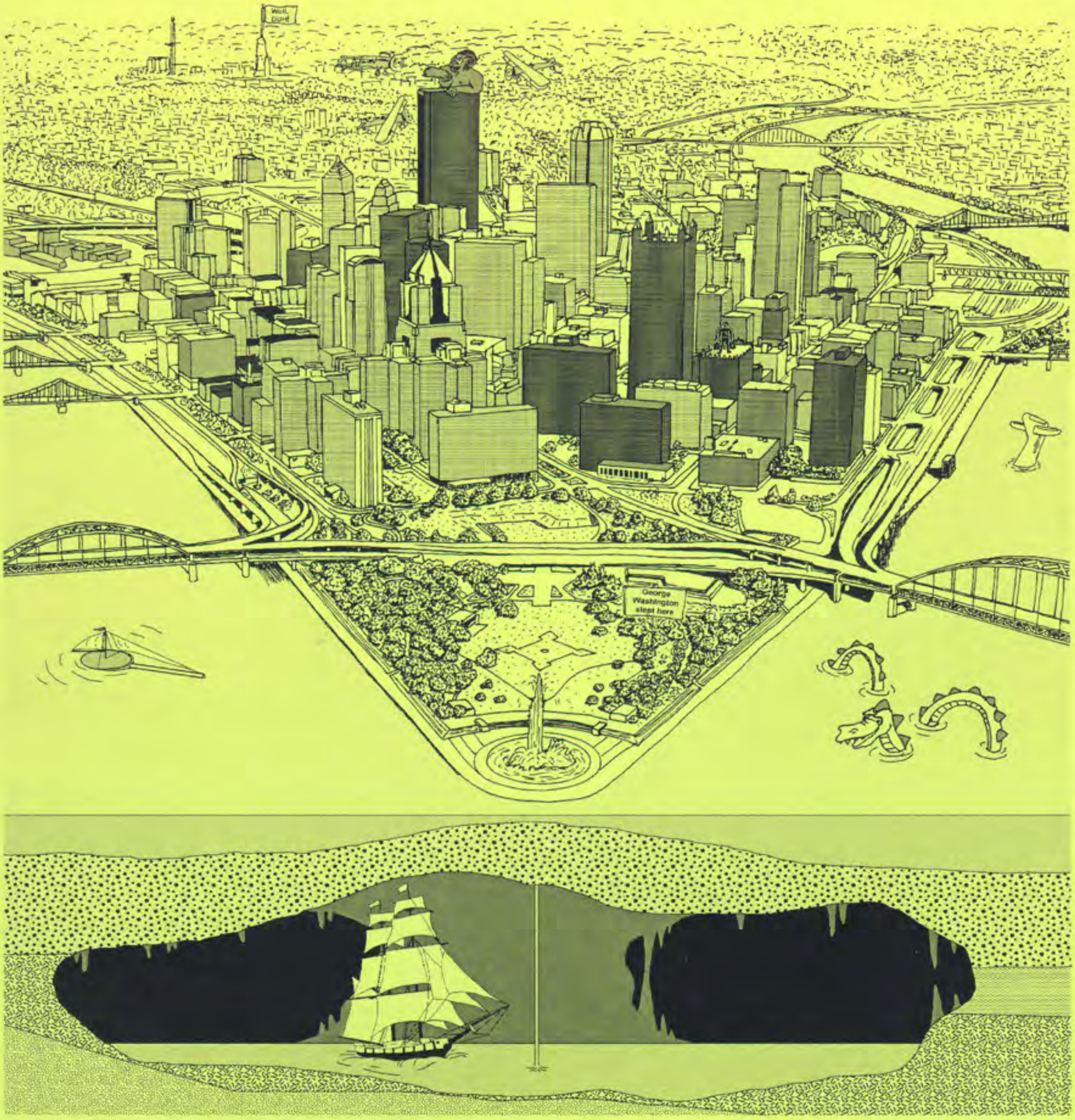
65th Annual Field Conference of Pennsylvania Geologists

PITTSBURGH AT THE MILLENNIUM: THE IMPACT OF GEOSCIENCE ON A CHANGING METROPOLITAN AREA



Hosts: Pittsburgh Geological Society
Slippery Rock University
Pennsylvania Geological Survey

October 5-7, 2000
Pittsburgh, PA

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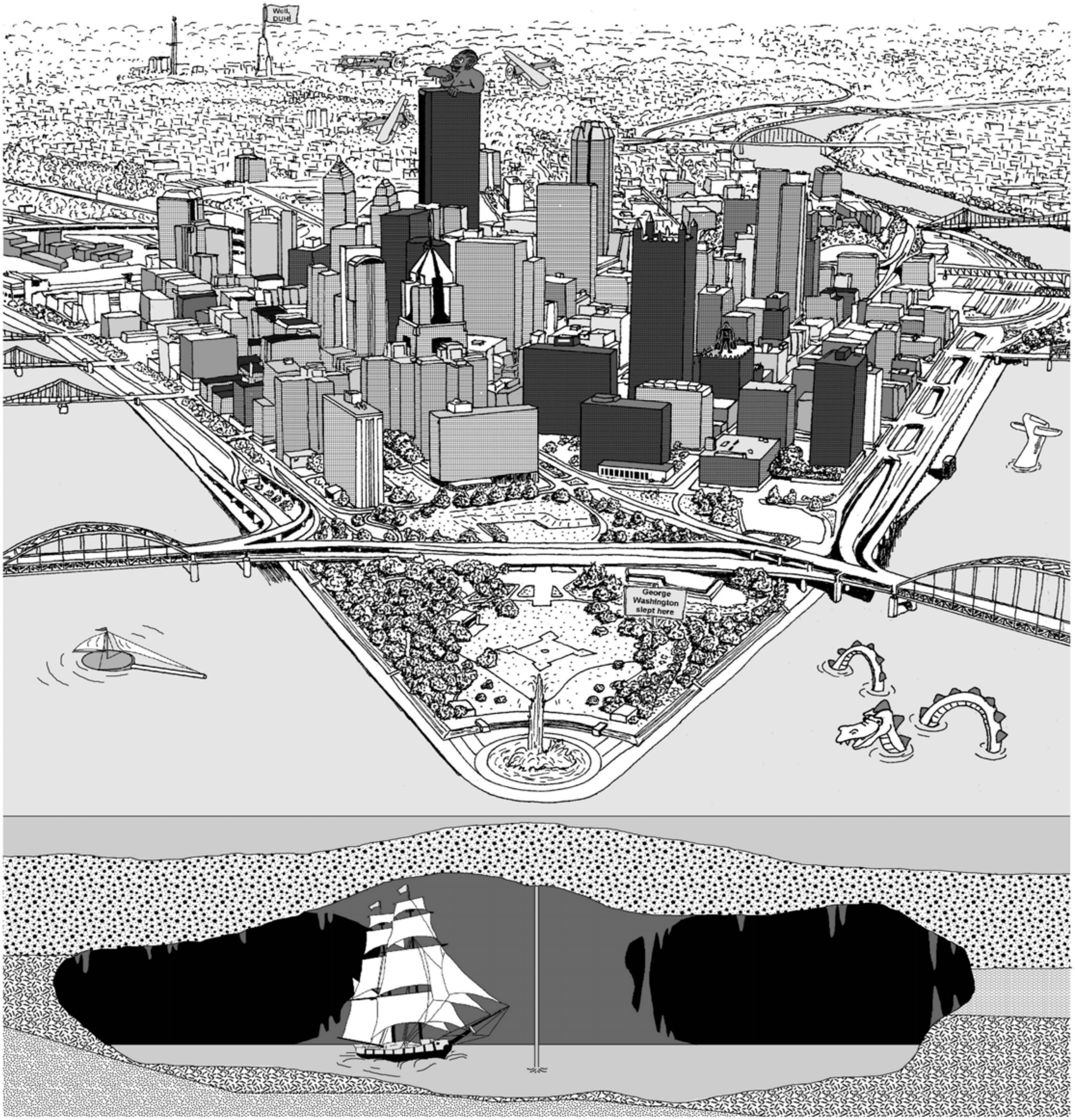

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Guidebook for the
65TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

PITTSBURGH AT THE MILLENNIUM: THE IMPACT OF GEOSCIENCE ON A CHANGING METROPOLITAN AREA

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Pennsylvania Geological Survey

Headquarters: Best Western Parkway Center Inn, Pittsburgh, PA

Cover: Strange happenings in the big city. Can you find: Pittsburgh's version of the Empire State Building (where's Faye Wray when you need her?); the University of Pittsburgh's Height of Ignorance; Pittsburgh's "Fourth River;" an early colonial bedroom; Darth Vader's Castle; the US Brig Niagara (following a wrong turn on Lake Erie!); a Monongahela monster; a very large Phillips screwdriver; the Good Ship Lollipop; and the super-secret A-bomb carrying plane that crashed in the Monongahela one night and was supposedly spirited away by the CIA while everyone was sleeping.

Cover and cartoons by: John A. Harper

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Group photograph of the 1999 Field Conference of Pennsylvania Geologists.

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WELCOME TO PITTSBURGH . . .

. . . gateway to the west; center of the French and Indian War; city of rivers and hills, museums and churches, medical centers and universities; home to the Steelers, Pirates, Penguins and about 2.4 million residents; and the location of a *mysterious plane-swallowing Fourth River*.

Welcome to Pittsburgh . . . home of salt and oil and gas and glass and coal and coke and steel and industrial-strength banking. These industries, spawned by minds named Carnegie, Frick, Mellon, and Westinghouse, relied on the talents and endless labor of immigrants who settled here. The legacies of their era remain in the form of endowments, theatres, parks, and very fine buildings.

Look at the city. Gone are the days when day was like night, and the city puffed and screeched and belched relentless plumes of grimy smoke, and Darwin's *natural selection* was playing out in our not-so-natural rivers. At the turn of the millennium, Pittsburgh is a land of robotics, lasers, transplants, maglev, and movies, and of course, home to *The Thunderbolt*, the number one-rated roller-coaster in the world.

If you were here for the last Field Conference in 1980, you may have seen Three Rivers Stadium, the first major renovation on the North Shore. Since then, Old Allegheny has exploded with growth to include the Carnegie Science Center, the Andy Warhol Museum, the new Alcoa building, and two "not-quite-yet" stadiums. The North Shore is also home to Voyager and Discovery, floating classrooms that use the rivers to give students hands-on learning, and . . . a submarine. If you arrived by air, you touched down at a new Pittsburgh International Airport, rated third best in the world; best in the US.

Since 1980, the Golden Triangle of Pittsburgh has experienced a continuous eruption of new buildings, including PPG Place, David L. Lawrence Convention Center, One Mellon Bank Center, Doubletree Hotel, CNG Tower, One Oxford Center, and Fifth Avenue Place. You can either walk to see these or take the T, a subway that can transport you, *almost at light-speed*, around the Triangle or even "overseas" to the restored Station Square, a former railroad station and freight yard. Come back a year from now and you will see a whole new Convention Center and two new, recently completed ballparks.

So here we are, at the "forks of the Ohio", cruising into the next century. One hundred years ago, air-conditioning did not exist, elevators were rare, building stone was still dragged into the city by mule-drawn carts, the city flooded regularly, and you could walk across the Ohio River during the summer.

One hundred years; not much time to change the geology, but more than enough to change a city.

Judy Neelan
Pennsylvania Deparment of Environmental Protection

GEOLOGY OF THE PITTSBURGH AREA

by
John A. Harper
Pennsylvania Geological Survey
Pittsburgh, PA

INTRODUCTION

The first references to geologic topics in the Pittsburgh area date from the early 1800s (Aigster, 1813; Meade, 1828; Daubeny, 1839). However, much of what we now considered to be the basic geologic knowledge of western Pennsylvania languished until Henry Darwin Rogers' First Geological Survey of Pennsylvania examined the entire state in the late 1830s and finally reached publication in the late 1850s (Rogers, 1858). The Second Geological Survey of Pennsylvania under J. P. Lesley provided even more information. Field investigations by Stevenson (1876, 1877 and 1878) and White (1878) produced seminal volumes of geological work during this period, including descriptions of coals, limestones, and other mineral commodities, and geologic maps of the areas studied. Both of these geologists later published syntheses of their work and the works of others (White, 1891; Stevenson, 1906) that helped establish much of the stratigraphic and structural nomenclature of western Pennsylvania. Follow-up studies during the third and fourth surveys provided a wealth of data and interpretations in geologic atlases and folios by Hughes (1933), Johnson (1925, 1929), Munn (1910, 1911a, 1911b), Shaw and Munn (1911), and Woolsey (1905, 1906) that stand, for the most part, as (if you'll pardon the pun) a rock solid foundation for later economic, geologic, geotechnical, and environmental investigations. It was these reports that provided the basis for the six-county Pittsburgh Regional Environmental Geologic Study (PREGS) during the 1970s (see the synopsis by Briggs, 1977) and many other more recent works.

PHYSIOGRAPHY

Most of southwestern Pennsylvania lies within the Appalachian Plateaus physiographic province, an area having a generally level surface at an altitude great enough to permit erosion of deep valleys by streams. This level surface results from the essentially flat-lying nature of the bedrock near the earth's surface. The area around Pittsburgh, including Allegheny, Beaver, and Washington counties where all of the Field Conference stops are located, is further subdivided into the Pittsburgh Low Plateau Section. The topography in this section is characterized by a relatively small amount of relief (Sevon, 1996). The hilltops in this area stand at about equal elevations, approximately 1,100-1,300 ft (335-400 m) above sea level, or about 350-550 ft (105-165 m) above the level of the rivers. By comparison, relief in the neighboring Allegheny Mountain Section to the east (from Chestnut Ridge to the Allegheny Front) commonly exceeds 1,500 ft (460 m) in the vicinity of the prominent high ridges that characterize hat section. Most of the hilltops of western Pennsylvania are the remnant of an ancient, relatively broad, relatively flat surface formed during the Cenozoic. This surface has been highly dissected by numerous antecedent streams, at least some of which probably became established during the Mesozoic (Sevon, 1993). This surface sloped very gently toward the northwest, toward the area of the present-day Great Lakes. At least the larger streams probably meandered in broad, shallow valleys cut only a little deeper than the surrounding landscape. Once this drainage pattern was set, the topographic relief gradually increased as the streams cut down into the rocks of the plateau, until the present-day relief we see in western Pennsylvania became established.

STREAMS AND TERRACES

Southwestern Pennsylvania is drained by the Ohio River drainage system, which includes the Monongahela and Allegheny drainage systems and their tributaries. The pool elevations of the various rivers and streams is regulated by a set of US Army Corps of Engineers dams set at intervals along the three rivers. The pool elevation at Pittsburgh is 710 ft (216 m) above sea level.

The Ohio River drains into the Mississippi River, which eventually drains into the Gulf of Mexico. This was not always so, however. It has been explained many times (Leverette, 1902, 1934; Wagner and others, 1970; Harper, 1997, 2000; Kaktins and Delano, 1999, and the story is even partially told in this volume (see Marine and Donahue, p. 28 of this guidebook). Suffice it to say that, prior to the first glacial advance into North America during the Pleistocene, all of the major rivers in western Pennsylvania drained northward into what is now Canada. The change to the current drainage probably occurred early during the Ice Age, perhaps during the first glacial advance (>770 ka BP).

The process of downcutting and lateral erosion by Pittsburgh's rivers during the Pleistocene excavated the bedrock bottoms and sides of their valleys to about 30 or 40 ft (9 to 12 m) below their present elevation. The river valleys became broad, flat-bottomed, and U-shaped valleys with steep walls (Figure 1). Glacial meltwaters filled the bottoms of the Allegheny and Ohio River valleys with silt, sand, and gravel outwash. In the Pittsburgh area, this sediment reaches thicknesses of up to 80 ft (24 m). The Monongahela and its tributaries, deprived of the outwash that flooded the Allegheny and Ohio valleys, built up their channels with sediments dderived from their watersheds to the south.

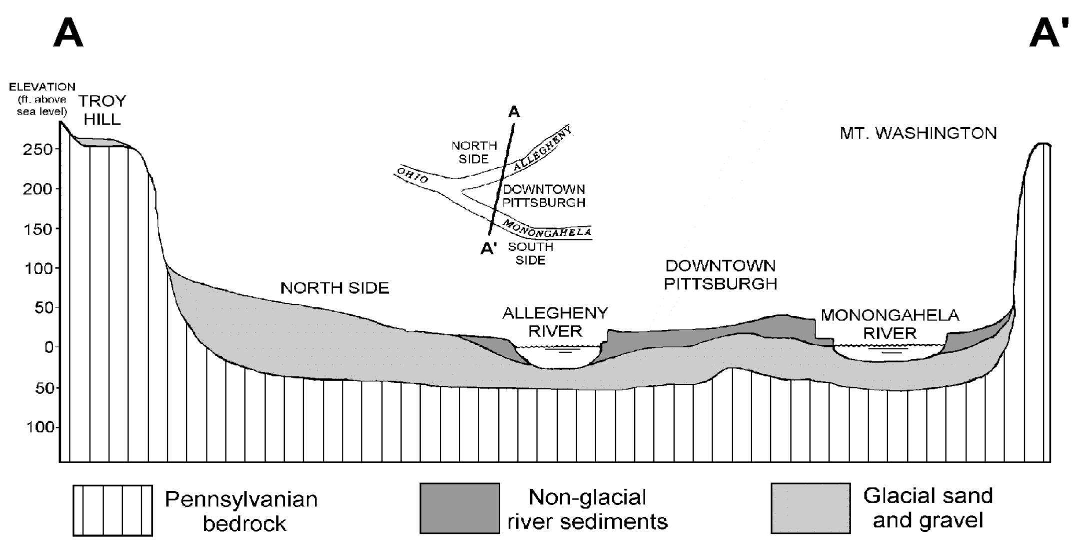


Figure 1. Cross section of the Allegheny and Monongahela river valley across downtown Pittsburgh (modified from Wagner and others, 1970).

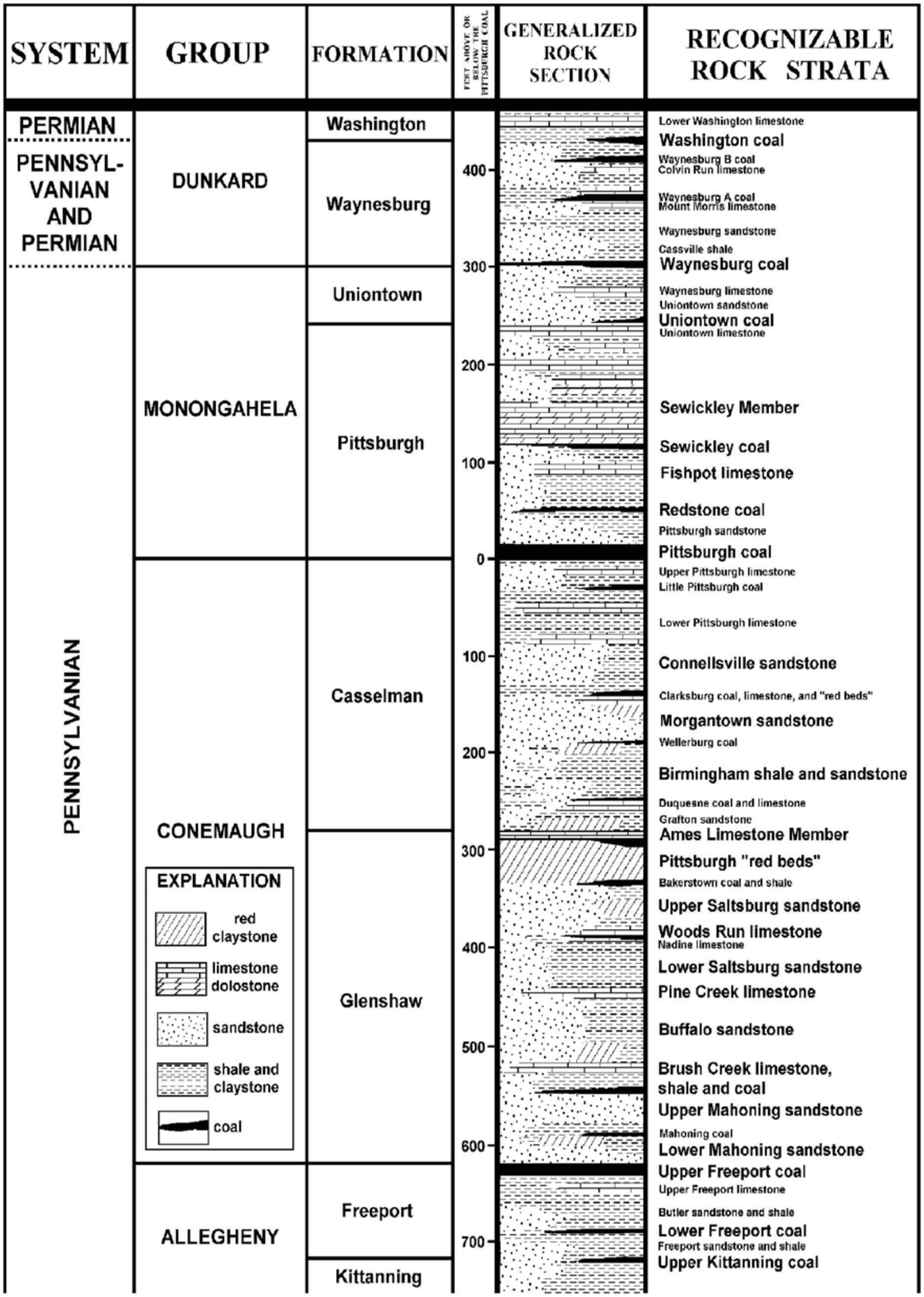


Figure 2. Generalized geologic column of the exposed rocks of Allegheny County.

After the retreat of the last glacier about 10 ka BP, the volume of water and sediment coming down the rivers decreased. The rivers cut new channels into the glacial valley-fill sediments, reworking the sediments in several areas. The results are low terraces, including the modern floodplain, about 10 to 30 ft (3 to 9 m) above present river level (Figure 1).

The porous gravelly valley-fill alluvium underlying the Allegheny and Ohio River is the primary source of ground water in Allegheny County. This aquifer recharges the rivers, and precipitation adds water to both. Unfortunately, the local population erroneously refers to the aquifer as "The Fourth River," and the local press does nothing to discourage it. This “Fourth River” does not really exist, obviously, because it is simply a part of the existing rivers, but popular mythology is difficult to dispel.

STRATIGRAPHY

Figure 2 represents a very generalized columnar section of the rocks exposed in Allegheny County – changes in thickness and interval are too variable to be shown in a more specific illustration. Figure 3 illustrates the distribution of the main units in Allegheny County.

The Allegheny Group crops out at only three places in Allegheny County, in stream valleys in the northern part of the county. Only the upper 100 ft (30 m) or so of the Allegheny crops out in the Pittsburgh area; the rest of the group lies in the subsurface. The largest area of exposure is along the Allegheny River from Tarentum to Freeport. Exposures also occur along PA Route 8 where it crosses the Kellersburg anticline near Fall Run Park (Stop 6). The Allegheny Group forms most of the bedrock north of the Ohio River in Beaver County.

The Conemaugh Group is the thickest sequence in western Pennsylvania, commonly comprising between 600-700 ft (180-210 m) of sandstone, mudrocks, marine and freshwater limestones, and coal. The coals consist of a few thin seams that are mined only in limited areas. The top of the Upper Freeport coal and the base of the Pittsburgh coal form the boundaries of this group. The top of the Ames Limestone divides the Conemaugh Group into two formations, the older Glenshaw Formation and younger Casselman Formation (Flint, 1965). Each of these formations is about 300 ft (90 m) thick, dividing the group into two roughly equal subdivisions.

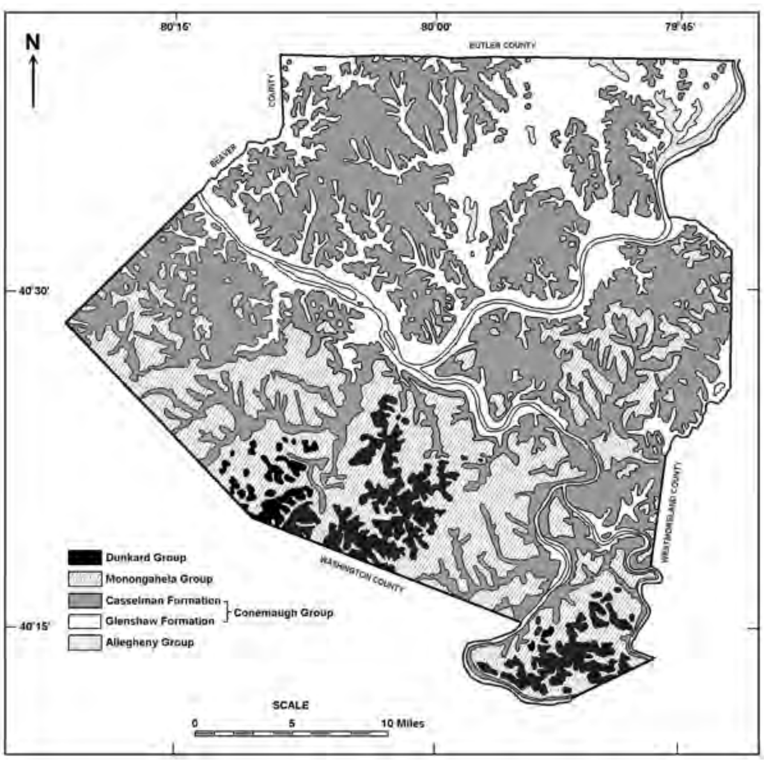


Figure 3. Geologic map of Allegheny County.

The Glenshaw Formation is characterized by up to six marine units in the Pittsburgh area. These range from thin argillaceous limestones sandwiched between organic-rich shale layers to even thinner calcareous siltstones and shales. The Casselman Formation typically contains no marine units, consisting instead of thick sandstones, red beds, shales, and thin coals.

The Conemaugh Group underlies almost all of the Pittsburgh area, but because of regional dip to the southwest, it crops out mostly in stream valleys in the southern half of Allegheny County (Figure 3). The Glenshaw Formation is best seen north of the two rivers and will be seen in detail on the second day of this field conference. The Casselman Formation is well exposed south and east of the Allegheny and Ohio Rivers. We will see a good chunk of it during the first day of the field conference. Although there are no complete, uninterrupted sections of the Conemaugh exposed in western Pennsylvania, there are places in Allegheny County where large portions of it can be seen in a single outcrop or roadcut.

The Monongahela Group lies almost entirely south of the Allegheny and Ohio Rivers. Its irregular outcrop pattern in Figure 3 is the result of stream erosion cutting deep valleys completely through the group and into the underlying Conemaugh. A few erosional remnants of the Monongahela Group remain on the tops of some high hills north of the rivers. The group is characterized by about 300 ft (90 m) of nonmarine carbonates, several highly productive coal seams, few red beds, a relative lack of sandstone, and prominent shales and siltstones.

The Dunkard Group contains the youngest sedimentary rocks in southwestern Pennsylvania. It is divided into three formations in southwestern Pennsylvania, the Waynesburg, Washington and Greene formations. However, only the Waynesburg and part of the Washington are present in the area of the Field Conference. The Waynesburg Formation, with the Waynesburg coal at its base, consists of about 180 feet of mixed claystones, shales, siltstone, and sandstones with minor amounts of coal and carbonates. The Washington Formation, with the Washington coal at its base, contains about 200 feet of mostly claystones and shales with minor amounts of other rock types.

STRUCTURE

The regional structure of southwestern Pennsylvania is shown in Figure 4. This area lies within the Pittsburgh-Huntingdon Synclinorium (also referred to as the Dunkard Basin), with the Dunkard Group occupying the center of the basin, and progressively older rocks cropping out towards the basin margins.

The strata of southwestern Pennsylvania are very gently folded, with axes trending approximately N35°E (Figure 5). The anticlines typically have flanks dipping less than 20 ft/mi (3.75 m/km), although some of the "more pronounced" folds in the Pittsburgh area have dips in the neighborhood of 200 ft/mi (38 m/km) – an amazing 2° slope! The typical fold tends to curve horizontally as well as vertically, resulting in serpentine structures marked by very gentle domes and saddles. Westward from the center of the Dunkard basin the folds become open and discontinuous. Eastward from the basin center the rocks become increasingly distorted by both folding and faulting, and the folds have more steeply dipping flanks and higher structural relief – for example, the Chestnut Ridge, Laurel Hill, and Negro Mountain anticlines. The principal surface fold axes in Allegheny County are shown in Figure 5, and a cross section illustrating the relation of structure to topography (at a GREATLY exaggerated scale) has been included as Figure 6.

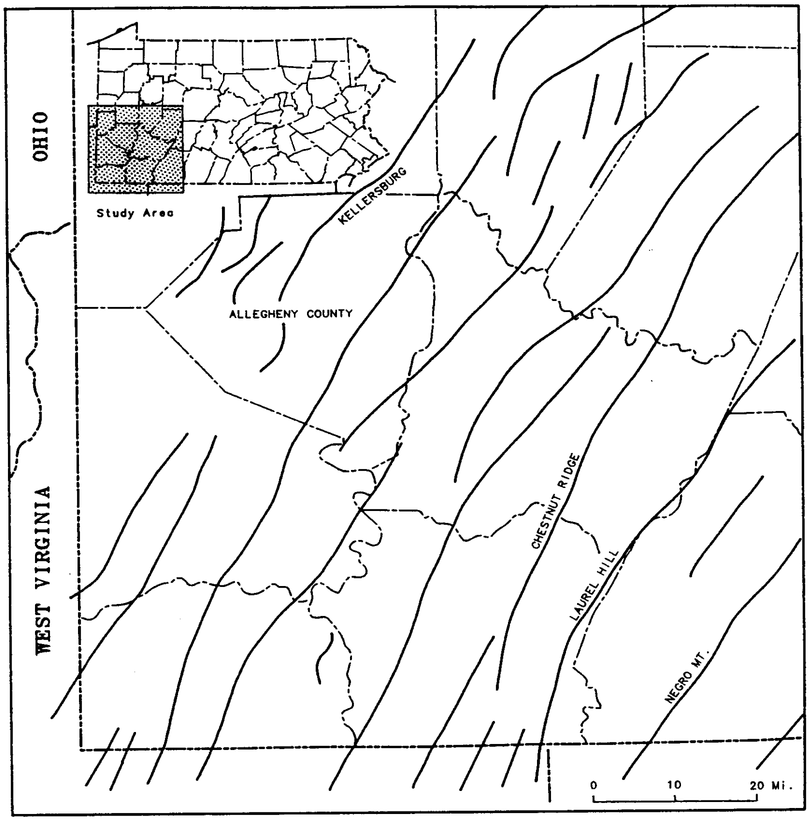


Figure 4. Map of southwestern Pennsylvania showing the trends of the major anticlinal axes. The three most prominent, Chestnut Ridge, Laurel Hill, and Negro Mountain anticlines, form high, deeply dissected ridges. From Harper (1995a).

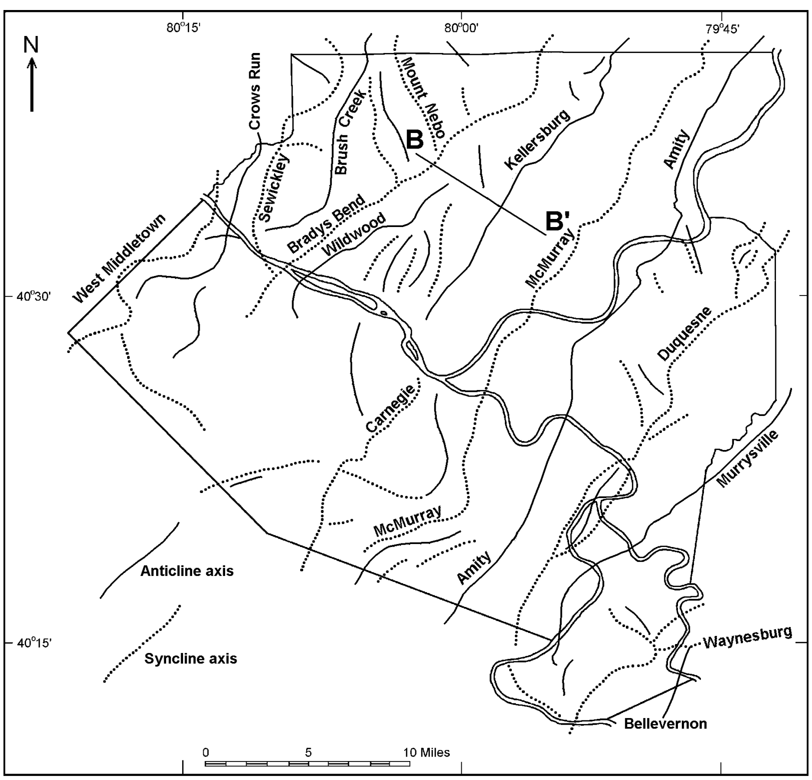


Figure 5. Structure map of Allegheny County (from Harper, 1995a). Cross section B-B' is shown in Figure 6.

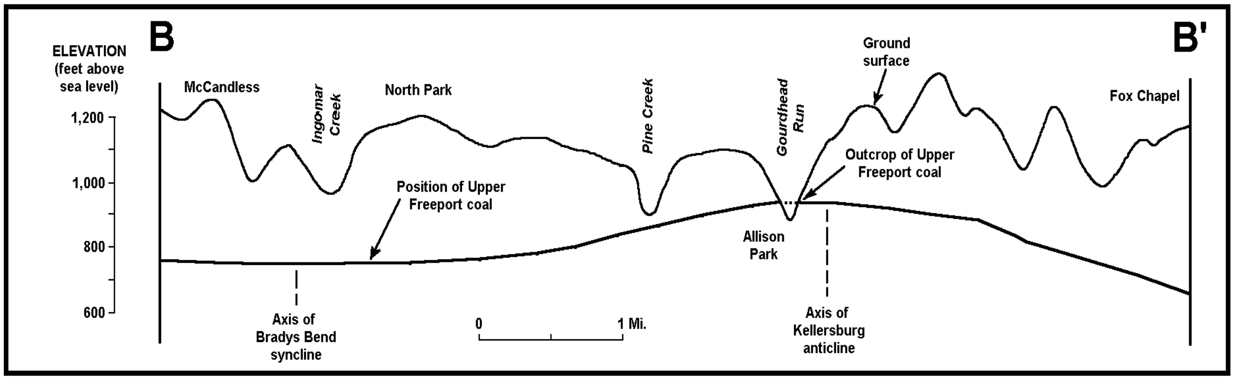


Figure 6. Cross section B-B' across the Bradys Bend syncline and Kellersburg anticline in northern Allegheny County (from Harper, 1995a). See Figure 5 for location.

Jointing is very common in southwestern Pennsylvania outcrops. The preferred orientations of the two principal joint sets, as measured in shales and sandstones, range from N10^{o}E to N40^{o}E and N50^{o}W to N80^{o}W (Nickelsen and Hough, 1967). In addition, two well-developed vertical and intersecting cleat sets have develop in the local coals. Western Pennsylvania joints play important roles in many aspects of regional geology. For example, they have affected surface drainage patterns by altering the predominantly dendritic pattern characteristic of essentially flat-lying strata to a trellis-modified dendritic pattern. Many of the streams in the region have long, straight segments that are oriented NW-SE or NE-SW as a result of the major joint sets (e.g. the Ohio River which flows in an almost straight channel from downtown Pittsburgh to Beaver). Joints create relatively easily eroded pathways that the antecedent streams followed as they cut down into the low folds of the Pittsburgh area. In addition to joints resulting from tectonic stresses, many joints also form approximately parallel to valleys, regardless of valley orientation, as a result of the release of stress (Ferguson, 1967). Many of these contributeto the plethora of landslide problems encountered in western Pennsylvania (see Hamel and Adams, this volume).

Faulting is not a common feature of the surface rocks of southwestern Pennsylvania, but faults do occur (Figure 7). Normal faults are the most common type present in the Pittsburgh area. Most, if not all, occurred penecontemporaneously with deposition as glide planes of slump blocks associated with stream-bank landslides. Reverse faults (Figure 7C) are far less common than normal faults in this area, but a good example can be seen in a roadcut along PA Route 28 at the Tarentum exit about 20 mi (32 km) north of Pittsburgh.

