |
|---|---|
| MW29U (MWL-8) | UPGRADIENT LOWER AQUIFER SYSTEM WELL (ORIGINAL WORK PLAN DESIGNATION) |
| MW29D (MWL-5) | DOWNGRADIENT LOWER AQUIFER SYSTEM WELL (ORIGINAL WORK PLAN DESIGNATION) |
| MWL-7; LAB WELL, ETC. | ADDITIONAL GROUNDWATER OBSERVATION WELLS |
| MWU1 | UPPER AQUIFER SYSTEM WELL |
| 950 | GROUNDWATER CONTOURS - LOWER AQUIFER SYSTEM (9/23/96)+FLOW DIRECTION |
| Pp | BEDROCK (Pl = LLEWELLYN FORMATION/Pp = POTTSVILLE FORMATION) |
| Pl | APPROX. GEOLOGIC FORMATION CONTACT |

Figure 65.

GROUNDWATER CONTOUR MAP
*KEYSTONE SANITARY LANDFILL COMPLEX*
DUNMORE BOROUGH , THROOP BOROUGH
PENNSYLVANIA

| REVISIONS | DATE |
|---|---|
| DESIGNED CA | DRAWN DCS |
| CHECKED | SCALE 1"=400' |
| JOB NO. 95-05-42 | DATE 10-11-96 |

GERALD ANNELL, P.G. REGISTRATION # 182-G
ALBERT J. MAGNOTTA, P.E. REGISTRATION # 14397-E

consulting engineers
p.o. box 985, scranton, pa. 18501 717-342-3101
ceco associates inc.

was the lowest and most extensively mined of the three seams present according to the available mine maps secured from the Pennsylvania Coal Company. Portions of the Dunmore No. 1 and Dunmore No. 2 seams were removed by glaciation near the center of the property but elsewhere on-site were also heavily mined to exhaustion. The mine maps indicate that in most areas of the site, first, second and even third mining occurred to remove the coal seams and pillars left beneath the site. Surface mining activities along the outcrops of the three seams started in the late 1950's and continued into the late 60's and early 70's.

## LANDFILL AND QUARRY HISTORY

Prior to the purchase of the Keystone Complex by the current owners, local municipalities began utilizing the abandoned and often unreclaimed stripping pits on-site as repositories for municipal trash and demolition debris. By the middle of the 1970's, the current owner purchased the property from the Pennsylvania Coal Company and obtained a solid waste disposal permit from the Pennsylvania Department of Environmental Resources (now Pennsylvania Department of Environment Protection). The permit was for an unlined, natural renovation landfill at the site of the mapped "Keystone" and "Logan" sites (Figure 65). The Keystone Site has been officially closed and covered while the smaller Logan site is scheduled for incorporation into the " Tabor Site". At the present time, the "Tabor Site" is active and was permitted as a state-of-the-art double-lined facility with its own leachate recovery and treatment facilities. Further upgradient, the Phase II Development Area received a permit for an additional 186 acre double-lined facility from the PaDEP on June 12, 1997. Development activities in this expansion area are only now getting underway. The Keystone Quarry also operates a 1 million ton per year processing facility in this same area under permit by the PaDEP. Dense Llewellyn sandstones and Pottsville conglomerates are processed to yield a variety of aggregate materials and rip-rap for both on-site (Landfill) use and off-site sales. Two thick deposits of Llewellyn sandstone above the Dunmore No. 2 coalbed are presently being quarried in two deep pit within the Phase II Development Area for off-site sales. Removal and processing of these dense sandstone units within the Phase II Area provides for efficient use of this valuable resource, while greatly reducing development cost associated with the planned landfill expansion. Additionally, thick on-site glacial tills are also being excavated to meet daily cover requirements at the "Tabor Site."

## GEOTECHNICAL CONSIDERATIONS AND GROUNDWATER MONITORING

The Keystone Complex's historical mining and landfilling activities presented two technical challenges which needed to be assessed for permitting purposes. From a geotechnical standpoint, the presence of old abandoned and collapsed underground mine working represents a potential surface and liner stability problem requiring substantial subsurface characterization before final engineering design considerations could be formulated. For the "Tabor Site" and the Phase II Development Areas, hundreds of core borings within and bordering the landfill footprint were needed to assess subsidence potential. Throughout the property, it was determined that subsidence had essentially been completed in much of the underground workings with the possible exception of some of the fortified main haulage ways identified from the mine maps and core borings. Depending upon the separation distance between any identified voids and the planned liner subgrade elevation, various remediation alternatives can be used to render the areas safe for construction. Some of the more common remedial measures include over excavation to the bottom of the void zone or blasting to complete the collapse. Other methods proposed but not yet employed involve a combination of over-excavation, backfilling and the installation of a "geosynthetic-geonet" to provide additional support to the liner and under-drain materials in the event of a localized collapse after landfilling has been started.

Groundwater monitoring for regulatory compliance needs is complicated at this site, again resulting from its historic coal mining activities. Two aquifer systems needed to be delineated and are currently monitored at thirty-five (35) locations throughout the property. "Upper Aquifer System" wells were established to monitor water quality associated with the Llewellyn Formation, while "Lower Aquifer System" wells monitor the Pottsville and deeper units below the Dunmore No. 3 seam. Since unlined stripping pits associated with the Dunmore Nos. 1, 2 and 3 seams served as the initial repository for municipal trash in the area, infiltrating waters percolating down to the mines needed to be monitored. Throughout the site, subsidence/roof collapse above the mines over the past 100 years have effectively de-watered the Llewellyn Formation—so that only in those areas where structural dips associated with the Dunmore No. 3 seam are present, can the infiltrating water (mine drainage) be effectively monitored. Monitor wells with collection sumps into the floor of the Dunmore No. 3 seam are used for the Upper Aquifer System.

Below the Llewellyn Formation, groundwater occurs in secondary porosity features—such as fractures—associated with the dense sandstone, conglomerates, and shales of the Pottsville and deeper units. When possible, aerial photography and geophysical techniques were used to select monitor well sites along fracture traces. Deep wells with bottom seals to isolate flows associated with the upper Aquifer System were installed to effectively monitor the Lower Aquifer System. The Lower Aquifer System is considered more important for monitoring and protection purposes since it essentially represents the first true aquifer unit beneath landfill. However, from a quality standpoint, both aquifer units are naturally impacted with acid mine drainage components (high iron, sulfates, total dissolved solids, etc.) and show tremendous variability across the site in both up-gradient and down-gradient of the landfill cells. To date, after over 10 years of monitoring, none of the more prominent landfill contaminants (i.e., Volatile Organic Compounds [VOC's]) have been detected. Effective closure and capping of the "Keystone Site" and the utilization of liners and leachate collection systems beneath the "Tabor Site" and Phase II Development Area greatly limits the potential for contamination of the areas groundwater resources.

## GAS MANAGEMENT SYSTEM

In 1992, closure activities including liner capping and a methane-gas-collection and flameless-flare installation were implemented on the "Keystone Site". The gas management system included a total of sixty-seven (67) collection wells. Closure activities associated with the "Tabor Site" occurs annually, and presently over twenty (20) additional gas collection wells have been installed out of a total ninety-six (96) planned for the site.

The primary objective of a landfill gas management system is to efficiently extract, transport, and dispose of land-fill gas that results from the decomposition of municipal solid waste. Methane gas extraction from the collection wells is achieved by applying a vacuum to the collection/manifold system with a fuel gas compressor. An enclosed flameless flange is employed as a backup and is utilized any time that the gas generation exceeds the output of the gas to electric facility. The initial operation of the gas to electric facility commenced in 1994 with a capacity of 3.2 megawatts/day. A second stage was built in 1996 which increased the capacity to 5.0 megawatts/day. Presently, the facility consists of seven (7) internal combustion reciprocating type engines.

The Caterpillar engines utilized are turbo-charged and of a lean burn design. This type of engine is considered "Best Available Technology" under 25 PA Code 127.12 (a)(5) and the "Air Quality Permitting Criteria, Including Test Available Technology Criteria, for Municipal Solid Waste Landfills," dated September 13, 1988. These engine are similar to the manufacturer's natural gas version, but have been modified to withstand the corrosive effects of landfill gas. Each engine is capable of combusting approximately 400,000 standard cubic feet of landfill gas per day, or 10 million BTU's higher heating value (HHV) per hour. Each engine generates 800 KW of electrical power at 4,160 Volts. Approximately 150 KW of power is required to operate the facility's auxiliary loads. The remaining power is transformed and delivered to the Pennsylvania Power and Light Company's electrical transmission system.

The gas-to-electrical generation facility converts methane contained in the landfill gas to useful energy. The facility is designed to efficiently combust the gas to insure destruction of non-methane organic compounds while minimizing the formation of air pollutants. It is important to note that the electrical power generated at this facility, which is not utilized on-site, is sold to the Pennsylvania Power and Light Company. Power sales are conducted in accordance with the Public Utility Regulatory Policies Act (PURPA), and reduce the amount of fossil fuel burned by Pennsylvania Power and Light Company in meeting its customers' demand for electrical power.

| | | |
|---|---|---|
| | | Leave STOP 11. Turn left onto public road at entrance to landfill. |
| 1.1 | 46.2 | Stop sign. Continue straight ahead onto interstate ramp with deep rock cuts (STOP 7B again!). |
| 0.3 | 46.5 | Merge with interstate, getting into left lane to follow signs for I-81S. |
| 0.5 | 47.0 | At Y intersection, bear left onto ramp for I-81S. |
| 0.4 | 47.4 | Merge with I-81S, getting into right lane as soon as possible. |
| 0.8 | 48.2 | To the right is a splendid cut exposing mine pillars of two thick lower Llewellyn coalbeds (probably Dunmores). Sandstones and shales over the lower coalbed have subsided into the mine workings (Figure 66). PennDOT has extensively rock bolted, grouted, and concreted the rocks in an attempt to stabilize the cut. |
| 0.5 | 48.7 | Cut in Llewellyn sandstone and shale to right. |
| 0.5 | 49.2 | Nay Aug Gorge, the post-glacial course of Roaring Brook, is to the right (see Pre-Conference Field Trip 2, Appendix A-2). |
| 0.3 | 49.5 | Pottsville/Mauch Chunk contact exposed to right. |
| 0.2 | 49.7 | Bear right at Exit 53 (Central Scranton Expressway). |
| 0.8 | 50.5 | Bear right onto Cedar Avenue exit. |
| 0.2 | 50.7 | Roaring Brook to right. |

Figure 66. Wedge failure over mine workings in one of the Dunmore(?) coalbeds on I-81 in Dunmore (mile 48.2). Nearby pillars of coal indicate that the mined seam was 4-5 feet thick.

0.3  51.0  Stop sign. Turn right onto Cedar Avenue.

0.1  51.1  Scranton Iron Furnaces to right (see Pre-Conference Field Trip No. 1). Historical marker reads:

*LACKAWANNA IRON. Iron was forged in Slocum Hollow by 1797. Nearby are remains of Lackawanna Iron Co. works begun in 1840 by Scranton & associates. Iron rails for the Erie R. R. were made here, 1847. Steelmaking began in 1875. Closed in 1902.*

To the left is the Scranton Army Munitions Plant of the Chamberlain Company. Some of the buildings here, including the "Blacksmith Shop" date from the days of the iron-and-steel works.

0.1  51.2  Pass under old Lackawanna Railroad bridge.

0.1  51.3  Traffic light. Turn right onto Lackawanna Avenue.

0.1  51.4  Turn left into parking lot of Radisson Lackawanna Station Hotel. End of Day-2 field trip. Thank you and have a pleasant journey home!

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# APPENDIX A
## PRE-CONFERENCE FIELD TRIPS

### 1. *Geology, History, and Mining in the Lackawanna Valley: the Anthracite Heritage Museum, Lackawanna Coal Mine, and Scranton Iron Furnaces.*

Leaders: Jon D. Inners, Chester Kulesa, Daniel K. Perry, Robert H. Prosperi, and Thomas Supey, Jr.

Scranton was founded in the 1840's because of its iron ore—which quickly gave out—and grew to greatness because of its anthracite—which early on fueled the local blast furnaces and then, over a span of nearly ten decades, powered the United States to a position at the top of the industrialized world. Now, a century and a half later, the old iron furnaces are a historical site and the anthracite mines are all closed—save for a single slope maintained as a tourist attraction. And the story of both is passed down to us and future generations through a splendid museum run by the Pennsylvania Historical and Museum Commission. On this half-day field trip, we will visit all three of these facilities (though in reverse order of their introduction above): the Anthracite Heritage Museum, the Lackawanna Mine Tour, and the Scranton Iron Furnaces.

The Anthracite Heritage Museum and Lackawanna Coal Mine in McDade Park constitute Stop 1 of the field trip (Figure A1); the Scranton Iron Furnaces site is Stop 2 (see Figure A4).

**THE ANTHRACITE HERITAGE MUSEUM**

The Anthracite Heritage Museum, one of four sites in the Pennsylvania Historical and Museum Commission's Anthracite Museum Complex (Figure A2), was opened in 1975. It presents an overview of

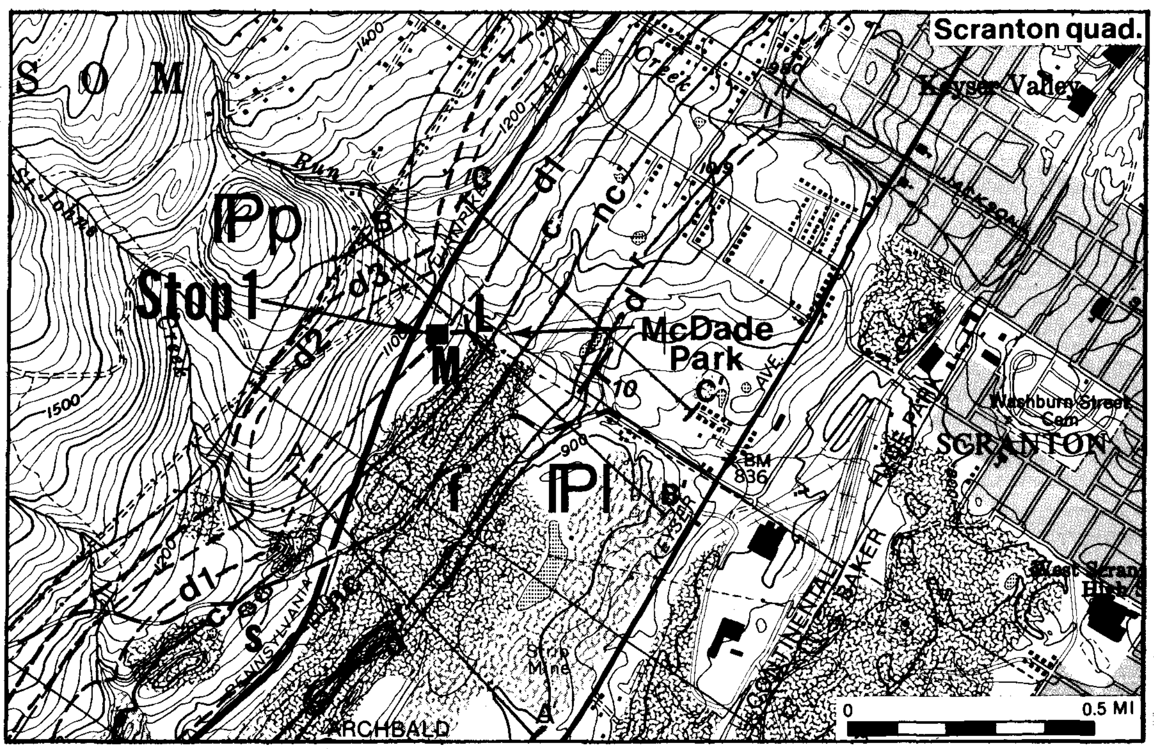


Figure A1. Location and geologic map of the McDade Park area (Stop 1). (M = Anthracite Heritage Museum, L = Lackawanna Coal Mine; Pl = Llewellyn Formation; s = subsidences over the Clark seam; f = ventilating fan along SR 3002. Coalbeds: d = Diamond; r = rock; nc = New County; c = Clark; d1 = Dunmore No. 1; d2 = Dunmore No. 2; D3 = Dunmore No. 3.)

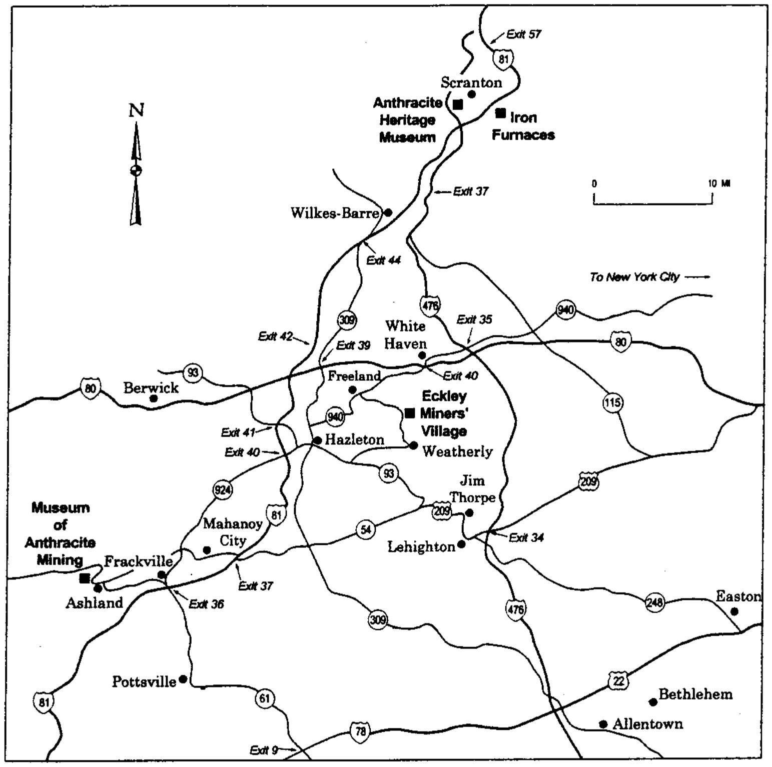


Figure A2. Map of sites in the Anthracite Museum Complex, northeastern Pennsylvania.

the growth and development of the Anthracite region with themes that include immigration and ethnicity; industry and transportation; the formation of social, religious, and labor organizations; deindustrialization; and cultural tourism. The other sites in the Complex have more limited roles in presenting the story of anthracite: the Museum of Anthracite Mining in Ashland deals with technology—the mining and processing of "hard coal." Eckley Miners' Village, a restored, mid-19th century "patch" town, allows the visitor to explore the daily life of mining families. The Scranton Iron Furnaces site, which encompasses the remaining blast furnace stacks of the Lackawanna Iron and Coal Company, was once the second largest producer of iron in the country and represent one of the significant 19th-century markets for anthracite coal. By cooperating closely, these sites provide a comprehensive interpretation of "the Region" and serve as repositories for related collections.

The sites of the Anthracite Museum Complex are owned by the Commonwealth and administered by the Pennsylvania Historical and Museum Commission (PHMC). In 1971 the Legislature of the Commonwealth of Pennsylvania created the Complex. This initiative occurred for a number of reasons, including awareness of public interest and leadership from historians such as J. Cutler Andrews, Philip Klein, and S. K. Stevens, who emphasized the importance of local and regional histories, as well as studies of ethnic heritage.

The Anthracite Museum Complex attempts to collect, preserve, study, and exhibit material culture and documentation relation to all facets of the culture and history of the "hard coal" region, as specified in its mission statement and its collecting policy. Each part of the Complex is involved in the acquisition process, and the collections at all four sites are catalogued in a unified system. The Complex has actively collected books, maps, manuscripts and oral histories, prints and paintings, folk art, photographs, textiles, tools, machinery, utensils, toys, and vehicles. These collections are related to regional, as well as localized patterns of immigration and ethnicity, transportation, settlement and urbanization, labor, government, work and industry, recreation and entertainment, and religious and community life.

A substantial collection of local and regional material culture, dating from the 18th century to the present has been acquired by the Complex staff over the last 26 years. The Complex follows standard and silk looms from textile mills in the Scranton area. (Many miners' wives and daughters worked in such mills in the first half of the 20th century.) Over the years, temporary exhibits have often emphasized the work of such noted "anthracite" photographers as George Harvan, Scott Herring, and John Horgan, Jr. (see Percival and Kulesa, 1995). (Several years ago, an exhibit at Ashland featured the work of George Bretz.) One of the recent collection acquisitions at the museum are some of the mine maps and cross sections from the Hazleton Shaft breaker—formerly operated by the Lehigh Valley Coal Company and the Jeddo-Highland Coal Company. (Much more of this material is housed at Eckley Miners' Village.) Thanks to many years of voluntary effort by Ms. Catharine Shulenberger, the museum also maintains an excellent, well catalogued library, which—despite its unfortunately limited physical space—is used widely by labor and mining historians, genealogists, even geologists! One of the library's great strengths is its nearly complete collection of detailed Anthracite Mine Inspectors' Reports (dating from 1870 to 1922, after which the reports become mostly statistical tables and informational abstracts). It also has a good collection of 2nd Pennsylvania Geological Survey reports and maps related to the Anthracite region, as well as several pre-2nd Survey mining manuals, such as Daddow and Bannon (1866).