MINERAL RESOURCES

Geologic resources in the Pittsburgh area have included, at one time or another: coal; crude oil and natural gas; low-grade iron ores (primarily siderite); sand and gravel for glass and construction; sandstone used for construction (aggregate, foundations, flagging, and even dimension stone); limestone suitable for construction, agriculture, flux, and other products; clay and shale suitable for bricks, pottery, and refractories; brine for salt; and water. Even slag, the waste product of the steel making process, has become a major mineral resource within the last 20 years.

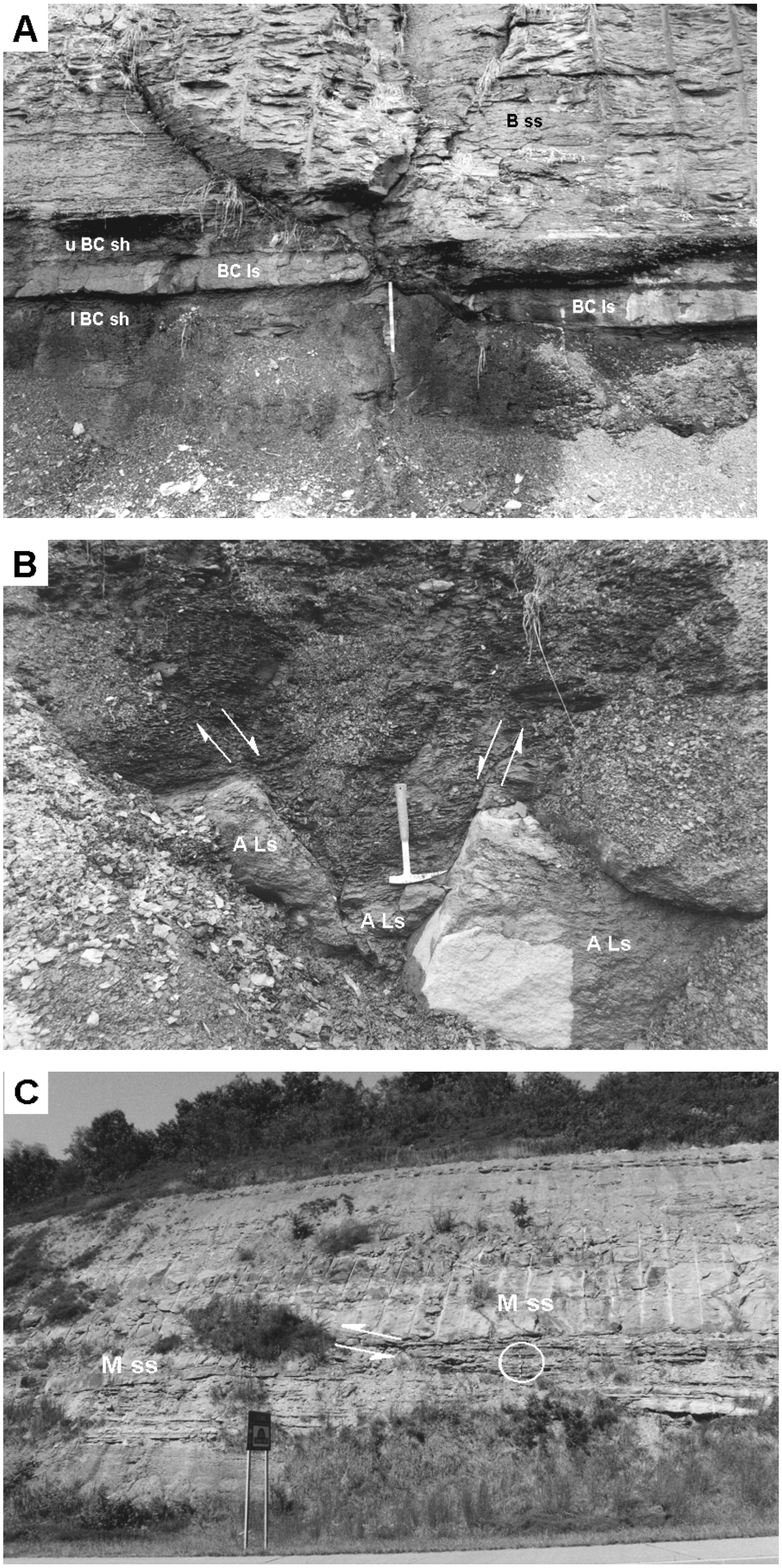


Figure 7. Photo of some faults found in Allegheny County. All examples are from the Conemaugh Group, Glenshaw Formation. A – Listric normal fault in the Brush Creek limestone (BC ls) and upper and lower Brush Creek shales (u BC sh and l BC sh) below the Buffalo sandstone (B ss) along PA Route 51 near the Sewickley Bridge. Scale is one meter. B – Graben formed in the Ames Limestone (A Ls) and adjacent shales along PA Route 28 near Creighton. Rock hammer for scale. C – Thrust fault in the Mahoning sandstone (M ss) at the Tarentum exit of PA Route 28. Scale (in circle) is one meter.

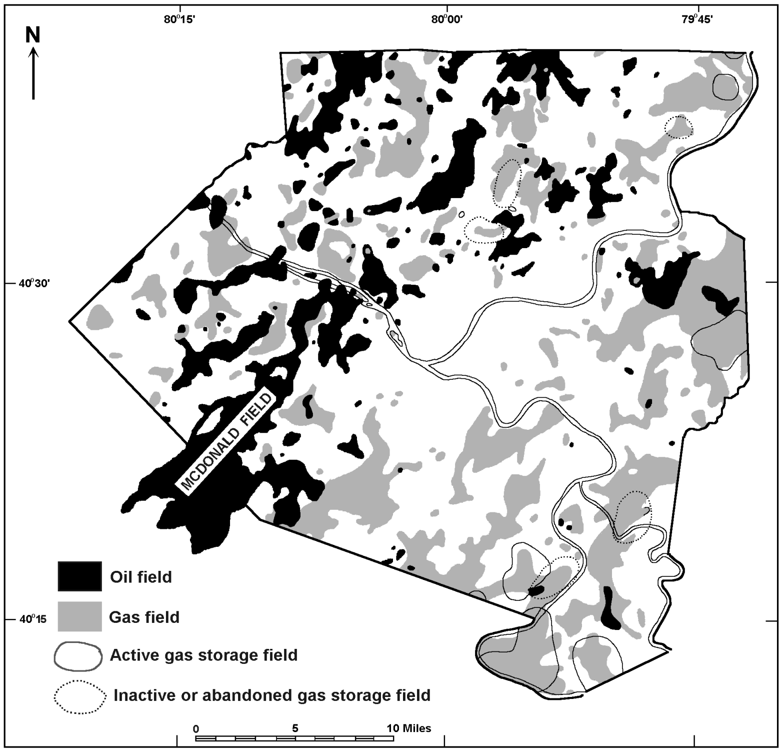


Figure 8. Oil and gas fields of Allegheny County. McDonald field is the second largest oil field in Pennsylvania. Adapted from Harper and others, 1982.

Fossil Fuels

Coal, historically the most important mineral resource to the Pittsburgh area's economy, has been mined in Allegheny County since the 1700s (see Stop 1). It became most important in the 1800s and throughout the 1900s as a source of coke in the manufacture of steel. Particularly significant are the Pittsburgh and Redstone coals of the Monongahela Group and the Upper Freeport coal of the Allegheny Group (Figure 3). The Pittsburgh coal, arguably, is the best known and most valuable of all the bituminous coal beds of the Appalachian basin

Crude oil was far more important to the Pittsburgh area in the 1800s than it is today. Thousands of oil wells were drilled throughout the area in the latter half of the nineteenth century, for example the McDonald oil field in Figure 8, was discovered in 1890 and was second in volume of production only to the famous "giant" Bradford oil field in McKean County. Today few companies operate the old wells and no one is drilling new ones. In contrast, natural gas has increased in value through the 1900s. There has been a concerted effort to find economical quantities of gas in the last 20 years. The value of natural gas as a clean, environmentally "friendly" fuel will continue to make it a viable geologic resource in the near future, as well. Figure 10 shows the locations of the oil and gas fields of the county. Many of these fields are now long abandoned.

Iron Ore

The earliest iron furnaces in the Pittsburgh area, as elsewhere in western Pennsylvania, produced pig iron from local low-grade iron ores, primarily siderite nodules and bog iron. Siderite is a common, if not abundant, source of iron typically associated with marine limestones and shales in western Pennsylvania, including those of the Glenshaw Formation (Figure 3). The Buhrstone ore, a layer of bedded and/or nodular siderite typically capping the Vanport Limestone of the lower Allegheny Group, provided the primary source of ore throughout the area for many years. By the 1850s, however, western Pennsylvania saw a major change as the supply of wood for charcoal and the best siderite deposits both became exhausted. Cheap, plentiful, high-quality iron ore from the Lake Superior region flowed into the Pittsburgh area, where coke from the Pittsburgh coal supplanted the exhausted forests and the rivers provided cheap and efficient transportation corridors. Pittsburgh remained the primary iron- and steel-making city in the US until the last quarter of the 20th century. Most of the mills are gone now, and only the legacy of iron remains.

Non-Metallic, Non-Fuel Resources

The quantity of resources such as sandstone (Figure 9A) and limestone remains high in and around the Greater Pittsburgh area. However, the production of those resources has fallen off dramatically since the end of World War II. It is highly ironic that the same population pressures creating increased demands for such mineral resources in the region have also helped reduce the amount of annual production over the years. Much of the loss of mineral industries in this area can be blamed on competing landuse pressures such as the need for additional space for construction, zoning laws, increased taxes, and other factors. Where there used to be numerous sandstone, limestone, and clay quarries around the county, now there are very few or none at all.

Sand and gravel are available in large supply in stream deposits of both Pleistocene and Holocene age (Figure 9B). Sand and gravel dredged from the beds of the Allegheny and Ohio rivers are, to a large degree, reworked glacial material containing durable rock; therefore, they are most suitable for construction aggregate. Some of the sand is suitable for glass manufacture as well and, in fact, Pittsburgh had a thriving glass manufacturing industry for many years. Sand and gravel also occur on the river terraces (such as in Figure 9B), but they contain a somewhat higher proportion of weathered pebbles than the deposits in the rivers and are, therefore, less useful and less valuable.

Local sandstones are abundant, but they typically exist as channel deposits that change thickness and lithology abruptly over short lateral distances. Internally, they often consist of thin beds and may contain enough iron minerals to limit their use as crushed rock and rough stonework. Where they are massively developed, even grained, and hard (as in Figure 9A), however, the sandstones have been quarried historically as dimension block for nearby use in bridge abutments, chimneys, and permanent building construction.

The majority of the carbonate rocks in the Pittsburgh area are impure, thin to nodular bedded, and irregularly distributed. The Sewickley Member of the Pittsburgh Formation (commonly called “Benwood Limestone”) is the thickest and, arguably, most useful of these today. An average analysis for the thicker usable Pennsylvanian limestones in this area shows calcium 80% to 85%, magnesium carbonate 2.3% to 5.6%, silica 5% to 8%, and combined alumina and iron oxide 2.4% to 10.8% percent (Johnson, 1929). When Allegheny County was mostly agricultural, farmers used most of the local limestones for agricultural lime, burning and mixing them in homemade kilns, until commercial mixes became available.

Deposits of clay and clay products, once of fairly high importance in Allegheny County, currently are considered of minor consequence. This is due more to the steadily shrinking area of the county available for clay pits than to a decrease in either raw materials or demand for clay products. Local clay resources include surficial clays in the Carmichaels Formation, residual clays, and claystones and shales mined at or near the surface. The Carmichaels clays are very plastic, but erratic in occurrence and locally mixed with varying quantities of sand or silt. They were especially valuable in the 1800s for making stoneware, roofing tile, and brick. The largest deposits of residual clay occur where the Sewickley Member of the Pittsburgh Formation crops out on top of broad, flat-topped hills, but these areas commonly are more valuable as farmland or

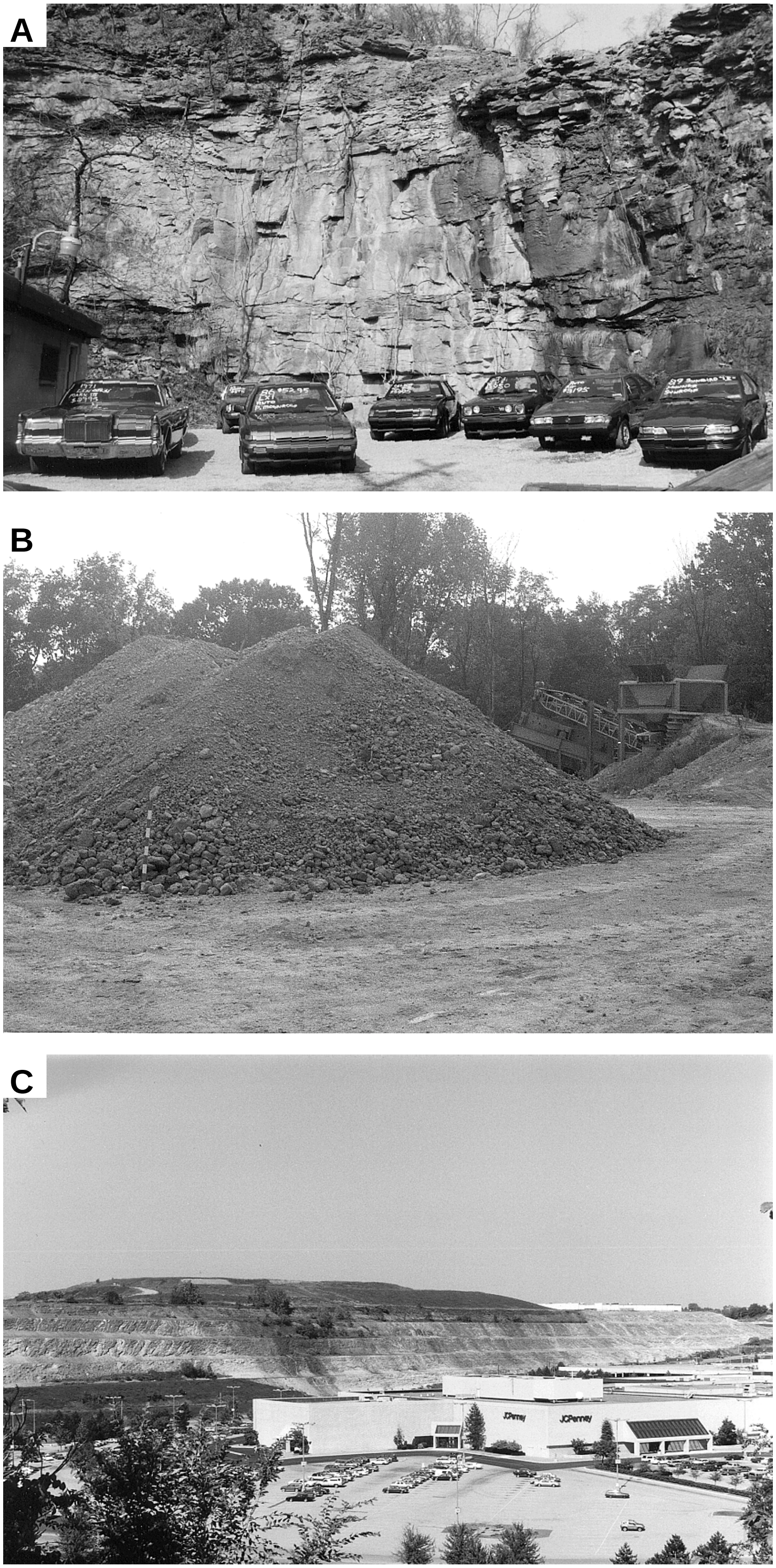


Figure 9. Photos of some of the non-fuel mineral resources found in Allegheny County. A. Sandstone – this particular quarry in Bauertown has been long abandoned, but others are still in operation. B. Sand and gravel – most resources are dredged from the rivers, but some terrace deposits still exist to be exploited. C. Slag – the latest “rock” type to gain acceptance as a commercially viable mineral resource.

housing developments (Johnson, 1929).

A more recent "mineral resource", slag has stopped being simply an eyesore in western Pennsylvania. Old slag dumps now command the attention of companies such as Lafarge and International Mill Service who are quarrying them for a number of purposes. The large slag dump in West Mifflin, Allegheny County (Figure 9C) now boasts a shopping mall and two shopping centers, as well as a "gravel" quarry. Quarrying operations in this dump, and others in Beaver and Westmoreland counties, provide fine aggregates, railroad ballast, PennDOT approved Type C coarse aggregates, PennDOT approved skid-resistant level H aggregates, and general fill (Barnes, 1997) (although, according to Hamel and Adams, p. 23 in this guidebook, the District 11-0 office of PennDOT currently prohibits the use of slag for use beneath roads and road shoulders). Another slag dump on Nine Mile Run in the Squirrel Hill section of Pittsburgh is currently being graded and covered with topsoil in an effort to develop it as an upscale townhouse community (see Stop 4).

From about 1815 to 1870, the salt industry played a major role in the economy of the Pittsburgh area. Producers drilled or dug holes into shallow brine aquifers, typically less than 500 ft (150 m) deep, extracted salt from the produced brine by evaporation, and sold it all over the eastern United States.. In the early 1800s Tarentum, the first place in western Pennsylvania where salt was produced from brine, became one of the more important salt producing areas of the country. Most of the brine came from sandstones of the Pottsville Group; oil and gas drillers still refer to these rocks as the Salt sands to this day. In fact, the technology of drilling wells began with the salt industry and soon spread to the oil and gas industry. "Uncle Billy" Smith, the man "Colonel" Edwin Drake hired to drill his famous well at Titusville, was working as a salt-well driller in Tarentum at that time.

WATER RESOURCES

The larger towns and cities of Allegheny County, which are located mainly along the three rivers, depend primarily on the rivers for their water supplies (Figure 10). Pittsburgh and much of the South Hills draw their drinking water directly from the Allegheny and Monongahela rivers. The rest pump water from the valley-fill deposits lining the river valleys to a depth of 60 or 70 ft (18 to 21 m). These deposits also constitute the chief source of water for air conditioning in the office buildings of downtown Pittsburgh, as well as the fountain at the Point.

The Allegheny and Ohio valley-fill deposits consist of clay, silt, sand, and gravel containing scattered cobbles and rare boulders. The Monongahela valley-fill is chiefly locally-derived fine sand, silt, and clay with scattered large clasts of bedrock. The permeability of all these deposits can vary within relatively short distances owing to changes in sorting of the sediments. Thus, yield will fluctuate between otherwise similar wells. The alluvium ranges in thickness from 30 to 85 ft (9 to 26 m), averaging about 60 ft (18 m), and typically is overlain by Holocene fine sand and silt up to 25 ft (8 m) thick.

Recharge from the rivers supplies most of the water resources in the valley-fill, and fluctuations in the water level in the alluvium occur as the result of changes in withdrawal rate.

Valley-fill groundwater is satisfactory for most ordinary uses – it contains less suspended matter, bacterial contaminants, and industrial wastes than the surface waters. Most contaminants are filtered out in whole or in part during movement of the water through the alluvium. However, chlorination and filtration are routinely used where the ground water is destined for human

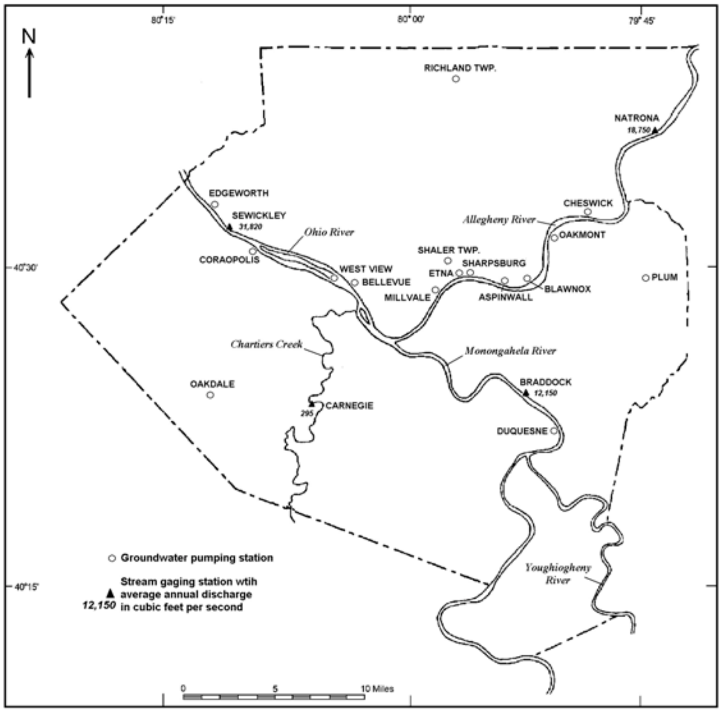
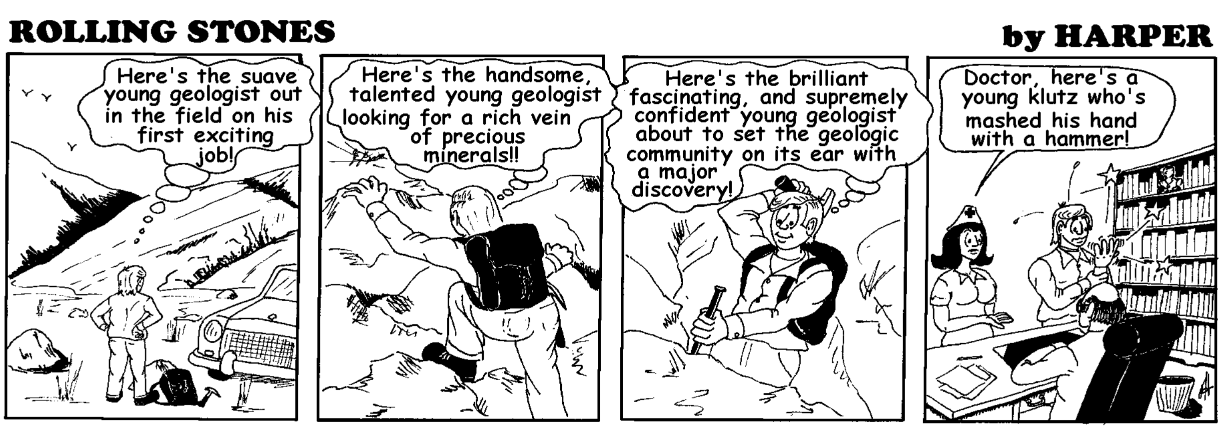


Figure 10. Map of Allegheny County showing locations of stream-gauging stations and of major areas of ground-water pumping by municipalities and townships (modified from Gallaher, 1973).

consumption. Unfortunately, this groundwater is harder and contains more iron and manganese than does the surface water.

The greatest proportion of groundwater used in Allegheny County, about 80% to 90%, comes from the alluvium. The remainder comes from bedrock aquifers, typically within the Conemaugh or Allegheny Groups. The better bedrock yields come from the sandstones, of which the Morgantown sandstone (Figure 2) is probably the best for consistent supply. The carbonate rocks of the Sewickley Member of the Pittsburgh Formation (Figure 2) is also a reliable source. In other units groundwater normally occurs at the top or base of an impermeable layer, or in communicating joint systems.

The Pittsburgh area was once blessed with an abundance of springs. The best tasting spring water came from the base of the Ames Limestone, the carbonate rocks of the Sewickley Member, and the Morgantown sandstone (Figure 2). The spread of residential areas following World War II, and mine subsidence problems, have led to local disruption and pollution of many springs. Only in the more rural areas of Allegheny and adjacent counties will one still find good quality springs.



UPDATE ON ENGINEERING GEOLOGY IN THE PITTSBURGH AREA

by
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INTRODUCTION

The last Field Conference of Pennsylvania Geologists in Pittsburgh twenty years ago placed heavy emphasis on Engineering Geology in its Guidebook entitled "Land Use and Abuse - The Allegheny County Problem" (Figure 11; Adams and others, 1980). Historically, Engineering Geology has been one of the main thrusts of applied geology in the Pittsburgh area (e.g., Philbrick and Nesbitt, 1941; Philbrick, 1953, 1959, 1960; Ackenheil, 1954; Ferguson, 1967). This results directly from our geology, topography, climate, and land use history (Gardner, 1980).

The technical problems and challenges of Engineering Geology in the Pittsburgh area have not changed over the past twenty years. The problem zones (e.g., undermined areas, weak rock units, unstable slopes) and bad sites of twenty years ago are still problem zones and bad sites today. Now, however, they are increasingly being modified, developed, and built upon because of changing economic conditions, decreased land availability, expanding infrastructure (e.g., transportation) requirements, and new geotechnical construction procedures. It is therefore appropriate to present an update on

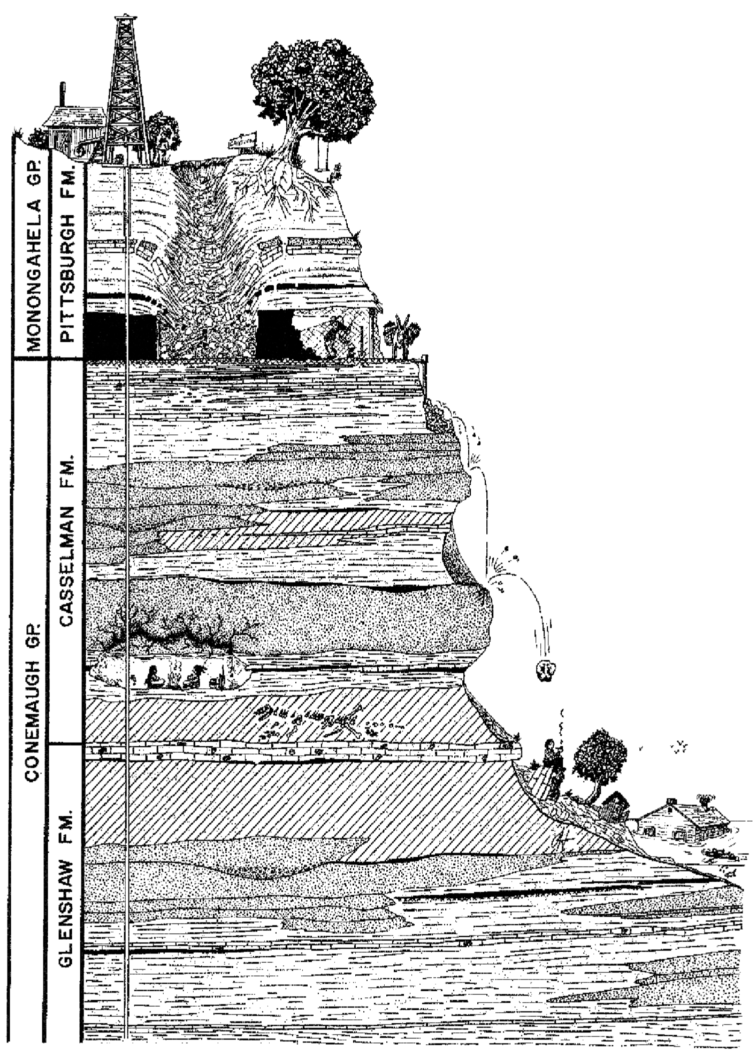

Figure 11. Geologic hazards of the Pittsburgh area (from Adams and others, 1980.)

Engineering Geology for the present Field Conference on "Pittsburgh at the Millennium: The Impact of Geoscience on a Changing Metropolitan Area."

Engineering Geology is broadly defined as "geologic work that is relevant to engineering, environmental concerns, and the public welfare" (Association of Engineering Geologists, 2000). As such, Engineering Geology is here considered to include Environmental Geology, Hydrogeology, and related portions of Geotechnical and Geoenviromnental Engineering. Emphasis in the following sections will be placed, however, on traditional aspects of Engineering Geology rather than on geotechnical and geoenvironmental construction and remediation.

After a brief review of Engineering Geology problems and challenges in the Pittsburgh area, we note some advances in local and regional Engineering Geology Practice that have occurred since 1980. Then we identify two major future challenges that we see for the region. Finally, we offer some suggestions for improvement of Engineering Geology Practice and repeat the oft-made pleas (e.g., Delano and Adams, 1999) for greater use of available information and existing knowledge in this regard.

ENGINEERING GEOLOGY PROBLEMS AND CHALLENGES

The most significant and widespread Engineering Geology problems and challenges in the Pittsburgh area are related to coal mining, slope instability, waste disposal, and flooding. Other, less significant and/or widespread problems and challenges involve clay and limestone mining, water supply, surface and subsurface drainage and erosion, and expansive materials.

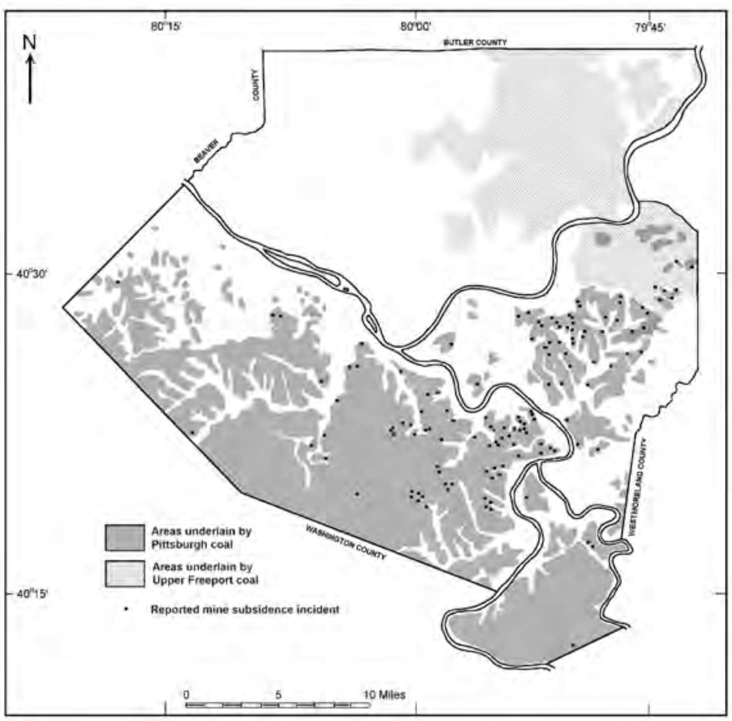

Figure 12. Areas of Allegheny County underlain by mineable coal. Each dot represents a reported incident of subsidence documented between 1960 and 1985 (modified from Bruhn, 1980).

Coal has been mined in the Pittsburgh area since about 1760 (Adams and others, 1980; Delano, 1985). The earliest mining was in the famous Pittsburgh coal (base of Pennsylvanian age Monongahela Group) which is exposed in many upland areas in and near Pittsburgh (Figure 12). Mining also has occurred in several other coal seams, especially the Upper Freeport (top of Pennsylvanian age Allegheny Group, typically about 650 ft [198 m] below Pittsburgh coal). Much of the near-surface, economically mineable coal has been removed over the past two hundred years. This has left a legacy of abandoned surface and underground mine workings and coal waste disposal areas.

Subsidence of the ground surface above abandoned underground workings (where some or all of the coal was removed, generally by

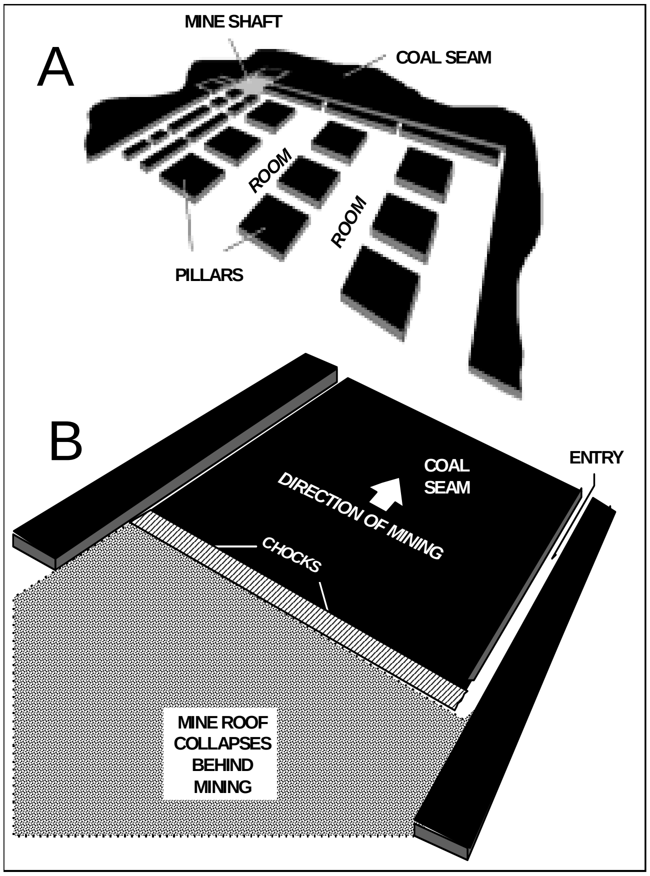

Figure 13. Diagrams of coal mining methods (from Pittsburgh Geological Society, 1999b). A. Room-and-pillar mining. Pillars of coal are left in place to prevent the mine roof from collapsing during mining. These are removed during retreat mining. B. Longwall mining, sowing collapse of the mine roof as mining advances and the chocks are moved forward.

room and pillar methods, Figure 13A) and acid drainage from abandoned surface and underground workings and coal waste areas have been long-term problems. Occasionally, underground mine fires and fires in surface mines and coal waste areas also occur. In addition, the extent of problems caused by disposal of sewage and residual and hazardous wastes in surface and underground coal mines is only now becoming known.

Most of the presently active coal mining in the region is south and southwest of Pittsburgh where the Pittsburgh coal is relatively deep underground and longwall mining methods are employed. These methods (Figure 13B) extract most of the coal in large panels with corresponding subsidence of the ground surface (Figure 14) over the panels and adjacent areas. This subsidence almost always has detrimental effects on watersheds, streams, and surface and subsurface water supplies as well as surface structures and facilities. For example, sections of Interstate Route 70 east of Washington, Pennsylvania (south of Pittsburgh) subsided as much as 5 ft (1.5 m) as a result of longwall mining earlier this year.

Act 54 of 1994 amended the Bituminous Mine Subsidence and Land Conservation Act of 1966 to facilitate longwall mining by allowing previously prohibited mining beneath certain structures (e.g., public buildings, dwellings) in place on April 27, 1966. Act 54 requires coal mine operators to repair structures damaged by subsidence and to replace water supplies affected by mining. Unfortunately, property owners are often forced to prove, at their own expense, that coal mining has caused their property damage and/or water loss. This has lead to increased concerns about irreversible environmental effects at and near the ground surface, e.g., surface water and groundwater gradients and flows, changes in stream habitats, damage to historic and other structures (Figure 15). Longwall mining of coal will provide significant future problems and challenges in Engineering Geology, both underground and at the ground surface.

Given the legacy of coal mining in the Pittsburgh area, reclamation of abandoned mine lands, i.e., surface and underground mines and coal waste disposal areas, will continue for the foreseeable future. Some of this reclamation is done for environmental enhancement, mainly with government funding. Other reclamation is done on a project-specific basis with government

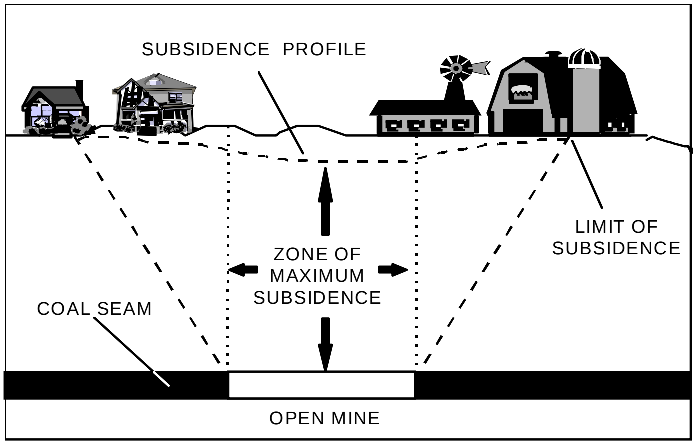

Figure 14. When a mine opening collapses, more surface area is affected than just the land directly above the collapsed void (modified from Pittsburgh Geological Society, 1999b). *Angle of Influence – under much discussion and dispute, particularly for longwall mining.

and/or private funding. Some of this latter reclamation involves surface mining of coal remnants, including pillars, and placement of engineered fill for various site improvements. More of these reclamation activities resulting in site improvements for subsequent development are anticipated as land shortages in the Pittsburgh area require future infrastructure improvements and other developments to be done on sites previously considered marginal or unbuildable.

Despite reclamation activities, surface subsidence above abandoned underground coal mines (generally where coal was partially extracted by room and pillar methods many years ago) is an on-going concern, both in older residential and commercial areas and in areas of expanding suburban developments. Absent surface stabilization, e.g., by mine grouting (Figure 16), insurance provides the best and most affordable protection against subsidence damage in most such cases. We generally recommend that home and business owners purchase Mine Subsidence Insurance (available since 1961 under the Pennsylvania Mine Subsidence Insurance Fund) where the cover is less than about 300 ft (91 m) above abandoned underground coal mine workings. Where there is potential for total extraction of coal in the future, e.g., by longwall mining or retreat mining with room and pillar methods, we recommend Mine Subsidence Insurance for all overburden thicknesses.

The Pittsburgh area has long been known for slope instability (Figure 17; Scharff, 1920; Ackenheil, 1954; Gray and others, 1979; Adams and others, 1980, Adams, 1986; Hamel, 1980; Hamel and Hamel, 1985; Pomeroy, 1982). Key aspects were summarized by Hamel and Ferguson (1999). Briefly, soil slope instability usually involves landslides that are common in collu-

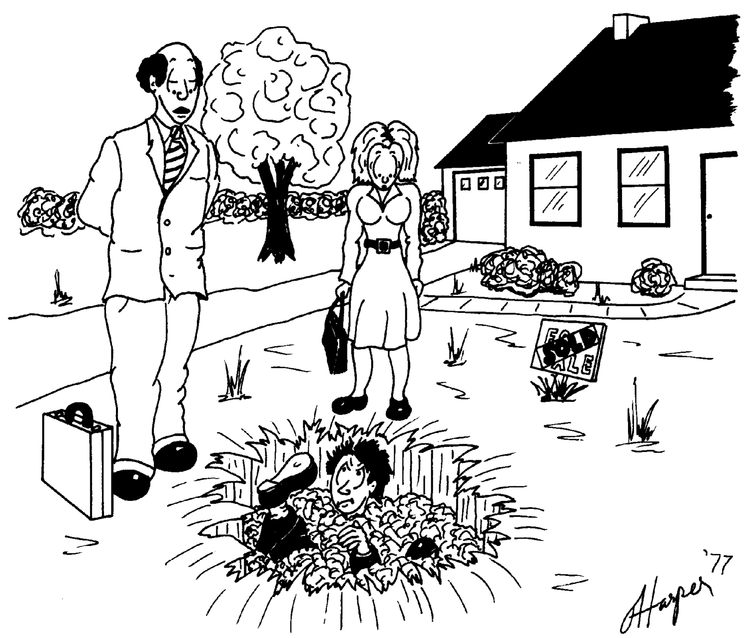

Figure 15. That reminds me, your deed includes the mineral rights – the Coal Company sold them back after they mined all the coal from under this area! (From Freedman , 1977).

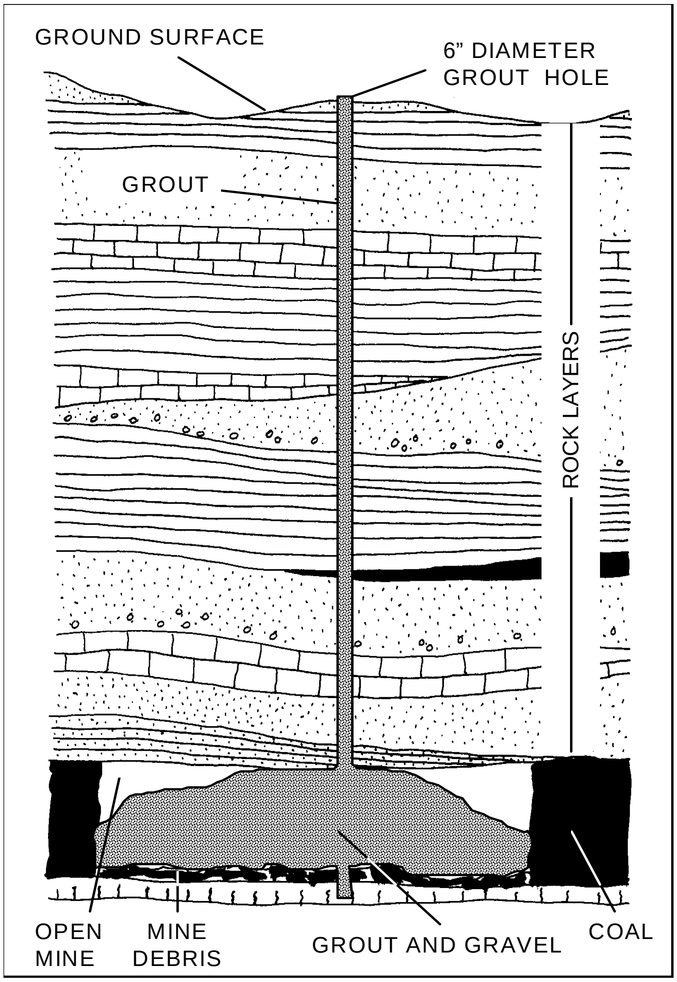

Figure 16. Using a grout column to fill a mine void (from Pittsburgh Geological Society 1999b).

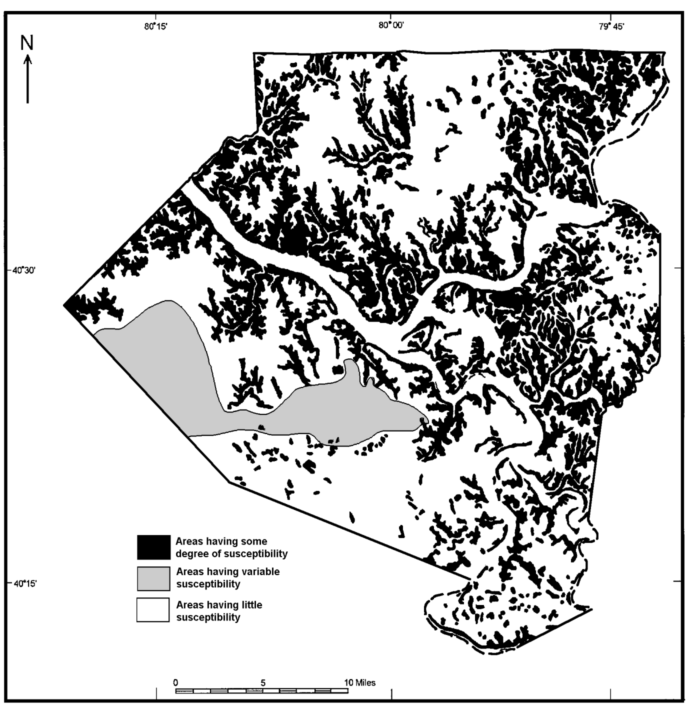

Figure 17. Generalized map of susceptibility to landsliding in Allegheny County. Modified from Briggs, 1977.

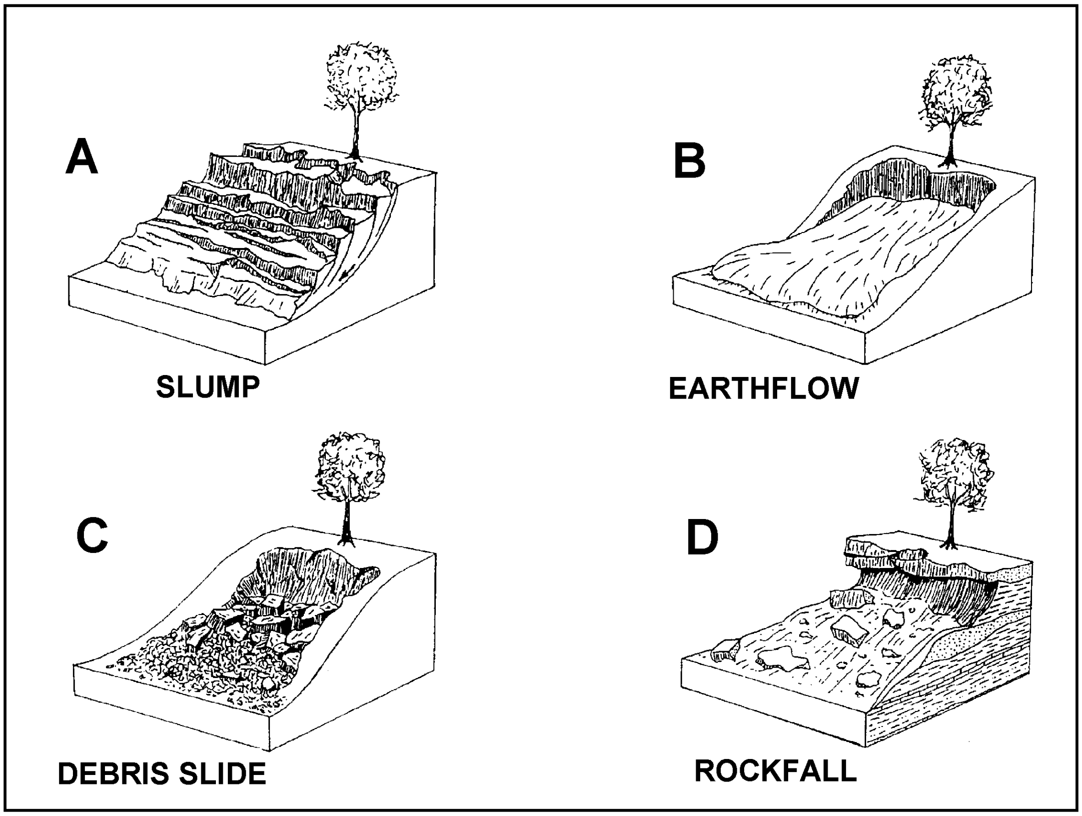

Figure 18. The most common kinds of landslides in the Pittsburgh area (from Pittsburgh Geological Society, 1999a).

vium (old landslide and/or creep debris) and man-placed fill, particularly non-engineered fill (Figure 18A-C). Rock slope instability generally involves rock falls (Figure 18D) and/or shallow rock slides in natural slopes as well as excavated slopes. Instability in portions of excavated rock slopes is prevalent along certain transportation corridors, particularly where the slopes were excavated many years ago with earlier design and construction methodologies; see Stop 6.

Our experience indicates that most landslides affecting people and their property in the Pittsburgh area result from (1) human activity, and (2) failure to apply existing knowledge. Expanded land use controls, e.g., building codes and grading ordinances, and stricter enforcement of these regulations offers great potential for reducing landslide hazards associated with new construction. A landslide insurance program (analogous to the above-mentioned Mine Subsidence Insurance) offers great potential for protecting homeowners and businesses from financial losses associated with landslides in areas of existing facilities unaffected by new construction. Several landslide insurance bills have been introduced in the Pennsylvania Legislature over the past twenty years but none has received the support necessary for passage. Much of the problem with developing support for these bills stems from the inability to devise a stable and long-term method of financing.

Given the mining and industrial history of the Pittsburgh area, along with its topography and Appalachian heritage of disposing of materials on hillsides and/or in holes in the ground (e.g., abandoned surface and underground coal mines, subsidence sinkholes), waste disposal has provided and will continue to provide Engineering Geology problems and challenges. These

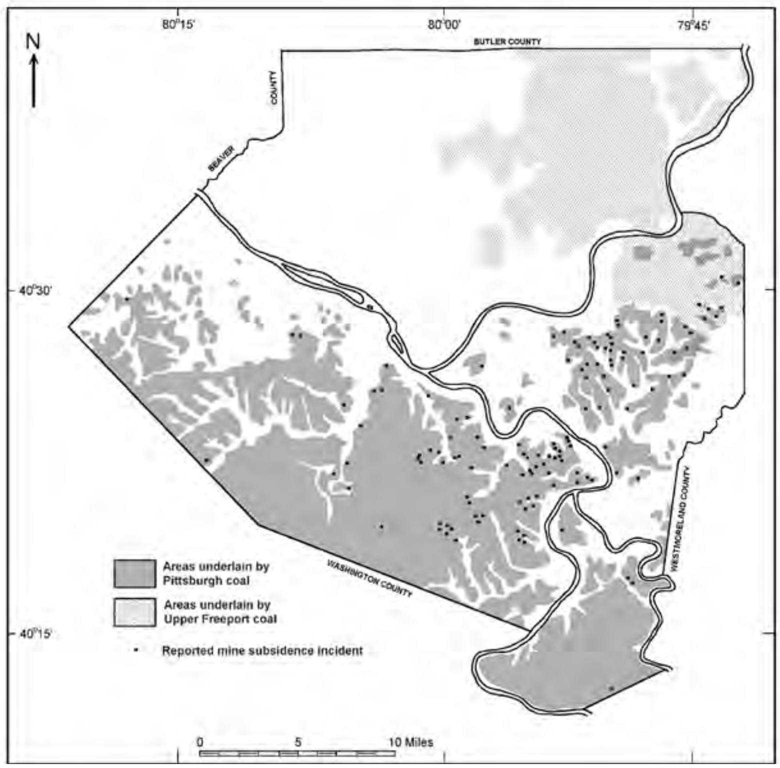

Figure 19. Generalized map of the flood-prone areas in Allegheny County. Modified from Briggs, 1977.

include cleanup of contaminated sites (e.g., toxic waste dumps, brownfields) and contaminated groundwater; dealing with mining and industrial wastes encountered during various construction activities; and provision of new and expanded sites for disposal and/or recycling of mining, industrial, and power generation wastes (see Stops 9 and 10). Side effects of waste disposal, e.g., methane generation and migration from municipal waste landfills (often in or near abandoned surface and underground coal mines), provide additional challenges.

The topography (including streams and rivers) and climatic conditions of the Pittsburgh area are such that it has long been prone to both local and widespread flooding (Figures 19 and 20). Floods on the major rivers have, to a considerable extent, been reduced by darns constructed on the main tributaries or in the headwaters of these rivers by the U. S. Army Corps of Engineers since 1936 (Johnson, 1979). These dams, originally constructed for flood control, are now multipurpose. They are much different in purpose, features, and operation from the navigation dams we will see during the barge trip of the present Field Conference.

Local flash floods from heavy precipitation events, e.g., severe thunderstorms, will occur forever in the Pittsburgh area. A thunderstorm on July 1, 1997, with 4 inches of rain in 1.5 hours, caused more than $11 million in damage and loss of one life in Pitcairn and Monroeville, eastern suburbs of Pittsburgh. More recently, 3 to 5 inches of rain on August 6-7, 2000, caused flash flooding with extensive damage at numerous locations in Southwestern Pennsylvania *(Pittsburgh Post-Gazette*, August 8, 2000, p. A-1, A-8). Ever increasing land development, which often includes removal of natural flood retarding features (including wetlands) along streams, exacerbates local flooding problems.

With increased development pressures on remaining open land in the Pittsburgh area, we anticipate more local flooding problems in the future, despite various storm water control regulations and ordinances. Storm water detention facilities are designed to retain extra runoff resulting from development for a storm of a certain recurrence interval, e.g., a 50-year storm which has a probability of occurrence of 2% in any given year, not an occurrence of once every 50 years. When a storm exceeds the design level, as happens from time to time, the extra runoff from a developed area (in excess of pre-development runoff) bypasses the detention facility to cause additional downstream flooding. Failure to consider soils and geologic conditions in design

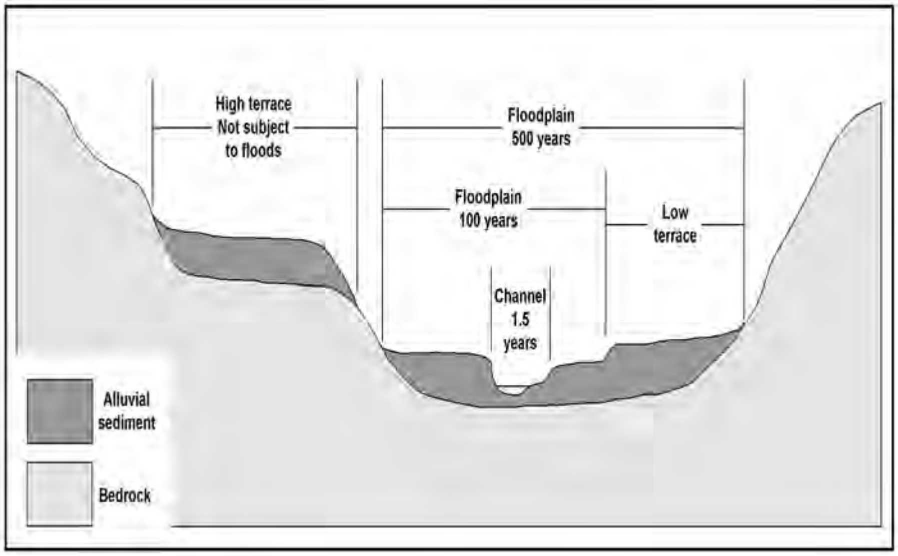

Figure 20. Cross section of a typical western Pennsylvania river valley showing the extent of flooding from periodic (1.5-year), 100-year, and 500-year floods. High terraces, formed before and during the Pleistocene, commonly occur between 150 and 250 feet above current river levels (from Pittsburgh Geological Society, 1999c).

and construction of storm water detention ponds has resulted in numerous slope failures in these facilities.

Insurance against flood damage is available through the National Flood Insurance Program. We generally recommend that home and business owners in flood-prone areas obtain this insurance where it is available.

Clay and limestone mining are much less widespread than coal mining in the Pittsburgh area, though some clay mining has occurred in conjunction with coal mining. The environmental effects of clay and limestone mines are not usually as deleterious as those of coal mines, though some subsidence damage has occurred over abandoned underground clay mines. One adverse effect of limestone mining in the ridges east of Pittsburgh has been the loss of caves with unique geologic features as well as bat habitats.

Much of the water supply in urban and suburban areas around Pittsburgh is from surface sources, especially the major rivers, either directly or through well fields. However, local and individual home water supplies are from wells and/or springs in most rural areas. Water supply problems, both large scale and local, are likely to provide more Engineering Geology challenges in the future.

Surface and subsurface drainage and erosion problems are generally local and/or site-specific. With increasing development in the Pittsburgh area, and particularly with increased development of marginal or previously unbuildable sites, we anticipate significant future drainage and erosion challenges, both surface and subsurface. An example of severe localized erosion from surface drainage can be seen along the most recent portion of Interstate Route 279, constructed approximately 11 years ago in northern Allegheny County. Surface runoff has eroded channels up to 3 ft (0.9 m) deep in highway fills. In places, these channels have exposed the full depth of the concrete shoulders of the road.

Expansive materials in the Pittsburgh area are both natural and man-made. Natural expansive materials are mainly sulfide minerals, e.g., pyrite, associated with coals and carbonaceous shales (Dougherty and Barsotti, 1972; Fasiska and others, 1974; Nixon, 1978). Manmade expansive materials are certain steel slags (Crawford and Burn, 1969, plus Discussions).

Problems with expansive materials, which are generally treated on a site-specific or project-specific basis, have in the past generally been few and far between. However, an elementary school approximately 30 mi (48 km) south of Pittsburgh in Washington County was recently constructed on pyritic soils and shale. This school heaved with considerable structural damage. Remediation has been slowed by continuing litigation.

We expect both the number and frequency of these problems to increase in the future with the increased (1) use of marginal or previously unbuildable sites, (2) use of excavated on-site but questionable materials in fills on these sites, (3) attempts to recycle old industrial wastes, and (4) tendency to forget lessons of the past. In this regard, we note that the use of any and all slag as fill under the roadway and shoulder areas is currently prohibited by District 11-0 of the Pennsylvania Department of Transportation, which includes much of the Pittsburgh area.

ADVANCES IN LOCAL AND REGIONAL PRACTICE

There have, of course, been many developments world-wide in Engineering Geology over the past twenty years. These include various computer applications and software; surveying and mapping systems, geographic information systems (GIS), and global positioning systems (GPS); techniques of geophysical investigation, in situ testing, field instrumentation, and laboratory testing; geosynthetics applications; and various environmental applications. All of these have been and continue to be used to some extent in the Pittsburgh area, but none is unique here.

The Pennsylvania Geologist Licensing Law, Act 151 of 1992, was a major advance for geology throughout the Commonwealth and certainly for Engineering Geology in the Pittsburgh area. The June 2000 letter from the State Registration Board for Professional Engineers, Land Surveyors and Geologists to all registrants in these professions regarding penalties for unlawful representation and/or practice in these professions is also significant regarding Engineering Geology Practice throughout Pennsylvania.

Progress in Engineering Geology Practice, here and elsewhere, is slow and incremental. Our short list of advances and developments of significance in the Pittsburgh area over the past twenty years is:

- Common use of wireline drilling with split inner barrels for improved recovery of soft and/or fractured rocks, e.g., claystones, common to the region
- Increased emphasis on Engineering Geology along with testing requirements for drilling inspectors and improved procedures for investigation, analysis, and reporting (e.g., "Supplemental Guidelines for Subsurface Exploration, Sampling and Testing in District 11-O," 1999) in District 11-0 of the Pennsylvania Department of Transportation, one of the largest users of Engineering Geology services in the Pittsburgh area
- Correlation and age dating of Pleistocene terrace remnants along the Upper Ohio and Monongahela Rivers in West Virginia, Pennsylvania, and Ohio (Jacobson and others, 1988), with geoarchaeological (Hamel and Jacobson, 1988) as well as engineering applications (Jacobson and others, 1988, fig. 4 shows slackwater and alluvial terrace correlations and elevations for more than 125 mi [200 km] of the Monongahela Valley upriver from Pittsburgh and for more than 188 m [300 km] of the Ohio Valley downriver from Pittsburgh). (Also, see Marine and Donahue on p. 28 of this guidebook..)
- Mineralogical and geochemical study of slag at Nine Mile Run site in Pittsburgh (Prellwitz, 1998; Stop 4)
- Documentation of widespread existence of deep-seated Pleistocene age rock slides and

clarification of their mechanism of occurrence as well as their geologic and engineering implications (Hamel, 1998; Stop 6)

- Publication in 1999 of the monumental and long-awaited book *The Geology of Pennsylvania* (Shultz, 1999) with its Part IX "Environmental and Engineering Applications" treating many items significant in the Pittsburgh area (most of the chapters in Part IX were prepared 10 to 15 years ago but their information is still very relevant.)

MAJOR FUTURE CHALLENGES

In addition to the previously mentioned problems and challenges, there are two broad future challenges that transcend technical areas:

- Decreasing availability of land
- Declining quality, expertise, and standards of geotechnical practice

Most of the Pittsburgh area has been developed in some manner in the past. Flat lands along the rivers, streams, and ridge tops were developed first. Then development extended into steeper land along the edges of these areas. All of the good sites and many of the marginal sites have already been developed. Much of the past development was built into the hillsides by hand or with limited mechanical equipment. Access to these areas consists of winding streets, which followed the original topography. These older residential and commercial areas now have deteriorated infrastructure, e.g., leaking water and sewer lines.

Virtually all presently undeveloped sites in the Pittsburgh area were passed over or left alone in the past because they have deficiencies, e.g., small size, difficult or limited access, and/or significant geological, geotechnical, and environmental problems, e.g., subsidence - prone shallow underground coal mines, coal mine drainage, slope instability, past waste disposal, flooding. Future development in the Pittsburgh area is thus severely constrained by geology, topography, climate, and previous land use. We are now facing a shortage of land suitable for development, particularly large areas for major developments. The significant issue of preservation of open space for aesthetic, social, and environmental reasons will not be addressed here.

Given this shortage of land, development is moving in two directions:

- Re-use and recycling of previously developed sites and areas, e.g., brownfields developments on former steel mill sites along major rivers, upscale housing in former hillside neighborhoods of moderate to low income homes
- Development of sites previously considered marginal or unbuildable because of topographic, geologic, and geotechnical problems requiring expensive engineering and construction solutions including large excavations and fills; road, stream, and wetland relocations; and complex infrastructure, e.g., roads, bridges, culverts, storm water detention facilities, utility lines

These two development directions are not always separate. Some projects blend elements of both, e.g., upscale housing extending from an old neighborhood onto a previously undeveloped unstable slope where expensive stabilization measures are required.

It should be obvious that high quality work, high levels of expertise, and high standards of practice are necessary for successful project completion under these conditions.

Unfortunately, we have observed in the Pittsburgh area and elsewhere over the past twenty

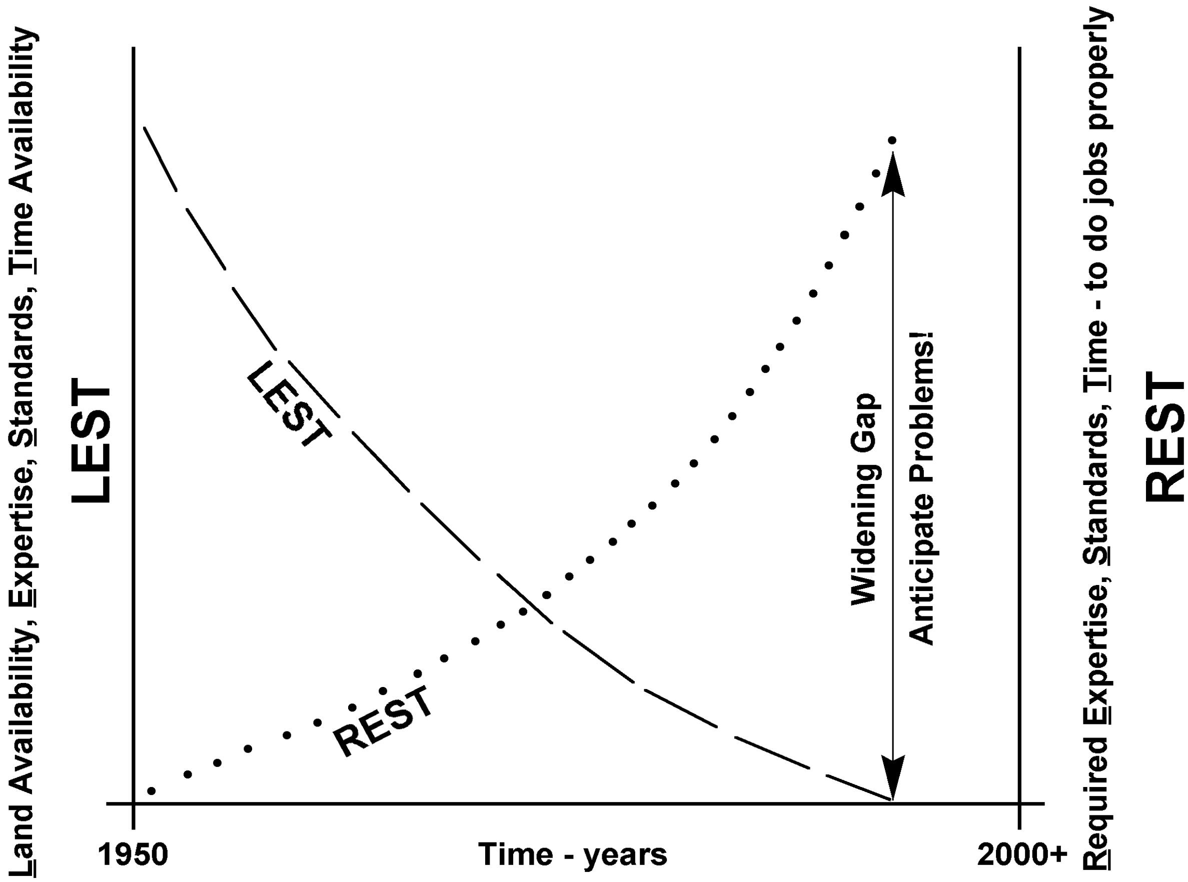

Figure 21. LEST-REST, the time dependent saga of geotechnical practice in the Pittsburgh area.

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years a general decline in quality, expertise, and standards in Engineering Geology and Geotechnical and Civil Engineering, the technical fields with which we are most familiar.

Dealing with decreased land availability and the general decline in quality, expertise, and standards of practice presents major challenges to Engineering Geology (and Geotechnical and Civil Engineering) in the Pittsburgh area for the New Millennium (Figure 21). Considering only technical issues, we cannot envision a way to deal effectively with land shortages other than to improve Professional Practices in Engineering Geology and related fields. Our suggestions along these lines are presented below.

SUGGESTIONS FOR IMPROVEMENT OF GEOTECHNICAL PRACTICE

Most problems and difficulties in geotechnical practice result from failure to apply available information, existing knowledge, and well-established project development procedures. Many, if not most, of these problems and difficulties result from failure to apply in an organized manner basic concepts and techniques of Engineering Geology.

In order to improve this situation and reverse the previously mentioned decline in quality, expertise, and standards of practice, we (Hamel and Adams, 2000, in press) have recommended emphasis on fifteen Fundamentals which apply equally well to Practice in Engineering Geology and Geotechnical Engineering:

Geology	Construction/Constructabilty
Geometry	Communication
Soil and Rock Mechanics (Geomechanics)	Diplomacy
	History
Observation	Field Emphasis
Imagination	Checking
Common Sense	Redundancy
Precedents/Experience	Flexibility

Most of these Fundamentals are, in fact, applicable to Professional Practice in all areas of geology and engineering.

We have further recommended focusing these Fundamentals on an observational Engineering Geology approach to developing the geotechnical framework (key elements of geology, geometry, history) of each site or problem (Hamel and Adams, in press). This has a heavy Field Emphasis (as in above list and present Field Conference).

With regard to use of available information and existing knowledge, we again draw attention to the problems of slope instability in the Pittsburgh area. Information and knowledge for dealing more effectively with these problems was available some twenty years ago in terms of the series of landslide inventory and susceptibility maps prepared by the U. S. Geological Survey (e.g., Pomeroy and Davies, 1975) and various technical publications (e.g., Hamel and Flint, 1969, 1972; Gray and others, 1979; Hamel, 1980; Hamel and Adams, 1981; Briggs and others, 1975; Pomeroy, 1982; Schuster and Krizek, 1978). Unfortunately most of this available information and previous knowledge on geologic conditions and geotechnical procedures does not regularly find its way into contemporary Practice in Engineering Geology and Geotechnical Engineering in the Pittsburgh area.

Considerable information is also available on the occurrence of and potential for coal mine subsidence in the region (e.g., Ackenheil and Associates, 1968; Cortis and others, 1975; Bruhn, 1980; Bushnell, 1975). Even so, it is not uncommon for Engineering Geology and Geotechnical Engineering reports to omit mention of coal seams, mining history, and subsidence potential.

Available information, existing knowledge, and proven technology are all such that we can do much better than we have in the past in meeting the challenges of slope instability, mine subsidence, and other geological/geotechnical problems of the Pittsburgh area. This will require serious efforts, however, in (1) upgrading geological and geotechnical practice, and (2) training and mentoring the next generation of practitioners.

DEDICATION

This paper is dedicated to three pioneering Field Geologists and Engineering Geologists of the Pittsburgh area who passed away since the 1980 Field Conference:

- Shailer S. Philbrick - former Chief of Foundation and Materials Branch, Pittsburgh District, Corps of Engineers; Professor of Geology at Cornell University; Consultant; and Honorary

Member, Association of Engineering Geologists

- Norman K. Flint - long time Professor of Geology at University of Pittsburgh, outstanding teacher, and mentor to many students, including the writers
- Harry F. Ferguson - former Chief of Geotechnical Branch, Pittsburgh District, Corps of Engineers; Consultant; Colleague; and Honorary Member, Association of Engineering Geologists

ACKNOWLEDGEMENTS

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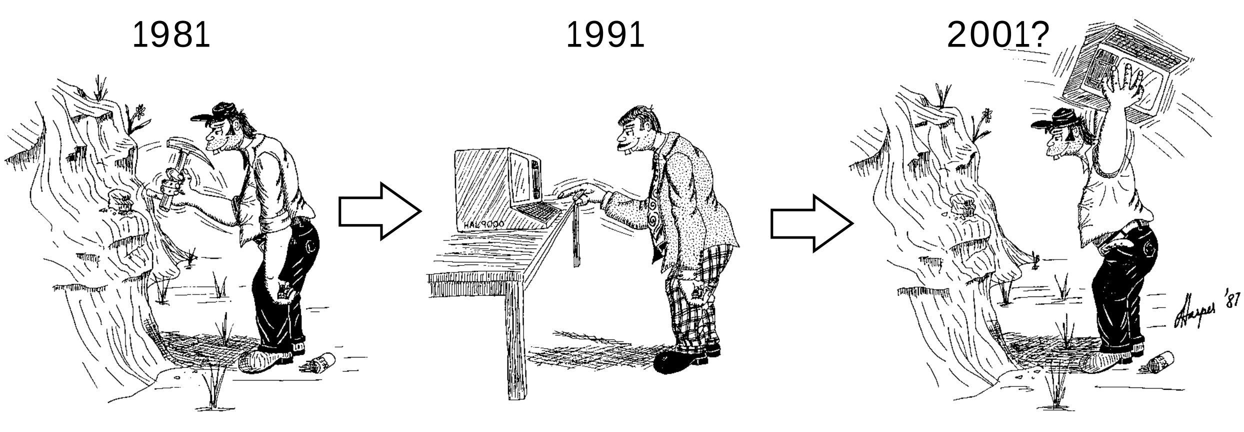

EVOLUTION OF GEOLOGY IN THE PITTSBURGH AREA

TERRACE DEPOSITS ASSOCIATED WITH ANCIENT LAKE MONONGAHELA

by
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INTRODUCTION

Early studies in western Pennsylvania and eastern Ohio established that the preglacial drainage of western Pennsylvania flowed northward into what is now the Lake Erie Basin (Figure 22A) (Carll, 1880; Foshay, 1890; Chamberlin and Leverett, 1894; and Leverett, 1934). Carll (1880) and Foshay (1890), in particular, used bore hole data (depth to bedrock) from oil wells to document the existence of northward dipping drift-filled channels in the Oil Creek and Beaver River drainages, respectively. They both speculated that these north-dipping channels carried the preglacial drainage of the areas toward the Erie Basin. Chamberlin and Leverett (1894) referred to this as the Monongahela-Beaver drainage (Monongahela River in Figure 22A).

White (1896) used bore hole data to compare the preglacial gradient of the rock floor of the

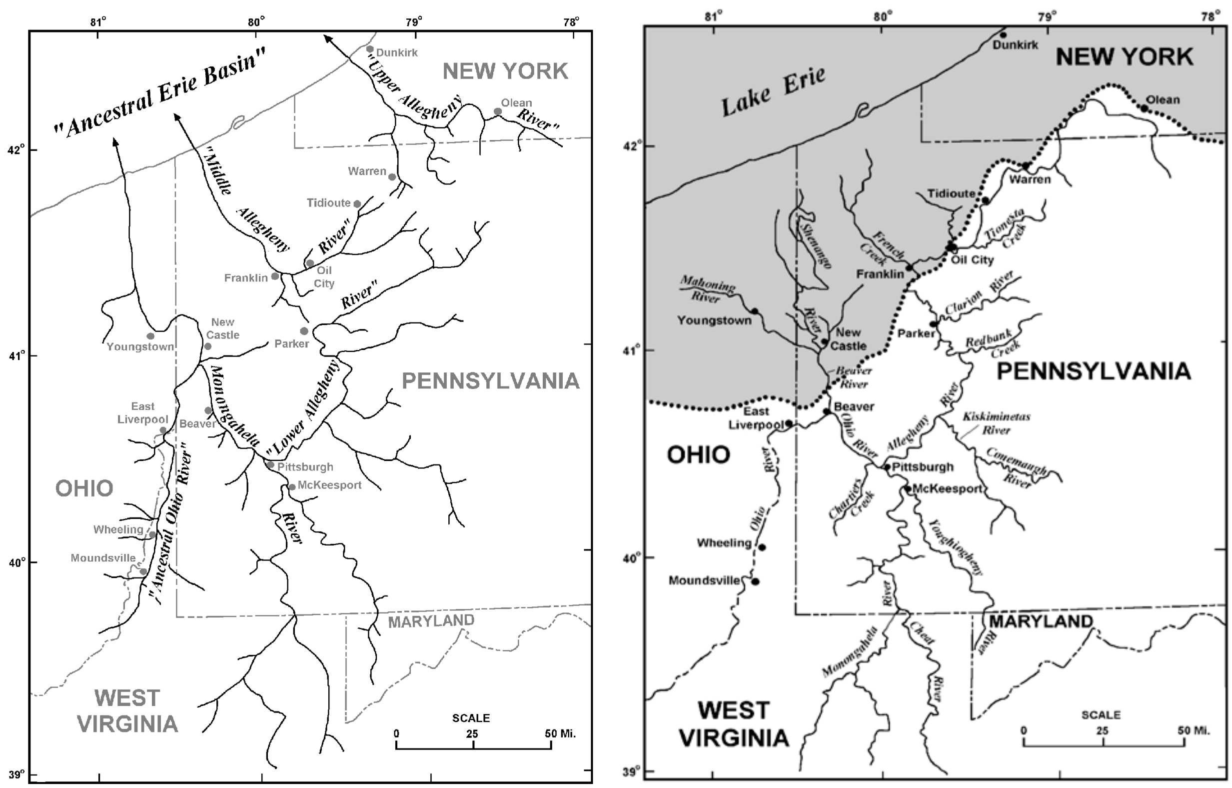


Figure 22. A. Preglacial drainage of western Pennsylvania. Modern towns and political boundaries, for reference, are subdued. Modified from Leverett, 1934. B. Present drainage of western Pennsylvania, and the areas affected by glaciation (shaded). Modified from Wagner and others, 1970. The dotted line represents the known southern limit of glaciation.