## THE LACKAWANNA COAL MINE

The Lackawanna Coal Mine is the former "190 slope" of the Moffat Coal Company, who operated here from 1959 to 1966. Prior to that time, workings in this area were part of the Continental mine, which opened in May of 1860. Reflecting the decline of the anthracite industry after World War 1 and the great strikes of the 1920's, 457 men and boys worked in the Continental mine in 1914 and 246,561 tons of coal were produced—but in 1964, only 84 men were employed at the "190 slope" and 51,872 tons produced. Mining here ceased in 1966 due to unfavorable mining conditions. (Hence, the slope survived the great Knox Mine Disaster of 1959 [see Appendix C] by seven years and was one of the last deep mines to operate in the Northern field.)

The idea of opening the "190 slope" as a tourist attraction originated in 1969, as part of a U.S. Bureau of Mines initiative to preserve the heritage of mining in the Scranton area. Work on restoring the mine was started in 1977 and by 1980 was 85 percent completed. But money ran out—and the project was held in abeyance until 1984, when, with broader federal funding sponsored by Congressman Joseph McDade and the cooperation of the Lackawanna County Commissioners, the mine restoration was completed. The "Lackawanna Coal Mine" opened as a tourist attraction in 1985. Total cost of the restoration was about $2.5 million.

### Geology

The "190 slope" is on the northwest flank of the Lackawanna synclinorium and is developed in coals of the lower Llewellyn Formation (from the Clark down to the Dunmore No. 2, according to the mine guides) (Figure A1). The slope entry is on the Clark coalbed at an azimuth of about S55E. It is about 750 feet long, "pitches" about 25 degrees, and reaches a depth of 250 feet below the ground surface where it intersects the main Clark gangway.

Geologic structure in the mine and immediate surrounding area is relatively simple, as is typical in the Lackawanna basin (see Darton, 1940). The coal seams strike about N35E and dip 20-25 degrees southeast near the outcrop, but the dip abruptly flattens out to10 degrees or less farther out into the basin (Figure A3, A-C). A cross section used in the mine restoration project shows a northwest-dipping, relatively high-angle thrust offsetting the Clark seam 30 to 50 feet at a distance of about 1200 feet southeast of the mine opening and several hundred feet downdip of the main Clark gangway (Figure A3, B). This same fault appears to offset the Dunmore No. 3 about 80 feet. (Note that sections to the southwest and northeast of the "190 slope" do not show this fault [Figure A3, A, C]). In addition, a thrust fault in the Dunmore No. 1 seam cuts out that coalbed and drags underlying strata into a localized

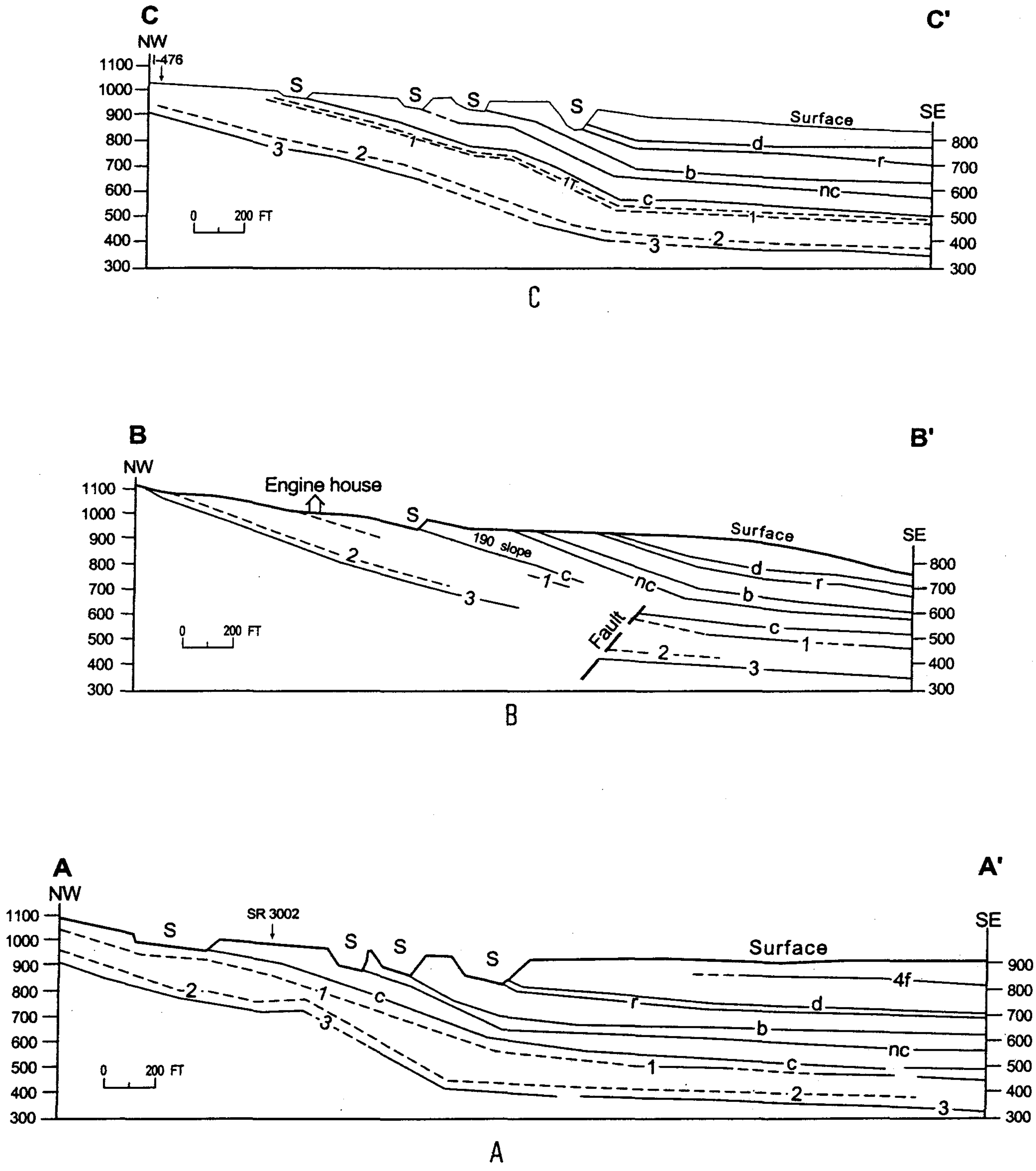


Figure A3. Geologic cross sections in the vicinity of the Lackawanna Coal Mine—see Figure A1 for symbols and locations of sections. (S = strippings; b = Big coalbed.)

"roll." (This "fault and roll" will be pointed out by the mine guide as we pass down the "191 tunnel" between the Clark and Dunmore seams.)

Three coalbeds were mined in the "190 slope" and can be examined first hand in the mine tour. The Clark is about 12 feet thick and has a sandstone or sand-silt laminite roof containing numerous large plant trunks. The Dunmore No. 1 is 2-3 feet thick where not cut out by the fault mentioned above; its roof rock is sandstone and conglomeratic sandstone. The Dunmore No. 2 at the end of the "191 tunnel" is generally 2.5 feet thick (a "monkey vein," according to the mine guide). The Dunmore No. 2 also has a sandstone roof, but it appears to be much more irregular than that of the Clark—being full of lumps and knobs that are probably the result of both loading on the soft peat of the incipient coalbed and erosional scour. The earlier, and much larger, Continental mine also worked the New County, Big, Rock, Diamond, and 4-Foot seams in ascending order above the Clark (Figure A3, A-C).

As noted at the tipple to the north of the slope entrance, coal from the "190 slope" was taken to a breaker at Taylor, two miles to the south, for processing.

**Ventilation**

The existing mine is ventilated by a large fan (#2) located at the top of the "escape way" in the Dunmore No. 2 gangway (with airlocks). The fan is capable of drawing about 22,000 $ft^3$/min of air from the slope entrance and through the gangways and "191 tunnel".

**Surface structures and equipment**

Much can also be seen above ground at the Lackawanna Coal Mine. The most obvious structure is the wooden tipple, which was reported in use from the 1930's to 1966. A few hundred feet west of the tipple are the #2 fan house and the hoist house (for the escape carriage). Equipment on display includes the original mine hoist from the Moffat Coal Company's "190 slope," an old Bucyrus-Erie diesel shovel (the type used for stripping many decades ago), a well preserved mine car (manufactured by American Car and Foundry Company in Berwick), and a mobile fire-fighting unit (from the Huber colliery in Ashley).

**********

At the completion of the underground and surface tour of the Lackawanna Coal Mine, proceed to Stop 2 as directed in the following road log.

| Miles | | |
|---|---|---|
| Int. | Cum. | |
| 0.0 | 0.0 | Leave parking lot of Anthracite Heritage Museum. |
| 0.3 | 0.3 | Turn right at Stop Sign. |
| 0.1 | 0.4 | Turn left at exit from McDade Park, |
| 0.4 | 0.8 | Stop Sign. Turn left on Keyser Avenue. |
| 0.5 | 1.3 | Traffic Light. Turn right onto Dalton Street. |
| 0.2 | 1.7 | Stop Sign. At this point Dalton Street becomes Luzerne Street. |
| 0.2 | 1.9 | To the left is the back side of Washburn Street Cemetery. Many of the miners killed in the Avondale mine disaster of 1869 are buried there (see Appendix C). |
| 0.6 | 2.5 | Traffic light at intersection with S. Main Avenue. Continue straight on Luzerne Street. |
| 0.5 | 3.0 | Traffic light at Railroad Avenue. Continue Straight on Luzerne Street. |
| 0.1 | 3.1 | Turn left onto Third Avenue. |
| 0.1 | 3.2 | Turn right onto Broadway Street. |
| 0.1 | 3.3 | Cross Lackawanna River. |
| 0.1 | 3.4 | Traffic Light at Washington Street. Continue straight as Broadway Street becomes Mattes Street. |

| | | |
|---|---|---|
| 0.2 | 3.6 | Directly ahead to the left are the former locomotive shops of the Delaware, Lackawanna, and Western Railroad. A much better view can be obtained from the parking lot at the iron furnaces. |
| 0.1 | 3.7 | Watch for a sealed entrance in the concrete wall paralleling Mattes Street on the left. This was an entrance to one of the "subways" that connected the various buildings of the DL& W shops (Slater, 1996). |
| 0.1 | 3.8 | Intersection with Cedar Avenue. No Stop Sign, but better stop before proceeding directly across Cedar to the iron-furnaces parking lot. |
| 0.1 | 3.9 | Parking lot of Scranton Iron Furnaces. Debark. |

## SCRANTON IRON FURNACES

The Scranton Iron Furnaces Historical Site is located on the north side of Roaring Brook at the edge of downtown Scranton (Figure A4). Of the five blast furnaces constructed between 1841 and 1857 (see Perry, this guidebook, p. 64-74), the massive stone stacks of four remain (Figure A5). Most of the roughly cut stone blocks (some of which are 6 feet or more in maximum dimension) are "white" Pottsville conglomerate and conglomeratic sandstone, especially in the lower parts of the stacks. All of the other stone used is sandstone, much of this being Pottsville as well, but some having a dark-gray, micaceous Llewellyn aspect. Many of the blocks show 3- to 4-inch-long, manual-drill holes. Each stack is about 45 feet square at the base and 30 feet high. The work arches (which opened into a large, wooden casting-shed between the furnaces and Roaring Brook) are about 15 feet across the base. Vertical iron strips and iron tie-rods gave support to the stonework.

**Geology of the Site**

The furnaces are built against a natural cliff of subhorizontal, crossbedded Llewellyn sandstone that is exposed to the west and can also be seen at the base of the stonewall behind the furnaces. The top of the cliff served as the charging terrace.

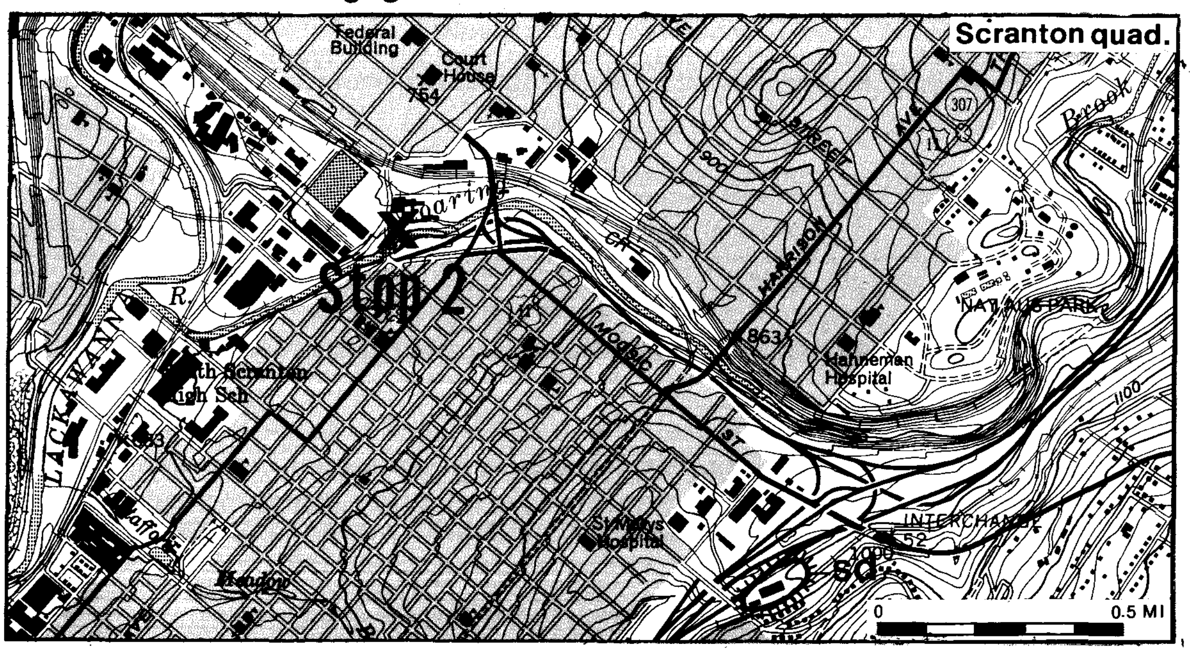


Figure A4. Location map of the Scranton Iron Furnaces Historic Site (Stop 2). (sd = slag dump.)

On the opposite side of Roaring Brook, a near vertical, 20-foot-high stream cut is eroded down through this sandstone and into an underlying 8-foot-thick coalbed—probably the Clark or somewhat

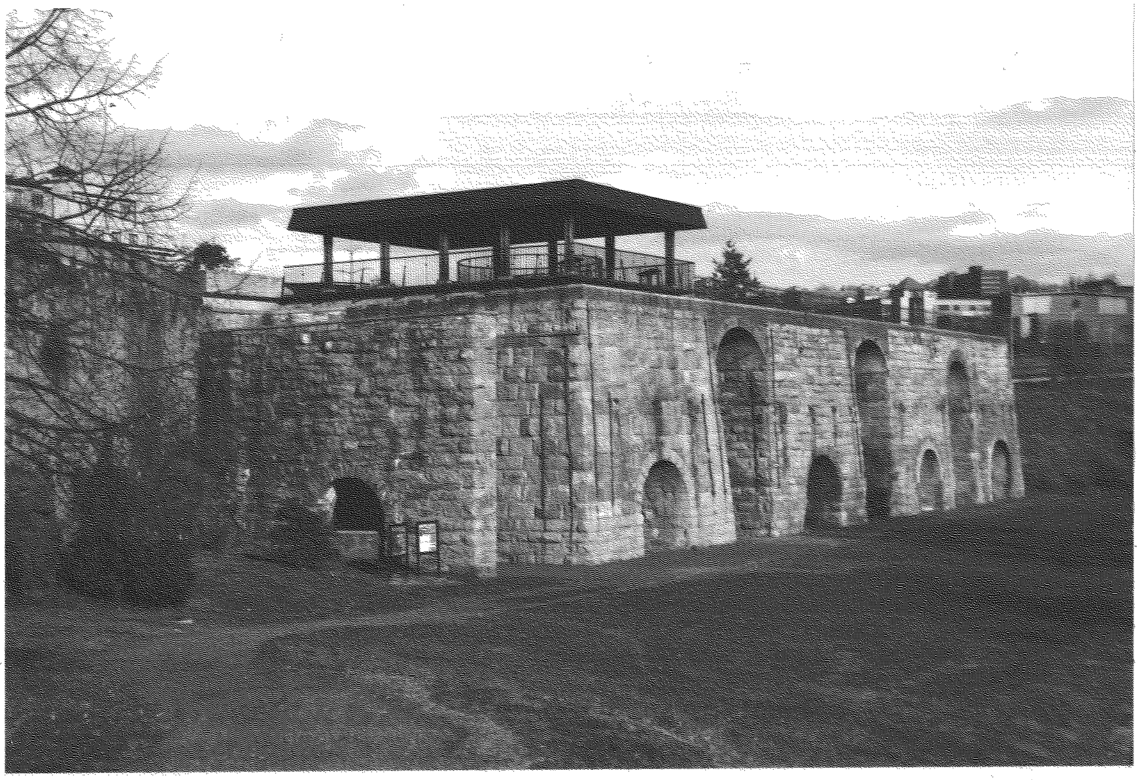

Figure A5. Four preserved stacks of the Lackawanna Iron and Coal Company at the Scranton Iron Furnaces Historical Site. These represent furnaces nos. 2 to 5 which were constructed between 1848 and 1857 (Perry, 1994). Furnace no. 1, built in 1841 was located some distance upstream and was in ruins by 1859, according to Lesley (1859).

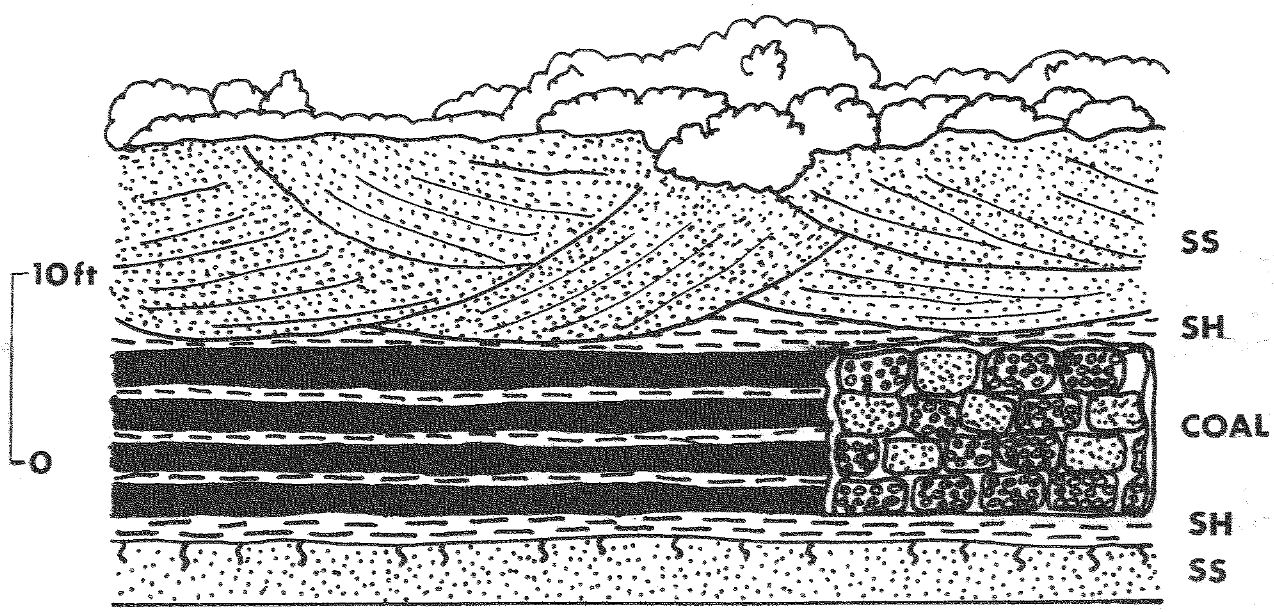


Figure A6. Schematic diagram of section exposed along Roaring Brook opposite the Scranton Iron Furnaces, with a walled up mine opening to the right. The coalbed is 8 feet thick in four benches, two of which are thicker than the diagram indicates. Plant trunks and stems occur in the carbonaceous shale beneath the coal bed.

higher seam (Figure A6). At least four drifts, now plugged by either concrete or stonework, are evident along less than one hundred yards of streambank. The mine workings here were part of the large Pine Brook colliery, owned by the Scrantons and a major supplier of anthracite to the furnaces (see Perry, this guidebook, p. 73). A small abutment near the west end of the exposure suggests that a low bridge once connected the coal workings with the furnaces. Although the "waysides" at the furnace site indicate that anthracite from the area immediately surrounded the furnaces was used early on—but then abandoned due to its poor quality, there is every indication "on the ground" that this thick coal seam was heavily used at the furnaces. It also appears to be of excellent quality, consisting of four bright "benches" (aggregating 6 feet or more in thickness) separated by three 4- to 6-inch shaly and bony partings. Perhaps more the problem with these particular workings are the facts that they lie so close to stream level and the coalbed dips very gently into the hillside (bedding attitude is N82E/2SE). They would have been highly prone to flooding—and difficult to drain if they were flooded. More study should be done on this phase of the furnace history.

**Sources of Ore and Limestone**

The original ores used in the furnaces was Mauch Chunk siderite from the valley of Stafford Meadow Brook, about 2.5 miles south-southeast of the furnaces. The poor quality of this ore eventually led to the necessity of importing large quantities of higher-grade material from Bloomsburg and Danville (Clinton "fossil ore") (Lesley, 1859) and Cornwall (magnetite ore)—and even New Jersey and upstate New York (see Perry, this guidebook, p. 64-74 and 1994, for further discussion of this problem).

The third ingredient needed to produce cast iron—limestone—was entirely missing from the Scranton area. Much of this material was apparently supplied via canal, and later train, from quarries in the Keyser-Tonoloway limestones at Lime Ridge, between Bloomsburg and Berwick (see Inners, 1981; Inners and others, 1995).