Pleistocene rivers between Weston, West Virginia and Sharon, Pennsylvania with the gradient of the present river system. He found that the present river bottoms fall 290 ft (88 m) between these two points, whereas the rock floor of the ancient stream falls only 110 ft (34 m) over the same distance. This indicates that the preglacial river valley had cut down practically to a base level condition. Leverett (1934) agreed, stating that the Monongahela-Beaver drainage had reached a stable condition by the time of the first glacial advance, resulting in gentle valley slopes and a moderately wide valley floor.

Foshay (1890), Chamberlin and Leverett (1894), Leverett (1934), and Fullerton (1986) further hypothesized that the preglacial Monongahela-Beaver River system drained an area nearly equivalent with the Pennsylvania portion of the present day Ohio, Monongahela, and Allegheny rivers.

The advance of glacial ice and/or gravel outwash from the melting glaciers modified the preglacial Monongahela-Beaver drainage by blocking the north-flowing drainage system. This purportedly resulted in development of a lacustrine environment that White (1896) named Lake Monongahela, where sediments were deposited along the gently sloping valley walls, mantling the already reduced topography with lacustrine clays and silts.

As the ponded waters of the lake rose, they eventually overtopped existing drainage divides and the water spilling over them eroded notches, or cols, in the divides. The escaping water formed new drainage channels that closely paralleled the ice margin. It is in this way that the modern Ohio River was formed (Figure 22B). The floods that resulted must have been quite spectacular, carving outlets across topographic ridges, being captured by existing channels, and reversing the regional flow from northwestward to southwestward. The ponded condition that occurred as the result of the next glacial advance never reached the level of the first ponding – the outlets (cols) were now at a lower elevation due to downcutting. Subsequent pondings then occurred at progressively lower elevations as the outlets were lowered and the river channels became entrenched.

GLACIAL LAKE MONONGAHELA

White (1896) recognized several high-level river terraces lining the valleys of the Monongahela, Allegheny, and Ohio rivers and their tributaries. In studying the sediments occurring on these terraces, he hypothesized that they were deposited in a vast lake-like reservoir that he named Lake Monongahela. He suggested that the north-flowing Monongahela-Beaver River had been impounded by advancing glacial ice that descended nearly to the mouth of the modern Ohio River near Beaver, Pennsylvania. White suggested that the impounded waters of Lake Monongahela rose to an elevation of 1100 ft (335 m) before spilling into the lower Ohio drainage, producing cols at Salem and Weston, West Virginia.

Leverett (1934) agreed with White's (1896) basic hypothesis of an ancient glacial lake but suggested a different cause. Based on the elevational distribution and coarseness of glacial gravels in the Ohio drainage near Beaver, Leverett (1934) suggested that the col in that area was no higher than 1000 ft (305 m). He correlated a lower set of terraces along the present course of the Monongahela River with Illinoian outwash terraces near Pittsburgh, and suggested that aggradation of pre-Illinoian gravels at the mouth of the Allegheny River ponded the waters of the Monongahela, thus forming Lake Monongahela.

Much of what is currently known about Lake Monongahela comes from studies of terrace

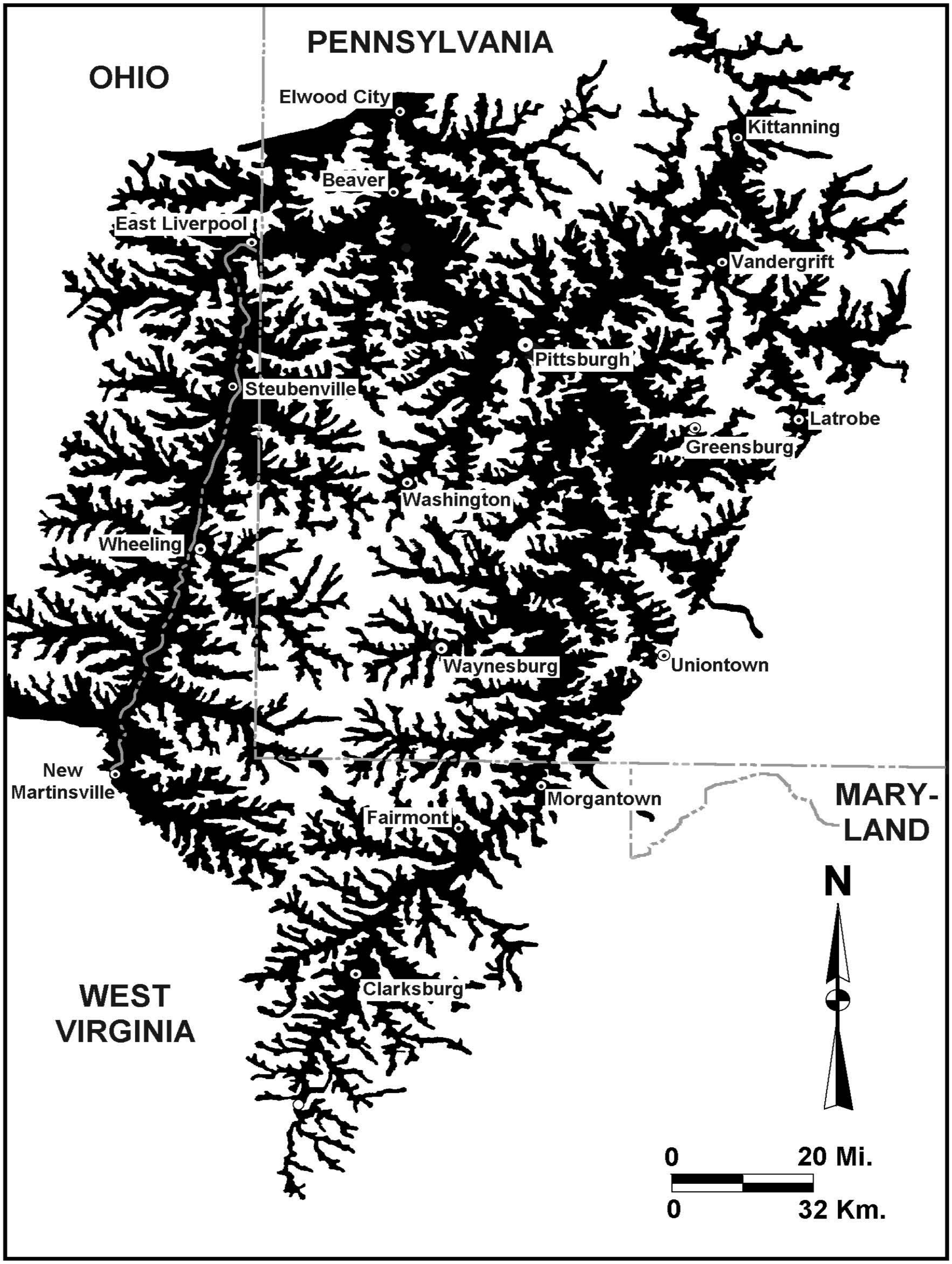


Figure 23. Reconstruction of Lake Monongahela based on the 1100 ft (335 m) maximum lake elevation (modified from Marine, 1997).

remnants located near the present Monongahela River channel in northern West Virginia and southwestern Pennsylvania (Wright 1890; White, 1896; Leverett, 1934; Gillespie and Clendening 1968; Morgan, 1994), and near the lower Allegheny channel north and east of Pittsburgh (Marine, 1997). Reconstructions of Lake Monongahela indicate that the lake's boundaries extended into the upper Ohio and the lower Allegheny drainages (Gillespie and Clendening. 1968) (Figure 23). It is evident from the reconstruction that Lake Monongahela was not a lake in the true sense of the word, but rather a ponded drainage system.

An accurate interpretation of the formation and depositional history of Lake Monongahela is complicated by several factors. Depositional events from repeated glacial advances and retreats have stratigraphically overprinted each other, making it difficult to decipher the drift boundaries of individual glacial events. The preglacial drainage of the Monongahela, upper Ohio, and lower Allegheny basins underwent continuous modification as a result of glacial intrusion. The Monongahela-Beaver River system probably was impounded several times, leaving lacustrine remnants at differing elevations (Leverett, 1934). This concept has been supported recently by Fullerton (1986) and Jacobson (1987).

There are two, possibly more, Pleistocene formations exposed on the river terraces. The glacial outwash deposits found on Allegheny and Ohio rivers terraces have no formal names. It is probable that, given the time and expertise, these deposits could be separated and correlated with the known glaciations of northwestern Pennsylvania (see White and others, 1969). Leverett (1934) described these deposits as rusty, deeply weathered gravel containing granite and other crystalline rocks. Most of the gravel is composed of small, well-rounded pebbles generally less than 1 in (2.5 cm) in diameter (Figure 24A). In some places the deposit is indurated sandstone, whereas in others it is a loose assortment of silt, sand, and gravel. These outwash deposits occur on several terrace levels.

In contrast, Campbell (1902) called the Lake Monongahela lacustrine deposits found throughout the Monongahela-Beaver drainage area Carmichaels Formation (Figure 24B) for Early Quaternary deposits preserved at Carmichaels, Greene County, Pennsylvania. Carmichaels deposits consist of clay, silt, and sand matrix, generally ranging in color from reddish-orange to tan, and containing subangular to well-rounded, cobble- to boulder-sized, typically sandstone

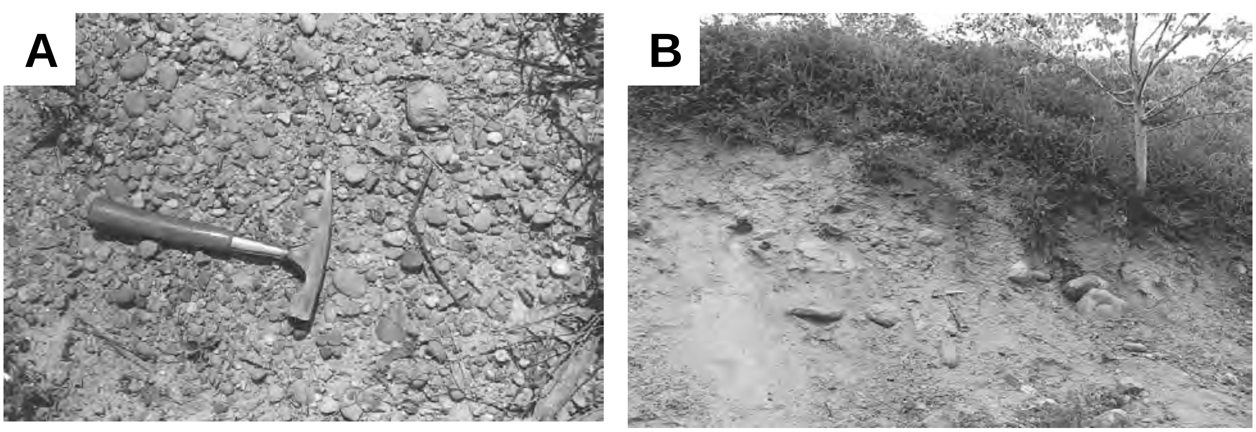


Figure 24. Terrace deposits on the Allegheny and Monongahela drainage. A. Glacial outwash preserved in a meander loop in O'Hara Township, Allegheny County (from Wagner and others, 1970). B. Red silt and clay, with sandstone cobbles, of the Carmichaels Formation, Speers, Washington County. Rock hammers for scale.

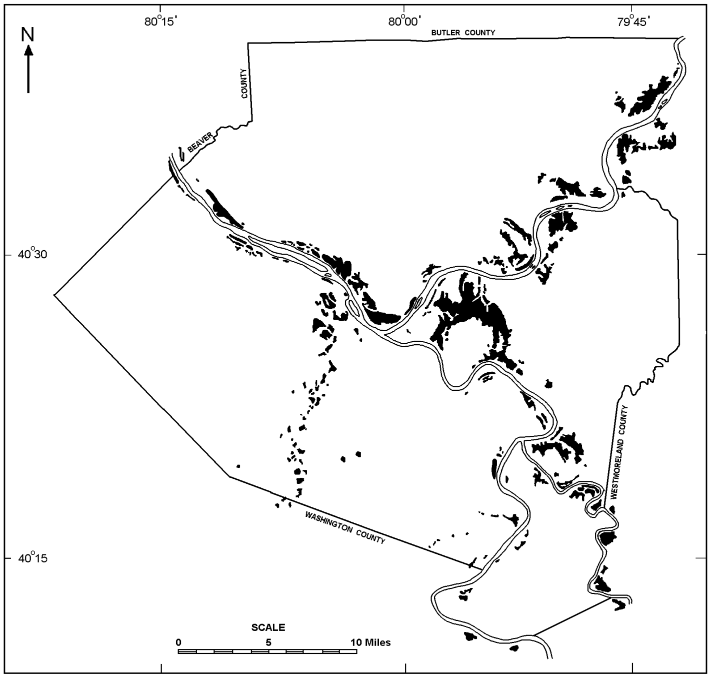


Figure 25. Locations of remaining river terrace deposits (Carmichaels Formation) in Allegheny County (compiled from Wagner and others, 1975).

(local bedrock) clasts (Donahue and Kirchner, 1998). The clays tend to be highly plastic; in fact, the Carmichaels acted as the source of clay for the early pottery industry in the Pittsburgh area. There is still some question as to the origin of the red clays in the Carmichaels, which occur not only in the Monongahela drainage, but in the lower Allegheny drainage as well, thereby seeming to rule out a source to the south of Pittsburgh. Donahue and Kirchner (1998) speculated that it could be derived from soils developed during the interglacial intervals of the Pleistocene. Carmichaels Formation deposits occur on the upper two terrace levels (Jacobson and others, 1988).

Extant high-level terrace deposits are dispersed (see, for example, Figure 25), but can be quite thick. Some preserved outwash deposits have been measured at more than 90 ft (27 m) thick, but Leverett (1934) estimated they may originally have exceeded 120 ft (37 m) in thickness. Carmichaels deposits tend to be much thinner, however, rarely exceeding 20 ft (6 m) (O'Neill, 1974).

HIGH-LEVEL TERRACES

High-level terraces lining the river valleys presented something of a puzzle to early investigators. These relatively flat landforms composed of scattered, highly weathered deposits of clay, silt, sand, and gravel are found at elevations as great as 300 ft (91 m) above present stream levels.

White (1896) documented a series of five high, erosional terraces near Morgantown, West Virginia along the valley walls of the Monongahela River and its major tributaries (Table 1). White suggested that the fifth terrace indicates the maximum elevation reached by ancient Lake Monongahela, with the lower terraces representing successive stages of lowering of the outlet from the ice and drift dam impounding its waters.

Lessig (1961) described a set of only four terrace remnants preserved mainly in former meander loops scattered along the upper Ohio valley in the vicinity of East Liverpool, Ohio. He found the highest terrace at elevations ranging from 960 to 1020 ft (293 to 311 m), whereas the lower terraces occur at general elevations of 720, 760, and 850 ft (220, 232, and 259 m). Jacobson and others (1988) also identified only four terrace levels when they correlated the terraces in the ancient Teays drainage basin with those of the ancient Monongahela-Beaver drainage basin.

Table 1: Terrace levels of the Monongahela River near Morgantown, West Virginia (after White, 1896)

Terraces	Ft (m) Above River Level	Ft (m) Above Sea Level
First	30-40 (9-12)	~830 (253)
Second	75-80 (23-24)	~875 (267)
Third	125-175 (38-53)	920-970 (280-296)
Fourth	~200 (61)	1000 (305)
Fifth	275-300 (84-91)	1050-1100 (320-335)

More recently, Marine (1997) documented five terrace levels along the lower Allegheny River and its tributaries (Table 2). Comparison of the data from Tables 1 and 2 confirms that the five terrace levels that occur along the lower Allegheny river and its tributaries correspond with White's (1896) documented five terrace levels in the vicinity of Morgantown, West Virginia. Slight differences in tabulation result from the ways the data were collected – White (1896) examined terraces in a limited area whereas Marine (1997) examined the entire lower Allegheny drainage system (see below). Some variation should also be expected due to the fact that these deposits were laid down over preexisting topography, and were differentially eroded through time.

First Terrace

The low water level of the modern Allegheny River is generally 30 to 40 ft (9 to 12 m) above the old rock floor of the valley. The presence of Wisconsinan (and Illinoian?) outwash gravels below river level and beneath the first terrace that borders the stream indicates that the valley had been cut to nearly its entire depth before the Wisconsinan glacial advance (Leverett, 1934). It appears then that the Wisconsinan gravels were deposited on the rock floor, and in the channel of the old river valley and were then mixed with and overlain by alluvium deposited during the Holocene.

The first terrace on the Allegheny River occurs at an elevation of 740 ft (226 m) in the

Table 2. Terraces of the Allegheny River and tributaries

Terraces	Ft (m)Above River Level	Ft (m) Above Sea Level
First *(modern floodplain)*	Variable	Variable
Second	200-210 (61-64)	900-920 (274-280)
Third	250-270 (76-82)	960-980 (293-299)
Fourth	290-310 (88-95)	1000-1020 (305-311)
Fifth	330-350 (101-107)	1040-1060 (317-323)

vicinity of Pittsburgh, about 30 ft (9 m) above river level. It is the modern floodplain of the river. This terrace then rises gently in the upstream direction maintaining the 30-ft (9-m) interval observed at the mouth. It should be noted that as the stream downcuts and lowers its gradient, remnants of the existing flood plain will be preserved, and will then be counted as terraces themselves (Hubbard, 1954). As the floodplain rises in the upstream direction it eventually reaches the elevation of the second terrace. It is in this way that one terrace level becomes the next. Thus what is the highest terrace level in the vicinity of the main channel may be the level of the first terrace of a lower order tributary.

"Second," "Third," and "Fourth" Terraces

The altitude of the pre-Wisconsinan (probably Late Illinoian) valley train gravel on the lower Allegheny is approximately 1150 ft (351 m) at the mouth of the Clarion River, falling to 1080 ft (329 m) at Redbank Creek, and 1040 ft (317 m) at the mouth of the Kiskiminetas River. From Natrona Heights in northern Allegheny County to the mouth of the Allegheny at Pittsburgh the sediment is at a level between 1000 and 1020 ft (305 and 311 m). The sediment also occurs at different heights in response to the stream's meandering, being higher on the inside meander loop and as much as 30 ft (9 m) lower on the outside of the loop. Thus the three seemingly separate terrace levels are actually different manifestations of the same event.

By the time of, at least, the Late Illinoian glacial advance, and probably even earlier than that, the drainage of the area was no longer northward to the ancestral Erie basin but westward through the proglacial Ohio River. In addition, the streams comprising the formerly northward-flowing "Middle" and "Upper" Allegheny systems were now joined to the "Lower" Allegheny system in a common southward discharge (Figure 22). Since the "Upper" and "Middle" Allegheny systems headed in glaciated areas, large amounts of outwash were transported down the joined river and deposited along the valley walls. Eventually so much outwash accumulated at the mouth of the Allegheny that another ponding episode occurred. This ponding episode is responsible for the slackwater deposits, the so-called lower Carmichaels Formation of Jacobson and others (1988), seen on terraces along the eastern tributaries of the Allegheny that did not head in glaciated areas.

There are several terraces along the main channel of the lower Allegheny that have the potential for exhibiting finer deposits consistent with Illinoian ponding. Field study, however, indicates that the second, third, and fourth terrace levels are mainly composed of sand and gravel with varying amounts of finer materials and an occasional boulder. The gravel consists of sedimentary rock of local (southwestern New York and northwestern Pennsylvania) origin, as well as igneous and metamorphic clasts that were transported by glacial ice from farther north. Terraces occurring at the same elevation along the eastern tributaries tend to have a high clay content with varying amounts of sand and boulders. Preservation of these remnants tends to occur inside meander loops of the eastern tributary streams where the stream energy is lower.

Fifth Terrace

There are terrace remnants along the Allegheny River and its tributaries that occur higher than the level of the local Illinoian gravel filling, suggesting that these deposits are of an earlier Quaternary age. These are the so-called upper Carmichaels Formation of Jacobson and others (1988). Where these deposits are high in clay content, they probably represent the highest level reached by Lake Monongahela (White, 1896; Leverett, 1934; Stout and Lamb, 1938; Fullerton, 1986; Marine, 1997). The lower terraces therefore formed as the impounded waters lowered the outlets through which they poured.

AGE OF THE TERRACES

Some controversy exists as to the age of the terrace deposits. Wright (1890) pointed to the existence of fresh organic material preserved in the terrace sediments as indicative of the youthfulness of these deposits. He believed that the terrace deposits were laid down during an impoundment of the Ohio River after it had cut down to its present elevation. Based largely on the degree of weathering of granitic clasts found in the terrace deposits, and on soil profile development, White (1896), Leverett (1934), and Lessig (1963) advocated a pre-Illinoian age for the terrace sediments.

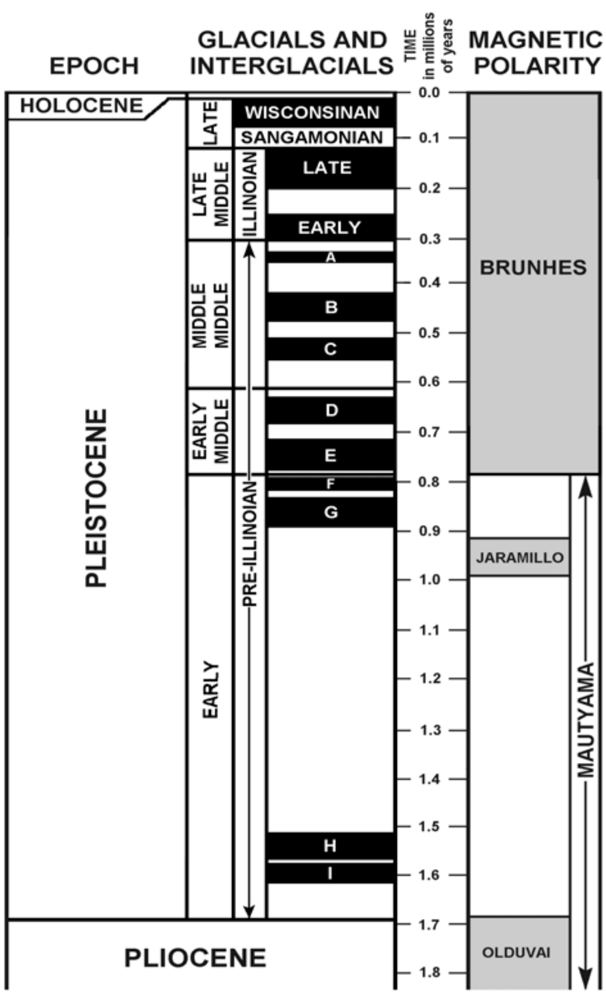


Figure 26. Time scale for the Pleistocene, with glacial (black) and interglacial periods and correlation with reversals of the earth's magnetic field (normal polarity is shown in gray).

Gillespie and Clendening (1968) found a radiocarbon date of 22,000 ± 1000 yr BP in organic material from a high terrace near Morgantown, West Virginia. Behling and Kite (1988) reported a similar radiocarbon date of 22,645 ± 515 yr BP from a recognizable white spruce branch collected from the same terrace. These radiocarbon dates indicate a Wisconsinan age for the terrace (Figure 26). Gillespie and Clendening (1968) felt their radiocarbon dates were suspect, however, owing to possible leaching. Unfortunately, radiometric methods are of little value in dating pre-Wisconsinan terrace remnants as their ages are beyond the resolution of ^{14}C dating (<50 ka) and do not contain the necessary volcanics to utilize K/Ar dating. However, the high clay content of the upper terraces makes them ideal for depositional remnant-magnetic dating.

Sediments from weathered magnetized rocks (i.e. containing ferromagnetic minerals), if they are small enough (like lacustrine clays), can become physically aligned with the earth's magnetic field, indicating the direction and intensity of the field at the time of deposition or consolidation. The memory of the field they retain is a detrital remnant magnetism (DRM).

Jacobson and others (1988) documented a paleomagnetic reversal in a terrace clay deposit near Mannington, West Virginia at

997 ft (304 m) that suggests an Early Middle Pleistocene age of >780 ka BP (Matsuyama Reversed) for this high stand of Lake Monongahela. Bonnett and others (1991) documented a magnetic reversal in the Minford Silt in Ohio, dating the deposit between 970-1700 ka BP which would place it within the Early Pleistocene.

Marine (1997) sampled and analyzed several terraces of various elevations in the lower Allegheny drainage with the objective of correlating these terraces with those in the Monongahela Valley. He collected and analyzed samples from three terraces at 980, 1000, and 1040 ft (299, 305, and 317 m) along the lower Allegheny drainage in Allegheny, Armstrong, and Indiana counties. He also collected and analyzed samples from a fourth terrace deposit at 960 ft (293 m) associated with Monongahela drainage in Westmoreland County for control purposes. Almost all were found to exhibit normal magnetic polarity signatures. A single sample collected at 1000 ft (305 m) at Pultneyville, Armstrong County exhibited a reversed magnetic polarity signature, but its value is suspect because the other samples from the same horizon all exhibited normal (Brunhes) polarity (Figure 26).

CONCLUSIONS

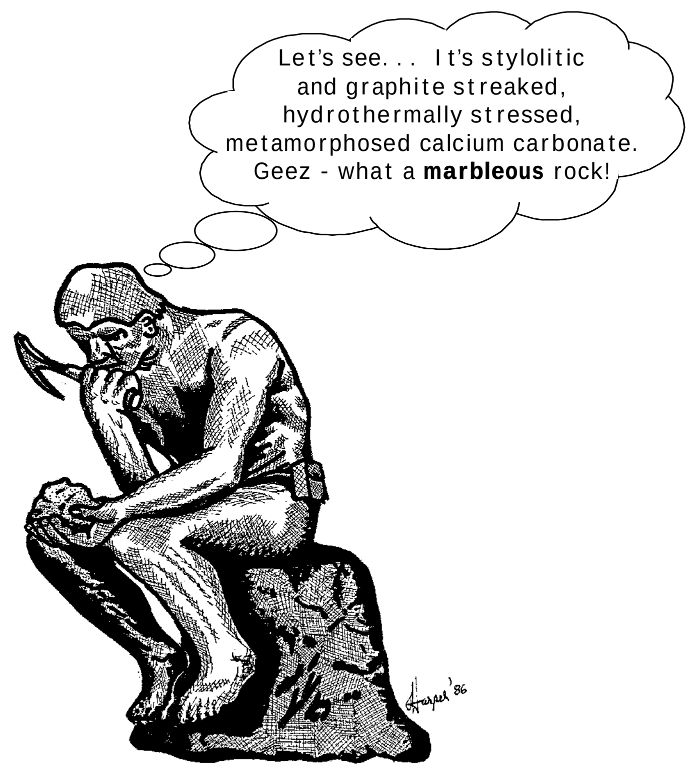
Marine (1997) found five terrace levels along the Monongahela and lower Allegheny river and their tributaries. Deposition of Carmichaels and outwash gravels on these terraces occurred as a result of two episodes of glacial damming: 1) terraces at ~1000-1100 ft (305-335 m) elevation (high-level terraces four and five) represent pre-Illinoian glaciation; and 2) terraces at ~900-970 ft (274-296 m) elevation (high-level terraces two and three) representing Illinoian glaciation. These elevations represent the upper limits of Lake Monongahela deposition. The oldest Lake Monongahela deposits (upper Carmichaels Formation of Jacobson and other, 1988) should be located on the highest terraces. The lowest level terrace (one) consists of Wisconsinan and Holocene deposits filling the river valleys cut to bedrock by the end of Illinoian time.

Marine (1997) could find no geomorphic evidence of lake-cut terraces or discernible paleoshorelines. In most cases the lacustrine silts and clays associated with Lake Monongahela rest directly upon bedrock, suggesting that Lake Monongahela did not form the high terraces themselves, but modified pre-existing river terrace remnants by mantling them with lacustrine clays and silts. The time duration of the ponded waters in the lower Allegheny and Monongahela valleys was not sufficient to cut terraces in the local bedrock.

Marine (1997) also found an asymmetrical distribution of Lake Monongahela deposits along the lower Allegheny River drainage. The terraces along the main channel are covered in most cases with glacial gravels and outwash. The tributaries that enter the main stream from the eastern side do not head in glacial terrain and consequently contain no outwash deposits. This is where Lake Monongahela deposits (Carmichaels Formation) are best preserved. These streams have well-developed broad valleys with relatively low gradients, conditions favorable for preservation of Lake Monongahela deposits. With the exception of Buffalo Creek in Butler County and Deer Creek in Allegheny County, the tributaries entering the Allegheny River from the west are higher gradient, steep, first or second order streams with steep valley walls, offering little opportunity for preservation.

The premise that ponded water should leave deposits of similar ages at similar elevations in both the lower Allegheny and Monongahela drainages is oversimplified and not supported by the paleomagnetic analyses. As stated above, Lake Monongahela did not form the high terraces, but simply modified pre-existing river terrace remnants. Since the original topography was not featureless, sediments deposited at the same time need not come to rest at the same elevation. Lacustrine sediments from Lake Monongahela capped or filled terrace remnants and other topographic highs and lows, explaining not only the terraces capped with lacustrine clays, but also the infilling of abandoned meander loops such as the Carmichaels channel. Assuming a more or less uniform rate of deposition within Lake Monongahela, and an average rate of erosion, then the terrace levels may be more indicative of the paleotopography of river terraces than actual ponding levels of Lake Monongahela.

The paleomagnetic results obtained by Marine (1997) suggest that the original paleomagnetic reversal documented by Jacobson and others (1988) needs to be verified. A larger paleomagnetic database needs to be compiled to better constrain the age of the high terrace deposits associated with Lake Monongahela.



Harper's "The Thinker"

GEOTECHNICAL ASPECTS AND PALEONTOLOGY OF THE "I-279 FOSSIL COLLECTING LOCALITY"

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INTRODUCTION

A large roadcut on I-279 just north of the exit to Camp Horne Road in Ohio Township (Figure 27) provides an opportunity to study the middle portion of the Conemaugh Group and to collect fossils from several rock units. It also provides an opportunity to examine the terraced design of many of the I-279 roadcuts. This site originally was intended as a field stop during the 65th Annual Field Conference of Pennsylvania Geologists. Anyone interested in visiting the site should read the warning at the end of the discussion.

STRATIGRAPHY

This large roadcut exposes the strata of the middle Conemaugh Group, from the Upper Saltsburg sandstone at the base to the Morgantown sandstone at the top. From the base of the cut upwards, you will encounter the following section (Figure 28): 1) gray sandstone at the level of the parking area; 2) seven terraces of red and gray claystones (red beds) containing caliche nodules; 3) five terraces of red and gray claystones, very weathered, with some spheroidal weathering, greenish reduction zones, root casts, manganese dendrites, and questionably, some trace fossils; 4) the Ames Limestone; 5) two terraces of red and gray claystones; 6) the top terrace, containing a small lens of gray sandstone and a barrier of

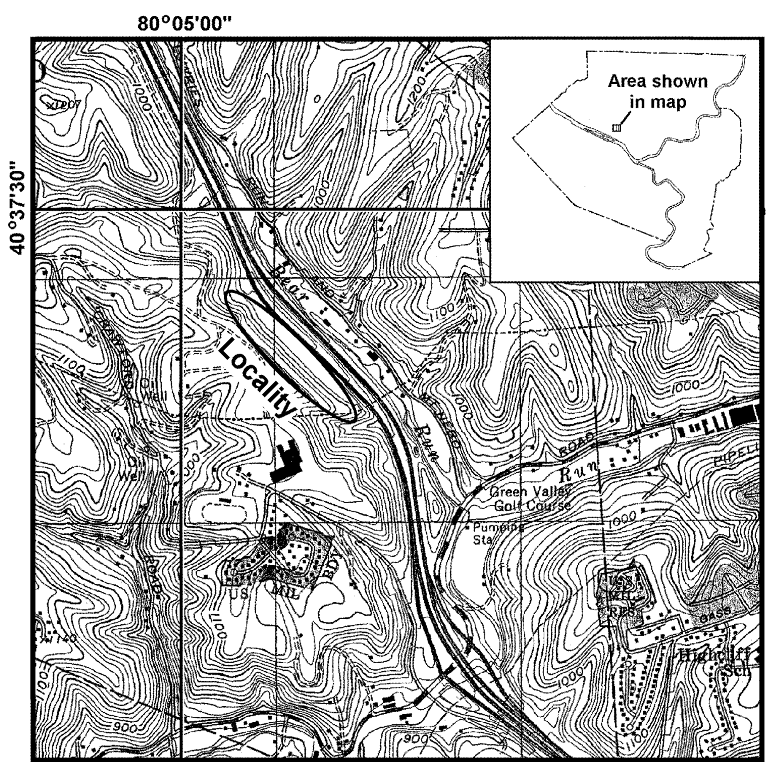

Figure 27. Location of the "I-279 Fossil Collecting Locality" on the Emsworth quadrangle.

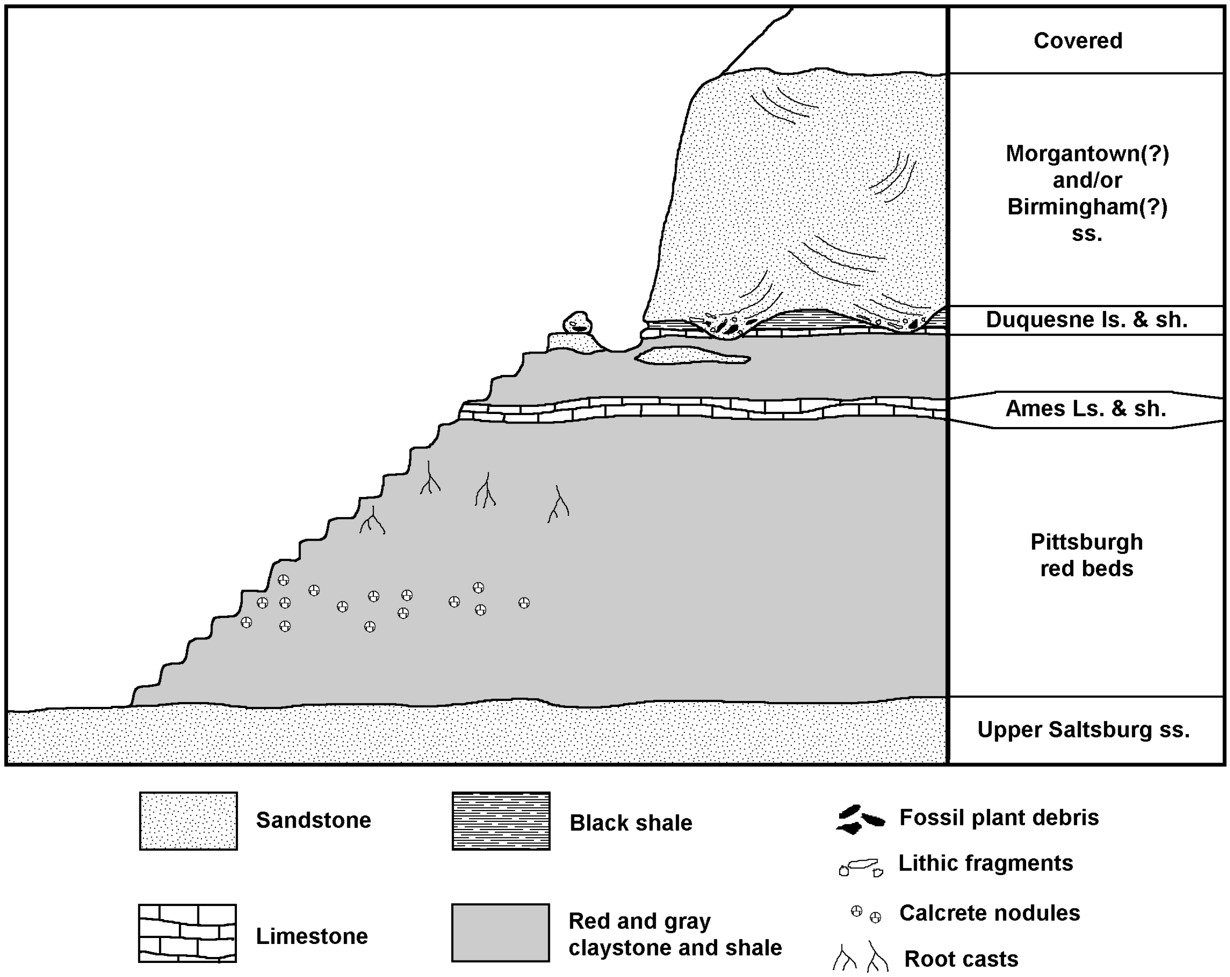

Figure 28. Generalized topographic and stratigraphic cross section of the "I-279 Fossil Collecting Locality" roadcut (from Shultz and others, 1995).

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large sandstone blocks used to prevent rockfalls from reaching the highway; and 7) the steep flat face of sandstone at the top which contains a basal layer of mud chips and slabs that exhibit soft-sediment deformation, indicating an origin in stream-bank failure. The sandstone originated as a channel dposit, but the exact nomenclature is in question. Although it is tempting to call this sandstone Morgantown, it might in fact represent a sandstone phase of the Birmingham shale, or be a combination of Birmingham and Morgantown sandstones. Notice the irregular base of this rock unit, typical of stream channels that cut into the surrounding strata and then fill the gaps with sand.

GEOTECHNICAL ASPECTS

The cyclic nature of the rocks of western Pennsylvania creates a plethora of design, construction, and maintenance problems because of their diverse and heterogeneous nature. Although thick, massive sandstones such as that at the top of this road cut might appear relatively stable, like the associated rocks (which typically consist of thin coals and limestones and thick sequences of mudrocks), they nonetheless present their own challenges to stable and safe slope design. Each of these rock types possesses different physical properties that, in conjunction with climate, slope, and other factors, affect their stability.

The massive sandstones almost always contain numerous fractures or discontinuities with a variety of origins. The humid climate in this region provides abundant moisture that, upon entering the sandstones as groundwater, helps to enlarge these discontinuities. These fractures are enlarged through hydrostatic forces and the numerous freeze-thaw cycles occurring in this region. Add to this the loss of support from the underlying weak rocks and this region becomes subject to frequent and some times deadly rockfalls.

Hence, the large bench was constructed at the base of the sandstone above to act as a “drop zone” for falling rocks and the large boulders were placed on the bench to help stop rockfalls from moving downslope. The bench also lessens the possibility of differential weathering and erosion removing the underlying softer rock that would result in loss of support for the sandstone. The large boulders are a unique technique to help minimize displaced rocks from traveling further down the slope. The use of boulders in this manner, which occurs at several places along this section of highway, may be the only use of this technique in this region.

The redbeds are notorious as the cause of most landslides in the Pittsburgh area. In comparison with an “average” Conemaugh sandstone, the redbeds have little strength (Table 3). They slake rapidly in water and therefore when exposed to the elements in a road cut, they weather rapidly forming a thick soil cover over the claystone. Kapur (1960) found that these typically red claystones tend to lose strength with each seasonal cycle (freeze-thaw, wetting-drying). Porosity is relatively high, up to 40% according to Pomeroy (1980), but permeability is very low. Therefore, the claystone-derived soils will retain considerable amounts of water and once saturated will not drain readily.

The terracing of road cuts, called serrated slopes, can be seen along I-279 between this locality and East Ohio Street on the North Side. The original intent of this type of terracing was to help develop a soil profile and vegetation growth on slopes underlain by medium hard rock. The design intent was to lessen erosion and the possible resulting rockfalls, rock topples, etc. However, the construction management staff involved in the construction of the highway apparently decided to use it everywhere except on the near vertical sandstone cliffs, regardless of rock strength.

There are two main reasons this technique is inappropriate for slopes underlain by claystones: 1) most facies of the claystones weather rapidly to relatively thick soils, that would

Table 3. Rock test data for the Pittsburgh red beds and Saltsburg sandstone (based on McGlade and others, 1972).

CHARACTERISTIC	PITTSBURGH RED BEDS	SALTSBURG SANDSTONE
Shear normal to bedding	320 psi	974 psi
Shear cross-angle to bedding	466 psi	1,255 psi
Unconfined compressive strength	1,661 psi	9,991 psi
Tensile strength	576 psi	4,330 psi
Bearing capacity	4-8 tons/ft^2	25 tons/ft^2

support plant growth, without the terracing; 2) the terracing of the redbeds allows water to collect on, and infiltrate into, the redbeds rather than sheeting off as originally intended with the slope becoming saturated and thus less stable. This inappropriate use of the terracing technique was compounded by the failure to seed the slopes – seeding that was supposed to begin within days of completion of the terraces apparently never occurred. Any attempts at seeding the slopes were not timely or sufficient and as a result ineffective. Thus with little or no seeds there can be few plants and no erosion control.

FOSSILS

A large variety of fossils can be found in several strata at this locality. The claystones within the interval of the Pittsburgh red beds contain vertical stains that probably represent root casts of land plants growing in a paleosoil (Figure 28). It also might be possible to find a few trace fossils of 'worms" that crawled over stream bottoms in the thin sandstones in this interval.

Ames Limestone

The Ames Limestone, the last of the Glenshaw marine events, is, arguably, the most fossiliferous stratum in western Pennsylvania. It contains a wholly marine fauna dominated by brachiopods and horn corals, but also has a rich molluscan assemblage of snails, clams, and cephalopods. Less obvious elements include 'algae,' foraminiferans, bryozoans, chiton plates, trilobites, crinoids (both intact and disaggregated), isolated starfish plates, and shark teeth. It also contains a wealth of trace fossils. Some of the more common fossils and trace fossils that can be found in the Ames Limestone in the Pittsburgh area are shown in Figures 29 and 30).

The Ames Limestone occurs here in its typically three-layered form. It includes a 0.5-3 in (1.25-7.5 cm) basal layer of hard calcareous shale, 18-36 in (45-90 cm) of very hard, very fossiliferous, argillaceous limestone, an upper layer about 1 0 in (25 cm) thick of brittle calcareous shale and all of these layers contain fossils.

The basal layer, which Brezinski (1983) called the calcareous shale lithofacies and Saltsman (1986) referred to as *Neochonetes*-mollusc shale lithofacies, commonly contains a hash of phosphatized shell debris and organic-matter stains. This is the molluscan layer of the Ames representing the initial transgressive phase of the Ames seaway into Pennsylvania. It is dominated by snails and clams, with some nautiloids (probably floated in after death), brachiopods, particularly *Neochonetes granulifer,* and other faunal elements. Most molluscs have shell structures of aragonite, the metastable form of calcium carbonate; after death and burial the aragonite tends to dissolve or recrystallize into calcite. In this lower molluscan layer, however, many of the molluscan shells have been either preserved as aragonitic shells (probably due to the organic matter in the sediment) or replaced by phosphatic minerals that preserve them in exquisite detail. The enterprising collector might even be able to spot a fossil or two with preserved color banding highlighting the shells. Look for pieces of limestone that appear to be coated with tar or asphalt. The whitish blotches in this dark tar-like organic material are fragments of shell material.

The middle layer of limestone, seemingly representing a single depositional event, constitutes the Ames Limestone proper or what is regarded as the typical Ames. This "single" open-marine depositional event actually represents a sequence of deposits that have more or less coalesced. Layer boundaries are extremely difficult to detect, but can be seen in terms of accumaccumulations of black phosphate pebbles and the horn coral *Stereostylus.* Saltsman

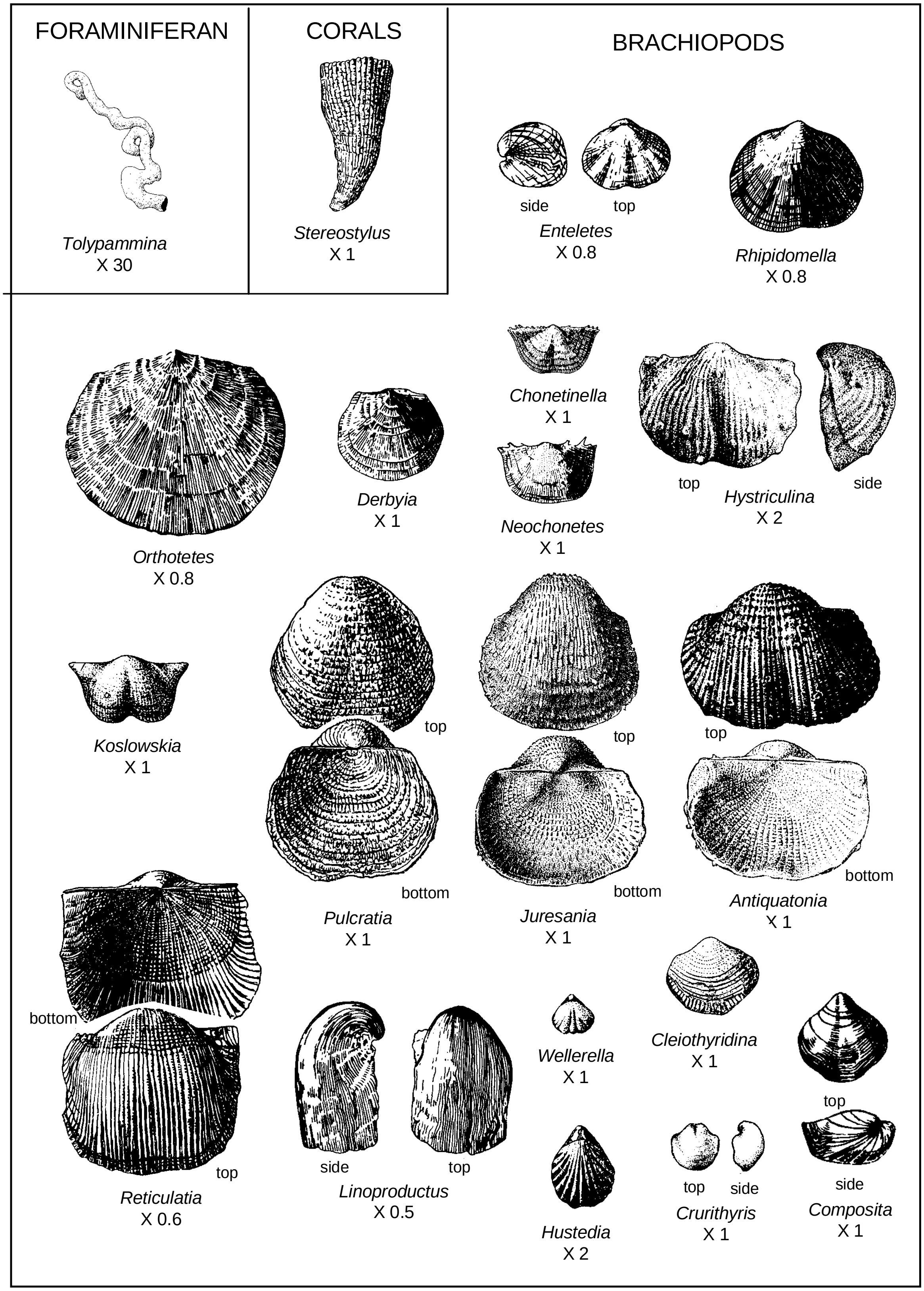


Figure 29. Some of the common marine fossils that can be collected from the Ames Limestone in western Pennsylvania.

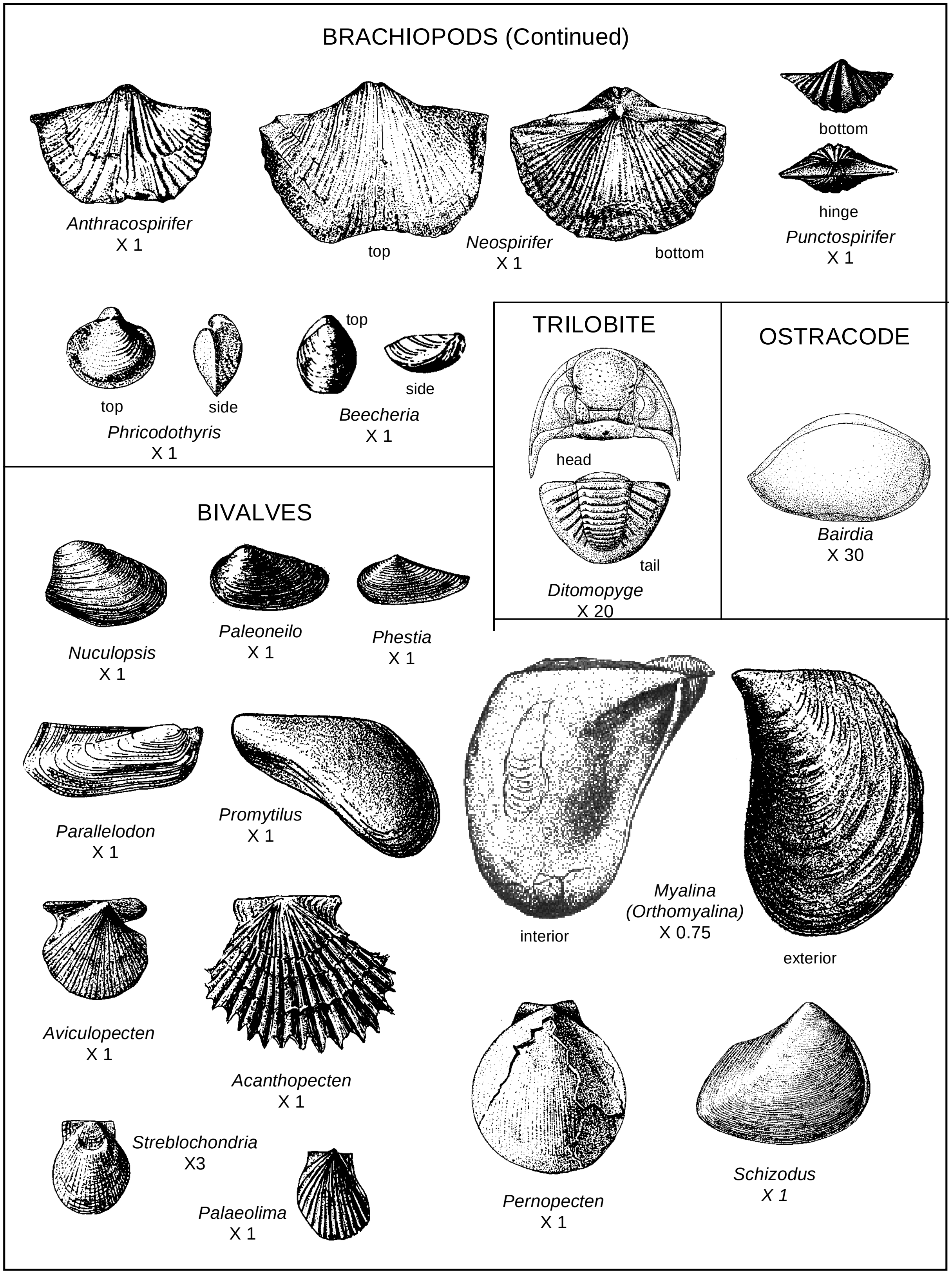
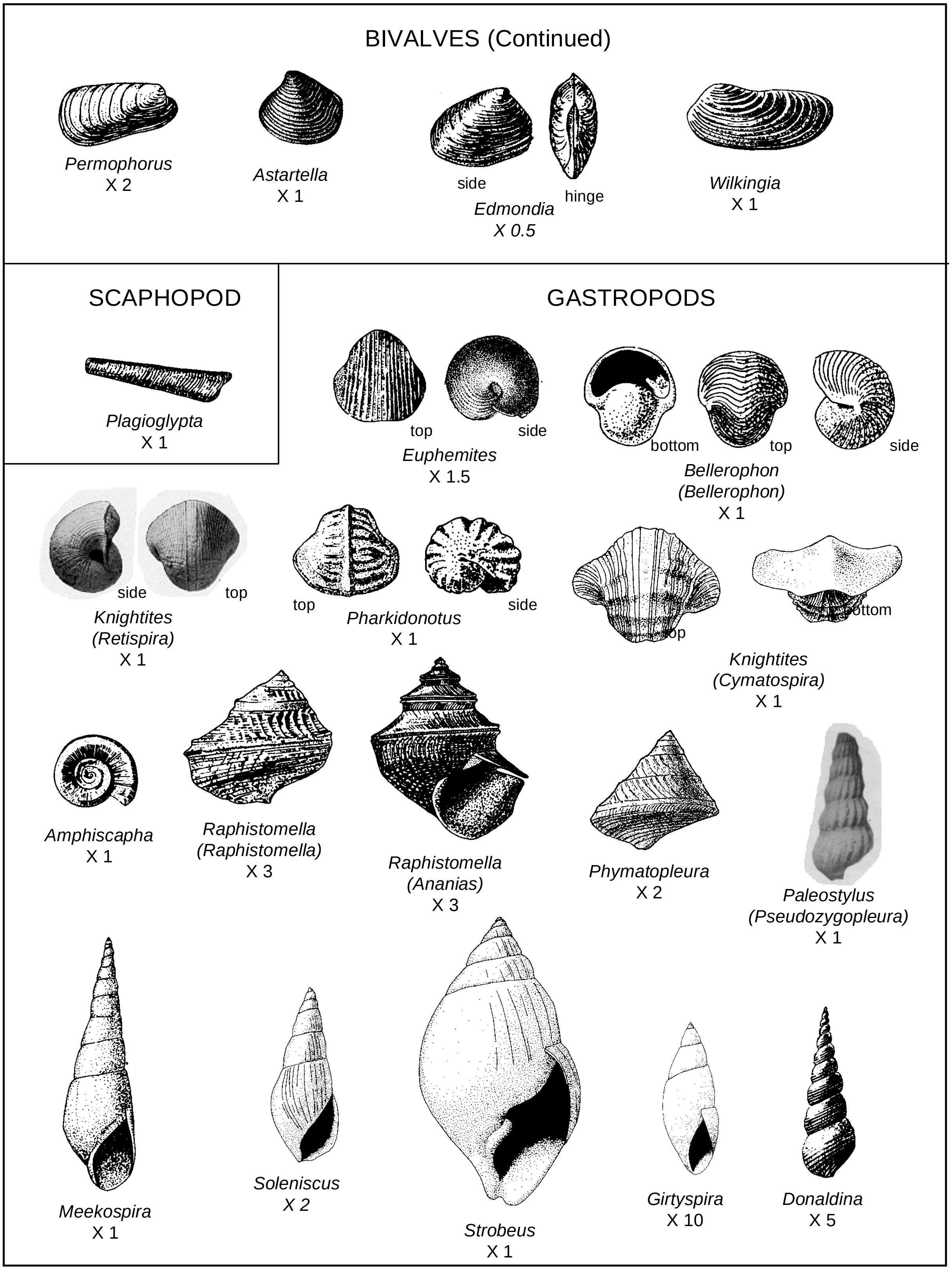


Figure 29. Continued



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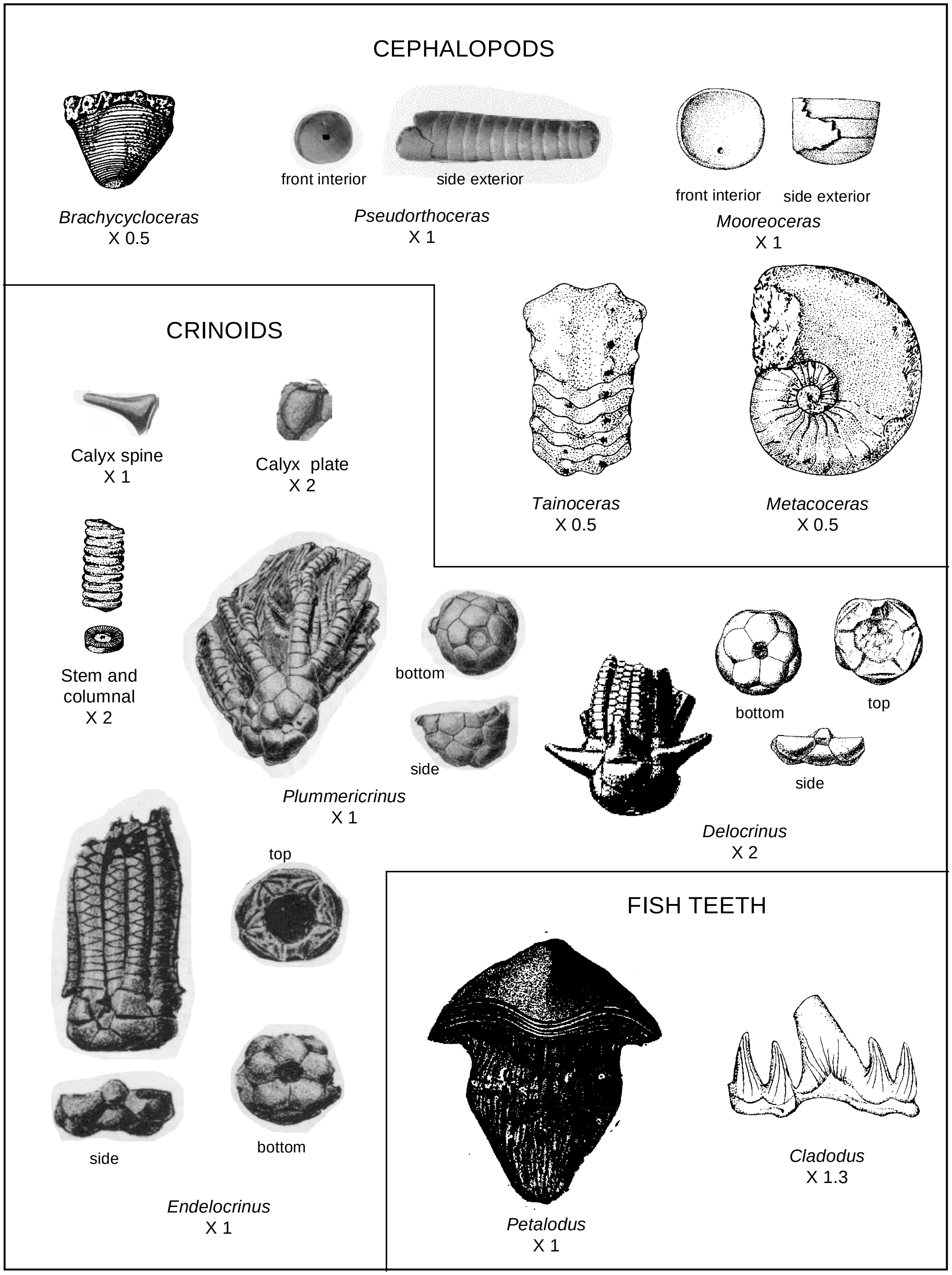

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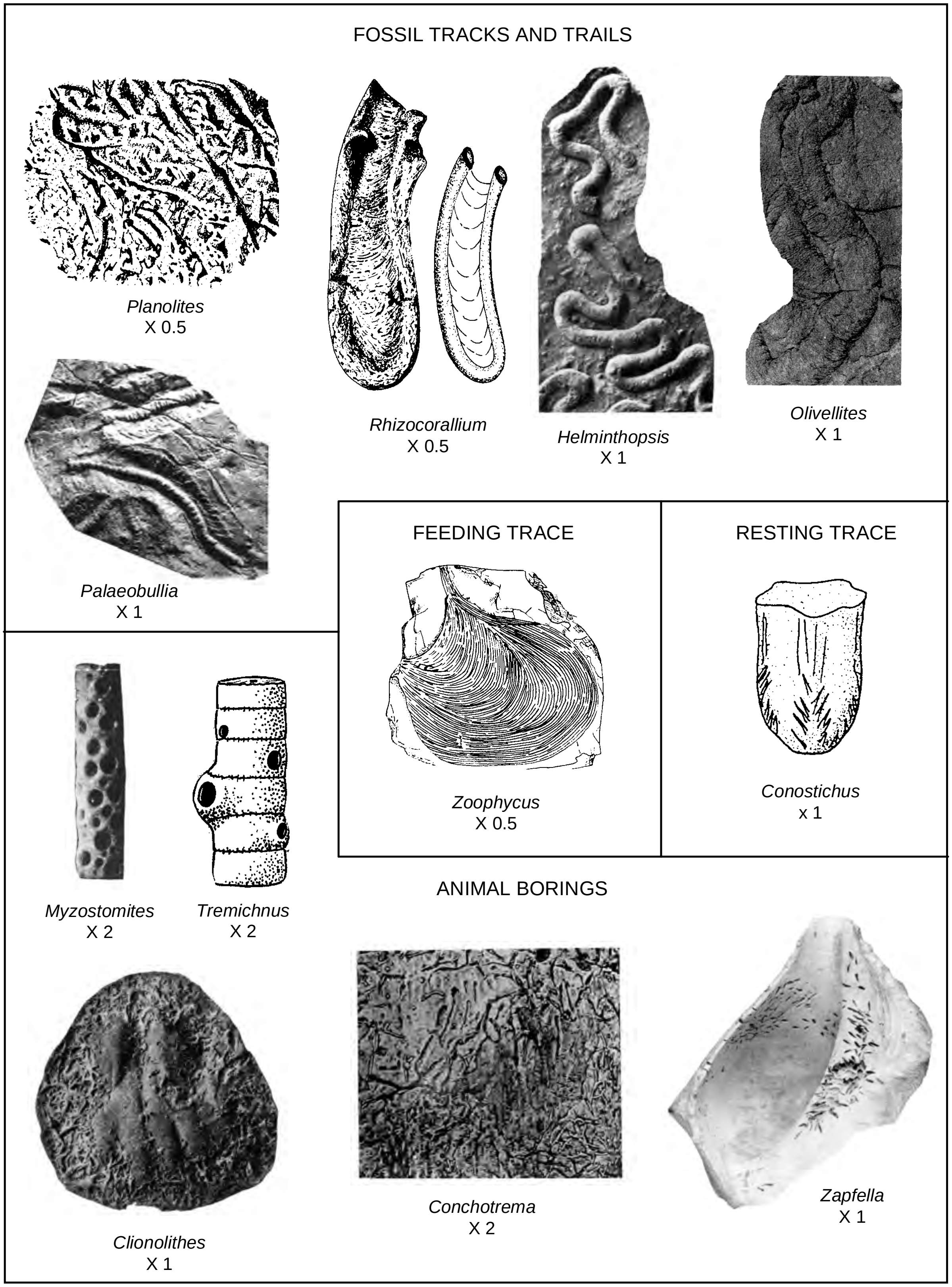


Figure 30. Some of the common trace fossils that can be collected from the Ames Limestone in western Pennsylvania.

(1986) recognized a variety of lithofacies in this layer, representing separate depositional environments.

The upper shale section of the Ames, which is highly weathered and not well exposed at this locality, typically contains abundant brachiopods (especially *Crurithyris* and *Composita).* *Crurithyris* commonly occurs in such abundance that it makes the rock look like a conglomerate. For this reason Saltsman (1986) called it *the Crurithyris shale* lithofacies. The rock itself consists of easily broken, buff-colored, slightly calcareous shales and other mudrocks, often containing a profusion of calcareous nodules, that represent the regressive phase of the Ames incursion. Fossil content decreases upward rapidly within this layer.

In most places where the Ames crops out, the collecting is almost unparalleled in western Pennsylvania. The easiest collecting occurs in the calcareous shales above and below the main limestone bed. These shales generally weather readily and the calcite shells, which are more resistant than the clay-rich matrix, readily erode out of the outcrop. In the limestone the rock and shells are equally resistant; therefore, the shells commonly break during attempts to remove them. Invertebrate shell fragments are commonly easy to find. More diligent searching is required to locate whole or almost complete specimens.

The most abundant marine invertebrate fossils in the limestones are species of the horn coral, *Stereostylus,* numerous kinds of brachiopods (especially *Crurithyris),* and the plates and columnals of crinoids. Many fossil forms, particularly molluscs, are more common and easier to collect, in the lower unit (Figure 29). The Ames Limestone also contains many ichnofossils (trace fossils) (Figure 30). *Conostichus,* interpreted as the resting trace of a jellyfish or sea anemone, occurs all through the Ames and can be collected near the upper surface. *Tremichnus* fossils, swollen pits in the surface of crinoid stems and plates, can be found almost anywhere crinoid debris is common. *Clionolithes, Conchotrema, and Zapfelia* are tiny borings made by sponges, worms, or barnacles in fossil seashells. And for those who prefer to use their hand lenses, calcareous smaller foraminifers such as *Tolypammina* commonly can be seen encrusting skeletal fragments.

Duquesne Shale And Limestone

The Duquesne interval, which occurs just below the nearly vertical sandstone cliff at the top of the cut, is limited in its extent here. The sandstone has cut out most of it, but the limestone can be seen at the north end of the road cut and blocks of black shale appear here and there in the talus under the vertical cliff face. The Duquesne interval is well known for its nonmarine fish fossils. Outcrops of the Duquesne limestone around the Pittsburgh area are particularly fossiliferous, containing large quantities of the worm tube *Spirorbis,* ostracodes, and conchostracans, in addition to the remains of bony fish and lungfish (Figure 31). The jet-black shale typically found above the Duquesne limestone also contains the remains of many fish. By carefully splitting the shale a collector may find hundreds of small, rhomboidal scales of the bony fish *Elonichthys,* as well as the spines and bones of this and other fish (Figure 31). It is possible at times to find patches of scales, indicating that the remainder of the fish may be present within the rock.

Plant Fossils In Sandstone

The sandstone at the top of the cut, regardless of the name chosen to label it, contains a

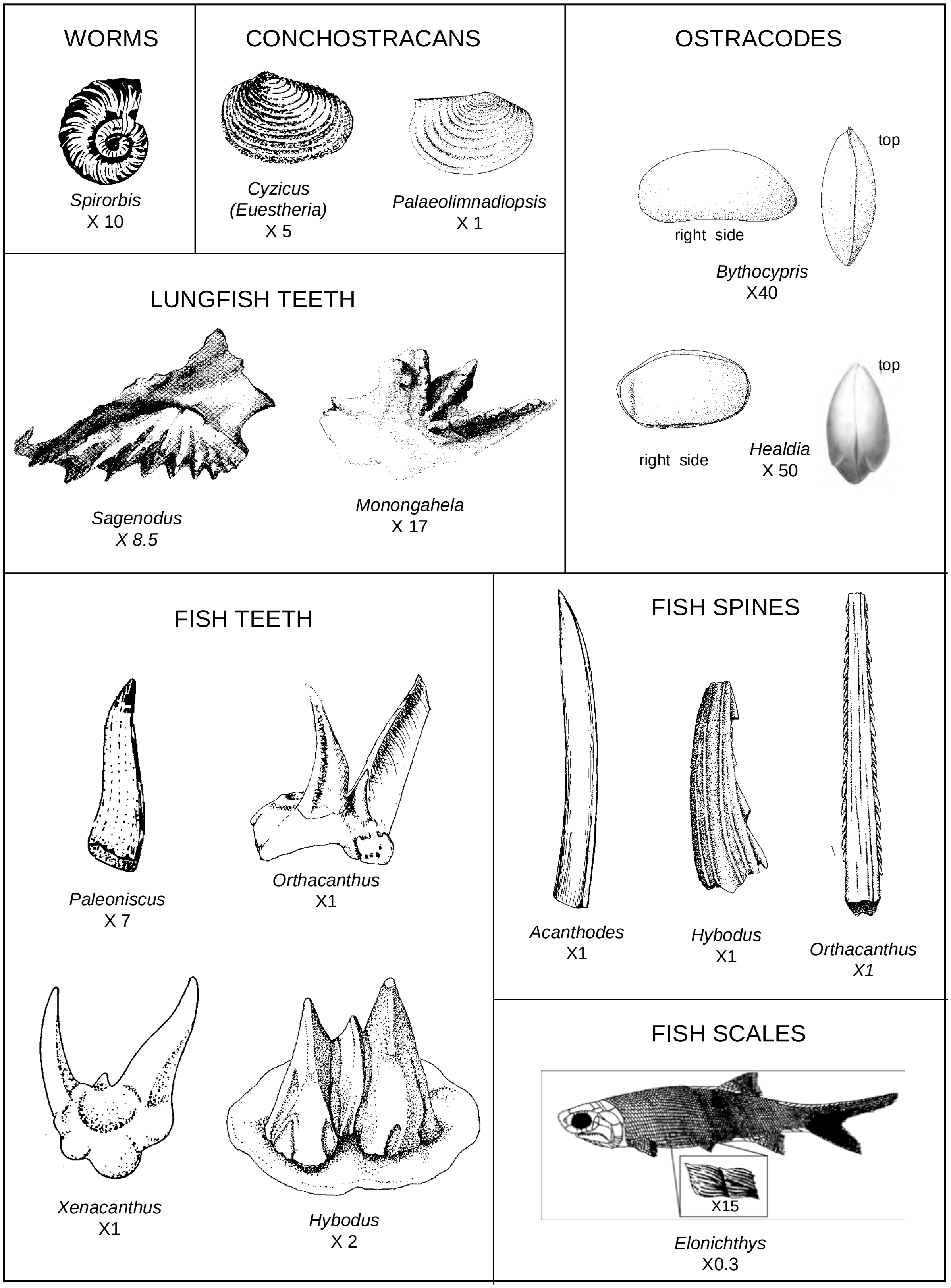


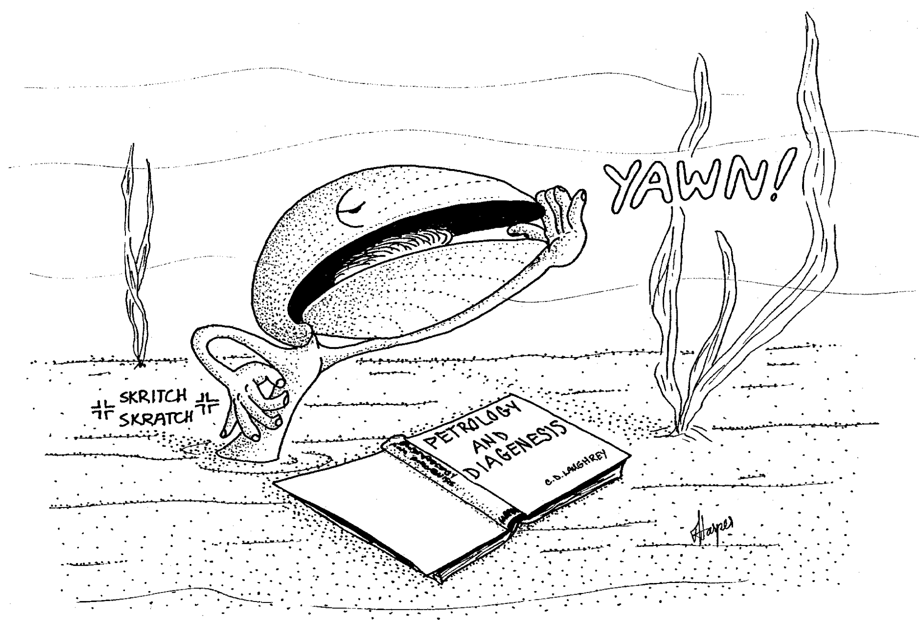
Figure 31. Some of the common nonmarine fossils that can be collected from the Duquesne limestone and shale in western Pennsylvania.

basal lag deposit of logs and other plant debris in association with abundant mud chips and slabs. These can be seen in many of the blocks laid out at the top of the terraced portion of the cut.

A WARNING

This roadcut, despite being well set back from the highway, is still maintained by the Pennsylvania Department of Transportation. Anyone wanting to visit to study the geology or collect fossils must first obtain permission by contacting the Engineering District 11-0 office in Bridgeville at (412) 429-5000.