**History**

A complete discussion of the history of the Scranton Iron Furnaces is given in Perry, this guidebook, p. 64-74.

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After touring the iron furnaces, proceed either to the Everhart Museum at Nay Aug Park or to the Radisson Lackawanna Station Hotel.

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## POSTSCRIPT

***Preface.*** In the summer of 1894 Stephen Crane (1871-1900), best known as the author of the classic Civil-War tale, *The Red Badge of Courage*, arrived in Scranton on a commission from *McClure's Magazine*, to write a description of anthracite mining in that city. The result of this trip was *In the depths of a coal mine*, a 16-page, illustrated sketch that was one of his best documentary articles (Colvert, 1984). Accompanying Crane as commissioned illustrator was the artist and draftsman Corwin Knapp Linson (1864-1959), a good friend of Crane's, who had been trained in France, had a studio in New York City, and had a long and productive artistic career (Stanislaus, 1995; Colvert, 1984). Crane would appear to have been a good choice for the writing assignment: In 1890 he had entered Lafayette College to study mining engineering. (Unfortunately, the dean asked him to leave after one semester for failure to attend classes!) (Colvert, 1984.)

Crane and Linson visited two mines in their two-day tour—the Oxford mine in the Hyde Park district of Scranton and the No. 5 mine in Dunmore (Figure A7; Stanislaus, 1995). As is evident from the often sensitive language of the article, Crane was very sympathetic to the plight of the workers in the mines--even where he rather sarcastically refers to the ambitions of the "breaker boys." To Crane's displeasure, *McClure's* removed some of his more critical comments--a reflection of the "Gilded Age" mentality of the early '90's when "muckraking" had not yet come into vogue (Stanislaus, 1995).

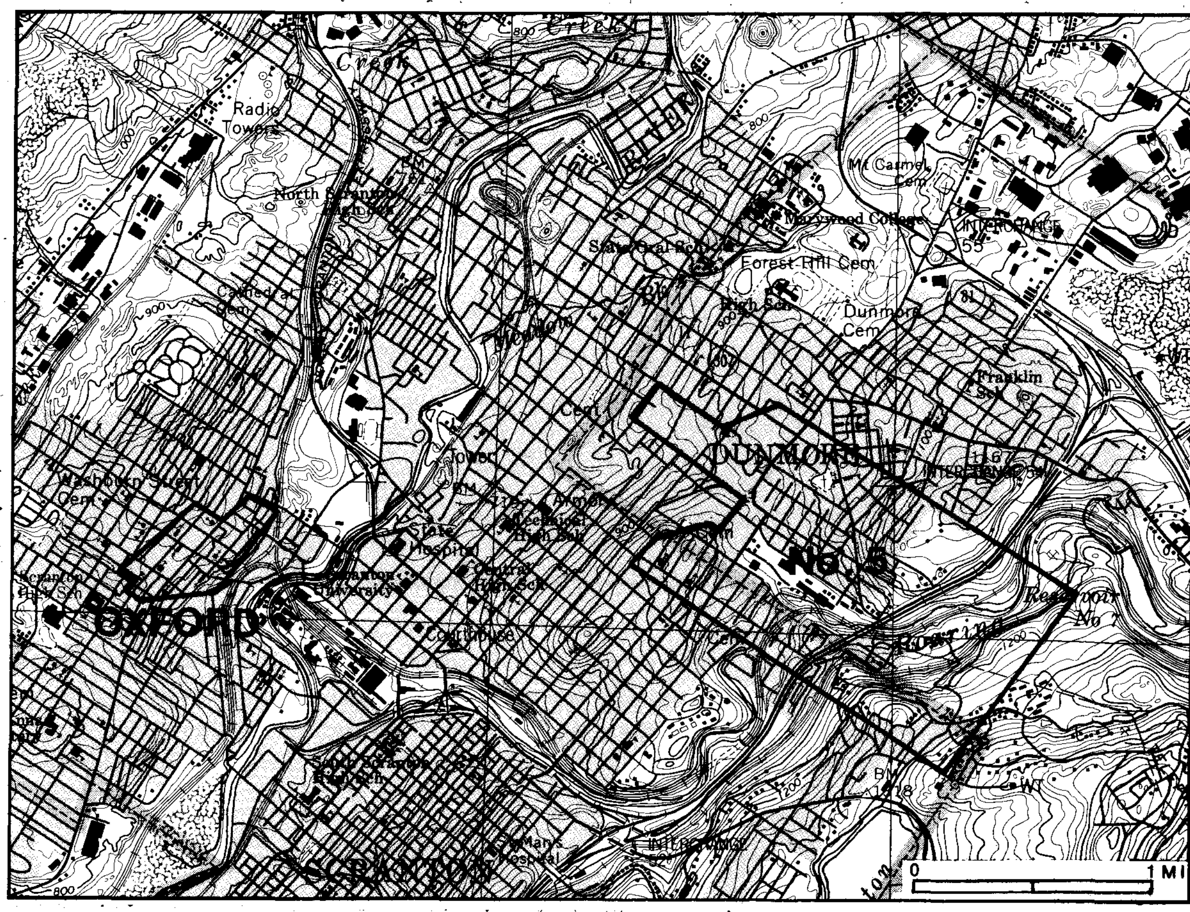


Figure A7. Map showing location of mines visited by Stephen Crane and Corwin Knapp Linson in 1894. The No. 5 mine was operated by the Pennsylvania Coal Co. of Pittston, who had constructed a gravity railroad over the Moosic Mountains in the 1850's.

Linson contributed sixteen charcoal drawings of various views and activities at the two mines, fourteen of which were used in the published sketch (Stanislaus, 1995; Colvert, 1984). These included views of a main gangway or tunnel, the Oxford breaker, slate-pickers ("breaker boys") at work, miners cutting coal, descent in a mine-carriage, and a mule stables (Stanislaus, 1995). Few originals of these survive, but one ("Mule Stables, Putting in a Team") is in the possession of Richard Stanislaus of Scranton.

*In the depths of a coal mine* is not Crane's only work dealing with the Wyoming-Lackawanna Valley. In September and October of 1899, he also wrote at least three "Wyoming Valley Tales"--*Ol' Bennet and the Indians* (published in *Cassell's Magazine*, v. 31 [New Series], p. 108-111, in December, 1900); *The battle of Forty Fort* (published in *Cassell's Magazine*, v. 31 [New Series], p. 591-594, April, 1901); and *The surrender of Forty Fort* (*Last Words*, London, Digby, Long & Co., March, 1902) (Gullason, 1963).

Because of the pertinence of Crane's article to our visit to the Lackawanna Coal Mine Tour--and because of the vivid images it evokes, the entire text is reproduced here. Notes are at the end.

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## IN THE DEPTHS OF A COAL MINE

by Stephen Crane

From *McClure's Magazine,* III (August, 1894), p. 195-209.

(As anthologized in Fryckstedt, 1963)

The "breakers" squatted upon the hillsides and in the valley like enormous preying monsters, eating of the sunshine, the grass, the green leaves. The smoke from their nostrils had ravaged the air of coolness and fragrance. All that remained of vegetation looked dark, miserable, half-strangled. Along the summit line of the mountain a few unhappy trees were etched upon the clouds. Overhead stretched a sky of imperial blue, incredibly far away from the sombre land.

We approached the colliery over paths of coal dust that wound among the switches.[1] A "breaker" loomed above us, a huge and towering frame of blackened wood. It ended in a little curious peak, and upon its sides there was a profusion of windows appearing at strange and unexpected points. Through occasional doors one could see the flash of whirring machinery. Men with wondrously blackened faces and garments came forth from it. The sole glitter upon their persons was at their hats, where the little tin lamps were carried. They went stolidly along, some swinging lunchpails carelessly; but the marks upon them of their forbidding and mystic calling fascinated our new eyes unit they passed from sight. They were symbols of a grim, strange war that was being waged in the sunless depths of the earth.

Around a huge central building cluster other and lower ones, sheds, engine-houses, machine-shops, offices. Railroad tracks extended in web-like ways. Upon them stood files of begrimed coal cars. Other huge structures similar to the one near us, upreared their uncouth heads upon the gills of the surrounding country. From each a mighty hill of culm extended. Upon these tremendous heaps of waste from the mines, mules and cars appeared like toys. Down in the valley, upon the railroads, long trains crawled painfully southward, where a low-hanging gray cloud, with a few projecting spires and chimneys, indicated a town.

Car after car came from a shed beneath which lay hidden the mouth of the shaft. They were dragged, creaking, up an inclined cable road to the top of the "breaker."

At the top of the "breaker," laborers were dumping the coal into chutes. The huge lumps slid slowly on their journey down through the building, from which they were to emerge in classified fragments. Great teeth on revolving cylinders caught them and chewed them. At places there were grates that bid each size go into its proper chute. The dust lay inches deep on every motionless thing, and clouds of it made the air dark as from a violent tempest. A mighty gnashing sound filled the ears. With terrible appetite this huge and hideous monster sat imperturbably munching coal, grinding its mammoth jaws with unearthly and monotonous uproar.

In a large room sat the little slate-pickers. The floor slanted at an angle of forty-five degrees, and the coal, having been masticated by the great teeth, was streaming sluggishly in long iron troughs. The boys sat straddling these troughs, and as the mass moved slowly, they grabbed deftly at the pieces of slate therein. There were five or six of them, one above another, over each trough. The coal is expected to be fairly pure after it passes the final boy. The howling machinery was above them. high up, dim figures moved about in the dust clouds.

These little men were a terrifically dirty band. They resembled the New York gamins in some ways, but they laughed more, and when they laughed their faces were a wonder and a terror. They had an air of supreme independence, and seemed proud of their kind of villainy. They swore long oaths with skill.

Through their ragged shirts we could get occasional glimpses of shoulder black as stoves. They looked precisely like imps as they scrambled to get a view of us. Work ceased while they tried to ascertain if we were willing to give away any tobacco. The man who perhaps believes that he controls them came and harangued the crowd. He talked to the air.

The slate-pickers all through this region are yet at the spanking period. One continually wonders about their mothers, and if there are any schoolhouses. But as for them, they are not concerned. When they get time off, they go out on the culm heap and play baseball, or fight with boys from other "breakers" or among themselves, according to the opportunities. And before them always is the hope of one day getting to be door-boys down in the mines; and later, mule-boys, and yet later, laborers and helpers. Finally, when they have grown to be great big men, they may become miners, real miners, and go down and get "squeezed," or perhaps escape a shattered old man's estate with a mere "miner's asthma." They are very ambitious.

Meanwhile they live in a place of infernal dins. The crash and thunder of the machinery is like the roar of an immense cataract. The room shrieks and blares and bellows. Clouds of dust blur the air until the windows shine pallidly afar off. All the structure is a-tremble from the heavy sweep and circle of the ponderous mechanism. Down in the midst of it sit these tiny urchins, where they earn fifty-five cents a day each. They breath this atmosphere until their lungs grow heavy and sick with it. They have this clamor in their ears until it is wonderful that they have any hoodlum valor remaining. But they are uncowed; they continue to swagger. And at the top of the "breaker" laborers can always be seen dumping the roaring coal down the wide, voracious maw of the creature.

Over in front of a little tool-house a man smoking a pipe sat on a bench. "Yes," he said, "I'll take yeh down if yeh like." He led us by little cinder paths to the shed over the shaft of the mine. A gigantic fan-wheel near by was twirling swiftly. It created cool air for the miners, who on the lowest vein of this mine[2] were some eleven hundred and fifty feet below the surface. As we stood silently waiting for the elevator we had opportunity to gaze at the mouth of the shaft. The walls were of granite blocks, slimy, moss-grown, dripping with water. Below was a curtain of ink-like blackness. It was like the opening of an old well, sinister from tales of crimes.

The black, greasy cables began to run swiftly. We stood staring at them and wondering. Then of a sudden the elevator appeared and stopped with a crash. It was a plain wooden platform. Upon two sides iron bars ran up to support a stout metal roof. The men upon it, as it came into view, were like apparitions from the center of the earth,

A moment later we marched aboard, armed with light lights, feeble and gasping in the daylight. There was an instant's creak of machinery, and then the landscape, that had been framed for us by the door-posts of the shed, disappeared in a flash. We were dropping with extraordinary swiftness straight into the earth. It was a plunge, a fall. The flames of the little lamps fluttered and flew and struggled like tied birds to release themselves from the wicks. "Hang on," bawled our guide above the tumult.

The dead black walls slide swiftly by. They were a swirling dark chaos on which the mind tried vainly to locate some coherent thing, some intelligible spot. One could only hold fast to the iron bars and listen to the roar of this implacable descent. When the faculty of balance is lost, the mind becomes a confusion. The will fought a great battle to comprehend some thing during this fall, but one might as well have been tumbling among the stars. The only thing was to await revelation.

It was a journey that held a threat of endlessness.

Then suddenly the dropping platform slackened its speed. It began to descend slowly and with caution. At last, with a crash and a jar, it stopped. Before us stretched an inscrutable darkness, a soundless place of tangible loneliness. Into the nostrils came a subtly strong odor of powder-smoke, oil, wet earth. The alarmed lungs began to lengthen their respirations.

Our guide strode abruptly into the gloom. His lamp flared shades of yellow and orange upon the walls of a tunnel that led away from the foot of the shaft. Little points of coal caught the light and shone like diamonds. Before us there was always the curtain of a impenetrable night. We walked on with no sound save the crunch of our feet upon the coal-dust of the floor. The sense of an abiding danger in the roof was always upon our foreheads. It expressed to us all the unmeasured, deadly tons above us, as it the roof were a superlative might that regarded with the supreme calmness of almighty power the little men at its mercy. Sometimes we were obliged to bend low to avoid it. Always our hands rebelled vaguely from toughing it, refusing to affront this gigantic mass.

All at once, for ahead, shone a little flame, blurred and difficult of location. It was a tiny, indefinite thing, like a wisp-light. We seemed to be looking at it through a great fog. Presently there were two of them. They began to move to and fro and dance before us.

After a time, we came upon two men crouching where the rood of the passage came near to meeting the floor. If the picture could have been brought to where it would have had the opposition and the contrast of the glorious summer-time earth, it would have been a grim and ghastly thing. The garments of the men were no more sable than their faces, and when they turned their heads to regard our tramping party, their eyeballs and teeth shone white as bleached bones. It was like the grinning of two skulls there in the shadows. The tiny lamps in their hats made a trembling light that left weirdly shrouded the movements of their limbs and bodies. We might have been confronting terrible spectres.

But they said, "Hello, Jim," to our conductor. Their mouths expanded in smiles--wide and startling smiles.

In a moment they turned again to their work. When the lights our party reinforced their tow lamps, we could see that one was busily drilling into the coal with a long thin bar. The low roof ominously pressed his shoulders as he bent at his toil. The other knelt behind him on the loose lumps of coal.

He who worked at the drill engaged in conversation with our guide. He looked back over his should, continuing to poke away. "When are yeh goin' t' measure this up, Jim?" he demanded. "Do yeh wanta git me killed?"[3]

"Well, I'd measure it up t'-day, on'y I ain't got me tape," replied the other.

"Well, when will yeh? Yeh wanta hurry up," said the miner. "I don't wanta git killed."

"Oh, I'll be down on Monday."

"Humph!"

They engaged in a sort of an altercation in which they made jests.

"You'll be carried out o' there feet first before long."

"Will I?"

Yet one had to look closely to understand that they were not about to spring at each other's throats. The vague illumination created all the effect of the snarling of two wolves.

We came upon other little low-roofed chambers, each containing two men, a "miner," who makes the blasts, and his "laborer," who loads the coal upon the cars and assists the miner generally. And at each place there was this same effect of strangely satanic smiles and eyeballs wild and glittering in the pale glow of the lamps.

Sometimes the scenes in their weird strength were absolutely infernal. Once, when we were traversing a silent tunnel in another mine, we came suddenly upon a wide place where some miners were lying down in a group. As they upreared to gaze at us, it resembled a resurrection. They slowly uprose with ghoul-like movements, mysterious figures robed in enormous shadows. The swift flashes of the steel-gleaming eyes were upon our faces.

At another time, when my companion, struggling against difficulties, was trying to get a sketch of the mule, "Molly Maguire," a large group of miners gathered about us intent upon the pencil of the artist. "Molly," indifferent to the demands of art, changed her position after a moment and calmly settled into a new one. The men all laughed, and this laugh created the most astonishing and supernatural effect. In an instant the gloom was filled with luminous smiles. Shining forth all about us were eyes glittering as with cold blue flame. "Whoa, Molly," the men began to shout. Five or six of them clutched "Molly" by her tail, her head, her legs. They were going to hold her motionless until the portrait was finished. "He's a good feller," they had said of the artist, and it would be a small thing to hold a mule for him. Upon the roof were vague dancing reflections of red and yellow.

From this tunnel of our first mine we went with our guide to the foot of the main shaft. Here we were in the most important passage of a mine, the main gangway. The wonder of these avenues is the noise--the crash and clatter of machinery as the elevator speeds upward with the loaded cars and drops thunderingly with the empty ones. The place resounds with the shouts of mule-boys, and there can always be heard the noise of approaching coal-cars, beginning in mild rumbles and then swelling down upon one in a tempest of sound. In the air is the slow painful throb of the pumps working at the water which collects in the depths. There is booming and banging and crashing, until one wonders why the tremendous walls are not wrenched by the force of this uproar. And up and down the tunnel there is a riot of lights; little orange points flickering and flashing. Miners stride in swift and sombre procession. But the meaning of it all is in the deep bass rattle of a blast is some hidden part of the mine. It is war. It is the most savage part of all in the endless battle between man and nature. These miners are grimly in the van. They have carried the war into places where nature has the strength of a million giants. Sometimes their enemy becomes exasperated and snuffs out ten, twenty, thirty lives. Usually she remains calm, and takes one at a time with method and precision. She need no hurry. She possesses eternity. After a blast, the smoke, faintly luminous, silvery, floats silently through the adjacent tunnels.

In our first mine we speedily lost all ideas of time, direction, distance. The whole thing was a extraordinary, black puzzle. We were impelled to admire the guide because he knew all the tangled passages. He led us through little tunnels three and four feet wide and with roofs that sometimes made us crawl. At other times we were in avenues twenty feet wide, where double rows of tracks extended. There were stretches of great darkness, majestic silences. The three hundred miners were distributed into all sorts of crevices and corners of the labyrinth, toiling in this city of endless night. At different points one could hear the roar of traffic about the foot of the main shaft, to which flowed all the commerce of the place.

We were made aware of distances later by our guide, who would occasionally stop to tell us our position by naming a point of the familiar geography of the surface. "Do you remember that rolling-mill yeh passed coming up? Well, you're right under it." "You're under th' depot now." The length of these distances struck us with amazement when we reached the surface. Near Scranton one can really proceed for miles, in the black streets of the mines.

Over in a wide and lightless room we found the mule-stables. There we discovered a number of these animals standing with an air of calmness and self-possession that was somehow amazing to find in a mine. A little dark urchin came and belabored his mule "China" until he stood broadside to us that we might admire his innumerable fine qualities. The stable was like a dungeon. The mules were arranged in solemn rows. They turned their heads toward our lamps. The glare made their eyes shine wondrously like lenses. They resembled enormous rats.

About the room stood bales of hay and straw. The commonplace air worn by the long-eared slaves make it all infinitely usual. One had to wait to see the tragedy of it. It was not until we had grown familiar with the life and the traditions of the mines that we were capable of understanding the story told by these beasts standing in calm, array, with spread legs.

It is a common affair for mules to be imprisoned for years in the limitless night of the mines.[4] Our acquaintance, "China," had been four years buried. Upon the surface there had been the march of the seasons; the white splendor of snows had changed again and again to the glories of green springs. Four times had the earth been ablaze with the decorations of brilliant autumn. But "China" and his friends had remained in these dungeons from which daylight, if one could get a view up a shaft, would appear a tiny circle, a silver star aglow in a sable sky.

Usually when brought to the surface, the mules tremble at the earth radiant in the sunshine. Later, they go almost mad with fantastic joy. The full splendor of the heavens, the grass, the trees, the breezes, breaks upon them suddenly. They caper and career with extravagant mulish glee. A miner told me of a mule that had spend some delirious months upon the surface after years of labor in the mines. Finally the time came when he was to be taken back. But the memory of a black existence was on him; he knew that gaping mouth that threatened to swallow him. No cudgellings could induce him. The me held conventions and discussed plans to budge that mule. The celebrated quality of obstinacy in him won him liberty to gambol clumsily about on the surface.

After being long in the mines, the mules are apt to duck and dodge at the close glare of lamps, but some of them have been known to have piteous fears of being left in the dead darkness. We met a boy who said that sometimes the only way he could get his team to move was to run ahead of them with the light. Afraid of darkness, they would follow.

To those who have known the sunlight there may come the fragrant dream of a lost paradise. Perhaps this is what they brood over as they stand solemnly flapping their ears. Perhaps they despair and thirst for this bloomland that lies in an unknown direction and at impossible distances.

In wet mines, gruesome fungi grow upon the wooden props that support the uncertain-looking ceiling. The walls are dripping and dank. Upon them, too, frequently grows a mosslike fungus, white as a druid's beard, that thrives in these deep dens, but shrivels and dies at contact with the sunlight,

Great and mystically dreadful is the earth from a mine's depth. Man is in the implacable grasp of nature. It has only to tighten slightly, and he is crushed like a bug. His loudest shriek of agony would be as impotent as his final moan to bring help from that fair land that lies, like Heaven, over his head. There is an insidious, silent enemy in the gas. If the huge fanwheel on the top of the earth should stop for a brief period, there is certain death. If a man escape the gas, the floods, the "squeezes" of falling rock, the cars shooting through little tunnels, the precarious elevators, the hundred perils, there usually comes to him an attack of "miner's asthma" that slowly racks and shakes him into the grave. Meanwhile he gets three dollars per day, and his laborer one dollar and a quarter.