TRACE FOSSILS WE'D LIKE TO SEE



#5 - A bored brachiopod shell

THE PETROGRAPHY AND GEOCHRONOLOGY OF THE MASONTOWN, PA KIMBERLITE INTRUSION: A SUMMARY

by
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INTRODUCTION

The Masontown kimberlite intrusion cuts through late Pennsylvanian and early Permian (?) sedimentary strata in the eastern portion of Fayette County, Pennsylvania near the village of Adah (Figure 32). The dike, which averages 3.3 ft (1 m) wide, has a vertical dip and a strike of N51°W. Sporadic surface outcrops can be found for about 1.9 mi (3 km) along strike. Exposures of the dike in the now abandoned underground coal mines were followed for over 3 mi (5 km) (Hickock and Moyer, 1940). A pre-existing fault zone, normal to the axes of the regional folding, provided a conduit for the intrusion (Roen, 1968).

The mineralogy of this kimberlite is consistent with other kimberlites found in the Eastern United States. The Masontown kimberlite contains sedimentary, metamorphic, and igneous rock xenoliths; some of the peridotite xenolith samples may represent rocks that occurred near the base of the continental lithosphere. Geochronology studies indicate a complex Mesozoic age for the kimberlite emplacement. See below.

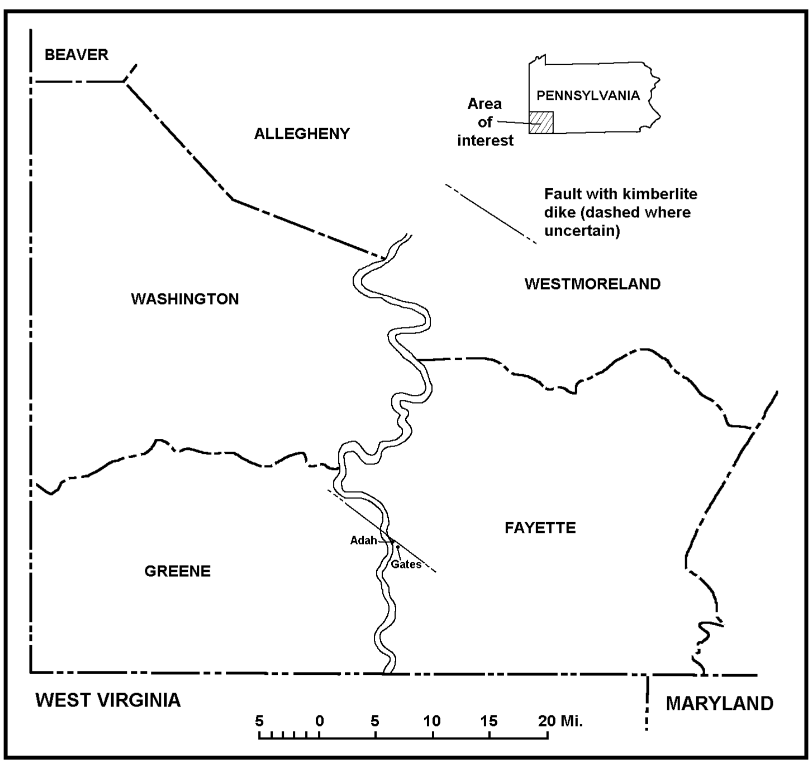

Figure 32. Map of southwestern Pennsylvania showing the location of the Masontown kimberlite dike.

This kimberlite was first described by Kemp and Ross (1907), followed by a more thorough report by Smith (1912), aided by many new exposures resulting from underground coal mining in the Pittsburgh seam. Sosman (1938) calculated an intrusion temperature of 550° to

600° C, based on laboratory coal coking experiments. Hickock and Moyer (1940) described the mineralogy of the kimberlite, as part of a Pennsylvania Geological Survey County Report. A more detailed description of the minerals in this kimberlite was provided by Hunter and Taylor (1983 and 1984) along with some trace element geochemical work on the phlogopite mica and garnets. A further petrographic description of the kimberlite and the contained xenoliths was given by Prellwitz (1994), and Prellwitz and Bikerman (1994).

GEOLOGICAL SETTING

The Masontown kimberlite intrudes through sedimentary rocks of the upper Pennsylvanian Monongahela Group, and the lower Permian (?) Waynesburg Formation (Figure 33). These beds consist mostly of shale, siltstone, sandstone, fresh-water limestone, and coal.

The attitude of the kimberlite dike is vertical, and strikes N51°W, in a pre-existing fault zone (Roen, 1968). Other parallel fracture zones can be seen in the immediate area, and one contains a small 2.5 in (6 cm) wide kimberlite dike that is about 100 ft (30 m) NE of the main dike. The main kimberlite dike averages 3.3 ft (1 m) wide (Figure 34). Outcrops are scarce, as the kimberlite decomposes at a faster rate than the surrounding country rock. There is no field evidence of contact metamorphism, except in an outcrop of the Waynesburg Coal, which was coked slightly from the heat of intrusion. Shale, siltstone, sandstone, and limestone contact areas show no mineral changes in thin section.

Some portions of the kimberlite have been extensively hydrated, while other parts of the dike appear fresh and unaltered. The more altered sections of the kimberlite weather and decompose more quickly than the unaltered areas; most "outcrops" of the kimberlite appear as trenches filled with red-orange mud, representing the decomposed dike. The few rare outcrops consist of the more competent unaltered portions of the dike (Figure 34). Occasional surface outcrops have been traced for more than 1.9 mi (3 km) (Prellwitz 1994), and over 3 mi (5 km) in

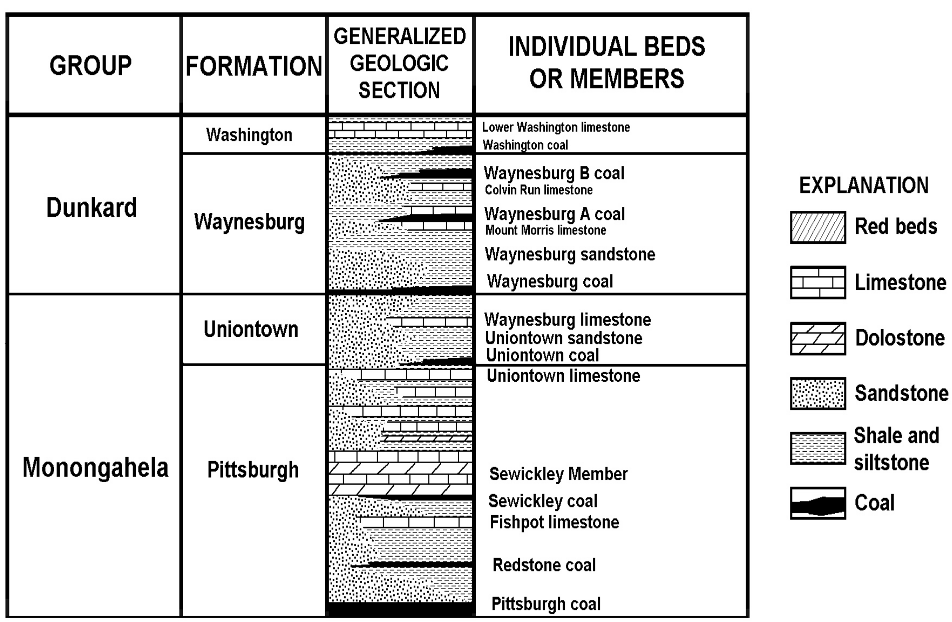

Figure 33. Generalized geologic column of the country rock exposed in the area of the Masontown kimberlite dike.

Figure 34. Photograph of an unaltered portion of the kimberlite dike in outcrop. Rock hammer for scale.

the abandoned underground coal mines. Northwest of the kimberlite surface outcrop area, the fault itself (devoid of igneous rock) can be seen in the south bank of Muddy Creek (Roen, 1968).

GEOCHRONOLOGY

Zartman and others (1968) reported the first K-Ar dates of the kimberlite at 368 ± 18 Ma, and 408 ± 20 Ma on coarse phlogopite. These dates are older than the country rock surrounding the kimberlite. Pimental and others (1975) obtained a K-Ar date of 184 ± 10 Ma on finer phlogopite mica, a date in agreement with field geological relationships. A phlogopite Rb-Sr date of 149 ± 5 Ma was calculated by Alibert and Albarede (1988). Prellwitz (1994), using K-Ar dating, reported 147 ± 1.5 Ma for the crystallization age of very fine-grained mica, and 353 ± 2.2 Ma for the coarsest phlogopite megacrysts. The larger phlogopite mica phenocrysts, with older dates of about 350 Ma, may be interpreted as an older crystallization event, or excess argon in the crystal lattice introduced in the magma stage.

Rb-Sr dates of 188 ± 0.7 Ma on coarse phlogopite and 170 ±1.3 Ma on fine phlogopite, and a four-point Sm-Nd scatterchron date of 145 ± 11 Ma using garnets, calcite and whole rock samples, were published by Bikerman and others (1997). Later, Bikerman and Phillips (2000), using laser step heating $^{40}Ar/^{39}Ar$ on single grains of fine phlogopite, calculated dates ranging from 161 to 176 Ma. Laser spot $^{40}Ar/^{39}Ar$ analyses of rims and cores of phlogopites in that study found no reproducible trend in the dates based on the location of the spots. The overall range of dates is from 149 to 167 Ma. The concentration of dates by different methods at about 180 and 147 Ma have led to the suggestion that the Masontown Dike is actually formed by two separate intrusions at those times (Bikerman and Phillips, 2000).

MINERALOGY AND PETROGRAPHY

The major minerals included in the Masontown kimberlite are olivine, phlogopite mica, titanium-rich ilmenite, magnetite, pyrope garnet, and perovskite in an aphanitic carbonate groundmass. The olivine and phlogopite both occur as phenocryst, xenocryst, and groundmass phase minerals. Alteration minerals include serpentine (from alteration of olivine) and secondary vein-filling calcite.

The olivines are magnesium-rich, and compositions range from Fo81 to Fo93. Most of the fresh, unaltered olivines are rimmed with magnetite. Many olivine crystals are partially or completely altered to serpentine, especially when in close proximity to secondary calcite vein material. The fractures, now filled with the calcite, probably provided a conduit for hydrating solutions to move through the kimberlite while still hot. Phlogopite mica occurs as phenocrysts and groundmass lathes, and is essentially unaltered, except for some minor local chloritization. Titanium ilmenite is seen as phenocrysts, and was mistaken in earlier reports as coal inclusions. The pyrope garnets, usually a deep blood red, are surrounded by a kelyphitic alteration rim, that is mostly chlorite, and very small perovskite grains (< 1 mm.) are scattered in the calcite groundmass.

Earlier reports (Hickock and Moyer, 1940) interpreted the calcite groundmass as an alteration product, produced by the contact of the ascending kimberlite with sedimentary carbonate beds. However, carbon and oxygen isotope evidence from a related kimberlite in Indiana County, PA indicate a primary, igneous carbonate source versus a sedimentary calcite (Deines, 1968). The initial $^{87}Sr/^{86}Sr$ ratios of the Masontown Dike whole rock [0.70513] and of an included vein calcite [0.70365] are similar to primary igneous and well below the normal limestone values (Bikerman and others, 1997). These findings are consistent with similar data from African kimberlites.

The texture of the kimberlite is porphyritic, with olivine up to 2 in (5 cm), phlogopite up to 1.5 in (4 cm), ilmenite up to 0.8 in (2 cm), and pyrope garnet up to 0.6 in (1.5 cm) as the phenocryst and xenocryst phases. The groundmass is aphanitic calcite, with small perovskite grains, and some rare apatite crystals. Small phlogopite mica lathes are found in the groundmass (up to 1 mm) and are usually aligned with the flow direction of the kimberlite. The small mica lathes are also seen in the contact area between a xenolith or large phenocryst, tangentially encircling the larger crystal. The large purple and blue crystals in Figure 35A are olivine with magnetite rims, the pale laths and blocks are phlogopite mica, and the groundmass is calcite. There is no evidence of hydration in this sample.

XENOLITHS

The xenoliths found in the Masontown kimberlite represent all three groups of rocks – sedimentary, metamorphic, and igneous. These xenoliths also provide a "window" to the rock types that would be encountered if one could drill a very deep core in southwestern Pennsylvania.

Numerous sedimentary xenoliths were found when kimberlite material was broken or slabbed. Many xenoliths of the Uniontown shale (Monongahela Group – see Figure 33) are located near the dike walls; sedimentary rock samples from greater depths include several samples of an oolitic limestone, and a very coarse immature quartz sandstone. Inferring what the host formation depth is from xenolith samples is very difficult, and interpretations are tenuous at best! Since there are no oolitic limestone occurrences at the surface in southwestern Pennsylvania, a depth lower than the Pennsylvanian System is inferred. A large cobble-sized xenolith of very coarse quartz sandstone was encountered in the kimberlite; the quartz grains are angular, and the sample shows evidence of some applied stress. The cobble is divided by slickensided surfaces, and contains a limestone xenolith with a Silurian coral fossil. This is an odd example of a xenolith within a xenolith in the kimberlite. This sandstone could represent the Lower Devonian Oriskany Sandstone.

The minerals in the granitic gneiss xenolith, shown in Figure 35B**,** are quartz, albite, biotite, and minor microcline. The sample from which the thin section was made clearly shows typical

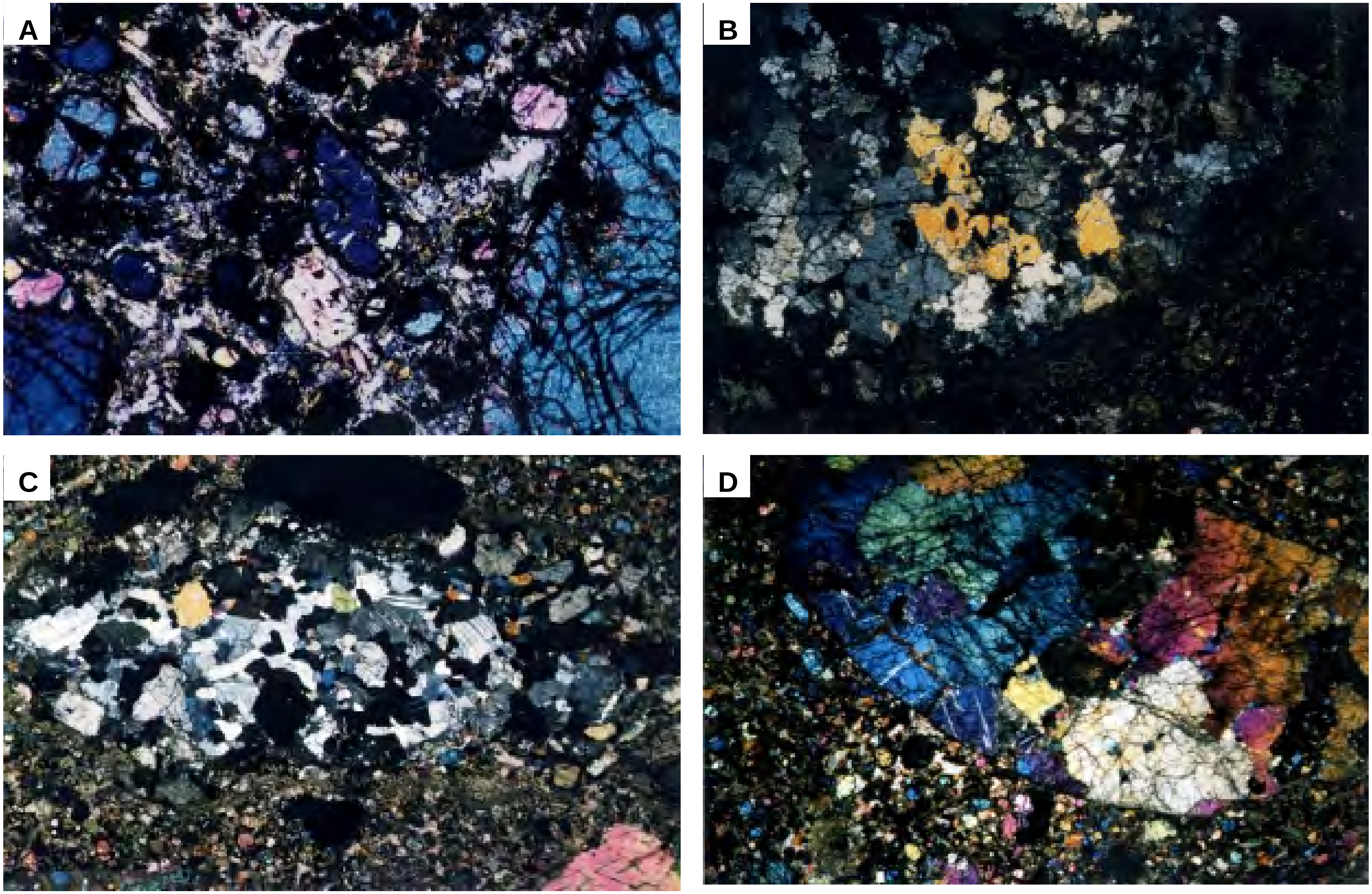

Figure 35. Photomicrographs of the Masontown Kimberlite, all under cross polarizers. A. Unaltered kimberlite. Field of view = 4 mm. B. Granitic gneiss xenolith in the kimberlite. Xenolith is 0.8 in (2 cm) long, and the quartz grains have an anomalous yellow color due to an overly thick slide. Field of view = 4 mm. C. Eclogite xenolith in kimberlite. Field of view = 4 mm. D. Spinel dunite xenolith in kimberlite. Field of view = 3 cm.

gneissic banding, and most probably represents the Grenville basement that is buried at least 3 mi (5 km) deep in southwestern Pennsylvania.

Another xenolith type commonly encountered in the kimberlite is eclogite. The minerals in Figure 35C are pyroxene and garnet; the many 120^{o} grain boundaries suggest a metamorphic rock. The composition of this mafic sample contrasts greatly with the granitic gneiss xenolith. This specimen may represent material in the continental crust that is below the MOHO boundary, and can be interpreted as the highest grade metamorphic rock type known.

The most common xenoliths found in the Masontown kimberlite are peridotites. One study examined over 30 samples (Prellwitz, 1994) and classified them into several groups including garnet lherzolites, spinel dunites, harzburgites, and dunites. The peridotite samples could represent material from the bottom of the lithosphere, at about 47 mi (75 km) depth. Temperature/pressure/mineral assemblage studies (Hunter and Taylor, 1984) indicate that the kimberlite itself could have originated at a 87.5 mi (140 km) depth, and may represent an asthenosphere melt. Figure 35D is a dunite containing olivine and a few very small blebs of spinel, which appear black in this figure. The olivine grains show a slight amount of undulatory extinction, indicating some strain was applied to this sample in its past history. Note the sharp contact between this xenolith and the surrounding kimberlite; there is little alteration, in contrast to alteration seen along the boundaries of more sialic xenoliths.

RECOMMENDED FURTHER STUDIES

As always, when a new study is initiated, and a particular topic is to be resolved, many new questions arise, which include:

- What is the carbon/oxygen isotopic composition of the calcite groundmass?
- Can the reason for conflicting old isotopic dates be resolved unambiguously?
- What are the radiometric dates on the xenolith minerals?
- How would trace element analysis on xenolith minerals compare with kimberlite minerals?
- Is there a variation in trace elements or isotopic ratios at the contacts?
- What would a true emplacement temperature be?
- Was this rock intruded as a liquid or a CO2 rich gas?

My new milkman is an unemployed geologist, so now I get my milk delivered in quartz!

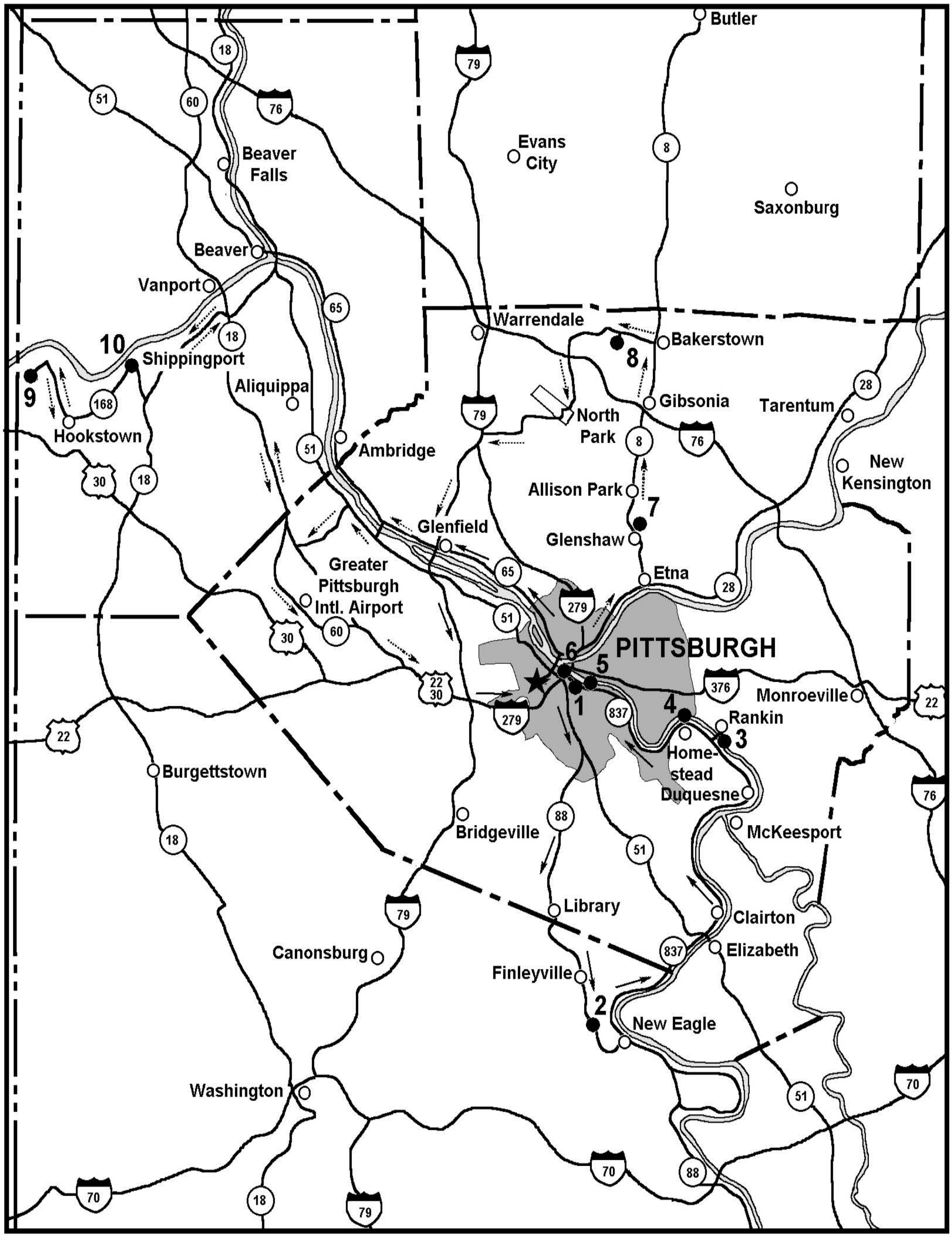

Figure 36. Map of the Field Conference routes and stops. Solid arrows indicate the route directions for Day 1 and dotted arrows indicate the route directions for Day 2.

ROAD LOG – DAY 1

Mileage Int	Cum	Description
0.00	0.00	**Leave** the Parkway Center Inn and **turn right** onto Parkway Center Dr.
0.05	0.05	At the traffic light **turn right** onto Green Tree Road.
0.95	1.00	At the stop sign **turn right** onto Woodville Avenue.
0.25	1.25	**Turn left** onto Minnotte Ct. This becomes Shaler St.
0.05	1.30	**Turn right** onto Wabash St. The street curves left and then enters PA 51.
0.05	1.35	**Turn right** onto PA 51 and get into the **left lane** (toward Uniontown).
0.20	1.55	Cross over the Parkway West (I-279 and US 22 and 30).
0.20	1.75	Outcrop to the left of the Birmingham unit (Conemaugh Group, Glenshaw Formation).
0.30	2.05	Get into the **left turn lane** and **turn left** at the traffic light onto Woodruff St.
0.20	2.25	South end of old tunnel of the Wabash RR on the right. The tunnel and old RR grade were going to be part of a busway to the airport, but plans fell through.
0.25	2.50	**Turn left** onto Merrimac St.
0.35	2.85	At the traffic light on the crest of the hill t**urn right** onto Grandview Ave.
0.10	2.95	Grandview Ave. in front of St. Mary of the Mount Church.

STOP 1. GRANDVIEW AVENUE OVERLOOK
Leaders: John Harper and Pete Briggs

This will be a brief stop. The buses will discharge the group near St. Mary of the Mount Church and turn around farther along Grandview Avenue. They will return to pick us up in approximately 15 minutes.

WELCOME TO PITTSBURGH, CITY OF THE FUTURE.

Once the mightiest industrial city in North America, Pittsburgh is now but a shadow of its former self. This is NOT a bad thing. Once cursed as loudly for its appalling environment (Figure 37) as it was praised for its importance to the growth and spirit of America, Pittsburgh, unlike the proverbial leopard, has been changing its spots. Gone are most of the steel mills and coke ovens. Gone are the relentless clouds of emphysema-causing black smoke and the asphyxiating smog. Gone is most of the urban blight that made the downtown area look like a shantytown. Gone are most of the atmospheric poisons that kept the hillsides bare of all but the hardiest vegetation. In their places are now a new financial, technological, educational, and medical economy, some of the best urban air in the country, a downtown area graced by some of the most innovative and beautiful architecture in the world, and hillsides and parks green with forests and gardens.

A PRODUCT OF ITS GEOLOGY

Throughout its history, Pittsburgh has been linked with its geology. Water provided transportation into and out of the city. Coal, originally used as a fuel for heating military garrisons and homes, became the backbone of the iron industry in the mid-1800s. Coke, formed wwhen coal is heated in the absence of oxygen, replaced charcoal in the iron-making process. As

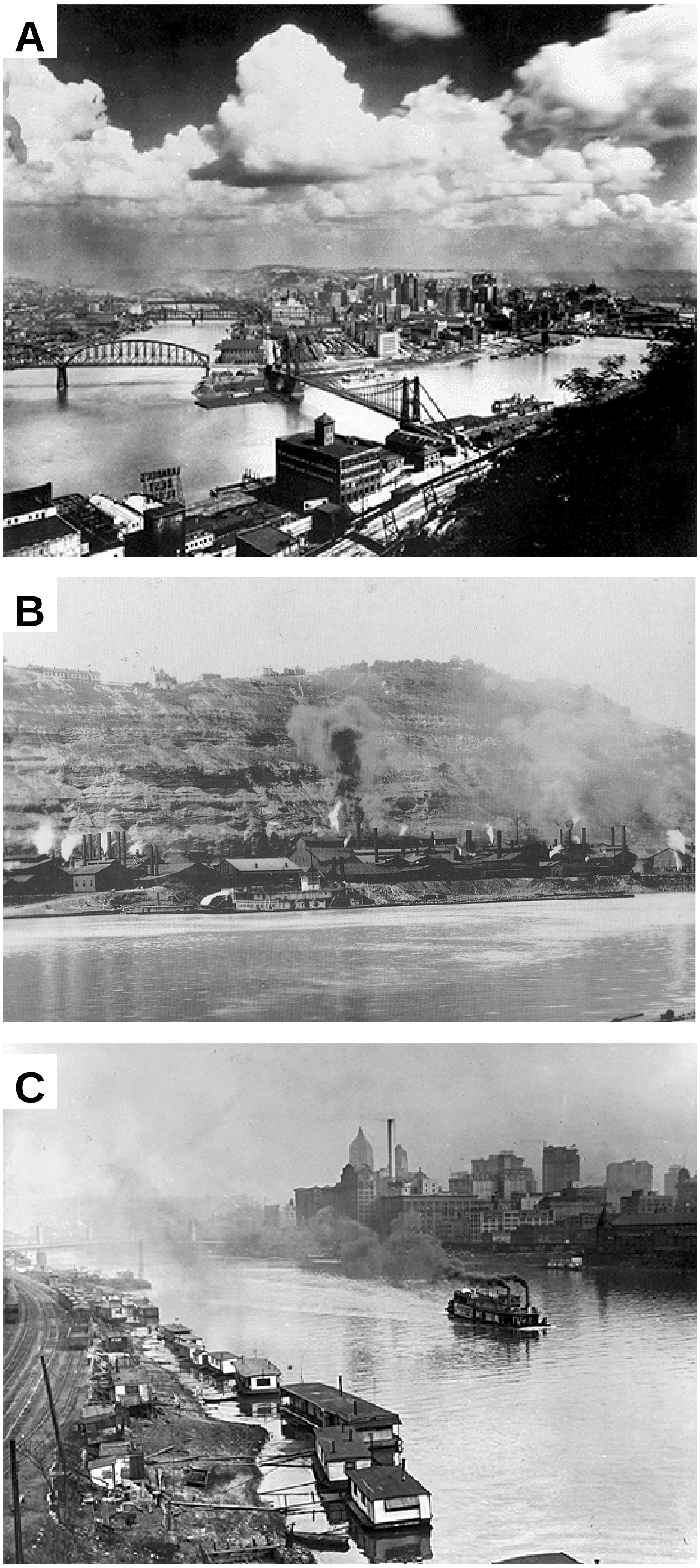

Figure 37. Pittsburgh as it once was – historical photos of Pittsburgh during its manufacturing heyday. A. The Point, ca. 1920. Notice the pall of smoke hanging over the city beneath the clouds. B. Mt. Washington, ca. 1900. The Clinton Iron & Steel Company occupied the Monongahela shore directly below us on the site currently occupied by the IC Light Amphitheater. At that time you could actually see the rock strata on the hillsides. C. A riverboat on the Allegheny River, ca. 1940. The skyscraper in the background almost obscured by smog is the Gulf Tower.

a result of the combination of abundant water and coal, Pittsburgh became the hub of iron and steel manufacturing in the US. Natural gas essentially was considered a waste product of the oil-exploration process until George Westinghouse suggested piping gas from Murrysville, 20 mi (32 km) east, into Pittsburgh for use as a fuel in manufacturing.

Pittsburgh's first natural resource, the three rivers, provided an abundance of water for drinking, manufacturing, and transportation. Boatbuilding was an important industry in the Pittsburgh area early on. In fact, the "New Orleans," the first steamboat to chug along on western waters was built in Pittsburgh in 1811 (Gardner, 1980). The only real problem with using the rivers for transportation was their tendency to all but dry up during the summer months, Pittsburgh's "dry season." Prior to construction of the lock-and-dam system on the rivers in the mid-1900s, the rivers often were shallow enough to ford in the summers. And during the spring thaws, heavy rainfall and snowmelt within the rivers' watersheds combined to create life-threatening floods about two or three times every decade.

The Pittsburgh coal, first mined here on Mt. Washington (formerly known as Coal Hill) around 1760, is considered the largest single mineral resource deposit in the world. The historical marker on the sidewalk across from the church commemorates the type locality of this great resource (Figure 38). If you were to climb down over the hillside, you would come across a few outcrops of the coal where it was left as pillars in mines dug well before World War II.

Because of the cyclic nature of western Pennsylvania's stratigraphy, almost every hillside had outcrops of sandstone, limestone, and claystone that could be quarried for building stone, lime manufacturing, and brick making, respectively. At depth, the sandstones often contained brine that, when evaporated, could be used as salt for seasoning and food preservation. Because of north-western Pennsylvania's glacial history, the floodplains and many of the terraces along the Allegheny and Ohio rivers consist of many tens of feet of sand and gravel; the sand, in particular, was excellent for making glass. Some of the terraces had plastic clays that were ideal for making pottery.

But geology can break, as well as make, a city. In contrast to Pittsburgh's many valuable geologic resources, there exist many insidious geologic curses. Steep hillsides slippery with unstable claystones and precariously hanging cliffs of fractured sandstone, stream valleys with seductively flat floodplains desir-able for building, and uplands underlain by mineable coals have cost Pittsburgh citizens and city fathers uncountable dollars and headaches in damage, and even lives, from landslides, floods, and mine subsi-dence. For example, the St. Patrick's Day flood of 1936, one of the most devastating in Pittsburgh's history, claimed numerous lives, injured more than 3,000, and left 100,000 people homeless (Lorant, 1988). In addition, local coals and carbonaceous shales commonly are rich in sulfide minerals, and

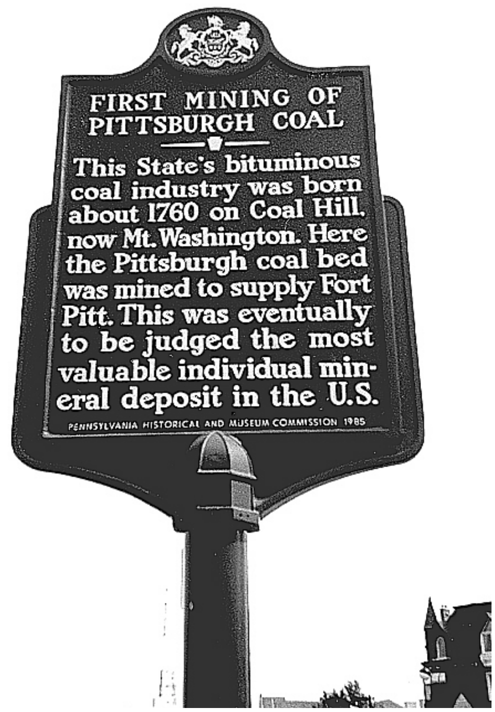

Figure 38. Historical marker on Grandview Avenue in Mt. Washington commemorating colonial mining of the Pittsburgh coal.

Figure 39. Panoramic photographs of the Pittsburgh area from Mt. Washington. Points of interest (letters and numbers) are listed in Table 4.

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shales and claystones often composed of expandable clays, that cause foundation heave. Black, organic-rich shales of the Conemaugh Group, especially those associated with the Brush Creek, Pine Creek, and Woods Run limestones (Figure 2), contain uranium minerals in concentrations high enough to create radon problems in structures built on them. And, of course, the people who came into the city to exploit its treasure trove of geologic resources didn't consider the consequences of dumping their industry's toxic wastes into the streams, or burying it in the permeable sand and gravel of the floodplains.

WHAT TO LOOK FOR

Figure 39 shows a panoramic view of the Pittsburgh area from where you are standing. Particular items of interest have been given letter or number designation tied to the list in Table 4.

The topography of Pittsburgh is undoubtedly its most striking geologic feature. Pittsburgh lies within the moderately dissected portion of the Appalachian Plateau Province known as the Pittsburgh Low Plateau Section. If you look out to the distant horizon you will see that the far hills blend together and appear to create a relatively flat plane. The highest hills in the Pittsburgh area generally are between 1100 and 1400 ft (335 and 427 m) above sea level. But this flat plane is highly dissected by numerous streams, including Pittsburgh's three rivers: the Monongahela directly below us, the Allegheny off to the north, and the Ohio off to the left. Because of this dissected topography most of the area, about 50-70% of it, consists of slopes. That leaves only 30-50% for the kinds of flat areas necessary for relatively stable construction of roads, buildings, and other structures. About half of that remaining total is floodplain – great for farms, parks, and woodlands, but potentially disastrous for residential, commercial, or industrial development.

In the Late Cenozoic western Pennsylvania was a low, rolling plain with meandering streams winding lazily in wide valleys only a few hundred feet lower than the highest elevations. Then during the Pleistocene, the rivers cut down into the countryside, not always along their former channels. This was accompanied by increased lateral cutting, resulting in wide valley floors that meander across the plateau.

During the Pleistocene glaciers dammed the Monongahela River, the main river in the Pittsburgh area at that time, and at least twice formed a huge imponded drainage called Lake Monongahela (Figure 23). Sometime after the first glaciation ended, the rivers began cutting down into the surrounding bedrock, creating new channel segments and leaving remnants of the old valley floors stranded above the new valley floors. The remnants of the pre-glacial valley floors, and the ancient floor of glacial Lake Monongahela, occur as flat areas along or near the larger rivers and their major tributaries at elevations about 200 to 300 feet above present stream levels. Some people call

Table 4. Points of interest shown in Figure 39.

Letter/number designation	Description
A	McArdle Roadway
B	Parker Strath at Shadeland
C	Carnegie Science Center, USS Requin, and Pittsburgh Voyager
D	New Pittsburgh Steelers football stadium
E	Riverview Park with Allegheny Observatory
F	Monument Hill, with Community College of Allegheny County
G	Three Rivers Stadium
H	The Point, with the Point Fountain
I	Fort Pitt Museum at Point State Park
J	Fort Pitt Bridge
K	Fort Duquesne Bridge
L	New Pittsburgh Pirates baseball stadium
M	Pittsburgh Hilton Hotel
N	Parker Strath at Troy Hill
O	Fifth Avenue Place
P	CNG (Consolidated Natural Gas) Tower
Q	PPG Tower
R	National City Center
S	PNC (Pittsburgh National Corporation) Tower
T	Gulf Tower
U	USX Tower
V	One Mellon Center
W	One Oxford Center
X	Parker Strath in Oakland, with University of Pittsburgh
Y	New Public Safety Building
Z	Sheraton Station Square Hotel
1	Smithfield Street Bridge
2	Station Square with Freighthouse Shops
3	Duquesne Bluff with Duquesne University
4	New County Jail
5	Panhandle Bridge (former railroad bridge converted to LRT)
6	Birmingham Bridge

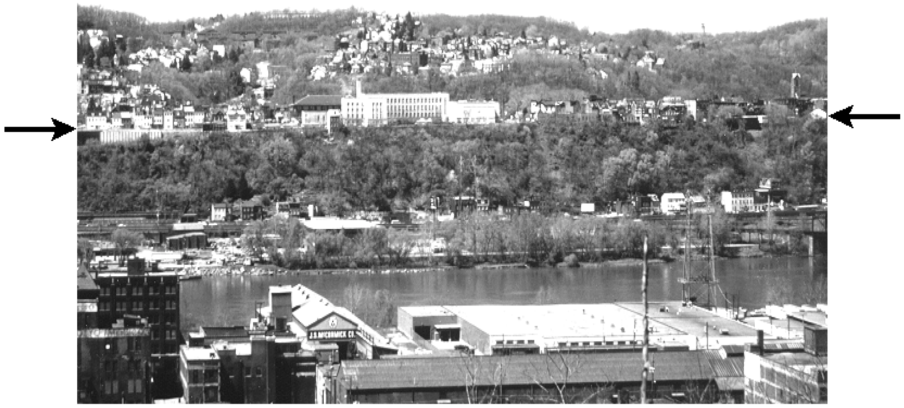


Figure 40. Troy Hill, on the north shore of the Allegheny River, is a good representative of the pre-glacial Allegheny River terrace (Parker Strath) in Allegheny County.

the highest of these remnants the Parker Strath. The remnant terraces often are very prominent features that can be identified on a topographic map by their very flat upper surfaces, in contrast to the adjacent hills. They show up on Figure 39 as items B, F, N, and X. These areas were built up with layers of clay, silt, sand, and some gravel derived from the sedimentary rocks of the surrounding Allegheny Plateau by lacustrine deposition. This unconsolidated material is known as the Carmichaels Formation.

Troy Hill on the north side of the Allegheny River (Figure 39, N) arguably is the best representative of these terraces in the Pittsburgh area. From a distance it looks like someone took a large knife and cut a flat-topped chunk out of the northern escarpment of the Allegheny River valley (Figure 40). Along the Ohio, the terrace is widest on the north side of the river. It occurs at Monument Hill on the North Side (Figure 39, F) and at Shadeland farther down the river (Figure 39, B).

In cutting new channels, the streams took completely new courses in some localities, leaving behind cutoff meanders high above present stream level. A well-developed abandoned channel occurs in the eastern part of Pittsburgh (Figure 41). A mile-wide, flat valley leaves the Monongahela Valley at Rankin, passes through Swissvale, Edgewood, and Wilkinsburg, follows Frankstown and Penn Avenues through Homewood to East Liberty and Shadyside, and then passes through Oakland back to the Monongahela River through Schenley Park. This abandoned meander of the Monongahela can be seen in the vicinity of the Cathedral of Learning at the University of Pittsburgh (Figure 39, X). The Cathedral of Learning sits on caissons that penetrate up to 40 feet of Carmichaels Formation sand, gravel, sandstone boulders, and layers of laminated plastic clay. The abandoned meander has provided easy access to the railroad main lines and several of Pittsburgh's principal east-west through streets. It is the only direct natural overland route toward downtown Pittsburgh from the east. As a result, this comparatively narrow valley was urbanized far earlier than the higher areas of Greenfield, Squirrel Hill, and Hazelwood to the south or the equally high elevations at Allegheny Cemetery, Stanton Heights, Highland Park, and the Veterans Administration Hospital to the north.

Although the Pleistocene glaciers never reached as far south as Pittsburgh, their influence on the area has been profound. Glacial meltwaters filled the bottoms of the Allegheny and Ohio River valleys with silt, sand, and gravel, up to 80 ft (24 m) in the Pittsburgh area. After the retreat of the last glacier, the volume of water and sediment coming down the rivers declined. The rivers cut new channels into the glacial valley-fill deposits, reworking the sediments in several areas. The results are low terraces, including the modern floodplain, about 10 to 30 ft (3 to 9 m) above present river level.

The porous gravely alluvium that underlies the Allegheny and Ohio valleys and the Golden Triangle (Figure 1) is the primary source of ground water in Allegheny County). This water supply is constantly given the erroneous names "Pittsburgh's Underground River" and "Pittsburgh's Fourth River". In fact, it is not at all an isolated body of water separate from the rivers above it. The "underground river" does not really exist because it is simply a part of the existing rivers. The fountain at the Point (Figure 39, H) is probably Pittsburgh's most famous use of the glacial valley-fill aquifer.

0.70 3.65 Buses turn around at end of Grandview Avenue and return to pick up conferees.

Leave Stop 1.

0.10 3.75 At the traffic light **turn left** onto Merrimac St.

0.40 4.15 **Turn right** onto Woodruff St.

0.40 4.55 **Turn left** onto PA 51, Saw Mill Run Blvd., and pass under the old Wabash RR trestle.

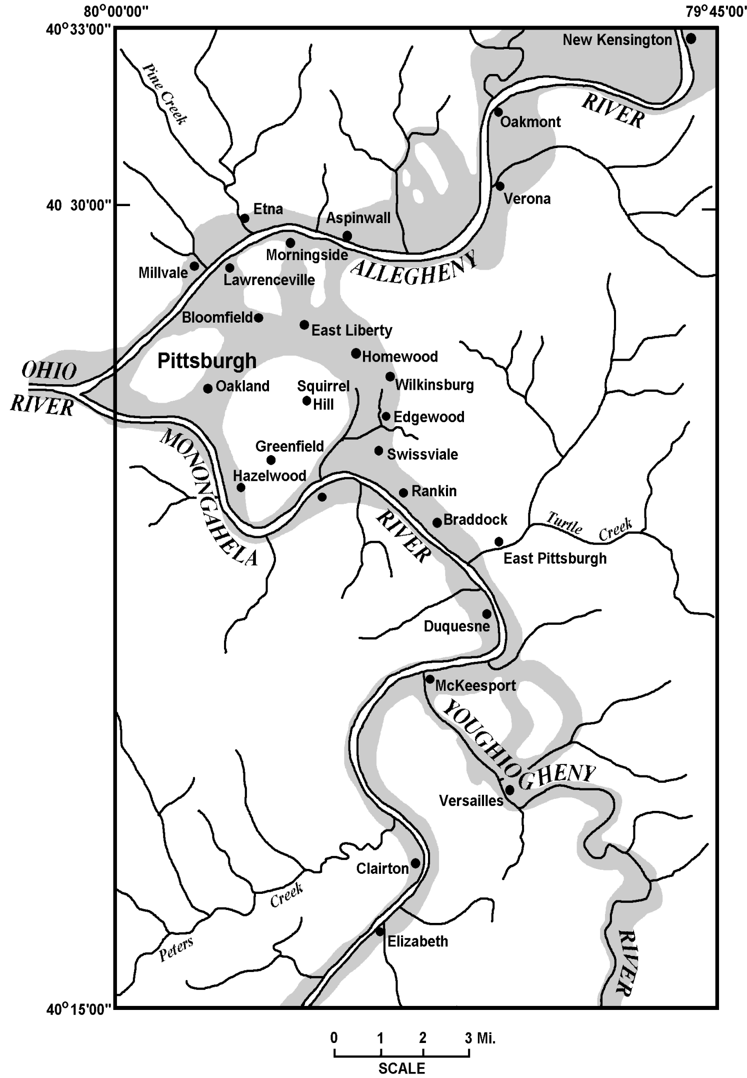


Figure 41. Pre-glacial channels and high-level terraces (shaded) on the lower ends of the Monongahela, Youghiogheny, and Allegheny River valleys. Modified from Leverett, 1934.

0.10 4.65 The vertical rock wall on the left is Morgantown sandstone. This is the scene of a devastating rockfall that occurred in 1983. Several people were killed (see Figure 42).

0.80 5.45 Traffic light at Warrington Ave. Pass under the busway and LRT bridges and **continue** on PA 51

0.15 5.60 Crossing over US 19 truck route, West Liberty Ave. The Liberty Tubes are on the left.

0.65 6.25 Good view of Saw Mill Run on the right. This stream commonly creates flash flood problems in the valley.

1.75 8.00 Traffic light at the intersection PA 51 and PA 88, Library Rd. **Bear right** onto PA 88.

Figure 42. Large destructive rockfall in the undercut Morgantown Sandstone along Saw Mill Run Boulevard between the Fort Pitt and Liberty tunnels in 1983. The rockfall occurred when vibrations set up by blasting loosened a large section of the exposure. The rockfall resulted in two deaths and one serious injury. Notice the rear portion of the car protruding from beneath a large boulder-size piece of rock on the right (at arrow). Photo by Helen Delano.

0.55	8.55	Traffic light at the intersection with McNeilly Rd. **Continue** straight on PA 88.
1.40	9.95	Traffic light at the intersection with Castle Shannon Blvd. **Continue** straight on PA 88.
0.80	10.75	Traffic light at the intersection of PA 88 and Connor Rd. (the Yellow Belt). **Continue** straight on PA 88.
0.50	11.25	Columbia Gas of Pennsylvania facility on the left. Notice the compressed natural gas filling station. This is the first such public "gas" station in the Pittsburgh area.
0.50	11.75	Traffic light at the intersection of PA 88 and Broughton Rd (the Yellow Belt) and Bethel Church Rd. **Continue** straight on PA 88
1.10	12.85	Traffic light at a 5-way intersection - Baptist Rd. to the left, Corrigan Rd. (the entrance to South Park) straight, PA 88 half right, and South Park Rd. to the right. Get in the **middle (straight) lane** and **continue** on PA 88.
1.55	14.40	Traffic light at intersection of PA-88 and Logan Road. **Continue** straight on PA 88.
1.15	15.55	Supposed RR crossing is actually a crossing for the Library branch of the LRT.
0.15	15.70	Entering the village of Library. Clifton Rd. (the Orange Belt) intersects from the right. **Curve left** and **continue** on PA 88

0.35	16.05	Overpass of the former Montour RR just after the Library post office (on the right). Off to the left here was the mine portal of the Montour #10 mine in the Pittsburgh coal at the base of the Pennsylvanian Monongahela Group. Abandoned in 1979, the mine flooded. In 1980 mine seals failed and the down-dip Montour #4 mine was flooded, forcing premature closure. Rising mine waters in that mine resulted in failure of mine-roof support with the resultant destruction of several school buildings and damage to other buildings.
0.30	16.35	Intersection with Brownsville & Library Rd. to the left. **Curve right** and **continue** on PA 88.
0.15	16.50	Entering Washington County.
0.75	17.25	Trax Farm Market on right.
0.70	17.95	On the right is Mineral Beach swimming pool. Here, on the crest of the Amity anticline, the Pittsburgh coal bed was mined at the surface. Thus the name Mineral Beach. **Continue** straight on PA 88.
1.70	19.65	Entering the village of Finleyville.
0.10	19.75	**Bear right** at the stop sign and **continue** on PA 88.
0.10	19.85	In Finleyville, **bear left** and **continue** on PA 88.
0.60	20.45	On the right you can see the old embankment of the abandoned interurban line to Charleroi. Bits and pieces of the old right of way can recognized, mostly on the left for the next 2.5 miles.
1.25	21.70	Pass under the Norfolk Southern RR bridge.
1.45	23.15	**Turn right** onto Ginger Hill Rd. and then pull into the construction area.

STOP 2. **MON-FAYETTE EXPRESSWAY CONSTRUCTION** SITE

Leaders: Terry L. Downs, P.G. and Bruce M. Camlin, P.G.

DESIGN AND CONSTRUCTION OF DUAL BRIDGES OVER A RAILROAD TRESTLE IN AN AREA UNDERLAIN BY COAL MINES INTRODUCTION

The Mon-Fayette Transportation Project includes the construction of a new 17 mi (27 km) toll highway from I-70 to PA Route 51 by the Pennsylvania Turnpike Commission (PTC). The toll road has been divided into fourteen final design/construction sections.

Dual bridges are being constructed across the valley of Mingo Creek and Froman Run near the intersecting boundaries of Carroll, Union, and Nottingham Townships in Washington County as part of Construction Section 52G (Figure 43). Bedrock units are members of the Pittsburgh Formation of the Monongahela Group and the Casselman Formation of the Conemaugh Group (Figure 44). The Pittsburgh coal has been mined by underground methods on both sides of the valley just above the valley bottom and there are active mines that continue to operate adjacent to the area.

The nine-span southbound and eight-span northbound structures will be approximately 2,550 ft (777 m) long (Figures 45 and 46). The structures will carry traffic across the two streams, PA Route 88, and the existing 200-ft (61-m) high Wheeling & Lake Erie Railroad bridge at a height of approximately 255 ft (78 m). Two bridge alternatives, consisting of a dual concrete box design and a dual steel continuous composite welded multi-girder bridge, were included in the construction bid package but the steel alternate was selected for construction. The project was designed by Gannett Fleming, Inc. (1998), who also did the geotechnical investigation and

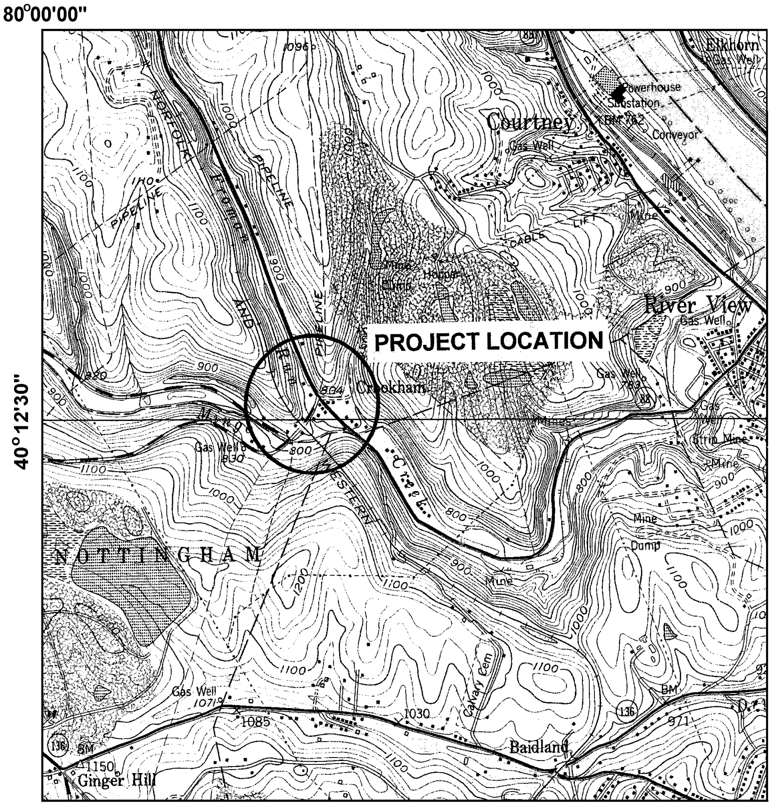


Figure 43. Location of the Mon-Fayette Expressway project area at Stop 2 on the Monongahela quadrangle.

foundation design.

GEOLOGY AND MINING

The Pittsburgh Formation (Figure 44) consists of cyclic sequences of shale, limestone, sandstone, and coal; the Pittsburgh coal is the basal unit of the Monongahela Group. The upper portion of the Casselman Formation consists of claystone, siltstone, limestone and sandstone. There are residual soils at the top of the valley slopes; colluvial soils are located on the lower portion of the valley slopes; and the valley floor is overlain by alluvium.

The top of the Pittsburgh coal ranges from elevation 776 ft± (237 m±) to elevation 788 ft± (240 m±). The seam varies from 8 to 12 ft (2.4 to 3.7 m) thick and underlies most of the piers and abutments. Much of the coal in the

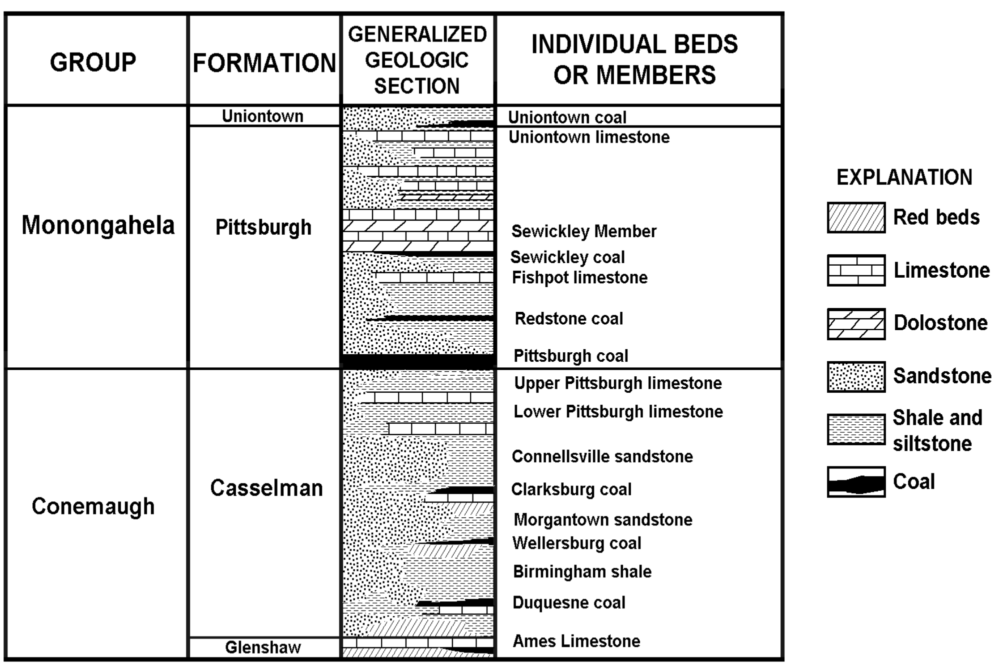


Figure 44. Generalized geologic column of the exposed rocks in the project area.

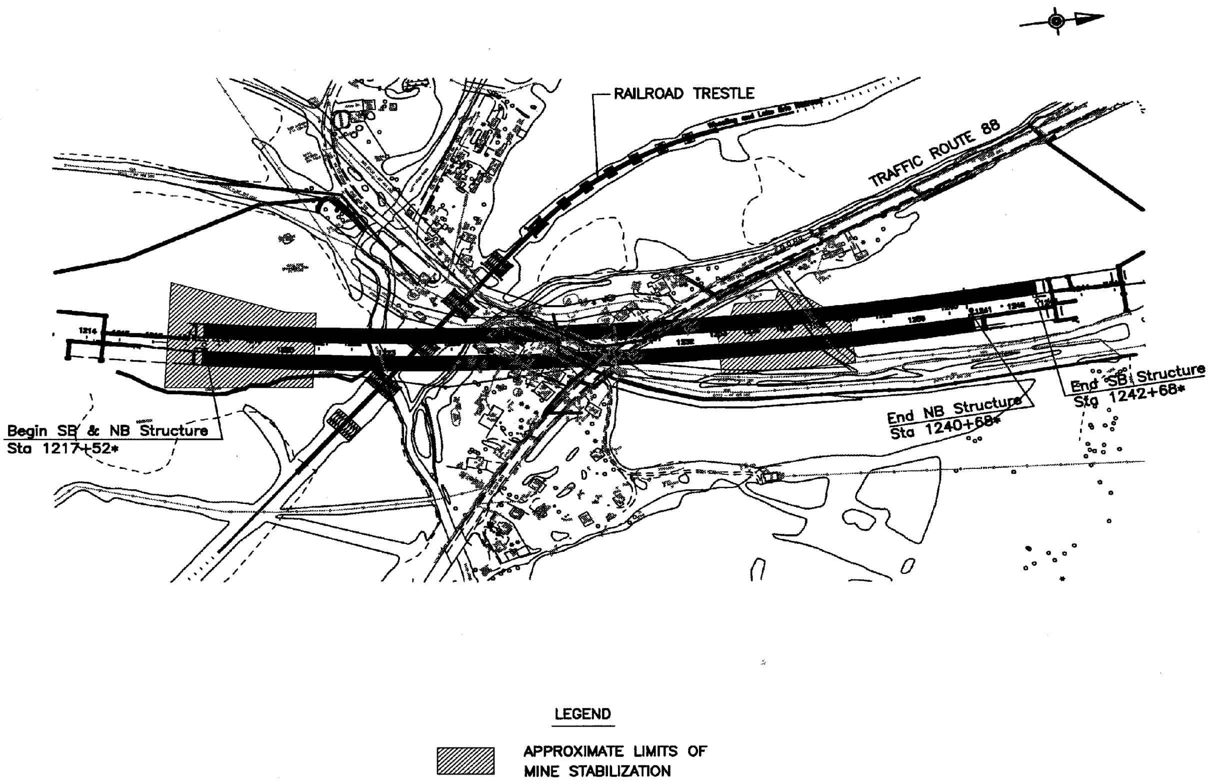


Figure 45. Plan view of the project area.

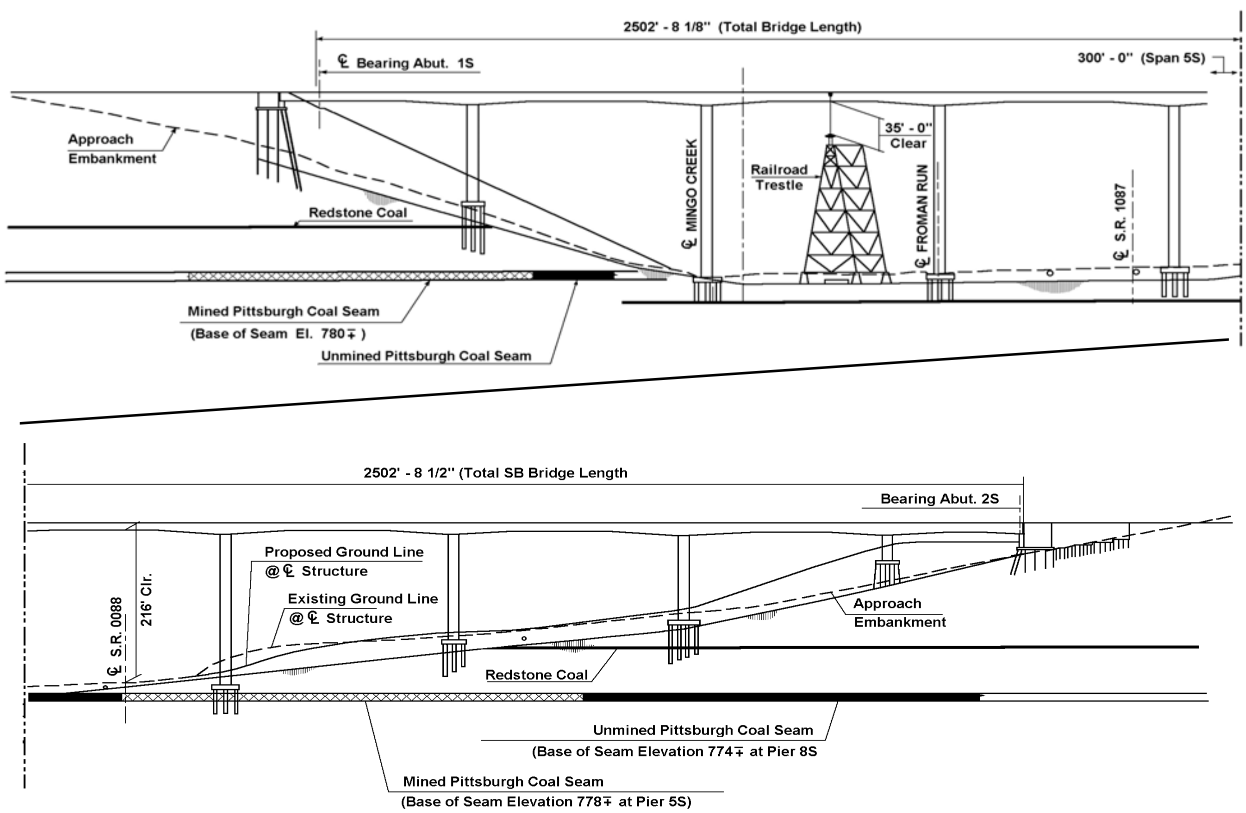


Figure 46. Profile of the project from south (top left) to north (bottom right).

valleys around Mingo Creek and Froman Run has been eroded. As with most of the surrounding area, the coal seam has been extensively deep-mined.

The bedrock over the Pittsburgh coal extends up into the Sewickley Member in the area of the bridges.

Mining of the Pittsburgh coal in the project area has been performed using room and pillar methods. This type of mining typically removes around 50% of the coal present. Most of the area was also retreat mined, which typically extracts as much as 85% of the coal and collapses overburden into the mine void. A significant portion of the coal seam has also been left unmined. There is an active haulage way just south of the southern abutment area that provides access to actively mined areas. The rock overburden above the mine level within the deep-mined limits contains broken and rubbled zones, delaminations along bedding planes, and vertical and sub-vertical fractures characteristic of a collapsed mine.

Mine collapse is likely in areas where underground mining has been performed. Collapse of underground mines causes the formation of strains in the bedrock overburden and results in fracturing and displacement of the strata.

FOUNDATION INVESTIGATION

Sixty-three borings were drilled for the bridge investigation. Standpipe piezometers were installed to evaluate groundwater conditions. Representative soil and rock samples were tested in the laboratory for classification, strength and durability.

Three borings that penetrated voids in the Pittsburgh coal were reamed to a nominal 4-in (10 cm) diameter to permit viewing by means of a borehole television camera system. The borings were viewed using axial (down-the-hole view) and right angle (side view) camera attachments. Openings larger than 10 in (25 cm) were viewed using a right angle spotlight attachment. The spotlight provided sufficient illumination to bedrock features within a horizontal distance of approximately 20 ft (6 m). The borehole camera study confirmed the depth of the mine horizon reported on the boring logs and revealed that the mine roof was collapsing and that there was water in the mine voids north of PA Route 88.

BRIDGE AND ROADWAY APPROACHES ABOVE MINED AREAS

Construction on the valley slopes above the mined areas includes four abutments, four piers and two roadway approach embankments (Figure 46).

Before construction, the approximate original ground surface varied from elevation 780 ft (238 m) MSL on the valley floor to elevation 985 ft (300 m) at the abutment locations. The *in situ* soils on the slopes consisted of soils mapped as ancient landslide colluvial deposits by Pomeroy and Davies (1975). This was confirmed by field observations of hummocky terrain and steep slopes. It was determined from test borings that these unstable clayey silt and silty clay soils varied from 3 to 20 ft (0.9 to 6 m) in depth.

Approach Embankments

Approach embankments, sloped at 2H:1V, were constructed to support the bridge abutments at the final roadway grade elevation. The approach colluvial soils were removed from the foundation areas before the approach embankments were constructed. The southern approach embankment is keyed into the bedrock surface with a 40-foot toe bench, whereas a 25-ft (7.6-m) wide toe bench was designed for the northern end. A rock blanket was constructed over the embankment slope for stability.

A steepened rock embankment was constructed between the two abutments on the northern end to meet bridge clearance requirements. However, the top 3 ft (0.9 m) of this area was to be constructed of embankment material to allow for the installation of guide rails.

Abutment and Wingwall Foundations

The bridge abutments and wingwalls are supported by steel end-bearing HP 14x89 H-piles driven through the approach embankments to refusal.

Pier Foundations

With one exception where H-piles were required, all the piers on the valley slopes are supported by 4.5-ft (1.4-m) diameter concrete caissons bearing on directly on bedrock. Many caissons extend through soil before rock is encountered.

BRIDGE PIERS IN THE VALLEY BOTTOM

The valley bottom is relatively flat (elevations 780 to 790 ft [238 to 241 m] MSL) and overlain by 10 to 15 ft (3 to 4.6 m) of alluvial soils. Four piers were constructed in this area. The alluvium consists of clayey silts and silty sands that are stiff to medium stiff and loose to medium dense respectively.

Bedrock in the valley is subject to differential weathering and proliferated with zones that are highly fractured. Borings in this area penetrated into the Connellsville sandstone (Figure 44).

Because the high piers in the valley bottom are located below the coal and mines, they are constructed on 54-in (137-cm) diameter caissons bearing on bedrock. The dimensions of the massive caisson caps are variable, ranging up to 40 by 30 ft (12 by 9 m), with concrete foundations up to 6 ft (1.8 m) thick.

MINE SUBSIDENCE REMEDIATION

Stabilization of Abandoned Deep Mine Workings

To maintain the long-term integrity of the founding rock materials for supporting the structure, a mine stabilization program was recommended to prevent future collapse and settling of the overburden. Since much of the mine appeared to have been collapsed, a stabilization scheme consisting of the injection of grout to the mine level was recommended. Stabilization was performed using low strength mixtures of cement, fly ash, aggregate, bentonite or admixtures placed through boreholes drilled from the surface. This method attempted to completely fill all remaining mine voids and penetrate and consolidate gob materials. The use of bentonite in the grout mix reduced shrinkage and helped maintain grout integrity in sections of the mine containing water. The stabilized area was isolated by a thicker barrier grout placed around the perimeter in injection boreholes spaced up to 10 to 15 ft (3 to 4.6 m) apart. In-place coal provided the perimeter containment in certain areas. Production grout was to have been laced inside the stabilization area from injection boreholes spaced 30 ft (9 m) apart. Secondary borehole locations provided a similar spacing for both barrier and production grouting to confirm grouting and provided additional injection points if needed. Verification drilling of materials at the mine level following completion of the grouting was also recommended to verify the grouted conditions and retrieve samples for testing.

Criteria established by the PTC to delineate the extent of stabilization measures are as follows:

- mined-out areas below bridge abutments or piers less than 50 feet in height should be stabilized within a fifteen-degree angle of draw from a point fifteen feet offset from the edge of the substructure, and
- mined-out areas below piers greater than 50 feet in height should be stabilized within a fifteen-degree angle of draw from a point thirty feet offset from the edge of the substructure.

The only exceptions to these criteria were Piers 5N and 5S at the edge of the valley on the northern end. Because the foundations for these piers are located just above the top of the coal, they are constructed on caissons bearing below the mine and coal seam.

The final limits of grouting were expanded somewhat beyond those dictated by the criteria to utilize areas of solid coal as barriers to production grouting instead of constructing barriers and to make layout and execution of the program easier during construction.

It was estimated that stabilization of the Southern Area would require approximately 40,200 linear ft (12,253 m) of injection hole drilling and 14,700 yd^3 (11,246 m^3) of grout. The Northern Area would require approximately 23,500 linear ft (7,163 m) of drilling and 12,500 yd^3 (9,563 m^3) of grout.

UNMINED COAL

Because portions of the project are underlain by coal that has not been mined and has the potential to be mined in the future, it was recommended that actions be taken to limit the future extraction of coal beneath the project area. The proposed bridge substructures required that coal be left in place to support the overburden and prevent damage from possible future mining operations. The recommended limits of support coal for unmined areas currently below the bridge substructures, established by the PTC are as follows:

- 100 percent of the remaining coal is required within a fifteen-degree angle of draw from a point fifteen feet offset from the edge of the substructure, and
- at least 50 percent of the remaining coal in unmined areas is required within a thirty-eight degree angle of draw from the edge of the substructure.

Additional PTC requirements for support coal for both the mined and unmined areas below the bridge and adjacent roadway areas, include:

- 100 percent of remaining coal is required in mined areas that have been designated for mine stabilization,

- 100 percent of remaining coal is required in the mined area below the south bridge approach embankment supporting Abutment 1N and 1S,
- at least 50 percent of the remaining coal is required in the unmined area below the north bridge approach embankment supporting Abutment 2N and 2S, and
- at least 50 percent of remaining coal is required in the unmined area within the right-of-way north of Abutment 2.

In addition, all future mining of coal in the unmined areas must be regulated so it is performed in a manner and method that will not produce collapse of the mine.

Mine Ventilation and Monitoring

There is an active haulage way that passes below the proposed roadway alignment south of Abutment 1. The haulage way provides access to areas currently being mined by Mon-View Mining Company. Because of concerns about possible explosive atmospheres developing in the mine in the area around the active haulage way, work in the Southern Area required the maintenance of ventilation boreholes and the performance of atmospheric monitoring during drilling operations. Ventilation and monitoring at the mine level were achieved through existing boreholes, the injection boreholes drilled as part of the grouting program, and two special, large diameter boreholes drilled for ventilation. Because of this, work in the Southern Area required coordination with the mining company, the Mine Safety and Health Administration (MSHA) and the Pennsylvania Department of Environmental Protection (PADEP) prior to and possibly during the execution of the stabilization measures

Prior to construction, nine boreholes drilled for design exploration work were left open to ventilate the Southern Area. Barrier and production holes were also used for ventilation. To ensure that adequate ventilation was provided during the mine-grouting program, two 20-in (50.8 cm) diameter boreholes were drilled. These boreholes were to be advanced no less than two weeks prior to the commencement of injection borehole drilling for the area. As the grouting program progressed, to maintain a safe environment at the mine level at all times, it was recommended that all drilling occur within 60 ft (18 m) of an active ventilation borehole.

Prior to drilling any boring, air monitoring was to have been conducted at the mine level of the nearest adjacent boring. Samples were tested for methane, oxygen, and carbon dioxide content with approved monitors. If detected concentrations of methane exceed 1.0% of the total air volume, all drilling activities were to cease and the mining company notified immediately. Work was allowed to resume only after the methane concentrations at the mine level dropped to below 1.0% of the total air volume.

Closure of Abandoned Coal Mine Air Shaft

There was an abandoned coal mine air shaft on the southern slope. The abandoned shaft was approximately 10 ft (3 m) square, had steel sheet piling around the perimeter, and was backfilled to an unknown depth with unknown material. It was assumed that the shaft is a continuous vertical conduit connected directly into the abandoned mine workings under the site. The area around the shaft was to have been excavated and backfilled with rock to stabilize the site. The Contractor was directed to take precautions to ensure the safety of workers and equipment during construction.