In the chamber at the foot of the shaft, as we were departing, a group of the men were resting. They lay about in careless poses. When we climbed aboard the elevator, we had a moment in which to turn and regard them. Then suddenly the study in black faces and crimson and orange lights, vanished. We were on our swift way to the surface. Far above us in the engine-rood, the engineer sat with his hand on a lever and his eye on the little model of the shaft wherein a miniature elevator was making the ascent even as our elevator was making it. Down one of those tremendous holes, one thinks naturally of the engineer.

Of a sudden the fleeting walls became flecked with light. It increase to a downpour of sunbeams. The high sun was afloat in a splendor spotless blue. The distant hills were arrayed in purple and stood like monarchs. A glory of gold was upon the near-by earth. The cool fresh air was wine.

Of that sinister struggle far below there came no sound, no suggestion save the loaded cars that emerged one after another in eternal procession and went creaking up the incline that their contents might be fed into the mouth of the "breaker," imperturbably cruel and insatiate, black emblem of greed, and of the gods of this labor.

***Notes:***

[1]This is undoubtedly a description of the Oxford colliery in Scranton (owned by the Delaware, Lackawanna, and Western Railroad), the first mine visited by Crane and Linson and the one shown in several of Linson's drawings (Stanislaus, 1995). Apparently most of Crane's article refers to the tour of this mine.

[2]Probably one of the Dunmores, most likely No. 3.

[3]The following verbal sparring between "Jim" and the miner is unexplained and raises the question, "Why might the miner be killed if Jim does not 'measure it up'?" Jim is evidently a mine foreman, and one of his responsibilities is to measure the height of the mine chambers for timber props. Once the miner knows the approximate height of the working chamber, he and his laborer will get props of the proper length, haul them back to the coal face, and install them (at no expense to the company, since the miner is on contract and paid only for the amount of coal that he produces--and the laborer is paid by the miner). Once the props are properly in place, the miner and his laborer are largely protected from local roof falls and will also be warned by the creak of the timbers if a general roof collapse, or "squeeze" is imminent (Thomas Supey, Jr., personal communication, August, 1997).

[4]As noted by Stanislaus (1995), mules were typically stabled underground and consigned to the depths for years on end only in shaft and deep slope mines. (The Oxford was located in the middle of the Lackawanna basin and was accessible only by shaft; the No. 5 in Dunmore was a large mine on the south edge of the basin and was probably entered by both shaft and slope.) In drift and tunnel mines, the mules were generally stabled outside and taken in an out of the mines daily.

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## 2. *Pleistocene History and Bedrock Stratigraphy of the Nay Aug Park Gorge—and a visit to the Brooks Mine.*

Leaders: Duane D. Braun, William E. Edmunds, and Gregory Herbster.

The Nay Aug Park Gorge is one of the scenic highlights of the Scranton area. Unfortunately, the shear rock walls, the high waterfall, and the deep plunge pool which give the gorge its picturesque beauty also make it an inviting "swimming hole" for reckless young people. Hardly a year passes without someone being killed or seriously hurt in attempting to dive from the rocky sides of the gorge into the pool at the base of the falls—or falling from the top onto the rocks below. Earlier in the 20th century, the gorge was included in Scranton's Nay Aug Park (now confined to the flats on the northwest side), but the numerous fatalities and injuries over the years have led to its closure by the City of Scranton. (In fact, suggestions to completely fill in the gorge with mine waste keep surfacing every few years!) The gorge area is now patrolled by a special police detail.

The Field Conference has obtained permission from the Scranton Bureau of Parks and Recreation to visit the gorge area. **Please be very careful when walking along the edge of the gorge, descending to the stream beyond the tunnel, and crossing the railroad trestle.** As an added treat, we will also tour the Brooks mine in the park behind the Everhart Museum. This was probably the first tourist coal mine in the country and has been closed for many years.

*Directions:* Participants will meet in the parking lot next to the Everhart Museum at the end of Mulberry Street, Scranton, and proceed to the parking area shown on the accompanying map (Figure A8). From in front of the museum, drive one block beyond Arthur Street to Colfax Street. Turn right onto Colfax and proceed four blocks to E. Gibson Street. Turn right onto E. Gibson, proceeding one block, then turn left onto Richter Street. Proceed down the hill, turn right onto Myrtle Street, and cross the bridge over Roaring Brook. Park in the gravelly area to the left on the near side of the railroad tracks (about a block beyond the bridge).

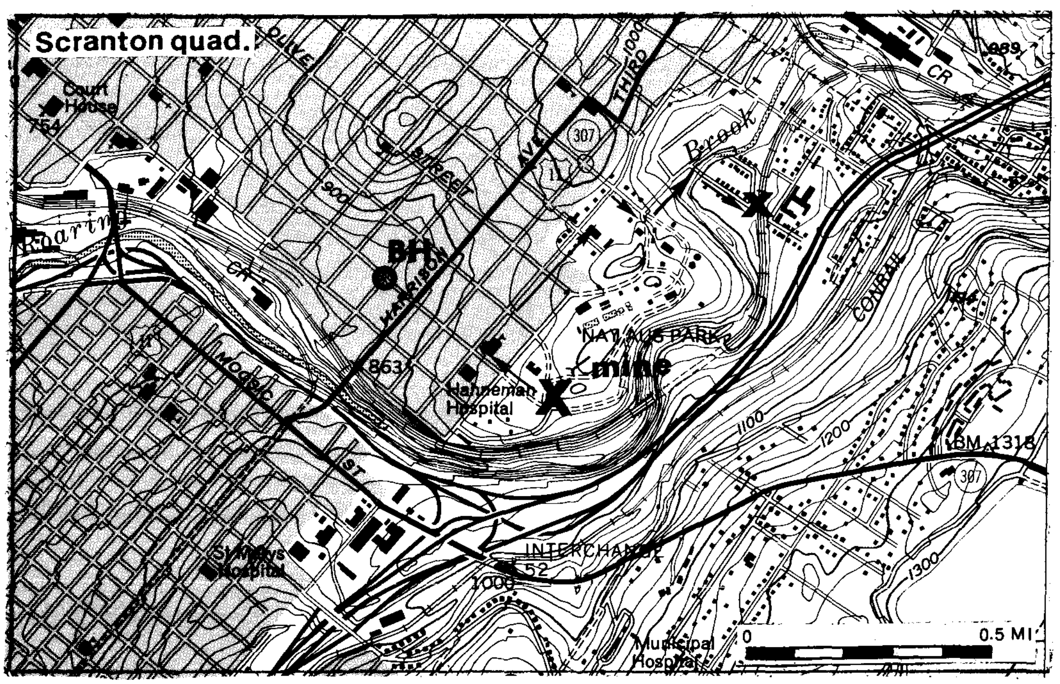


Figure A8. Location map of the Nay Aug Park area. (X = Pre-Conference Field Trip meeting point at Everhart Museum: x = parking area for hike through Nay Aug Park Gorge; arrows indicate driving route to parking area; BH = 2nd Survey borehole).

At the conclusion of the trip through the gorge, participants should return to the Everhart Museum. Personnel from the museum and the Scranton Bureau of Parks and Recreation will then open the Brooks mine for a brief inspection.

## ORIGIN OF THE NAY AUG PARK GORGE (Braun)

The Nay Aug Park Gorge is a 150-foot deep, southwest-trending canyon cut by Roaring Brook through the Pottsville Formation and into the Mauch Chunk Formation (Figure A9). At its upstream end, the gorge has two meander bends incised into the Pottsville Formation. A railroad tunnel has been driven through the meander spur of the downstream bend. At the apex of that bend is a 40-foot high set of waterfalls that end in a 15-foot (or more) deep pothole plunge pool. This site is the narrowest and highest "knickpoint" anywhere along the course of Roaring Brook. Downstream of the falls and a railroad bridge, the floor of the gorge widens on the Mauch Chunk Formation and gradually makes a 90 degree turn to the northwest to enter downtown Scranton.

Roaring Brook starts in the center of the Pocono Plateau near Gouldsboro. It then flows northwesterly, almost perpendicular to regional strike, across the Pocono Plateau and the southeast limb of the Lackawanna synclinorium to enter the Lackawanna Valley (Figure A10). There is a short, southwesterly valley segment just before it cuts through Moosic Mountain in a 800-foot-deep water gap (Figure A10). (The I-84/380 road cut on the north side of the water gap is STOP 7A-B of the main conference field trip.) After going through the gap, Roaring Brook again turns southwesterly along strike (Figure A10). There it flows through a series of low amplitude incised meanders carved in the Pottsville Formation. In the upper one-half of this along-strike reach, the bends are incised 40 to 60 feet in the floor of a broader, straighter valley form. In the middle of the along-strike reach in Dunmore, the valley turns a short distance to the northwest, in line with a wind gap through the ridge on the northwest side of the valley. The floor of the wind gap is only 10 feet above the present channel of Roaring Brook. Downstream of this, the along-strike incised meanders continue with three shallowly incised bends followed by the two deeply incised bends at the head of Nay Aug Park Gorge (Figures A9 and A10).

The juxtaposition of the Nay Aug Park Gorge knickpoint and, almost immediately upstream, the Dunmore wind gap is the "classic" signature of a drainage diversion (derangement). The older, broader northwesterly course through the wind gap to the Lackawanna River north of downtown Scranton (Figure A9, long arrows) has been abandoned for a deeper, narrower ("younger") southwesterly course through Nay Aug Park (Figure A9) (Itter, 1938). The "into the glacier" orientation of the wind gap course and the "away from the glacier" orientation of the gorge course indicate that the diversion was caused by the glacier blocking the wind gap (Figure A9 and A10) (and there is no other way to temporarily block the gap). The ice itself must have been the main blocking agent because the floor of the gap is presently bedrock with a thin veneer of glacial deposits. More typically the older drainage course is permanently blocked (infilled) by thick glacial deposits (see Braun, this guidebook, p. 1-15).

The direction of glacier flow and the expectable resulting ice margin pattern suggest that the entire Roaring Brook course upstream of the Nay Aug Park Gorge was once an ice marginal channel (Figure A10). That means that Roaring Brook was receiving meltwater along its entire length and its meltwater discharge could have been considerably larger than its present discharge. As the ice receded farther north, even larger meltwater discharges may have occurred as an outlet for Glacial Lake Wallenpaupack opened across a saddle into the Roaring Brook drainage upstream of Curtis Reservoir (Figure A10). This sluiceway has a series of waterfalls with a much wider floor than at Nay Aug Park Gorge. These large meltwater discharges would have helped to carve the Nay Aug Park Gorge more rapidly than in postglacial times. On the other hand, such meltwater lasted only a

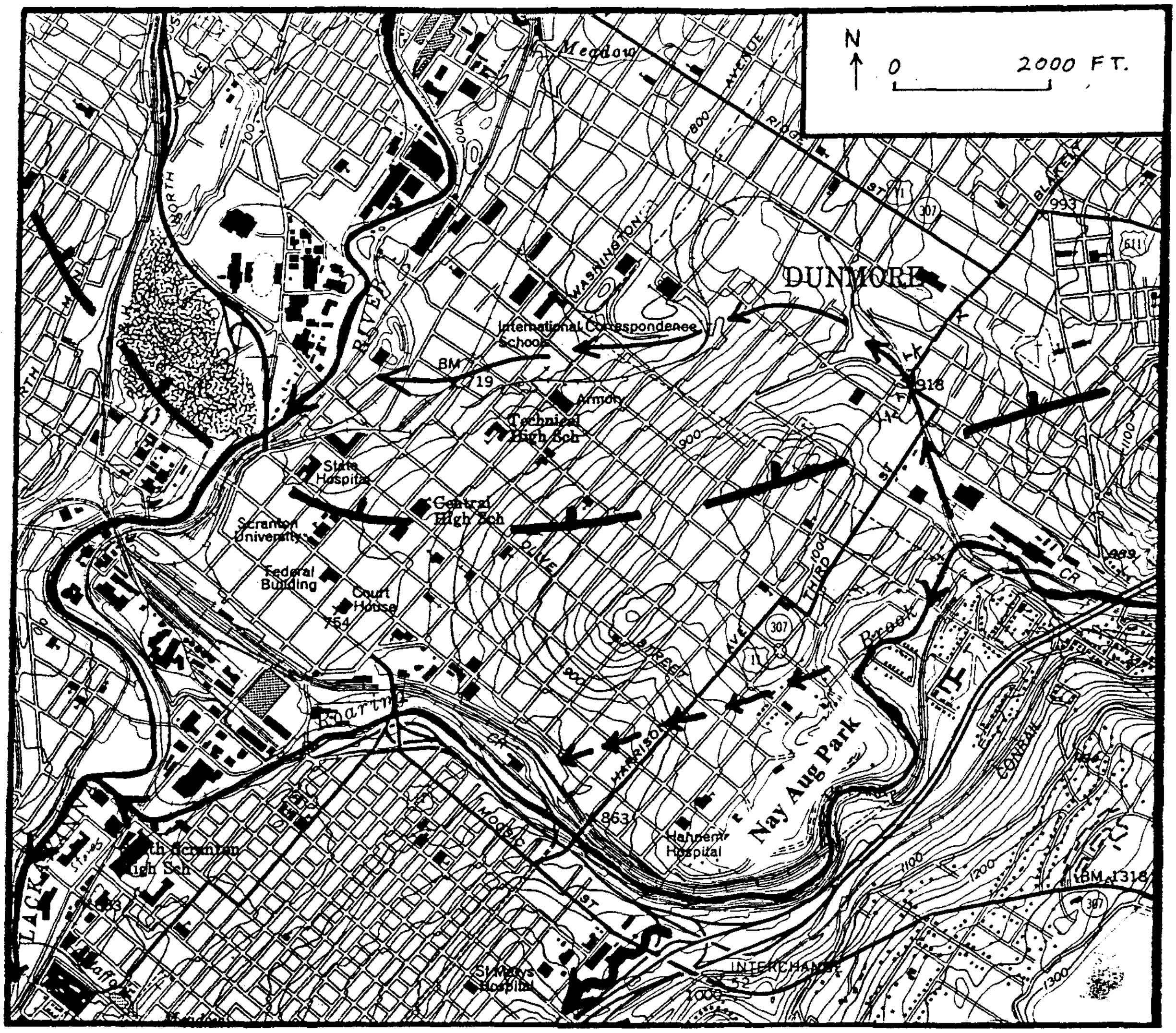


Figure A9. Topographic map of the area around the Nay Aug Park Gorge. Glacial ice blocked the preglacial course of Roaring Brook that went through Dunmore to reach the Lackawanna River (long dashed arrows) and diverted the stream to its present course through Nay Aug Park. The ice margin that blocked the Dunmore windgap is shown as dashes with tick marks pointing toward the ice. Two possible older diverted courses of Roaring Brook are shown as a series of short dashed arrows and a wavy arrow.

few decades to, at most, a few centuries (see Braun, this guidebook, p. 1-15). There have been about 17 to 18 thousand years of post-glacial discharges and they should have also done significant cutting of the gorge, just at a slower rate.

The Nay Aug Park Gorge need not have been carved exclusively during and after the last glacial retreat. The direction of older glacial advances was remarkably similar to that of the last glaciation (see Braun, this guidebook, p. 1-15). The first glaciation should have blocked the Dunmore wind gap and started the cutting of the Nay Aug course. That course may not have been cut down enough in the first glaciation to permanently divert Roaring Brook but eventually in later glaciations permanent capture would occur. That the diversion predates the last glaciation is

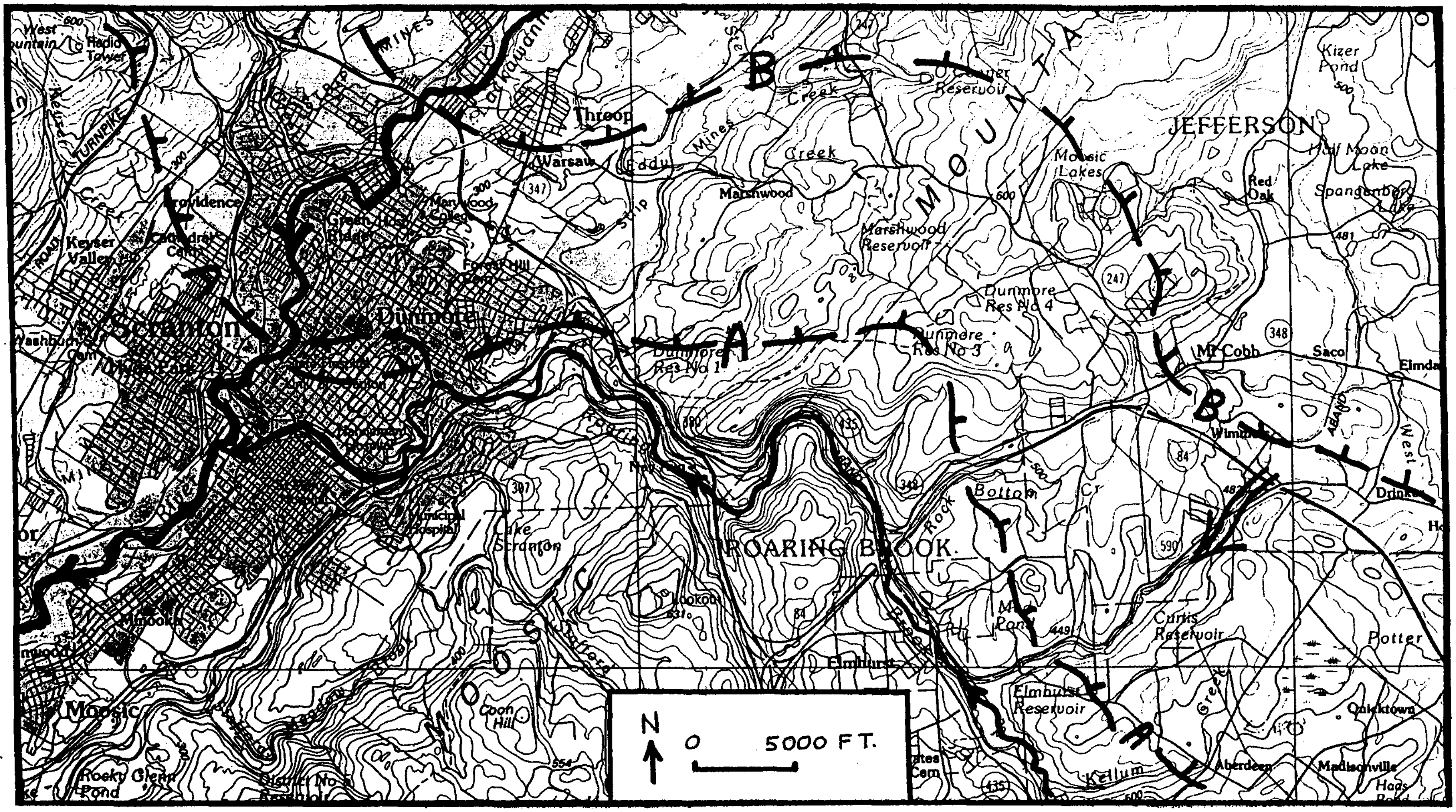


Figure A10. Topographic map of the course of Roaring Brook from the Pocono Plateau, across Moosic Mountain, and through the Nay Aug Park Gorge to the Lackawanna River. The glacially blocked course of Roaring Brook through Dunmore is shown as a line of two arrows. The ice margin that blocked the old course and provided meltwater to Roaring Brook is shown as a line of dashes with tick marks facing the ice labeled A. A later ice margin labeled B added Glacial Lake Wallenpaupack drainage through a sluiceway marked with a double line arrow.

suggested by the shallow, wide-floored incised meanders between the Dunmore wind gap and the Nay Aug Park Gorge. This shallower valley could be the initial, early Pleistocene form of the diversion channel. At that time the knickpoint waterfalls would have been just starting to cut the Nay Aug Park Gorge at about where the Harrison Avenue bridge crosses the entrance to the gorge (Figure A9). Successive glacial and interglacial erosion events throughout the Pleistocene would have collectively caused the migration of the knickpoint to its present position. There may also be other older, shallower and now partly buried diversion courses. One such course may exist across the ridge just north of Nay Aug Park (Figure A9, short arrows). There the broad Roaring Brook valley upstream of the gorge might connect westerly under a saddle in the ridge to a broad hollow that drains to Roaring Brook just downstream of the gorge. Another possible older, shallower diverted course may have trended southwesterly along strike and connected with the Rocky Glen ice marginal sluiceway (Figure 1, wavy arrow across the Scranton Expressway/ I-81 interchange). More detailed work is needed to fully develop the evidence for the entire sequence of Pleistocene events in the Nay Aug Park area.

## STRATIGRAPHY (Edmunds)

(Adapted Eggleston and Edmunds, 1993)

### Introduction

After cutting through the southeastern mountain rim of the Lackawanna basin at the Cobbs Gap (mile 15.9 of Day-2 road log), Roaring Brook runs mostly on sandstones and conglomerates of the Pennsylvanian-age Pottsville and Llewellyn Formations, but for a few thousand feet in the post-glacial Nay Aug Park Gorge, the uppermost 110 feet of the Mississippian Mauch Chunk Formation rises above creek level. We will examine a small part of the Mauch Chunk below the sub-Loyalhanna unconformity, the paleosol at that unconformity, a lateral facies equivalent of the Loyalhanna Member of the Mauch Chunk Formation, the unconformable contact between the Loyalhanna-equivalent beds and the overlying Sharp Mountain Member of the Pottsville Formation, and the basal conglomerate of the Sharp Mountain (Figure A11)). The exposures to be examined at this stop are located at the southwest portal of the Erie-Lackawanna Railroad tunnel, in the cliffs along Roaring Brook downstream and upstream of the railroad trestle located immediately beyond the portal, and in the railroad cut southwest of the trestle.

The Mauch Chunk Formation at this site is remarkable in that it contains virtually no red color and only a small part of the Loyalhanna-equivalent bears strong resemblance to that distinctive unit. The section was first studied by I. C. White (1881, p. 54-56), who shrewdly recognized these highly atypical beds as belonging to the Mauch Chunk, but observed "it is difficult to imagine that these mostly hard, gray, sandy, and even pebbly deposits--constituting a formation only 170' thick, and with only 10' of reddish shale--can represent the 3000' of deep red shales at Mauch Chunk [now Jim Thorpe]..."

### Basal Mauch Chunk Formation (units 1-5)

The greenish-gray sandstones and siltstones comprising units 1 through 5 (Figure A11) represent the uppermost part of the basal Mauch Chunk Formation underlying the sub-Loyalhanna unconformity. These units are exposed in the left bank of Roaring Brook immediately downstream of the railroad trestle.

The total thickness of section underlying the unconformity is unknown. The entire sub-Loyalhanna Mauch Chunk is missing at the roadcut on I-84/380 (STOP 7B of Conference Field Trip), 2.7 miles to the east. However, the record of an old bore hole located at the intersection of Preston and Mulberry Streets in Scranton, 0.7 mile to the west (see Figure A8), seems to indicate that this part of the Mauch Chunk may be from 120 to 170 feet thick, depending upon interpretation. If the record is reliable, correctly interpreted, and not affected by other factors (such as faulting), it means that 120 to 170 feet of section is lost by erosion at the sub-Loyalhanna unconformity in a little over three miles.

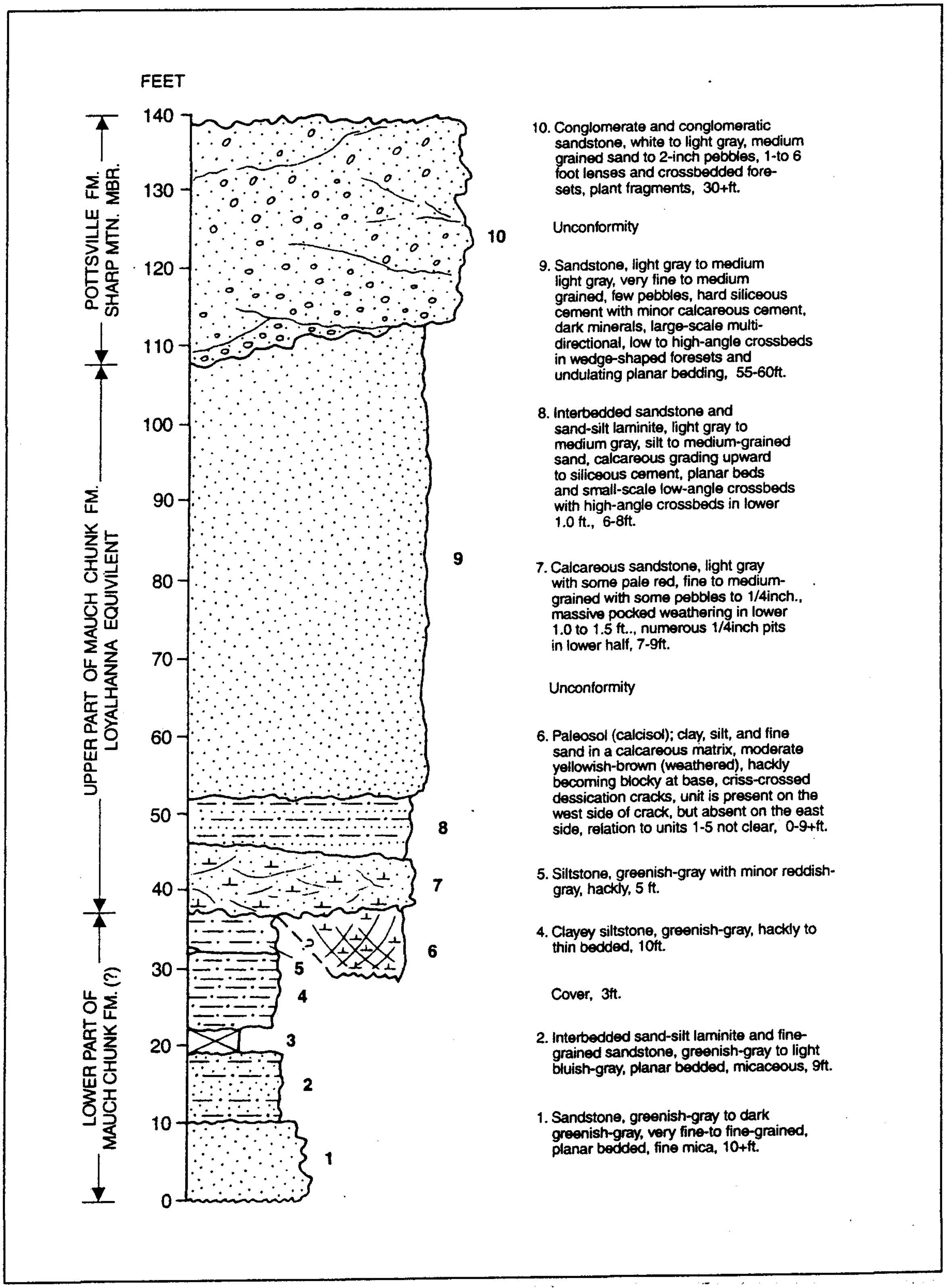


Figure A11. Stratigraphic column exposed of Mauch Chunk and Pottsville rocks exposed in the Nay Aug Park Gorge.

This part of the formation is probably middle to late Osagean in age (c. 342 Ma). Prior to the onset of erosion associated with the sub-Loyalhanna unconformity, it is likely to have been something of the order of at least several hundred feet thick.

**Sub-Loyalhanna unconformity (unit 6)**

Unit 6 is a poorly sorted mixture of clay, silt, and fine sand in a calcareous matrix, with pronounced development of criss-cross desiccation cracks. It is interpreted as a paleosol (calcisol of Mack and others, 1993) formed on the sub-Loyalhanna erosion surface. The unit is 5 feet or more thick at creek level on the right bank immediately upstream from the railroad trestle. This paleosol is absent a few hundred feet away on the left bank just downstream from the trestle where the lowest Loyalhanna-equivalent bed (unit 7) rests unconformably on the top of siltstone unit 5.

The sub-Loyalhanna unconformity here is part of a widespread erosion surface that is continuous throughout most of the central Appalachians from northeastern Pennsylvania to western Virginia and eastern Kentucky. Missing by erosion and non-deposition is section of late Osagean to all but latest Meramecian age (c. 342 to 332 Ma). The unconformity developed on the positive surface of an uplifted tectonic feature more-or-less coextensive with the unconformity in approximately early Meramecian time (c. 338 Ma) (Edmunds, 1993a, 1993b).

**Loyalhanna-Member equivalent (units 7-9)**

The Loyalhanna Member of the Mauch Chunk Formation is a near ischronic, late Meramecian-Stage unit which can be traced from northeastern Pennsylvania to northern West Virginia, northeastern Kentucky, and southern Ohio. Throughout most of this area it lies closely above the early Meramecian region unconformity. On the southeast it appears to grade laterally into the prograding red clastics of the Mauch Chunk delta. To the southwest in West Virginia, it correlates with part of the marine limestones of the Denmar Member of the Greenbrier Formation. To the northwest, it is believed to wedge out against the topographically rising surface of the underlying unconformity.

Throughout most of its area, the Loyalhanna is readily recognized as an arenaceous limestone or calcareous sandstone with striking high-angle crossbedding in complex sets. Weathered surfaces often display a characteristic fluting and pocking. This typical Loyalhanna is most commonly interpreted as a shallow-marine sandwave deposit, although drowned eolian dunes has also been proposed.

In eastern Pennsylvania, there appears to be a number of other facies as well, reflecting related, but somewhat different depositional settings. The Loyalhanna-equivalent exposed here is one such case. Only the lower 7 to 9 feet (unit 7) resembles typical Loyalhanna. This is overlain by several feet of interbedded sandstone and sand-silt laminite, the lower one foot of which is calcareous and displays small high-angle crossbeds. But the remainder is non-calcareous and planar bedded or with low-angle crossbeds (unit 8). The bulk of the remaining Loyalhanna-equivalent interval (55-60 feet thick) is dominantly hard, siliceous sandstone with minor calcareous zones. Bedding is in undulating planar beds and large-scale wedge-shaped foreset with low- to high-angle crossbeds (unit 9). Some aspects of units 8 and 9 resemble a fluvial deposit, perhaps a distributary of some sort. Other interpretations are welcomed.

Units 7 and 8 are exposed in the right bank of Roaring Creek a short distance upstream from the trestle. Unit 9 is best exposed in the lower part of the railroad tunnel, along the cliff face adjacent to the tunnel portal, and in the railroad cut southwest of the trestle.

**Pottsville Formation (Sharp Mountain Member) (unit 10)**

The lowest 30 feet of the Pottsville Formation is exposed above and adjacent to the railroad tunnel portal and along the cliff adjacent to the portal. The Pottsville forms the falls of Roaring Brook near the head of Nay Aug Park Gorge and underlies much of the bedrock course of Roaring Brook for a half mile upstream from the falls. A fairly complete section of the Pottsville is exposed in the railroad cuts between the cliff southwest of the trestle and the Harrison Street Bridge (see Figure A8). In this area the entire Pottsville is about 200 to 225 feet thick.

The basal Pottsville exposed above the portal is quartzose conglomerate and conglomeratic sandstone with rounded to subrounded pebbles (mostly vein quartz) up to 2 inches in diameter. It is customarily interpreted as a high-energy, braided alluvial-plain deposit.

The Pottsville Formation of the Northern Anthracite field is equivalent to the Sharp Mountain Member, which is the uppermost of three members of the formation in the Southern and Middle Anthracite fields to the south. The basal contact of the Sharp Mountain is unconformable throughout eastern Pennsylvania. Erosion at the unconformity cuts down section in a general northerly direction, sequentially removing the underlying Schuylkill and Tumbling Run Members of the Pottsville (about 1300 feet) and something on the order of 2500 feet of upper Mauch Chunk Formation. At this stop, only 70 to 80 feet of Mauch Chunk (all Loyalhanna-Member equivalent) remain between the two regional unconformities. On the north rim of the Lackawanna basin a few miles north of here (STOP 10 of conference field trip), all Mauch Chunk strata are gone and the Pottsville rest unconformably on the Pocono Formation.

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Following the Nay Aug Gorge hike, return to the Everhart Museum, where we will tour the Brooks Mine.

## <u>THE BROOKS MINE</u> (Herbster)

The Brooks mine in Nay Aug Park behind the Everhart Museum is one of the "original" model coal mines in the United States. It was conceived and built in about 1900 by Reese G. Brooks, at the time superintendent of the Greenwood mine near Moosic, as a centerpiece for the new park. Mr. Brooks had previously been the superintendent of the Capouse mine of the Lackawanna Iron and Steel Company (see Perry, this guidebook, p. 64-74). (Capouse was an early name for Scranton.)

The "mine" is developed on the outcrop of an 18-inch-thick coalbed, probably the Dunmore No. 3, or "China," vein (in the deep shaft mines, getting to this vein was like going to China). This coalbed is well exposed at the portal and extends back through the mine about 3 feet off the floor. The mine is reported to be 150 feet long, with a crosscut in the rear. A 1947 plan to greatly expand the mine (to a length of about 250 feet with three mine chambers) was never carried out.

Newspaper accounts on the later history of the mine are somewhat conflicting. It was apparently open continuously (?) from about 1900 to 1938. (It may then have been opened briefly in 1953, but the clipping supposedly from this time is probably misdated.). A major renovation and grand reopening did take place in May of 1961, however. The mine was retimbered by Moffat Coal Company, new lighting was installed, and a narrow gauge rail line with an "electric mule" was added for authenticity. A taped narrative told the history of coal mining in the area, and a guide dressed in miner's clothes was on duty to explain mining in a more personal manner. In the first two months of operation, 25,000 people reportedly visited the mine. When the mine closed again is uncertain.

In 1995, Scranton Parks personnel and state inspectors toured the mine to evaluate its condition and to determine what improvements would be necessary to reopen the mine to the public. To meet minimum standards, it was found that the following would have to be added:

1. An escapeway to the surface (a 5x5-foot opening would be adequate); and
2. A ventilation fan capable of introducing 200 $ft^3$/min of air for each person in the mine.

The preferred location for both of these would be at the rear of the mine. Total cost of the rehabilitation, including educational kiosks and a sound system, would be about $40,000. These improvements are still under consideration.

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# APPENDIX B
## MEASURED SECTIONS AND DRILL HOLES

**1.** Description of measured section of upper Llewellyn Formation along PA 29 between Exits 1 and 2, about 1.75 miles west-southwest of Ashley, Hanover Twp., Luzerne Co. (41°12'12"N/75°56'12"W, Wilkes-Barre West quadrangle). (See STOP 1, Figure 28). Bedding attitude varies from N74E/44NW at the east end of the cut to E-W/51N at the west end. Section by J. D. Inners and J. A. Fabiny, assisted by John Wenner.

| UNIT | THICKNESS (ft) | DESCRIPTION |
|---|---|---|
| | **175+** | **LLEWELLYN FORMATION** (part) |
| | | Concealed. |
| 38 | 18± | SANDSTONE, th to md bd, md dk gy, f-g to m-g, mica, rusty weath; x-bd; flag in upper half; unit composed of 3 fluvial bodies, w/ rel planar contacts. |
| 37 | 0-0.1 | COAL, banded, & SHALE, carb, fissile; blk. |
| 36 | 2 | CONGLOMERATE, md bd, md gy to md dk gy, c-g to 1-cm qtz pebs; erosional base that also partly intertongues with unit 34. |
| 35 | 1.6± | Interbd CONGLOMERATIC SANDSTONE & SAND-SILT LAMINITE SHALE, th to md bd, dk gy (slt) & md gy (s), slt to 1-cm qtz pebs; erosional intertongueing of units 36 & 34. |
| 34 | 6.1 | SAND-SILT LAMINTE SHALE, w/ SANDSTONE bds at top, lam to th bed, dk gy (slt) to md gy (s), slt to m-g, highly mica; rippled ss bds in upper 3-4 ft. |
| 33 | 9.1 | SANDSTONE, partly conglomeratic, md bd (to 2 ft), md dk gy, c-g to 1-cm pebs; pebs scattered to locally concentrated; x-bd; abun dk grains give "salt-and- pepper" appearance; rusty weath; few v-th coaly streaks, probably individual trunks; erosional base. |
| 32 | 0-0.6 | COAL, banded, blk; discontinuous, locally cut out by overlying ss. |
| 31 | 0-2 | SANDSTONE, locally coaly & conglomeratic, md bd, dk gy to md gy, m-g to 1-cm qtz pebs (at top), mica; discontinuous, complex channel filling, w/ coal stringers to 0.5-cm thick. |
| 30 | 0-1.5 | SANDSTONE, slightly conglomeratic, md bd (lensoidal, bd pinches & swells), md dk gy, c-g to 1-cm± pebs; sh clasts to 5 cm; rusty weath; carb, w/ plant stems (c); erosional base. |
| 29 | 0-3 | SILTSTONE, fine sandy, nonbd (hackly), slt to f-g, mica. |
| 28 | 9.2 | SANDSTONE, locally conglomeratic, md to thk bd, md gy to md lt gy, c-g to 2-cm pebs (qtz & chert); 0.5- to 1-ft thick peb lenses at base & near top, thinner bands in middle; few 8-cm± sh clasts at top; rusty weath; rel smooth, but erosional base. |
| 27 | 0.5-2 | SANDSTONE grading up into SANDY SILTSTONE, md bd, md gy, slt to f-g; small siderite nods & specks (c); deeply weath at top; grades laterally into unit 26. |
| 26 | 6.2-7.2 | CLAYSTONE, shaly, slty, nonbd (hackly) to v-th bd; poorly developed sideritic calcrete at top; siderite nods (a) throughout, forming discrete band 3 ft above base. |
| 25 | 7.2 | CLAYSTONE, shaly, sl slty, nonbd (hackly) to v-th bd, md gy; calc siderite nodules & specks (a), w/ several lenses of gy-rd weath sideritic calcrete at top. |
| 24 | 2.5 | CLAYSTONE, sl slty, nonbd (hackly), dk gy to md lt gy; dk-gy-rd sideritic calcrete in th stringers at top & bottom & as 1- to 2-cm nodules near base; lt gy, v-limy band (0.5 ft thk) at base. |
| 23 | 2.1 | CLAYSTONE, sl slty, nonbd (hackly), dk gy to md dk gy; sideritic calcrete locally in small to large, irregular masses to 0.5 ft thk & in irregular, linear "veins" perpendicular to bd; calcrete nodules contain unidentified, soft white mineral. |
| 22 | 6 | SANDSTONE, silty, & SAND-SILT LAMINITE, lam (bot) to nonbd (top), md gy, slt to v-f; small, irregular sideritic calcrete masses in upper 1 ft; calc throughout, w/ iron-rich carbonate nodules & blebs (a). |
| 21 | 4.6 | SANDSTONE, f-g, grading up to SAND-SILT LAMINITE, md bd, md dk gy to md lt gy, silt to f-g, mica; x-bd; consists of two fluvial bodies, upper grading into unit 22; some dk-gy-rd, iron-rich blebs & streaks; erosional base. |
| 20 | 25.9 | SANDSTONE, md to thk bd, md lt gy, m-g to c-g, highly mica; trough & lateral accretion x-bds (a); consists of 6 stacked fluvial bodies separated by thin "shaly" bands; some dk-gy-rd, iron-rich bands in upper 8-10 ft. |

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| 19 | 1-2 | SANDSTONE & SAND-SILT LAMINITE, th bd, md dk gy to md gy, m-g to c-g, mica; appears mostly planar bd, but w/ some 0.2- to 0.3-foot-thk, x bd lenses; contains many v-th carb prtgs (plant trunks?). |
| 18 | 0-5 | SANDSTONE, md to thk bd, md lt gy ("salt & pepper"), c-g to pebbly, x-bd, w/ several vague channels; siderite clasts (2-5 cm) & qtz pebs locally concentrated at base; contains a v-th discontinuous coal; sharp to erosional base. |
| 17 | 0-0.2 | COAL, banded, blk; locally w/ v-th carb (<0,25 in) CLAY SHALE at top; rel continuous, but cut out by overlying ss of unit 18 higher on cut and squeezed out by loading locally. |
| 16 | 0.2 | CLAY SHALE, carb, fissile, gy blk; plant stems (a). |
| 15 | 1.6-2 | SANDSTONE, md bd, md dk gy, c-g to gran, mica; qtz & coal grans (a), siderite pebbles (a), & blk sh clasts (to 0.3 ft) (c); contains at least 3 inclined, "point-bar" coals to about 0.5 in thk; erosional base. |
| 14 | 3.8 | CLAY SHALE, slty, v th bd (fissile to splintery), dk gy to md dy gy; iron-oxide stained; poorly preserved plant stems & frags (c). |
| 13 | 2.2 | CLAY SHALE, slty, v th bd (fissile); plant leaves (*Neuropteris*, etc.), stems, & frags (unc). |
| 12 | 0.7 | SILTSTONE, calc, md dk gy; forms single, prominent bed continuous along outcrop. |
| 11 | 0.9± | CLAYSTONE, slty, nonbd (hackly), md dk gy. |
| 10 | 12.6 | CLAYSTONE, shaly to nonbd (hackly), w/ lam SANDSTONE, th bd, f-g, forming a discontinuous lens 2± ft thk in lower part; zones of dk-gy-rd sideritic calcrete in irregular masses to 2± ft thk near top & in smaller masses about 5 ft above base; irregular "veins" of calcrete, perpendicular to bd, extend down several ft from the upper zone. |
| 9 | 14.2 | SANDSTONE, locally conglomeratic, md to thk bd, md dk gy to md gy, c-g to pebbly, highly mica; calc in upper 1± ft (deeply weath & friable); 2-ft-thk cong band about 4 ft above base; sharp lower contact. |
| 8 | 1.4 | SANDSTONE, v-f-g to f-g, grading laterally into SAND-SILT LAMINITE; v th to th bd, mica. |
| 7 | 1.8 | CLAYSTONE (seatrock), nonbd (hackly), dk gy. |
| 6 | 1.4 | COAL, banded, blk; bony in lower 0.4 ft; *Calamites* at top; ***No. 7 coalbed.*** |
| 5 | 0.5 | SHALE, carb, v th bd, dk gy. |
| 4 | 12 | SAND-SILT LAMINTE & SANDSTONE, v th to th bd, md gy, slt to f-g, rusty weath. |
| 3 | 1.5 | SANDSTONE, th bd, md gy, f-g; small-scale x-bds defined by v-th, black, highly mica streaks. |
| 2 | 1 | SAND-SILT LAMINATE, v th bd, md dk gy, slt to v-f-g, very highly mica; deeply weath, soft. |
| 1 | 3.5 | SANDSTONE, md bd, md gy, f-g, highly mica; contains dk-gy sh clasts to 7 cm (a); deeply weath, soft. |
| | | Concealed. |

**2.** Description of section measured along the abandoned Central Railroad of New Jersey grade, north of The Seven Tubs Natural Area, Plains Twp., Luzerne Co. (Top of section: 41°14'34"N/75°48'42"N; bottom: 41°14'04"N/ 75°48'48"W (Wilkes-Barre East 7.5' quadrangle). (See STOP 3, Figure 37.) Section by W. E. Edmunds and J. R. Eggleston.

| UNIT | THICKNESS (ft) | DESCRIPTION |
|---|---|---|
| | 110+ | **POTTSVILLE FORMATION** (part) |
| 52 | 20+ | Sandstone, medium gray, medium grained; planar bedded to possible large-scale crossbeds; subangular to subrounded grains, silica cement; plant fragments (u). |
| 51 | 90± | Conglomerate and conglomeratic sandstone, light to medium light gray, medium grained to 1-inch pebbles, strongly crossbedded, with cut-and-fill structures; silica cement and clay to silt matrix; plant trunk and branch impressions (c). |
| | | **Structurally disturbed Pottsville Formation** |
| | | FAULT |
| 50 | 55± | Conglomerate and conglomeratic sandstone; same as unit 51. |
| | | FAULT |
| 49 | 12± | Conglomerate and conglomeratic sandstone; same as unit 51. |
| | | FAULT |
| 48 | 11± | Conglomerate and conglomeratic sandstone; same as unit 51. |
| | | FAULT |

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| 47 | 8± | | Clay shale, grayish black; plant fragments and root impressions (c). May be Campbells Ledge. |
| | | | FAULT |
| 46 | 9± | | Conglomerate and conglomeratic sandstone; same as unit 51. |
| | | | FAULT |
| 45 | 25 | | Sandstone, medium gray, medium grained; silica cement; similar to unit 52. |
| | | | FAULT |
| 44 | 20± | | Sandstone, medium gray, medium grained; silica cement; same as unit 45, similar to unit 52. |
| | | | FAULT |
| | | | **MAUCH CHUNK FORMATION** |
| | | **495** | **Upper part** |
| 43 | 12± | | Sandstone, hard, greenish gray, fine to medium grained; planar bedded; silica cement (secondary recrystallization, grains obscured); strong, close-spaced jointing. |
| 42 | 49 | | Sandstone, hard and dense, medium bluish to greenish gray, silt to fine grained; planar bedded; silica cement (secondary recrystallization, grains obscured). |
| 41 | 15 | | Covered interval. |
| 40 | 61 | | Sequence of 10- to 12-foot-thick, fining-upward cycles--sandstone grading up to siltstone and silt shale. Sandstone is medium light bluish gray, fine to medium grained; crossbedded in channels, silica cement. Siltstone and silt shale is medium light bluish gray, greenish gray, and reddish gray; lower few feet grad laterally into top of unit 39. |
| 39 | 5-10 | | Silt shale, grading upward into siltstone, medium greenish gray and grayish red; upper few feet grad laterally into base of unit 40. |
| 38 | 7.5 | | Sandstone, medium bluish gray and medium light gray, fine grained; planar bedded; silica cement; thin grayish-red silt shale zone in middle. |
| 37 | 13 | | Siltstone and silt shale, grayish red, grading upward to medium light gray with grayish-red mottling. |
| 36 | 5 | | Sand-silt laminite, medium light gray; small trough crossbeds. |
| 35 | 4 | | Covered interval. |
| 34 | 6 | | Sandstone, medium light bluish gray, very fine to fine grained; flaser bedding; silica cement. |
| 33 | 30 | | Siltstone and silt shale, medium gray, medium light gray, and pale red; siltstone is gray; silt shale is banded red and gray; some calcareous zones; plant fragments (r). |
| 32 | 23 | | Clayey silt shale (25%) and siltstone (75%), both calcareous, grayish red; siltstone fraction increases upward; lower 4 feet only slightly calcareous. |
| 31 | 8 | | Sandstone, medium light gray, fine to medium grained; planar bedded; silica cement; lower 2 feet calcareous. |
| 30 | 20 | | Siltstone and silt shale, pale grayish red, weak fissility. |
| 29 | 6 | | Sandstone, medium light gray with some grayish red stringers, medium grained, micaceous; planar bedded; silica cement. |
| 28 | 3 | | Covered interval. |
| 27 | 4.5 | | Sandstone, medium bluish gray, coarse grained, micaceous; wedge crossbed sets. |
| 26 | 2.5 | | Sandstone, calcareous, light gray, coarse to very coarse grained, irregular bedded; 30% large red-shale and carbonate clasts. |
| 25 | 6 | | Siltstone, grayish red. |
| 24 | 6 | | Covered interval. |
| 23 | 64 | | Sequence of 8- to 12-foot-thick, fining-upward cycles; sandstone (85%) grading up to siltstone (15%); sandstone is grayish red, very fine to fine grained, planar beds and low-angle crossbed sets with scoured bases; silica cement; siltstone is grayish red. |
| 22 | 6 | | Covered interval. |
| 21 | 11 | | Siltstone, grayish red, slightly calcareous in places. |
| 20 | 4 | | Covered interval. |
| 19 | 18 | | Siltstone, grayish red, slightly calcareous in places. |
| | | ***99*** | ***Loyalhanna Member*** |
| 18 | 36 | | Sandstone, calcareous, grayish red, very fine to fine grained, grading upward to fine to medium grained; high- to low-angle crossbeds in 2- to 8-foot-thick sets with truncated tops and tangential bases; some non-calcareous zones; some small red shale clasts. |
| 17 | 2 | | Siltstone, grayish red, hackly. |
| 16 | 30 | | Sandstone, calcareous in part, grayish red to pale red, very fine to medium grained; high angle crossbed sets in 2- to 4-foot-thick sets with truncated tops and tangential bases; zones of |

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| | | | pedogenic calcium carbonate clasts; fluted weathering along crossbedding. |
| 15 | 10 | | Sandstone, calcareous, grayish red, very fine to fine grained, grading up to fine-grained; massive. |
| 14 | 1± | | Siltstone to sandstone, calcareous, grayish red, silt to very fine grained. |
| 13 | 19 | | Sandstone, non-calcareous in lower part--calcareous in upper, light gray grading up successively to pale red and grayish red, medium grained grading up to very fine and fine grained; low- to high-angle crossbeds in 2- to 4-foot-thick sets with truncated tops and tangential bases; some fluted weathering along crossbedding. |
| 12 | 0.7-1 | | Siltstone, calcareous in upper part, grayish red, hackly. |
| 11 | 1.5-2 | | Sandstone, grayish red, very fine to fine grained; few scattered pebbles to 0.6 cm. |
| | | | *Regional unconformity* |
| 10 | 0-5 | | Paleosol (vertic calcisol), composed of coarse-grained quartz sand and quartz pebbles to 1.25 cm and calcium-carbonate and red-shale clasts set in a pale-red to grayish-red limestone matrix; contorted bedding; criss-crossed, curved pedogenic slickensides form wedge-shaped peds. |
| | | | **MAUCH CHUNK FORMATION** |
| | | **70-75** | **Lower part** |
| 9 | 12 | | Sandstone, slightly calcareous in places, light greenish gray, medium to coarse grained grading up to fine to medium grained; silica cement; planar beds and wedge-shaped crossbeds; micaceous. |
| 8 | 0-0.7 | | Silt shale, clayey, grayish red, hackly. |
| 7 | 25 | | Sandstone, greenish gray, medium gray and medium dark gray (with some grayish red), fine to coarse grained; medium- to small-scale wedge crossbeds and cut-and-fill; silica cement, clay matrix; micaceous, scattered red- shale clasts to 20 cm. |
| 6 | 0-3 | | Silt shale, grayish red, hackly. |
| 5 | 10± | | Sandstone, light gray, coarse to very coarse grained; planar beds; silica cement; dark minerals. |
| 4 | 10 | | Claystone, grayish red, hackly. |
| 3 | 7 | | Silt shale, pale red to grayish; wavy bedding, with shallow cut-and-fill, micro-crossbeds; rootworked. |
| 2 | 8 | | Silty claystone to clay shale, pale red, hackly to irregularly wavy bedded. |
| | | | **POCONO FORMATION** (Part) |
| 1 | 5+ | | Sandstone, medium light to medium dark gray, medium to coarse grained; low angle crossbeds; silica cement; dark minerals. |

**3.** Description of section measured in the "315 Quarry" of the American Asphalt Paving Company, north of Ridgewood Road, 0.8 mile northwest of the village of Keystone, Plains Twp., Luzerne Co. (41°16'54"N/75°48'18"N, Pittston 7.5' quadrangle). (See STOP 4, Figure 42.) Section by W. E. Edmunds and J. R. Eggleston.

| UNIT | THICKNESS (ft) | DESCRIPTION |
|---|---|---|
| | | **LLEWELLYN FORMATION** (part) |
| 15 | 40 | Sandstone, light to medium gray, medium to coarse grained, angular to subangular grains; micaceous, dark minerals; large-scale trough- and wedge-shaped foreset crossbeds; large sandy shale lenses to several feet (some carbonaceous); plant fragments (c). |
| 14 | 1 | Coal, ***Upper Ross***. |
| 13 | 10 | Interbedded sandstone, medium gray, very fine to medium grained, <u>and</u> silt shale, medium dark gray; rootworked in upper few feet; plant fragments (c). |
| 12 | 1 | Coal, ***Lower Ross***. |
| 11 | 0-1 | Claystone, sandy, medium gray. |
| 10 | 32 | Sandstone, medium light to medium dark gray, medium to coarse grained, angular to subangular grains; micaceous, dark minerals: large-scale trough and wedge foreset crossbeds, some planar beds; large *Stigmaria* in top several feet, also other plant fragments (c). |
| 9 | 12 | Silt shale, medium dark gray to grayish black; plant leaves, branches, and fragments (c-a). |
| 8 | 2-8 | Siltstone to very fine-grained sandstone, dark gray, with zone of well rounded, medium-grained sand floating in finer matrix; abundant dark minerals; plant fragments (a); lower part is displace laterally by unit 6. |
| 7 | 0-5 | Coal, ***Upper Red Ash***; displaced laterally by unit 6. |
| 6 | 0-25 | Sandstone, medium light gray, medium to very coarse grained, angular to subangular grains; |

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| | | minor mica and dark minerals; massive planar beds and lenses; laterally displaces or cuts out all or part of units 4, 5, 7, and 8. |
| 5 | 0-13 | Sandstone, medium dark gray, medium to very coarse grained; micaceous, abundant dark minerals; irregular bedding; carbonaceous; plant trunks, branches, and other fragments (c); locally cut out by unit 6. |
| 4 | 2-5 | Sandy silt shale, dark gray, carbonaceous; leaves and other plant fragments (c); partly cut out by unit 6. |
| 3 | 4 | Sandstone, dark gray, very fine to fine grained; micaceous, abundant dark minerals and coal fragments; rootworked; plant fragments (c); encloses tops of tree stumps from unit 2. |
| 2 | 1 | Silty clay shale, grayish black, carbonaceous; *in-situ*, upright tree stumps; plant fragments (a). |
| 1 | 0-3 | Coal, ***Middle Red Ash***. |
| | | (Bottom floor of quarry.) |

**4.** Description of measured section along exit/entrance ramp (Interchange 1) on I-84/380 in the southeastern part of the Borough of Dunmore, Lackawanna Co. (41°24'09"N/ 75°-35'48"N, Olyphant quadrangle). (See STOP 7B, Figure 53.) Section by W. E. Edmunds.

| UNIT | THICKNESS (ft) | DESCRIPTION |
|---|---|---|
| | **121+** | **POTTSVILLE FORMATION (*Sharp Mountain Member*) (part)** |
| 30 | 40+ | Sandstone, medium gray to medium light gray, fine to medium grained; mostly planar beds and low-angle crossbeds; some silt shales to 3 inches; some mica and dark minerals; plant fragments (unc). |
| 29 | 2 | Sandstone grading up to sandy silt shale, light-olive-gray weathered, silt to fine grained. |
| 28 | 0.3 | Shaly coal, black, crushed, poor exposure. |
| 27 | 13? | Sandstone, laminated medium gray and medium light gray, medium to coarse grained; low-angle crossbeds; micaceous; plant fragments (r). |
| 26 | 11-14 | Sandstone and conglomeratic sandstone, medium gray to medium dark gray, medium grained to 0.5-inch pebbles; wedge crossbeds, cut-and-fill; plant fragments (r); incised basal contact. |
| 25 | 0-1 | Clay shale, dark gray to grayish black, carbonaceous; plant fragments (r). |
| 24 | 0-2 | Sandstone, medium gray, fine to medium grained; plant fragments (r). |
| 23 | 10 | Conglomerate, light gray to white, coarse grained to 0.5-inch pebbles; large lensoidal crossbeds, cut-and-fill; plant fragments (r). |
| 22 | 16 | Sandstone and conglomeratic sandstone, laminated light gray and medium gray, medium grained to 0.75-inch pebbles; strongly crossbedded, with imbricated 3-inch- to 1-foot-thick sets, cut-and-fill; plant fragments (r). |
| 21 | 22-26 | Conglomerate and conglomeratic sandstone, very light gray to white, coarse grained to 2-inch pebbles; large lensoidal crossbeds, cut-and-fill; some lenses of grayish-black silt shale (0-3 feet thick); plant fragments (c); incised basal contact. |
| 20 | 0-0.5 | Silty clay shale, grayish black, carbonaceous; coal stringers and plant fragments (a). (***Campbells Ledge shale bed.***) |
| 19 | 0-3 | Sandstone, light gray, fine to medium grained; lensoidal crossbed sets, composed of 0.5-inch convex-up crossbeds with truncated tops and bottoms; carbonized plant trunks, branches, and other fragments (c). |
| | | *Regional unconformity* |
| 18 | 0.6 | Paleosol: clay shale, grayish-yellow, intensely weathered. |
| | **19** | **MAUCH CHUNK FORMATION** |
| | ***9-13*** | ***Loyalhanna Member equivalent*** |
| 17 | 9-13 | Sandstone, light gray to medium light gray upward, medium to coarse grained grading up to fine to medium grained, with a few quartz pebbles to 0.75 inch; trough and wedge, low-angle crossbeds with tangential bases; siderite concentrated along crossbedding in lower 3 to 4 feet; slightly calcareous in lower few feet; 1-foot thick siderite(?) zone one foot down from top. |
| | ***6*** | ***Loyalhanna Member*** |
| 16 | 6 | Two crossbed set of calcareous sandstone, both medium light gray. Lower set (0.5-4 feet thick) is medium-grained; high-angle crossbeds with truncated tops and tangential bases; fine fluted weathering along crossbeds. Upper set (2.5-4 feet thick) is medium to coarse grained; high-angle |

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| | | | crossbeds with truncated tops and tangential bases; concentration of large carbonate nodule clasts, dark mineral grains, and calcareous invertebrate fragments along crossbed planes; pocky weathering. |
| | | | *Regional unconformity* |
| | | | Paleosol |
| 15 | 14-15 | | Calcareous siltstone (calcisol), light olive gray grading up to dark gray, hackly fragments, increasingly calcareous upward (top half is almost a limestone), scattered quartz pebbles to 1.5 inches; curved, criss-cross desiccation cracks throughout; sand-filled vertical desiccation cracks at top; many carbonate nodules and zones in top 1 foot. |
| 14 | 0-1.2 | | Silty claystone to clay shale, light olive gray, hackly to fissile; pale red, pedogenic limestone nodules, pocky weathering. |
| 13 | 0-0.7 | | Calcareous siltstone (calcisol), pale red, similar to siltstone of unit 12, but completely impregnated with calcite; resembles a "hard pan." |
| | | 126+ | **POCONO FORMATION** |
| 12 | 2.5 | | Siltstone, medium gray to olive gray, non-calcareous, except in fractures. |
| 11 | 0.5± | | Silty clay shale, light olive gray. |
| 10 | 25 | | Siltstone to sandstone, medium gray to medium light gray, silt to very fine- grained sand, hard; mostly planar or near-planar beds, some small-scale crossbeds, some cut-and-fill; 1-foot-thick hackly zone near middle of unit (rootworking?); banded reddish hematitic (?) zones in top half (weathered from siderite); plant fragments (unc) in lower 2 feet. |
| 9 | 0-0.7 | | Clayey silts shale, dark olive gray, dark gray, and grayish black; carbonized plant fragments (r). |
| 8 | 26 | | Sandstone, light olive gray, light gray, and medium light gray; medium to coarse grained, grading up to very fine to fine grained, few pebbles to 0.75 inch in lower few feet; 2- to 8-foot-thick beds; some dark minerals and mica; zones of reddish-brown pin-head hematite (?) spots (weathered from siderite). |
| 7 | 3-7 | | Clayey silt shale to siltstone, medium gray to grayish-black upward, hackly to blocky, hard; weathers with slight reddish tinge; possibly rootworked. |
| 6 | 17.5 | | Sandstone, light gray, fine to medium grained; planar beds; abundant reddish-brown pin-head hematite (?) spots (weathered from siderite). |
| 5 | 1-8 | | Sandstone, medium light gray, medium grained; low angle crossbeds with tangential bases and truncated tops in 0.5 foot-beds; abundant dark minerals and mica; few quartz pebbles and shale clasts; some reddish brown pin-head hematite (?) spots. |
| 4 | 0.2-2 | | Siltstone and silt shale, grayish black with iridescent bluish cast, hackly. |
| 3 | 8-16 | | Sandstone, greenish gray, fine to medium grained grading up to very fine to fine grained; some sand-silt laminite; planar bedded with minor troughs; micaceous; upper half channeled out and filled with units 4 and 5. |
| 2 | 20 | | Sandstone, light gray to white, very coarse grained to granular grading up to medium to coarse grained; angular grains; clear to white quartz grains with silica cement overgrowths; some dark minerals and mica; low angle crossbeds with tangential bases and truncated tops in 1- 3-foot-thick sets; wedge bedding. |
| 1 | 10+ | | Interbedded (0.5-1.0 foot interbeds) clayey silt shale, medium dark gray; sand-silt laminite, yellowish gray, silt to very fine sand, micaceous; and sandstone, light olive gray, fine grained, clayey. |
| | | | (Lower part of Pocono Formation is largely concealed in long covered interval between STOPS 7A and 7B.) |

5. Description of measured section along northbound lanes of US 6W-11N in Leggetts Creek gap (just north of Interchange 57 on I-81) in northernmost part of the City of Scranton, Lackawanna Co. (41°27'33"N/75°40'00"W, Scranton quadrangle). Bedding attitude is about N55E/15SE. (See STOP 10, Figure --.) Section by W. E. Edmunds.

| UNIT | THICKNESS (ft) | | DESCRIPTION |
|---|---|---|---|
| | | 18+ | **LLEWELLYN FORMATION** (part) |
| 20 | 15+ | | Clay shale, dark gray to grayish black; two 2-inch-thick coal stringers in lower 1.5 feet; plant fragments and leaves (c-a). |

| | | | |
|---|---|---|---|
| 19 | 2.9 | | Coal (*Dunmore No. 3)*, black to grayish-black, banded; deep mined. |
| | | 179 | **POTTSVILLE FORMATION (*Sharp Mountain Member*)** |
| 18 | 6 | | Silt shale, dark gray grading up to grayish black, rootworked; plant fragments (a). |
| 17 | 13 | | Sandstone, medium dark gray, medium to coarse grained; medium-size, overlapping lenses; crossbedded; abundant dark minerals and mica; discontinuous coaly stringers to l-inch thick; plant fragments (c-a upward). |
| 16 | 0-0.3 | | Coal, black, weathered, granular. |
| 15 | 2-14 | | Sandstone, medium gray, medium grained; channel fill; bedded in broad wedges; common dark minerals and mica; plant fragments (c). |
| 14 | 0-0.5 | | Coal, black, weathered, granular. |
| 13 | 6-18 | | Sandstone, medium dark gray, fine to medium grained, planar bedded; abundant dark minerals and mica; cut by channel. |
| 12 | 0-0.3 | | Bony coal, grayish black. |
| 11 | 12 | | Silt shale, dark gray, planar beds; top 1 to 2 feet is rootworked siltstone; plant fragments (a). |
| 10 | 35-40 | | Sandstone, light gray, medium to coarse grained; bedded in large lenses and wedges; 0.3-foot-thick lens of grayish black coaly siltstone; trunk and branch impressions (unc). |
| 9 | 15-22 | | Interbedded sandstone and conglomerate, medium dark gray to light gray, very fine grained sand to 0.5-inch pebbles; planar beds, trough crossbeds, and lenses; cut by channel. |
| 8 | 22-25 | | Sandstone, medium gray to medium dark gray, very fine to fine grained; lensoidal bedding; crossbedded; 1-foot-thick conglomerate sandstone bed near middle of unit; abundant dark minerals, common mica. |
| 7 | 5-8 | | Interbedded sandstone and conglomerate, medium dark gray to light gray, very fine grained sand to 0.5-inch pebbles; planar beds, trough crossbeds, and lenses. |
| 6 | 7-11 | | Conglomerate and conglomeratic sandstone, very light gray, medium grained sand to 0.5-inch pebbles; imbricated lenses and crossbeds. |
| 5 | 7-9 | | Interbedded sandstone and conglomerate, medium dark gray to light gray, very fine grained sand to 0.5-inch pebbles; planar beds, trough crossbeds, and lenses. |
| 4 | 8-9 | | Siltstone, medium dark gray to medium gray grading upward to grayish black and black; lower 1 foot is irregularly bedded silt shale with crossbeds; remainder is weakly bedded to unbedded, hackly; top 1 foot is carbonaceous; curved slickensides with secondarily reorganized 0.25-inch siltstones [or iron-manganese mineralization] along slickensided planes; incipient paleosol. |
| 3 | 15-16 | | Interbedded sandstone and conglomeratic sandstone, light gray with some dark gray, medium-grained sand to 0.5-inch pebbles; planar beds with some wedge bedding and crossbeds; rare to abundant dark minerals; some mica on bedding planes. |
| | | 31+ | **POCONO FORMATION** |
| 2 | 7-8 | | Siltstone to sandstone, mottled medium light gray and medium dark gray, sit to very fine grained sand; hackly with no bedding except irregular planar beds in top 1 foot locally; non-calcareous; common pin-head limonite-filled pits (probably weathered from siderite); rounded, lumpy weathering; weathers grayish orange; probable paleosol (vertisol). |
| 1 | 23 | | Sandstone, light gray to medium light gray, fine to coarse grained, planar bedded; common to abundant dark-red hematite(?)-filled, pin-head pits (probably weathered from siderite); weathers grayish-orange to dusky yellowish-brown. (Part of remainder of Pocono Formation is exposed in cliffs between US 6W-11N and I-81 just to north of measured cut.) |

**6.** Record of bore hole drilled at the intersection of Prescott and Mulberry Streets, Scranton (41°24'12"N/75°39'00"W) (Hill, 1888, part 3, sheet IX, section 18). Tentative stratigraphic nomenclature by W. E. Edmunds.

| | | |
|---|---|---|
| Surface | 15' 7" | |
| **Llewellyn Formation (part)** | | **86' 2"** |
| Micaceous sandstone | 21' 9" | |
| Dunmore No. 2 coalbed | 5' 6" | |
| Fine hard sandstone | 54' 6" | |
| Dunmore No. 3 coalbed | 4' 6" | |
| **Pottsville Formation (Sharp Mountain Member)** | | **203' 4"** |

| | | | |
|---|---|---|---|
| Gray sandstone | | 19' 9" | |
| Hard sandstone | | 19' 9" | |
| Conglomerate | | 163' 10" | |
| **Mauch Chunk Formation** | | | **197' 7"** |
| **Loyalhanna Member equivalent (?)** | **24' 9"** | | |
| Fine white sandstone | | 24' 9" | |
| **Sub-Loyalhanna units** | **172' 10"** | | |
| Blue-green rock | | 19' 9" | |
| Black shale | | 2' 0" | |
| Soft red shale | | 99' 1" | |
| Fine green sandstone | | 24' 9" | |
| Blue sandstone | | 17' 6" | |
| Red sandstone and shale | | 9' 9" | |
| **Pocono and Spechty Kopf Formations** | | | **437' 8"** |
| Blue and white rock | | 145' 6" | |
| Hard black shale | | 29' 8" | |
| Blue and white sandstone | | 128' 9" | |
| Hard sandstone | | 133' 9" | |
| **Catskill Formation (part)** | | | **1121' 6"** |
| Red shale | | 74' 3" | |
| Black sandstone | | 19' 9" | |
| Hard blue rock | | 7' 11" | |
| Red sandstone | | 5' 0" | |
| Red slate | | 33' 8" | |
| Blue sandstone | | 59' 5" | |
| Red shale | | 19' 9" | |
| Light blue sandstone | | 24' 9" | |
| Red shale | | 14' 10" | |
| Hard blue sandstone | | 52' 6" | |
| Red shale | | 29' 8" | |
| Hard blue sandstone | | 14' 10" | |
| Hard white sandstone | | 19' 9" | |
| Red shale | | 14' 10" | |
| Hard blue sandstone | | 39' 7" | |
| Red shale | | 14' 10" | |
| Soft black sandstone | | 9' 11" | |
| Hard blue sandstone | | 9' 11" | |
| Soft red sandstone | | 29' 8" | |
| Hard white sandstone | | 3' 0" | |
| Hard blue sandstone | | 0' 5" | |
| Red shale | | 19' 9" | |
| Hard blue sandstone | | 503' 6" | |

This bore hole is extraordinarily long, and it is difficult to discern the purpose. There is, of course, no way to verify the original logging--and it has likely gone through several transcriptions. The stratigraphic nomenclature seems to be the best fit, but somewhat surprising. At 173 feet, the sub-Loyalhanna Mauch Chunk is thicker than might be expected this far north. Even transferring the lower three units to the Pocono leaves 121 feet, still high considering that this interval is interpreted to be totally missing just 3 miles to the east at the I-84/380 road cut (STOP 7B of conference field trip). At 438 feet, the Pocono-Spechty Kopf is strikingly thin. Adding the lower three units from the Mauch Chunk only increases it to 489 feet.

7. Summary of measured sections of the Catskill, Spechty Kopf, Pocono, Mauch Chunk, and Pottsville Formations near Campbells Ledge, Luzerne County (Pittston 7.5' quadrangle). Original description in Kehn and others (1966, p. 44-56); formational boundaries reinterpreted by W. E. Edmunds.

The powerline A section extends from the top of Campbells Ledge northward along the cliff face to the base of the Pocono Formation, which caps the cliff just south of the creek draining Falling Springs Reservoir. The powerline B section was measured along the creek that flows southwestward from the Falling Springs Reservoir dam; the base of the section is at the top of the cliff overlooking the North Branch Susquehanna River, and the top of the section is at the dam. The powerline C section extends from the base of the powerline B section, along the creek draining the Falling Springs Reservoir to the highway along the east side of the North Branch; from there it extends northward along the highway to a point approximately 2000 feet north the powerline that crosses the river from the electric generating station. (Powerlines B and C are continuous).

Stratigraphic units according to Kehn and others (1966):

*Powerline A*

| Unit(s) | Stratigraphic Units | Thickness (ft) | |
|---|---|---|---|
| | **Pottsville Formation** | **76** | |
| 47 | Sharp Mountain Member | | 75 |
| 46 | Campbell[s] Ledge Shale | | 1 |
| | **Pocono Formation** | **567** | |
| 45-11 | Upper part | | 415 |
| 10-1 | Griswold Gap Member | | 152 |
| *Powerline B* | | | |
| | **Susquehanna Group** | | |
| | **Catskill Formation** | **1931** | |
| 13-1 | Zone E [176 ft] | | |
| *Powerline C* | | | |
| 124-68 | Zone E [850 ft] | | 1026 |
| 67-31 | Zone D | | 423 |
| 30-1 | Zone C (part) | | 482+ |

Stratigraphic units according to W. E. Edmunds:

*Powerline A*

| Unit(s) | Stratigraphic Units | Thickness (ft) | |
|---|---|---|---|
| | **Pottsville Formation** {1} | **76** | |
| 47 | Sharp Mountain Member | | 76 |
| 46 | Campbells Ledge shale bed [1 ft] {2} | | |
| | Unconformity | | |
| | **Mauch Chunk Formation** {4} | **300** | |
| 45-22 | [Upper beds] | | 209 |
| 21-17 | Loyalhanna Member {5} | | 91 |
| | Unconformity {6} | | |
| 16-1 | **Pocono Formation** {7} | **267** | |
| *Powerline B* | | | |
| 13-5 | **Spechty Kopf Formation** {8} | **141** | |
| | **Catskill Formation** {9} | **1790** | |
| 4-1 | Undifferentiated [35 ft] | | |
| *Powerline C* | | | |
| 124-1 | Undifferentiated [1755 ft] | | |

***NOTES:***

{1} The Sharp Mountain Member is the only part of the Pottsville Formation present in the Northern Anthracite field. The Schuylkill and Tumbling Run Members, which underlie the Sharp Mountain elsewhere in the Anthracite region are unconformably missing.

{2} The Campbells Ledge shale is treated here as a "bed" within the Sharp Mountain Member rather than as a separate member of the Pottsville Formation as presented by Kehn and others (1966). The election to treat the Campbells Ledge shale as a "bed" is based upon the fact that in many places (as here), it is underlain by additional conglomerate readily assignable to the Sharp Mountain, and, in addition, is thin, discontinuous, and difficult to map at any conventional scale.

{3} This major unconformity is added to the description of Kehn and others. Read (1944) and Edmunds (1988, 1996) believe it to be present below the Sharp Mountain Member throughout the Sharp Mountain Member throughout the Anthracite region. Kehn and others (1966) were aware of it presence here, but chose not to include it in their description.

{4} Units 17 through 45 were included in the Pocono Formation by Kehn and others, (1966), but are interpreted here as Mauch Chunk Formation. Kehn and others were aware that I. C. White (1883, p. 157-160, unit 4) considered units 22 through 45 to be the Mauch Chunk Formation in this area; but, unaware of the major unconformity between units 16 and 17, they chose to treat units 22 through 5 as a diachronous facies of the Pocono because of the near total lack of red coloration.

{5} Units 17 through 21 are interpreted here as the lateral equivalent of the Loyalhanna Member of the Mauch Chunk Formation and the basal unit of that formation in this immediate area, overlying a major regional unconformity. I. C. White (1883, p. 157-160, unit 5) considered units 17 through 21 to be part of the Pocono Formation at this cite, and Kehn and other continued that usage. Neither White nor Kehn and others were aware that the Loyalhanna and its underlying regional unconformity were present in the area of the Northern Anthracite field.

{6} The unconformity is added to the description of Kehn and others. It is interesting to note that, in describing this same section, White (1883, p. 157, unit 6) recorded a two-foot-thick "Layer of conglomerated with breccia of shale and sandstone" underlying what is here considered to be Loyalhanna equivalent (units 17-21). It was not noted by Kehn and others but sounds significantly like the lag breccia-paleosol which occurs frequently in association with the sub-Loyalhanna unconformity.

{7} For reasons discussed in note 4, the top of the Pocono Formation is placed at the top of unit 16. Units 1 through 10 of the Pocono Formation were called the "Griswold Gap Member" by Kehn and others, following the usage of I. C. White (1883, p. 157-161). Because the "Griswold Gap" at its type section near the extreme north end of the Northern Anthracite field is actually part of the Sharp Mountain Member of the Pottsville Formation, the use of the term has been discontinued (Sevon, 1969, p. 64-69).

{8} Units 5 through 13 were included at the top of the Catskill Formation by Kehn and others, but are considered here to be Spechty Kopf Formation as used on the *Geologic Map of Pennsylvania* (Berg and others, 1980). These units appear to be the upper part of the "Pocono-Catskill transition" of I. C. White (1883, p. 158-161, unit 16). They are also "lithologic component 1" (tilloid-pebbly claystone) which forms the base of the "lower member of the Pocono Formation" of Sevon (1969, p. 6-15). This "lower member" later became part of the Spechty Kopf Formation. The upper and lower contacts of the Spechty Kopf are believed to be unconformable, although the amount of missing section is unclear in both cases.

{9} The top of the Catskill Formation is placed at the top of unit 4 to accommodate the Spechty Kopf as discussed in note 8. In Kehn and others, the Catskill Formation is shown as part of the Susquehanna Group, but as the latter term has fallen into disuse, it is deleted. Kehn and others also divided the Catskill into informal members lettered "A" through "E." As these informal members are not used elsewhere and are useful here only by the reference to the text, they also have been deleted.

# APPENDIX C

## HISTORICAL CHRONOLOGY OF THE MINING INDUSTRY IN THE NORTHERN ANTHRACITE FIELD AND NEARBY AREAS

compiled by
Jon D. Inners

*The morning calm was shattered on that day in fifty-nine,*
*The whistle blasts meant there had been disaster in the mine.*
*And blood ran cold for they all knew that lives again were lost.*
*The price of coal was set in blood and miners bore the cost.*
Ray Stephens, "Last Day of the Northern Field"

1662 Charles II of England grants to the colony of Connecticut all land covering the 42d degree of latitude from Narragansett Bay westward to the Pacific (except the lands in New York and New Jersey already occupied by settlers). This becomes the basis for the Connecticut claim to the Wyoming-Lackawanna valley.

1681 King Charles grants all of present-day Pennsylvania (expect the "Erie Triangle") to William Penn and his heirs, setting the stage for the future "Yankee-Pennamite" War.

1753 "The Susquehanna Company" is formed in Windham, Connecticut, to purchase the Wyoming-Lackawanna valley from the Iroquois Confederacy.

1756 The Penns finalize the Albany Purchase with the Iroquois, confirming their claim to the Wyoming-Lackawanna Valley; two days later the Indians sell the Wyoming Valley to the Susquehanna Company.

1762 John Jenkins, mapmaker for the Susquehanna Company, reports the existence of coal in the Wyoming Valley.

1768 The first permanent settlers—forty Connecticut Yankees of the Susquehanna Company—come to settle in the Wyoming Valley.

1769 "Pennamites" under Captain Amos Ogden arrive in the Wyoming Valley bearing a commission from Governor John Penn to take possession of Pennsylvania's claim; two weeks later, Connecticut Yankees show up to stake their claim to the valley. Confrontation leads to the "Yankee-Pennamite War," which "rages" until 1771, when Yankees under Zebulon Butler join with Pennsylvania renegade Lazarus Stewart (of the infamous "Paxton Boys") to finally oust the Pennamites.

Obidiah Gore and his brother Daniel use "stone coal" (anthracite) at their Wyoming Valley forge, finding that when properly ignited and fanned by a bellows it is far superior to charcoal in maintaining intense heat. This is the first recorded example of the use of anthracite for a practical purpose.

1776 Two boatloads of anthracite are shipped from the Wyoming Valley down the Susquehanna to Harrisburg for use by gunsmiths at Carlisle to manufacture cannons for the Continental Army.

1778 Wilkes-Barre Fort erected at the present site of the square in Wilkes-Barre. It included the Court House of the Connecticut County of Westmoreland.

(July 3) "Wyoming Massacre." In the third year of the Revolutionary War, Indians and Tories overwhelming defeat a force of Continental militia, mostly Connecticut men, near Forty Fort on the north side of the Susquehanna River. All four Continental forts in the Wyoming Valley (Wilkes-Barre, Forty Fort, Wintermoot's, and Pittston) are surrendered and abandoned. By July 18, the entire valley is depopulated--with many settlers fleeing over the southern mountain rim and through the dark and swampy "Shades of Death" toward Stroudsburg and Bethlehem.

1779 (July 31) General John Sullivan leading a large force Continental regulars sets out from Wyoming on his famous and decisive "march" up the North Branch Susquehanna River to destroy the power of the hostile Iroquois Indians of New York's Finger Lakes/Genesee Valley region. By October 15, he is back in Easton, having effectively removed the Iroquois as a major factor in the war.

1786 (September 25) Luzerne County, named for Anne Cesar, Chevalier de la Luzerne, is created out of Northumberland County. The Chevalier was responsible for raising large sums of money for the continental army during some of the darkest hours of the American Revolution.

1787 Jesse Fell of Wilkes-Barre begins using anthracite for the manufacture of nails. He also starts experimenting with various ways of burning the fuel.

1788 Philip Abbot sets up a grist mill in Deep Hollow (later Slocum Hollow) along Roaring Brook, at the future site of Scranton.

1798 Slocum brothers purchase Abbot's grist mill and also construct a forge, a distillery, and a saw mill.

1799 A compromise finally resolves the Yankee-Pennamite controversy: the Yankees keep their lands, but they agree to submit to the Pennsylvania government.

1806 Wilkes-Barre becomes a borough.

Abijah Smith, newly arrived from Derby, CT, begins mining an outcropping vein of anthracite ("Red Ash vein") on his property on Ransom Creek in Plymouth Township, Luzerne County. He ships his first boatload of coal to Columbia (Lancaster County) the next year, but can't sell it.

1808 Jacob Cist (1780?-1825) settles in Wilkes-Barre. In subsequent years, he becomes one of the great boosters of Northern-field anthracite.

(February 11) Jesse Fell (since 1798 a judge of Luzerne County Court) successfully uses a fire's natural draft to burn anthracite in an open grate. Within days, new grates modeled on Fell's appear all over Wilkes-Barre.

(Summer) Abijah Smith and his brother John ship two more arkloads of coal to Columbia. By demonstrating Fell's grate, they successfully sell the entire shipment.

1813 George Hollenback sends the first Wyoming Valley coal to Philadelphia.

1814 Wurtz brothers begin to develop the anthracite resources of the Carbondale area, shipping their first coal down to Philadelphia (via Wallenpaupack Creek, Lackawaxen Creek, and the Delaware River) in 1815..

1818 (March) Abijah Smith and John Flanigan, a rock-quarry powderman from Milford, CT, conduct the first successful drilling and blasting of an anthracite vein at Smith's Plymouth Township mine.

1820 By this time, at least 8000 tons of anthracite have been shipped down the Susquehanna from the Wyoming Valley, much of it from Abijah Smith's "Red Ash vein" outcropping (26 feet thick). But only about one in three arks were succeeding in reaching downstream markets.

1822 After a seven year interruption, Maurice and William Wurtz raft more anthracite from the Carbondale area down the Delaware River to Philadelphia, but find the market already saturated by coal from the Lehigh region.

1823 New York State a charter to the Wurtzes' Delaware and Hudson Canal Company to transport coal from the Carbondale area to New York City.

1825 (July 13) Construction of the Delaware and Hudson Canal begins at Summitville, NY, on July 13. Philip Hone, for whom Honesdale is named, is president of the canal company.

1828 (October) The 108-mile-long Delaware and Hudson Canal is officially completed between Honesdale, PA, and Eddyville, NY. From Honesdale, the canal follows the Lackawaxen River to the Delaware, parallels that river to Port Jervis, NY, then passes up the valley of the Neversink River and the Rondout Creek valley to tidewater. The first boats carrying coal arrive at Rondout, NY, from Honesdale on December 5.

1829 Completion of the Delaware and Hudson's gravity railroad between Honesdale and Carbondale. Designed by John B. Jervis, the "Gravity" is later extended to Archbald (1847) and Scranton (1860). It operates until 1899.

Horatio Allen drives the *Stourbridge Lion,* a steam locomotive manufactured in England, from Honesdale to Seeleyville on the Delaware and Hudson's tracks.. This 3-mile run is the first operation of any railroad locomotive in the United States and leads to the eventual proliferation of a great railroad network throughout the Anthracite region later in the century.

1835 First Pennsylvania Geological Survey, headed by Henry Darwin Rogers, begins work in the anthracite fields. Initial field studies are completed in 1841.

1838 William Henry buys land in Slocum Hollow to build an iron furnace.

Pennsylvania Coal Company chartered to do general coal-mining business in the Pittston area.

1840 (July 3) David Thomas, an immigrant Welsh ironmaker, successfully blows in an anthracite blast furnace at Catasauqua, Lehigh County. Within fifteen years more iron is being smelted with anthracite than with any other fuel.

1840-41 Scranton brothers erect their first anthracite-iron furnace in Slocum Hollow. Two attempts to "blow in" the furnace in October, 1841, fail. Another attempt on January 3, 1842, fails.

1842 (January 18-February 26) Thanks to the assistance of John F. Davis of Danville, Pennsylvania (via Tredegar, Wales), the first short--but fairly successful--campaign of the No. 1 furnace at Scranton results in the production of approximately 75 tons of pig iron. (This furnace is eventually abandoned and falls to ruins.) Four more stacks—still standing—are added by 1857.

E. R. Biddle Company (Philadelphia) initiates first blast at its iron works in the Rolling Mill Hill section of Wilkes-Barre. For six years, the plant is a major industry in the city, but it then runs into creditor problems and sells out to the Montour Iron Company in Danville (to which place the plant is moved).

1843-44 Nailworks and rolling and puddling mill are constructed at the Scranton Iron Works. The nail manufacturing operation failed because of a lack of adequate transportation facilities and the brittleness of the nails.

1844 Gideon Bast erects the first anthracite breaker at Wolff Creek colliery near Minersville in the Southern field. Bast used a system of steam-driven roll crushers and screens developed by Joseph Batten of Philadelphia.

1846 (January 12) The great "Carbondale squeeze." A huge roof collapse and subsidence--involving an area of 50 acres--at an underground mine in Carbondale is brought on by inadequate roof support. Although many trapped men and boys are rescued, 14 lives are lost. As the industry matures in subsequent decades, better mine design leads to the elimination of such "general collapse" disasters.

(September 16) The Scrantons negotiate a contract with the New York & Erie Railroad for the manufacture of 4000 (12,000?) tons of T-rails to be used on trackage between Piermont and Binghamton, NY. The railroad loans them $90,000 to construct a rolling mill and to furnish the necessary track. Successful completion of this contract on December 27, 1848 (just four days before the expiration of the Erie's charter) saves both the railroad and the iron works.

1848 Blast furnaces #2 and #3 constructed at the Scranton iron works.

Pennsylvania Coal Company begins construction of a gravity railroad from Pittston to Hawley, where it is connected to the Delaware and Hudson Canal.

1849 (January 22) Terence V. Powderly, future leader of the Knights of Labor, is born in Carbondale, PA.

1849-53 The Scrantons are instrumental in constructing the Delaware and Cobb's Gap railroad (incorporated 1849) from Scranton to Stroudsburg and the Leggett's Gap Railroad (organized in 1851 and later called the Lackawanna and Western) from Scranton to Great Bend, NY.

1850 The Ashley Planes of the Lehigh and Susquehanna Railroad (later part of the Central Railroad of New Jersey) begin transporting anthracite through Solomons Gap and over the mountains to the Lehigh Canal and, later, the main line of the CNJ.

1853 The Scrantons reorganize their iron manufacturing company to form the Lackawanna Iron and Coal Company (LI&C). By this time, the iron works includes three furnaces, a rolling and puddling mill, a foundry, two blacksmith shops, a car shop, two carpenter's shops, 200 company houses, and ore and coal mines. Blast furnace #4 is constructed.

Delaware and Hudson's miners successfully strike for 2-1/2 cents per ton increase in piece rate.

(April) The Delaware and Cobb's Gap Railroad and the Lackawanna and Western Railroad are consolidated to form the Delaware, Lackawanna and Western Railroad (DL&W). About this time, the DL&W commences mining operations by opening the Diamond Mine at the foot of Hyde Park hill to begin the transformation of Scranton into a "coal metropolis." The Mount Pleasant Shaft is also opened in the same area.

1854 The Baltimore Tunnel breaker, the first coal breaker in the Wyoming Valley, is constructed by the Baltimore Coal Company in Wilkes-Barre. It operates until February 20, 1897, when it is destroyed in a fire, scourge of the 19th-century wooden breaker.

1855 DL&W Railroad completed between New York and Buffalo, via Scranton. Shops are located in Scranton.

1856 Thomas Dickson establishes a machine shop and foundry near the LI&C plant in Scranton. In 1863 this is expanded into the Dickson Manufacturing Company, maker of boilers, railcars, and locomotives.

1857 Blast furnace #5 constructed—last of the anthracite furnaces at Scranton.

1865 The Laflin, Boies and Turck Powder Company of Saugerties, NY, sends Henry Boies to Scranton to represent their interests. Boies starts the Moosic Powder Company in 1869, and later perfects a safer gunpowder carriage for use in the mines.

1866 Scranton is given a city charter, with the two nearby boroughs of Hyde Park and Providence incorporated within it.

Pennsylvania legislature extends to anthracite coal operators the right to maintain private police forces, a privilege previously held by railroad companies. Thus is born the "Coal and Iron Police."

1869 Pennsylvania legislature passes its first mine safety law (which applies only to Schuylkill County), requiring the ventilation of mines by either furnace or fan and the employment of a "mine boss" responsible for certain aspects of mine safety. Provision is also made for a single state mine inspector.

(June-July) Coal miners in the Wyoming Valley join a region-wide strike to implement the "basis system," a sliding scale based on the price of coal. As in other areas, the strike of the northern miners is broken

(September 6) Avondale Mine Disaster. Fire at the Avondale colliery of the Steuben Coal Company near Pittston kills 110 men and boys. A new breaker --built directly over the only entrance to the mine--catches fire, trapping the workers underground. This is the first major mine disaster in the anthracite fields, and no subsequent accident exacts a higher toll of lives.

1870 As a result of the Avondale disaster, the state legislature strengthens the 1869 mine safety act and applies the new law to all anthracite mines. Important provisions include requiring two or more openings for shaft and slope mines and maintenance of accurate mine maps. The law also increases the number of state mine inspectors to six.

Slate picking tables and "breaker boys" are introduced at the Hill and Harris colliery in Mahanoy City in the Western Middle field.

(February 4) John Mitchell, future head of the United Mine Workers of America, is born in Braidwood, IL, the son of a coal miner.

(December) Miners in the Northern Anthracite field, organized by the Workingmen's Benevolent Association (WBA), go on strike to protest a 30 percent pay cut--but their compatriots in the Middle and Southern fields keep working.

1871 Wilkes-Barre is incorporated as a city.

(April 4-8) A series of clashes between striking WBA miners (commonly urged on by their equally combative wives) and strike-breaking laborers at several Scranton-area collieries leaves two men dead. As a result, Governor John Geary sends in the Pennsylvania State Militia and the Scranton area is placed under martial law.

(May 16) While labor unrest rocks Scranton, a meeting which results in the founding of the American Institute of Mining Engineers (AIME) is held in Wilkes-Barre. One of the chief organizers is Eckley B. Coxe of Drifton (near Hazleton), Luzerne County.

(May 17) Two Welsh miners are killed in a violent confrontation in Hyde Park between a band of armed, mostly Irish laborers being escorted home from the Briggs' Shaft by William Scranton and a mob of WBA. miners and their supporters (mostly Welshmen). Within a week, the strike is broken--and most of the miners are back at work on the operators' terms.

(May 27) Twenty men are suffocated underground by smoke from a burning breaker at the West Pittston colliery of the Lehigh Valley Railroad Company.

1872 Lackawanna Iron and Coal Company erects a large, iron-sheathed coke-fired furnace at its Scranton works.

1875 Paul Ambrose Oliver (1831-1923), Civil War veteran (Brigadier-General of Volunteers in the Army of the Potomac), begins operations at his new black-powder mill on Wilkes-Barre Mountain. Nearby he erects the workers' settlement of Oliver's Mills. The Oliver Powder Company remains in operation for 27 years (until purchased by DuPont in 1902), supported by six patents for black-powder manufacture which Oliver receives between 1868 and 1889. Oliver also opens a large quarry in the Mauch Chunk Formation at Oliver's Mills, where much of the red sandstone used in the construction of many Wyoming Valley churches and other buildings is carved out of the mountain. Ruins of some of the powder-mill buildings remain, but the quarry seems to have disappeared.

1875-76 Steel mills added to Lackawanna Iron and Coal Company works, Bessemer converters being installed at site across Cedar Avenue across from anthracite furnaces.

1877 (July) At a time of great labor unrest, particularly marked by the great national Pullman Strike, the DL&W's miners strike in response to the company's refusal to increase wages following a long depression in the industry and a series of pay cuts.

(August 1) The Scranton City Guards—commanded by W. W. Scranton of the L. C. & I. Co.--fire into a crowd of rioting strikers and their sympathizers, killing four Irishmen and wounding twenty-five others. For the next three months the city is under martial law. The striking mineworkers hold out until October, but then capitulate.

1878 Terence V. Powderly elected mayor of Scranton on the Greenback-Labor ticket. He serves for the next six years.

(August 13) Lackawanna County is created out of Luzerne County. The name is derived from an Indian word meaning "stream that forks."

1879 Powderly becomes head of the Order of the Knights of Labor and leads the Knights to a peak membership of over 700,000 in 1886. Throughout the 1880's, the reform-minded Powderly is the most popular and influential labor leader in the country.

(April 23) The Sugar Notch "entombment." Seven men and boys are buried underground by a cave-in and feared lost in the No. 10 slope of the Wilkes-Barre Coal Company at Sugar Notch. They are all rescued six days later.

1881 William Scranton leaves LI&C and, with brother Walter, erects the Scranton Steel Company works on the banks of the Lackawanna River about a mile from Slocum Hollow.

1884 Patrick Mahon, miner, discovers the "Archbald pothole," as a rush of rounded stones and water follows an underground blast in a heading on the Clark (or Archbald) coalbed in the Jones, Simpson and Company mine. John C. Branner, topographical geologist with the Pennsylvania Geological Survey, visits the site in February, not long after the initial discovery, and writes a report on its probable origin as a "plunge pool" at the base of a glacial waterfall. (His explanation is still generally accepted.)

Lackawanna Iron and Coal Company renamed Lackawanna Iron and Steel Company.

1885 Miners' and Laborers' Amalgamated Association formed.

(December 18) Inrush of "quicksand" (water-saturated sand-and-gravel) at the Nanticoke No. 1 mine of the Susquehanna Coal Company kills twenty-six. More than 100,000 yd3 of debris fills workings as miners intersect part of the "buried valley of the Susquehanna."

1886 (January) Frank Pardee, general superintendent of the Pardee mining interests in Hazleton, makes the first successful use of hydraulic mine-flushing in battling a "squeeze" at the Laurel Hill No. 5 mine at Hazleton. During the 20th century, the method is widely adopted in American and European coal mines to fill worked-out mine sections and prevent cave-ins.

1886 (November 26) Twelve miners lose their lives in a gas explosion at the Conyngham colliery (Wilkes-Barre) of the Delaware and Hudson Coal Company.

1888 Henry Bois, owner of the Moosic Powder Company, founds the Bois Steel Wheel Company to manufacture his patented flexible steel wheel for locomotives.

1890 (January 20) Knights of Labor District No. 135 and the American Miners' Federation , successor to the Amalgamated Association, merge to form the United Mine Workers of America (UMWA).

(May 15) Methane explosion at the Jersey No. 8 mine (Ashley) of the Lehigh and Wilkes-Barre Coal Company claims 26 lives.

1891 Lackawanna Iron and Steel and Scranton Steel merge, adopting the former's name. Scranton Steel's plant becomes the "south works."

(November 8) Twelve men are killed by an explosion of gas at the Susquehanna No. 1 mine (Nanticoke) of the Susquehanna Coal Company.

1894 (February 13) Massive roof fall results in the deaths of 13 men at the Gaylord colliery (Plymouth) of the Kingston Coal Company.

(August) Stephen Crane's "In the depths of a coal mine"--vividly describing his descent into the Oxford and No.5 mines in the Lackawanna basin--appears in *McClure's* magazine. Corwin Knapp Linson (1864-1959) supplies fourteen charcoal illustrations for the article.

1896 (June 28) Twin Shaft Mine Disaster. Fifty-eight men are entombed underground by a massive cave-in at the Twin Shaft colliery (Pittston) of the Newton Coal Company. The bodies are never recovered.

1897 (March) In-rush of water and debris devastates the Mt. Lookout mine at Wyoming. The mine being idle, there are no casualties.

(September 10) "Lattimer Massacre." Climaxing a month of strikes and labor unrest, about 300 miners--mostly Slavs and Hungarians from the Austro-Hungarian Empire--march to Lattimer near Hazleton in the Eastern Middle field to close down the mines there. As they approach the west end of the village, 19 are killed and 32 wounded, when deputies under Luzerne County Sheriff James Martin fire on them with Winchester rifles.

1898 (January 11) John Mitchell elected vice-president of the UMWA at convention in Columbus, OH.

(March 10) Sheriff Martin and his deputies are acquitted of the murder of Michael Cheslak (the only killing for which they were tried) at am acrimonious trial in Wilkes-Barre.

(September) Mitchell becomes acting president of the UMWA on resignation of elected president.

(November 5) A mine car falls down the shaft of the Lehigh Valley Coal Company's Exeter mine (West Pittston), crushing nine men in the cage. That same day, the last boatload of anthracite to be shipped on the Delaware and Hudson Canal departs from Honesdale.

1899 (January) "Johnny" Mitchell elected president of the UMWA at convention in Pittsburgh.

(March 2) William Haynes Truesdale assumes presidency of the Delaware, Lackawanna and Western Railroad, beginning a twenty-six years reign which brought more modern management practices and great improvement in the rolling stock and infrastructure of the "Road of Anthracite."

(Fall) Mitchell personally initiates the UMWA's anthracite organizing- campaign, setting up headquarters in the old Valley Hotel in Hazleton.

*The coal you dig isn't Slavish or Polish or Irish Coal, it's coal.*
John Mitchell

1900 (August) As the McKinley-Bryan presidential campaign, Mitchell calls a convention of the three anthracite districts in Scranton.

(September 17) Mitchell calls anthracite miners out on strike.

(October 29) Strike ends. Operators tacitly accept compromise terms endorsed by union--including a 10 percent pay boost. This marks the miners' first major victory in more than fifty years of disputes. The date is still commemorated in the Anthracite region as "Johnny Mitchell Day."

1901 Mary Harris Jones, a.k.a. "Mother Jones," comes to Scranton to assist female workers (many of whom are miners' wives and daughters) striking against silk mill operators.

*I reside wherever there is a good fight against wrong.*
Mother Jones

1902 The Lackawanna Iron and Steel Company relocates to Lackawanna, NY. The Scranton works is completely dismantled and moved to the shores of Lake Erie, where Mesabi Range iron-ore, western Pennsylvania coke, and New York limestone are readily available. Only the great stone stacks of four of the anthracite furnaces remain as monuments to the industry that "put Scranton on the map."

DL&W begins its "Phoebe Snow" advertising campaign, introducing the immaculate lady in white who epitomized the safety, convenience, and comfort of railroad passenger travel for nearly sixty years. In the popular imagination, the "Road of Anthracite" becomes the "Route of Phoebe Snow."

(May 12) Beginning of the "The Great Strike": 145,000 anthracite miners go out on strike for more than five months.

*Me workin' in de Prospect,*
*Vorkin' Dorrance shaft, Conyngham, Nottingham--*
*Every place like dat.*
*Vorkin' in de gangway, workin' in de breast,*
*Labor every day, me nevair gettin' rest.*
*Me got plenty money, nine hoondred, maybe ten,*

*So strike kin come, like son-of-a-gun--*
*Me Johnny Mitchell Man.*

Con Carbon (On eve of 1902 Strike)

(July) Troops are stationed throughout the Anthracite region.

(August 14-30) Escalating labor violence, in part brought on by "goon squads" and coal-and-iron-police hired by the operators, culminates in a fortnight of riots, destruction, and injuries.

(October 13) President Theodore Roosevelt intervenes and forces the miners and operators to submit their differences to arbitration by a commission agreeable to both sides. Mitchell calls off strike on October 21.

(October 23) Most mine employees return to work.

(November 14) Anthracite Strike Commission opens its hearings in Scranton, Clarence Darrow being the miners' chief counsel. Hearings at Scranton and Philadelphia last three months.

*If the civilization of this country rests upon the necessity of leaving these starvation wages to these miners and laborers...if...it rests upon the labor of these poor little boys, who from twelve to fourteen years of age, are picking their way through the dirt, clouds and dust of the anthracite coal...if it is not based on a more substantial foundation than that...it is time that these captains of industry resigned their commission and turned it over to some theorists to see if they cannot bring ruin and havoc a good deal quicker..."*

Clarence Darrow

(November 26) Last of miners accept arbitration and go back to the collieries.

1903 (March 10) Anthracite Coal Commission delivers its findings after the most exhausting inquiry into the anthracite industry ever made. The miners win another 10 percent pay increase and creation of an Anthracite Board of Conciliation, but do not get recognition of the UMWA as bargaining representative.

This settlement marks the beginning of an 18-year period of relative peace and rising prosperity in the anthracite fields. But stability and higher wages are bought at the cost of the monopolistic practices exposed by socialist Scott Nearing in his *Anthracite—an instance of natural resource monopoly* (1918). For throughout this time, more than 96 percent of all anthracite coal lands are owned by the railroads, with 91 percent of the deposits owned outright--and J. P. Morgan interests control companies that transport one-third of all anthracite mined in Pennsylvania.

1904 (November 2) Ten men die when a cage falls down a shaft at the Auchincloss colliery (Nanticoke) of the DL&W Railroad Company.

1905 Truesdale breaker constructed by the DL&W in Hanover Township, Luzerne County. Originally built of wood, the Truesdale was completely renovated into a modern steel and glass structure in 1915.

1905 (April 26) Another cage accident, this one at the Conyingham colliery (Wilkes-Barre) of the Delaware and Hudson Coal Company, claims 10 lives.

1908 President William Truesdale of the DL&W hires architect Kenneth Murchison to design a new railroad station in Scranton. The result is the magnificent structure that now houses the Radisson Lackawanna Station Hotel.

(March 19) John Mitchell bids farewell to the United Mine Workers and becomes head of the trade agreement department of the National Civic Federation..

1911 DL&W constructs "Concrete City" as housing for workers at its Truesdale colliery. The 20 two-story double houses are constructed entirely of reinforced concrete. The site is abandoned in 1924.

(April 7) Pancoast Mine Disaster. Seventy-two men die in a mine fire at the Pancoast colliery (Throop) of the Price-Pancoast Coal Company.

1914 DL&W erects the Loomis "breaker, one of a new "breed" of anthracite breaker constructed of reinforced concrete, structural steel, and glass.

(December 9) Thirteen men are killed when a cage falls down the shaft at the DL&W's Diamond colliery (Scranton).

1915 (February 17) An explosion of methane at the Prospect colliery (Wilkes-Barre) of the Lehigh Valley Coal Company claims 13 lives.

1917 Anthracite production throughout the "Region" peaks at more than 100 million tons, mostly from deep mines. Production in 1918 is only 1 million tons less.

1918-19 Influenza pandemic rages throughout the United States, as well as the rest of the world. A one-million-ton drop in anthracite production in 1918--at the height of American involvement in World War I--is due in part to the temporary shut-down of numerous collieries at the height of the pandemic in September, October, and November.

*The mines closed down almost with the first whiff of influenza. Men who for years had been drilling rock and had chronic miner's asthma never had a chance against the mysterious new disease; and even younger men were keeling over, so the coal companies had to shut down the mines, leaving only maintenance men, such as pump men, in charge.*

John O'Hara, "The Doctor's Son" (1935)

1919 Hudson Coal Company erects the steel, glass, and concrete Loree breaker at Plymouth.

(June 5) Baltimore Tunnel Mine Disaster. Ninety-two men die in an explosion of powder and dynamite at the Baltimore Tunnel of the Delaware and Hudson Coal Company's No. 5 colliery.

(September 10) John Mitchell, then chairman of the New York State Industrial Commission, dies in New York City. He is buried in Scranton a few days later.

1920 John Llewellyn Lewis becomes president of the UMWA.

Marvine No. 2 breaker erected by the Hudson Coal Company at Scranton.

1921 Pennsylvania legislature passes the Kohler-Fowler Act, the first serious attempt to regular subsidence caused by underground coal mining. On appeal by the Pennsylvania Coal Company to the U.S. Supreme Court the law was declared unconstitional.

(September 1) Coal properties of the DL&W Railroad transferred to the Glen Alden Coal Company.

1923 (November 2) David Lloyd George, wartime Prime Minister of Great Britain, visits Scranton and is greeted at the Lackawanna Station by thousands of Welsh-Americans.

1924 (June 6) Gas explosion kills 14 men at the Loomis colliery (Nanticoke) of the Glen Alden Coal Company.

(June 24) Terence V. Powderly dies in Washington, DC.

1925 (August 3) Ten die in a methane explosion at the Dorrance colliery (Wilkes-Barre) of the Lehigh Valley Coal Company.

1928 Due to hard times and high unemployment, "work equalization" emerges as a major issue in the anthracite fields.

(May 25) A gas explosion rips the Baltimore No. 5 mine (Wilkes-Barre) of the Delaware and Hudson Coal Company, killing ten.

1938 (June 2) Explosion of gas claims 10 lives at the Volpe mine (Pittston Township) of the Volpe Coal Company.

1939 (February 1) Glen Alden Coal Company begins operating the new Huber breaker at its colliery in Ashley, replacing the outdated Maxwell breaker (1895). Mining at the site begin in 1851 (Hartford colliery), with the first breaker being erected in 1856.

1942 *How Green was my Valley*, John Ford's film based on Richard Llewellyn's novel about 19th-century coal miners in Wales, is premiered in Scranton. According to William D. Jones in *Wales in America* (1993), this was "the final time" that "Scranton would figure prominently in the history of the Welsh."

1943 (Spring) Sullivan Trail Coal Company closes its operations in West Pittston.

1944 (February 8) Jule Ann Fulmer, age 2, is swallowed up by a sudden mine subsidence while walking down Mill Street in Pittston. After 30 hours and the excavation of 550 tons of rock, coal, and dirt, her body is recovered.

1947 Ashley Planes of the Central Railroad of New Jersey are shut down.

(January 15) Fifteen men die in a methane explosion at the Glen Alden Coal Company's Nottingham colliery in Wilkes-Barre.

(April 10) Explosion of gas kills 10 men at the Schooley colliery (Exeter) of the Knox Coal Company.

1950 (June 12-October 15) Fifteen core holes are drilled along the path of the "Conewingo Tunnel," a proposed 102 mile-long drainage tunnel that would have extended from Glen Lyon in the Northern field, through Sheppton in the Eastern Middle field and Pottsville in the Southern field, to Chesapeake Bay. This is the last great scheme devised to revitalize the dying anthracite industry.

1954 (February 21 and 23) Mine collapses trigger the Wilkes-Barre pseudoearthquakes. Despite the fact that it was early on recognized that these tremors were non-tectonic in nature, the Wilkes-Barre "earthquake" is dutifully—and often—recorded in the earthquake history of the United States.

1955 (September) "Hurricane Diane" spawns disastrous floods in northeastern Pennsylvania. As a result the U.S. Army Corps of Engineers begins a major effort to improve flood control on the upper Susquehanna. At the request of the Corps, the U.S. Geological Survey--in cooperation with the U.S. Bureau of Mines--conducts a program of bedrock and surficial mapping in the Wyoming Valley from 1961 to 1963, aimed particularly at providing information on geologic factors affecting flood control, mine subsidence, and engineering in the area.

1959 (January 22) Knox Mine Disaster. Twelve men drown as the Susquehanna River breaks into the Ewen mine of the Knox Coal Company at Port Griffith. To stop the deluge of water--which threatens to flood many of the mines in the valley, 30 gondola cars, 12,000 $yd^3$ of dirt, and 900 balls of excelsior are pushed into the opening. On May 27, 1230 $yd^3$ of concrete are added to the plug, slowing down the flow of water into the mines to 400 gal/min. But the damage is done, and the decline of the anthracite industry in the Northern field sharply accelerates toward extinction.

1959-66 Moffat Coal Company operates the "190 slope" on the Clark coalbed in what is now McDade Park in Scranton--one of the last active deep mines in the Lackawanna basin. This mine is refurbished between 1977 and 1985 to create the "Lackawanna Mine Tour," run by the Lackawanna County Department of Parks and Recreation.

1960 (October) The DL&W and the Erie Railroads merge to form the Erie-Lackawanna.

1972 (June) The "Hurricane Agnes" flood--greatest flood in the recorded history of the North Branch Susquehanna River--devastates the Wyoming Valley from West Pittston to Shickshinny. This is the "knock-out punch" that effectively ends deep mining in the Northern field.

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