		Leave Stop 2. Turn right onto PA 88.
0.10	23.35	Crossing the bridge over Mingo Creek.
0.55	23.90	Mon View Mining Co. Mathies Mine supply area can be seen on the right for the next 0.4 mi. The mine is in the Pittsburgh coal bed.
0.40	24.30	Crossing the bridge over the Mathies tramway. The mine portals are on the left.
0.25	24.55	Outcrop of Pittsburgh coal in hillside to the left.
0.10	24.65	Crossing the bridge over Mingo Creek.
0.30	24.95	Intersection PA 88 and PA 837 in New Eagle. **Turn left** onto PA 837.
0.50	25.45	Notice the coal conveyor crossing the road to the rail and barge loading facility of Mathies Mine on the right.
0.20	25.65	Power plant on the right.
0.45	26.10	Notice the old cable conveyer crossing the road.
0.40	26.50	There's a good view of the Monongahela River on the right
1.20	27.70	The wet, reddish-brown stain of mineralized mine drainage (AMD) from Pittsburgh coal bed mines is quite prominent on left for the next 0.5 miles.
0.50	28.20	Norfolk Southern RR yard can be seen on the right for the next 0.6 miles.
1.45	29.65	Finley-Elrama Rd. intersection. **Continue** straight on PA 837.
0.15	29.80	Boundary between the villages of Elrama and Florette. Reenter Allegheny County
0.20	30.00	Notice Orion Power's Elrama power plant on the right
0.10	30.10	Ashland Oil Co. tank farm. Site of the largest chemical spill in Allegheny County. This occurred in January 1988 when an aboveground diesel fuel storage tank collapsed. About four million gallons of diesel fuel surged out of the collapsed structure almost instantaneously. Fortunately, the company had constructed earthen dikes around the tank in the event of a spill, and they contained most of the problem. However, the dikes were constructed to contain a gradual spill, not the catastrophic tidal wave that splashed out of the collapsed tank. The fuel crested the dikes and an estimated 750,000 gallons escaped into the Monongahela River and flowed through Pittsburgh and down the Ohio River. Because the Monongahela and Ohio provide drinking water to large segments of the population of Allegheny County, and communities farther downstream, this spill proved to be a major disaster for the area. Many people were forced to conserve water or obtain water from sources other than their normal purveyors. Cleanup efforts were costly for local, county, tate, and federal governments, as well as for Ashland Oil, which also had to pay restitution costs. Even weeks after this spill, the Ohio River in West Virginia and Ohio had high diesel fuel concentrations. Approximately 11,000 fish and 2,000 birds died, and miles of shoreline became contaminated. Despite the best efforts of those involved in the cleanup effort, it has been estimated that only one third of the fuel was ever recovered. The rest either flowed to the Gulf of Mexico via the Mississippi River, or is incorporated in shore and benthic sediments between Pittsburgh and New Orleans where it might eventually be

		reincorporated into the flowing surface waters.
0.75	30.85	The Hercules Chemical plant on the right is the location of a former superfund site. If you look behind the plant, you should be able to see Lock and Dam No. 3 on the Monongahela River.
0.40	31.25	Entering West Elizabeth.
0.60	31.85	Crossing under PA 51. The town of Elizabeth is directly across the river to the right. **Continue** straight on PA 837.
0.50	32.35	Birmingham unit capped by Morgantown sandstone on left.
0.65	33.00	Entering the city of Clairton.
0.65	33.65	On the right for the next 1.1 miles are the Clairton Coke Works. The St. Clair Steel Co. built a plant at the site in 1901 and at that time it had steelmaking facilities. U.S. Steel bought it three years later and built Clairton's first coke-oven batteries in 1918. Clairton Works' last blast furnace shut down in the 1970s. Its rolling mills closed in 1984. Since then, the plant has produced only coke and coking byproducts. In the early 1970s, the plant produced 22,000 tons of coke a day; this accounted for 13 percent of all coke production in the U.S. This was believed to be the largest coking plant in the world at that time. Today, its 13,300 daily tons account for 20 percent of total U.S. production. Clairton Works' annual output is 4.8 million tons. Byproducts include 55 million gallons of tar a year.
0.60	34.25	Crossing beneath the Union RR.
0.30	34.55	Crossing Peters Creek.
0.60	35.15	The bridge across the Monongahela River to the right at the traffic light will take you to Glassport and Elizabeth. **Continue** straight on PA 837.
0.75	35.90	**Curve right** at the traffic light in Coal Valley and pass under the Norfolk Southern RR bridge. Continue on PA 837.
0.30	36.20	You can't see it, but the USX Irvine Works are uphill to the left for about 1 mile.
1.10	37.30	Traffic light at Phillip Murry Rd. General Motor's Fisher Body Plant is located up this road to the right. **Continue** on PA 837.
0.65	37.95	In Dravosburg, passing beneath the Mansfield Bridge that crosses the Monongahela River between Dravosburg and McKeesport.
0.85	38.80	After crossing the RR tracks, there begins a series of excellent outcrops on left that chiefly exposes the Morgantown sandstone of the Casselman Fm., Conemaugh Group (see Figure 2). Outcrops extend beyond the McKeesport-Duquesne Bridge.
0.05	38.85	Outcrop of Morgantown sandstone at road level on the left for the next few miles. Notice the multitude of features associated with stream channel deposition.
0.35	39.20	Across the Monongahela to the right is the confluence with the Youghiogheny River at McKeesport.
0.45	39.65	At a few spots along here for the next mile or so you can see white stripes on the rocks to the left. This is acid mine drainage from abandoned Pittsburgh coal mines about 150 ft. above road level. The white is the result of aluminum, rather than iron.
0.95	40.60	The hollow area in the cliffs to the left is an old sandstone quarry in the

		Morgantown sandstone. The McKeesport-Duquesne Bridge crosses the Monongahela River to the right. **Keep in the right lane** and **continue** on PA 837.
0.45	41.05	Old buildings on the right are all that remains of the former USX Duquesne Works.
0.55	41.60	Traffic light at Grant St. and PA 837 in Duquesne. **Continue** straight on PA 837.
0.50	42.10	Crossing over the Union RR rail yards.
0.75	42.85	Entrance to Kennywood Park, one of the oldest large amusement parks in the country. Kennywood boast "The Thunderbolt", the number one rated wooden rollercoaster in the world, according to American Coaster Enthusiasts (ACE). The flat area we are riding on is the Parker Strath, the highest of the high-level terraces of the old pre-glacial Monongahela River.
1.00	43.85	Morgantown sandstone exposed on the left.
0.50	44.35	Traffic light at Morgan St. and PA 837 in Whitaker. Get in the left through lane and prepare to continue straight on the ramp to the Rankin Bridge. The Birmingham unit is exposed in the cliffs to the left. Notice the red coloration of the claystones.
0.25	44.60	**Turn right** and **cross** the Rankin bridge over the Monongahela River. The flat areas with buildings to the left and right ahead are Rankin and Braddock, respectively. The flat areas are remnants of the Parker Strath, the highest of the old pre-glacial Monongahela River's high-level terraces.
0.50	45.10	**Turn sharp right** onto the off ramp.
0.10	45.20	**Turn left** at the traffic light onto Braddock Avenue and enter the town of Braddock. This was once a prospering mill town. With the demise of the steel industry in Pittsburgh, the town has become an example of the depression that has settled in the Mon Valley.
0.75	45.95	Carnegie Library on the left at Library St. The library was closed recently when it was discovered that there was a gas leak in the basement. Investigators found an old well casing in the basement floor that was leaking natural gas, but no one knows what the source of the gas is. The well is being vented so the library can be reopened.
0.10	46.05	**Turn right** onto 9th St. Be careful - the street has no street sign.
0.20	46.25	Intersection with Washington Ave. at stop sign. **Turn left** onto Washington Ave.
0.15	46.40	Intersection with 11th St. facing the gate to the US Steel's Edgar Thompson Works. Andrew Carnegie founded the J. Edgar Thompson Steel Works in 1873, and in 1875 installed the first of the new Bessemer Converter furnaces. Strong, durable, versatile, mass-produced steel changed Pittsburgh, and the world, forever, and southwestern Pennsylvania became the hub of the industry. This and related industries flourished in the valleys along the Allegheny, Monongahela, and Ohio rivers. The Edgar Thompson Steel Works later became the Carnegie Steel Company, and by 1900 U.S. Steel Corporation. **Turn right** onto 11th St.
0.10	46.50	Cross the busy RR tracks and **turn left** at the sign to Lock and Dam No. 2.
0.35	46.85	Park the buses and disembark.

STOP 3. **BRADDOCK DAM**
Leader: Brian H. Greene, P.G.

At this stop we will leave the buses and board the US Army Corps of Engineers' barge for a ride down the Monongahela and Ohio Rivers as far as Emsworth Lock and Dam, where we will reboard the buses for the ride back to the Parkway Center Inn. Along the way, we will learn about the geologic and engineering efforts required to build a new dam, redevelop some major brownfields sites, keep some roadways in place, and hold up Pittsburgh's unstable slopes. Lunch will be served on the barge.

ENGINEERING GEOLOGY AND FOUNDATION DESIGN OF THE NEW BRADDOCK DAM PROJECT

The new Braddock Dam (replacing existing Monongahela River Dam 2 located directly upstream from Pittsburgh, PA) will be built without the use of cofferdams, using innovative in-the-wet construction techniques. In-the-wet technology was initially developed for offshore drilling platforms and immersed tube tunnels. The work at Braddock will be the first time that a navigation dam on a US inland waterway will be constructed using in-the-wet technology. Pittsburgh is currently the largest inland waterways port in the United Sates and the new dam at Braddock will be an important component of the region's navigational infrastructure. The dam's construction procedure calls for fabricating two large concrete segments, which consist of reinforced concrete shells, at an off-site location. The segments will then be floated from the fabrication site to the construction area. Once a segment is precisely positioned, it will be sunk onto a preinstalled drilled shaft foundation. After each dam segment is set into place, tremie concrete will be pumped into its internal hollow chambers, displacing water from the interior of the segment. The remainder of the work that is above water will be accomplished using traditional construction methods.

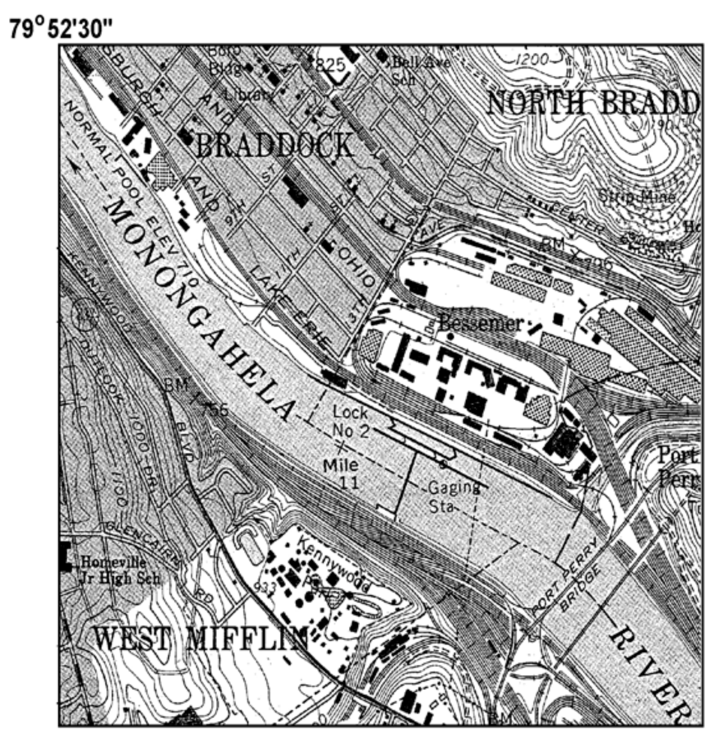


Figure 47. Location of Lock and Dam No. 2, Stop 3 on the Braddock quadrangle.

LOCATION AND DESCRIPTION OF PROJECT

The project is located on the lower portion of the Monongahela River at Braddock, Pennsylvania. Existing Locks and Dam No. 2 is located at River Mile 11.2 measured from the Point at Pittsburgh (Figure 47).

The existing structure consists of two lock chambers on the right descending bank and a non–navigable, fixed crest dam. The locks, constructed between 1951 and 1953, replaced the original lock built between 1902 and 1906. The locks have a lift of 8.7 ft (2.7 m) from normal lower pool elevation 710.0 ft (216.4 m) to normal upper pool elevation 718.7 ft (219.1 m). The fixed crest concrete weir dam is 748 ft (228 m) long and is supported by timber piles and rock filled cribbing. Existing Dam 2 at Braddock, PA is one of the oldest concrete structures in the Pittsburgh District of the Corps of Engineers.

The proposed project consists of constructing a gated dam, approximately 500 ft (152 m) upstream from the existing dam. The new dam will raise the normal upper pool approximately 5 ft (1.5 m) from elevation 718.7 (219.1 m) to elevation 723.7 ft (220.6 m). Additional work proposed for this project includes construction of a new caisson abutment wall, reinforcing portions of the existing river wall and removal of the existing older dam. In addition, modification of structures affected by the permanent 5-ft (1.5-m) increase of the upper pool level will be necessary, including raising a bridge and in-pool relocations. The new Braddock Dam will be constructed using innovative in-the-wet construction techniques, which are intended to achieve a time and cost savings over traditional methods of construction employing cofferdams. The Pittsburgh District made the decision to use in-the-wet construction for the Braddock Dam in July 1997.

REGIONAL GEOLOGY

The Monongahela River in the study area flows north in a series of entrenched meanders through the Pittsburgh Low Plateau Section of the Appalachian Plateaus Province. A mature plateau of moderate relief characterized by rounded hills and ridges, it becomes sharper and more deeply dissected toward the southwestern corner of Pennsylvania. Locally relief is about 500 ft (152 m). Flood plain elevations are at about 700 ft (213 m) and the tops of surrounding hills are at about 1200 ft (366 m) above sea level.

The most significant geologic structure in the region is a series of gently dipping, roughly symmetrical, subparallel folds. The axes of these folds strike N30-50E and plunge gently to the southwest.

Sedimentary rocks exposed in the region belong to the Conemaugh and Monongahela Groups of Pennsylvanian age. These are cyclic sequences, chiefly shales, claystones, siltstones, limestones and coals. The major economic coal bed, the Pittsburgh coal, occurs above elevation 1000. It has been mined extensively in the general area but is not present at the project site.

GEOLOGY OF THE SITE

Soils

Dam. -- The soils along the proposed dam axis are alluvial. The soils are predominantly cohesionless, non–plastic, loose to moderately dense, coarse to fine-grained sub-rounded to sub-angular sands and gravels. Materials vary from brown to gray in color and classify as sandy gravels, silty gravelly sands, and clayey gravelly sands. The top of overburden varies in elevation from about 715 to 696 ft (218 to 212 m) along the new dam alignment. The thickness of overburden along the dam alignment varies from 30 to 45 ft (9 to 14 m).

Abutment. -- The left descending riverbank in the area of the proposed dam has a nearly vertical bank face that rises about 30 ft (9 m) above the river's edge. The floodplain from top of bank to the left valley wall is relatively level, approximate elevation 747 ft (228 m) and is approximately 500 ft (152 m) wide. Within 140 ft (43 m) from top of bank are six active railway lines. The two lines closest to the top of bank are elevated on a trestle structure and are within 30 ft (9 m) of the bank edge.

The bank face is nearly vertical, as a result of being built up by the dumping of molten slag from nearby steel mills. Slag is a fused by–product of the steel making process formed by the action of a flux (limestone) upon the gangue of an iron ore or upon the oxidized impurities in a metal. It is composed of approximately 40% lime (CaO), 35% silica (SiO2), 13% alumina (Al203), 10% magnesia (MgO), and 2% sulfur (S). It may include as much as 30% iron.

Physically, the slag varies considerably in density because of the varying quantities of gases or steam trapped in the molten slag during cooling. The bulk specific gravity may range from 2.12 to 2.34. Small pockets of slag with a very high iron content have considerably higher unit weights. In situ, in the abutment area, this slag fill varies irregularly from a loose granular fill with a high permeability to a very dense impermeable material with a high metal content.

The slag was deposited along the riverbank in a molten condition from side dumping railcar ladles. Borings indicate the original riverbank was extended at least 250 ft (89 m) riverward by this side dumping process. Borings drilled on the existing top of bank, reveal the slag fill to be about 30 ft (9 m) thick and in a fractured condition. Below this depth, natural flood plain alluvial deposits are encountered. They include thick layers of loose sandy clays underlain by a deposit of sandy gravel, which in turn, lies above the top of rock.

BEDROCK STRATIGRAPHY

Bedrock at the project site belongs to the Upper Glenshaw Formation of the Conemaugh Group, which consists principally of thick beds of claystone and siltstone; and thin beds of sandstone and limestone of Lower Pennsylvanian age. The geologic cross section presented on Figure 48 gives the general sequence of the principal foundation rock units present at the Braddock Dam site. For purposes of correlation, the bedrock at the site has been categorized into two distinct units: Units 8 and 9. Both will be encountered during construction of the dam. As found from borings, the elevation of the contact between units 8 and 9 varies only slightly across the site.

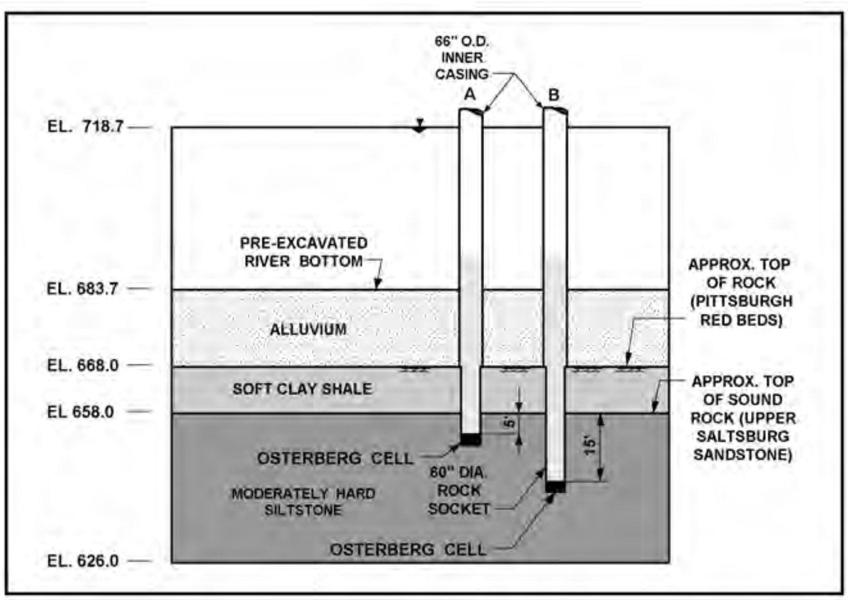


Figure 48. Geologic cross section of the new Braddock dam project site with test drilled shafts.

Unit 8 (Pittsburgh red

beds) is principally a clayshale, which extends from the top of rock surface in the river channel, approximately elevation 673-668 ft (205-204 m), down to elevation 661-655 ft (202-200 m). This rock is soft to medium hard, highly fractured, variably weathered, thinly bedded to massive, and gray to red in color. At the top of Unit 8 there is a thin cap of sandstone that varies from being absent to a few ft in thickness.

Unit 9 (Upper Saltsburg member) is siltstone, which extends from elevation 661-655 ft (202-200 m down to about elevation 630 ft (192 m). Generally, this siltstone is medium hard to hard, unweathered to slightly weathered, massive, lightly to moderately fractured, and gray in color. The upper part of the unit, 1.0 to 3.0 ft (0.3 to 0.9 m) in thickness, is more fractured and not as hard as the underlying siltstone.

Structural Geology

Deformation during the late Pennsylvanian and Permian Periods produces the typical Appalachian folds of central and western Pennsylvania. The major geologic structure in the region is a series of gently dipping sub parallel folds. The axes of these folds strike N30-50E and plunge gently to the southwest. The project site is located on the west flank of the Duquesne-Fairmont Syncline. The axis of this syncline strikes about N50E and lies about 4000 ft (1219 m) upstream of Locks and Dam 2. At the project site bedding dips to the southeast toward the synclinal axis at less than one degree, or about 13 ft per 1000 ft (4 m per 305 m). No evidence of significant faulting has been detected in the immediate area.

SOILS TESTING

Soils tests were performed on samples obtained from borings taken at, or near, the new dam centerline and in the area of the new dam abutment. Laboratory testing of soils included determination of moisture content, gradation, relative density, and strength tests. Soils were classified according to the Unified Soils Classification System (USCS).

Relative Density Tests. -- The relative density tests were done for the purpose of determining the field conditions of the materials for testing in direct shear boxes. Relative density tests were performed on composite Laskey samples since there was not enough material in any individual sample to conduct the test. Samples were combined which had similar gradations.

Direct Shear Tests. -- Due to the difficulty in determining the strength of cohesionless soils during triaxial testing, several direct shear tests were performed. One suite of three direct-shear tests was made on remolded samples of gravelly sand to measure shear strength of soil under drained conditions. Gradation tests were run on Laskey samples with consistent agreement. Minimum and maximum values for unit weight and moisture contents were obtained during relative density testing. With this information, remolded samples were brought back to the maximum unit weight and moisture content for approximation of near field conditions before being sheared.

R-Bar Triaxial Compression Tests. --R-Bar triaxial compression tests were made on composite samples of brown, coarse to fine, angular, subangular and subrounded gravelly sand (SP-SM). The tests were performed using confining pressures of 1.0, 2.0, and 4.0 tons/ft^2. These load levels represent confining overburden pressures at depths of 18 ft, 36 ft, and 72 ft, respectively. The effective stress measurements from these tests result in a drained strength of 37 degrees with no intercept.

FOUNDATION ROCK TESTING

General

Each of the testing programs described and summarized below are contained within individual laboratory test reports issued by the Corps Ohio River Division Laboratory (ORDL) formerly located in Cincinnati, Ohio.

ORDL TESTING – 1990

As part of the subsurface investigation in August 1990, core samples were obtained to conduct a laboratory testing program. Ten samples of 2-in diameter core from borings were tested to determine unconfined compressive strengths, moisture contents, and unit weights. Seventeen samples of 4-in diameter core from borings were tested to determine shear strengths. Six of these samples were from the Unit 8 Claystone and 11 were from the Unit 9 siltstone.

ORDL TESTING – 1992 AND 1993

ORDL conducted rock mechanics and index property testing on core samples following the 1992 drilling program. Test samples were obtained from borings drilled along the alignment and left abutment of the proposed replacement dam and below the existing lock walls. The rock cores from these borings were NQ, PQ, and 4-in sizes. Rock core samples were tested for the following properties:

- Unconfined compressive strength
- Elastic modulus
- Direct shear strength
- Sliding friction
- Unit weight/moisture content
- Rock anchor bond strength (pull–out tests)

Determination of Shear Strength

All of the 1990 and 1992-93 rock mechanics testing was reviewed to determine shear strength failure envelopes for Units 8 and 9. Shear strength failure envelopes were developed by linear regression analysis.

Unit 9 Siltstone. --The peak strength envelope for direct shear testing on siltstone samples resulted in a angle of 38.5^{o} and cohesion of 81.6 PSI. The residual stress envelope produced by further testing of these same samples resulted in a angle of 29.2^{o} and a cohesion of 13.9 PSI. Shear testing on natural fractures in siltstone resulted in a angle of 27.3^{o} and a cohesion of 7.6 PSI. The recommended shear strength parameters for Unit 9 siltstone are based on residual and natural fracture stress envelopes, rather than peak stress envelopes, to produce conservative values. The recommended values are a angle of 28^{o} and cohesion of 11 PSI.

Unit 8 Clayshale.--The recommended shear strength parameters for Unit 8 clayshale are based on natural fracture stress envelopes to produce conservative values. Laboratory testing resulted in values of cohesion of 6.7 PSI and a angle of 23.4^{o}. Slightly more conservative values of cohesion of 5.0 PSI and a angle of 23.0^{o} are being recommended for use in design analysis.

Determination of Bearing Capacity

Corps engineering manuals were followed in determining the allowable bearing capacity. The average unconfined compressive strength of 3630 psi of 18 different Unit 9 siltstone samples tested in the laboratory, divided by a factor of safety (FS) of 5 yields 52.3 tons/ft^2 and was considered to be suitably conservative for this design. Unit 8 clayshale had an average unconfined compressive strength of 840 psi.

FULL SCALE DRILLED SHAFT LOAD TEST

The foundation for the dam was originally planned to be constructed within cofferdams and called for both vertical and battered (i.e. inclined) drilled shafts. When the decision was made to construct the dam in-the-wet, battered shafts were no longer viable. Therefore, vertical shafts needed to be designed to withstand the appreciable lateral and axial loads imposed by the gated dam. In order to validate the adequacy of vertical shafts to serve as a foundation system, a comprehensive (both axial and lateral) load test of two full-scale test shafts was deemed necessary.

As cited earlier, subsurface conditions at the site of the proposed dam were found to typically consist of 30-45 ft (9-14 m) of alluvial sands and gravels underlain by bedrock consisting of flat lying clayshale and siltstone. The upper rock unit, a soft clayshale, is about 10 ft (3 m) thick. Below the clayshale unit is a moderately hard layer of siltstone that was deemed to be a more competent bearing strata for the drilled shafts. Figure 48 shows a generalized subsurface profile along with a cross-sectional view of the two test shafts. One test shaft, designated test shaft ‘A’, extended one shaft diameter (5 ft [1.5 m]) into siltstone. The second shaft, test shaft ‘B’, extended 3 diameters into siltstone.

The choice of a site for this load testing was restricted. An onshore site was preferable, however such a site was not available because of extensive land development along the area’s riverbanks. In addition, geological conditions vary over across the site; therefore the location deemed most representative of the foundation conditions for the new dam was in the river. The location of the chosen test area was about 70 ft (21 m) from the downstream edge of the proposed dam.

The two test shafts were built in the river using barge mounted construction equipment. It was determined that test shafts having a rock socket diameter of 5 ft (1.5 m) would be representative of future production shafts of a slightly larger diameter. Two casings for each test shaft were installed; an inner casing 5.5 ft (1.8 m) in diameter vibrated to rock, and an outer casing 10 ft (3 m) in diameter was set on the river bottom. The purpose of the outer casings was to support working platforms and mitigate the effects of waves and river currents during the actual load tests. Once the inner casings were set, the alluvium was drilled from within the inner casing using augers and buckets. Upon encountering rock, the drilling tools used included a variety of rock augers and bucket augers. Following drilling, each shaft was airlifted to remove

Figure 49. Photo of instrumented rebar cage for test shaft.

cuttings from the hole and a caliper was used to determine hole diameter and roughness of the sides of each hole.

The contractor fabricated two reinforcing cages to which instrumentation was affixed (see Figure 49) for a photograph of one of the instrumented cages). The cages consisted of longitudinal no. 18 steel bars and no. 8 bars serving as hoops. There was a greater density of hoops corresponding to the soil-rock interface because of greater bending moments anticipated at this zone.

In order to generate axial loads, the Osterberg-cell method was used. Osterberg cells consist of large hydraulic jacks symmetrically arranged between two circular steel plates. The cells, which are placed at the base of each shaft, use end-bearing resistance as the reaction force to push the shaft upwards to develop side friction, or likewise, use side friction as the reaction to develop the shaft tip resistance. The primary advantage of the Osterberg-cell method is that a loading frame and reaction shafts aren't needed, resulting in a major cost savings for an in-river test.

In order to generate lateral loads for the test, a system was utilized that consisted of pulling the two test shafts together, thereby eliminating the need for a lateral reaction frame. Two 2.5 in (6.4 cm) diameter, grade 80 steel bars were passed through both shafts and coupled in the middle (see Figure 48). A hydraulic jack was placed on the outside of one of the shafts. On the outside of the opposite shaft an electronic load cell was affixed. In order to avoid shaft-soil-shaft interaction a spacing of 50 ft (15 m), or 10 shaft diameters was deemed to be acceptable.

Instrumentation for the lateral load tests consisted of strain gages and fixed-in-place inclinometers. Spot weldable strain gages, for measurement of axial strains of the rebar in the shafts, were placed at frequent intervals on both the inside and outside (relative to the loading direction) of each shaft.

Instrumentation for the test shafts was monitored using computer-controlled data loggers. Leads from each test shaft were fed to six multiplexers that were connected to each data logger. Measurements from the data loggers were controlled and stored by two laptop computers. The system allowed for the entire instrumentation array to be read in approximately one and one-half minutes.

The axial load test results revealed that test shaft A, the shorter shaft, was adequate for design. Failure occurred at 3300 tons, which was almost twice what was previously assumed for design. The failure was in side shear and the downward displacement of the lower plate of the Osterberg cell was less than 0.15 in (.38 cm), indicating that only a fraction of the end bearing resistance had been mobilized and that bearing capacity estimated from unconfined compressive lab tests was very conservative.

The standard lateral load test was successfully run and held at a maximum load of 350 kips which corresponds to the highest extreme loading condition that the production shafts could experience. Test shaft A had a maximum ground line deflection of 1.1 in (2.8 cm) as compared to the allowable deflection criteria of 1.2 in (3.1 cm) for an extreme loading condition. Test shaft B exhibited a maximum deflection of only a few hundredths of an inch less than test shaft A. It was concluded that the additional socketing of test shaft B into siltstone did not offer any significant improvement in lateral capacity. Again, test shaft A was deemed adequate.

As a result of the load testing, the final production shafts have been designed with six-foot diameter rock sockets that are 16 ft (5 m) deep. Overall the in-situ testing resulted in a more efficient, cost-effective design for the new gated dam's foundation.

LEFT ABUTMENT AND RIVERWALL TIE-IN CONSTRUCTION

As a first item of work for construction of the new dam, the left abutment and right bank tie-in had to be constructed. This was deemed to be construction work that could be done, in advance (starting in the fall of 1998), to facilitate the later dam construction.

The left abutment wall was designed by the Pittsburgh District to be an anchored concrete retaining wall consisting of 78 structural caissons and 78 lagging caissons. The tangent caisson wall called for concrete shafts to be overlapping with conventional reinforced concrete for the structural caissons and low-strength concrete for the non-reinforced lagging caissons. The structural caissons were socketed into bedrock to a depth of 20 ft (6 m), whereas, the lagging caissons were seated on top of bedrock. Drilling of the structural caissons was accomplished with a hydraulic casing oscillator manufactured by CMV of Venafro, Italy. The casing oscillator drilling equipment was very unique and Braddock Dam represents one of the first U.S. projects that this caisson drilling technology has been used on. The oscillator drill bit into the adjacent lagging caissons that had been installed first over a reach of the wall. After the wall was complete, an upper row of rock anchors (71 total) was installed in the wall. A lwer row of 71 anchors will be installed later when the old dam is removed. Instrumentation consists of 11 load cells to measure variations in anchor loads as construction progresses, 6 in-place (and 6 redundant) inclinometers to measure caisson wall deflection and creep, and 4 piezometers to measure water levels and gradient behind the completed wall.

The right bank tie-in will be with the river wall of the existing lock. However, since the existing river wall was constructed of mass concrete founded on granular filled steel sheet pile cells, the wall needed to be strengthened. Drilling of grout holes was accomplished to fill any voids between the top of cell fill and the overlying mass concrete of the lock wall. A series of concrete drilled shafts socketed into bedrock were installed immediately riverward of the existing wall. Then, a heavily reinforced concrete section was constructed on top of the drilled shafts, which structurally tied the old wall into its new drilled shaft foundation.

DRILLED SHAFT FOUNDATIONS FOR NEW DAM

While the two float-in dam segments are being fabricated off-site (Figure 50), at the time of the Field Conference, work at the project site will be progressing to complete the dam foundation system. The basic foundation system is comprised of upstream and downstream cut-off walls, a graded gravel base and a grid of reinforced concrete drill shafts that extend from the riverbed into bedrock.

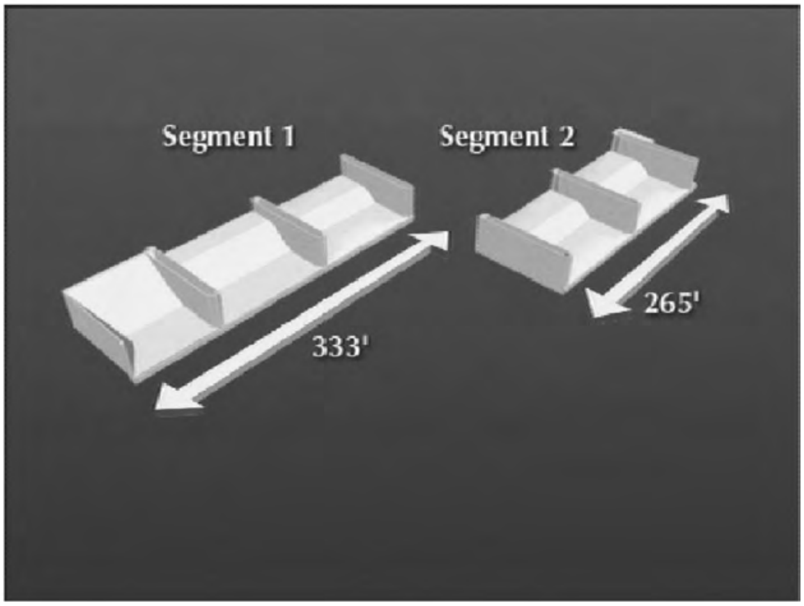


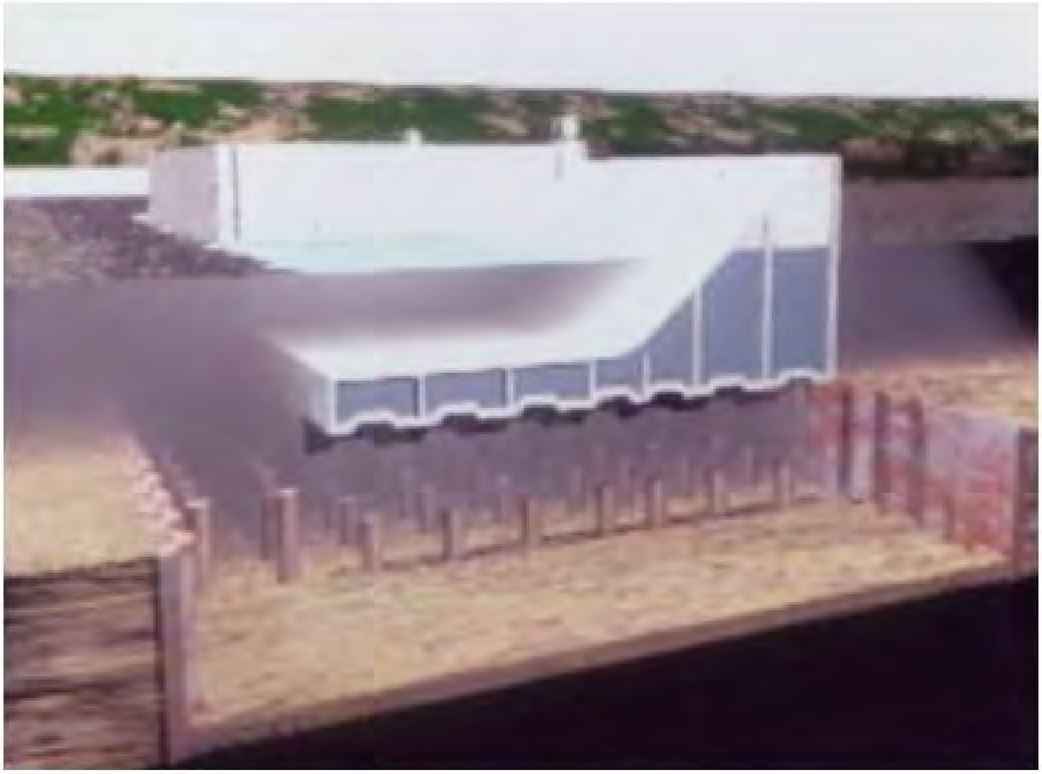
Figure 50. Dimensions of float-in dam segments.

Eighty-nine reinforced concrete drilled shafts will carry the weight of the dam and transfer loads into the bedrock (Figure 51A). Each shaft will be 78 in (198 cm) in diameter (with a 72-in [183 cm] rock socket) and about 30 ft (9 m) in length. Almost 16 ft (5 m) of each shaft will be drilled into bedrock to assure a secure connection and transfer of loads. Pre-excavation for the dam foundation has been accomplished and will consist of excavating the riverbed from the existing lock river wall to the left bank abutment toe. This will also provide the necessary draft for the delivery, positioning and set-down of the float-in segments.

After pre-excavation was completed, steel sheet piling was installed to provide both upstream and downstream cut-off walls and to serve as retaining walls for various stages of work on the dam. A prerequisite pile-driving program was used to determine the elevation of rock to which sheets were driven. Sheets were ordered to accurate lengths once these elevations were determined. Using a barge-mounted vibratory pile driver, steel sheets approximately 45 ft (14 m) in length were installed in 35 ft (11 m) of water between H-piles with pre-installed interlocks at a 19-ft (6-m) spacing.

The downstream cut-off wall was installed in a similar manner. The downstream cut-off wall is composed of a structural system of 24-in (61-cm) diameter pipe piles and sheet piles. This system is required to resist the loads imposed by the retained alluvium when the downstream face of the wall is later excavated to rock in order to install downstream scour protection. The pipe piles were driven to rock from which point a reinforced concrete rock socket was extended 6 ft (1.8 m) into bedrock. The pipe piles were strategically positioned to support the downstream edge of the tailrace structure. Then a 12-in (30.5 cm) layer of 1½ inch crushed stone was placed over the footprint of the foundation area. Once these operations were completed, the dam foundation system construction was started and is comprised of a drilled shaft foundation system for the dam piers and gate sills and an H-pile foundation system for the tailrace.

For the dam foundation system, two types of drilled shafts are being constructed. Set-down drilled shafts will support the dead weight of the float-in dam segments at set-down and foundation drilled shafts will support the completed dam. Six (6) set-down drilled shafts will be provided for each dam segment. Seventy-seven foundation-drilled shafts will be provided beneath the dam piers and gates sills. All drilled shafts will be step-tapered with a 72-in (183-cm) diameter rock socket drilled through a 78-in (198 cm) diameter permanent steel casing. PPermanent casings will be driven and seated into the top of the clayshale rock layer. Drilling wwill remove all material from within the casing and the 72-in (198 cm) diameter rock socket will then be drilled roughly 5 ft (1.5 m) into the lower siltstone rock layer. Drilled shafts will be



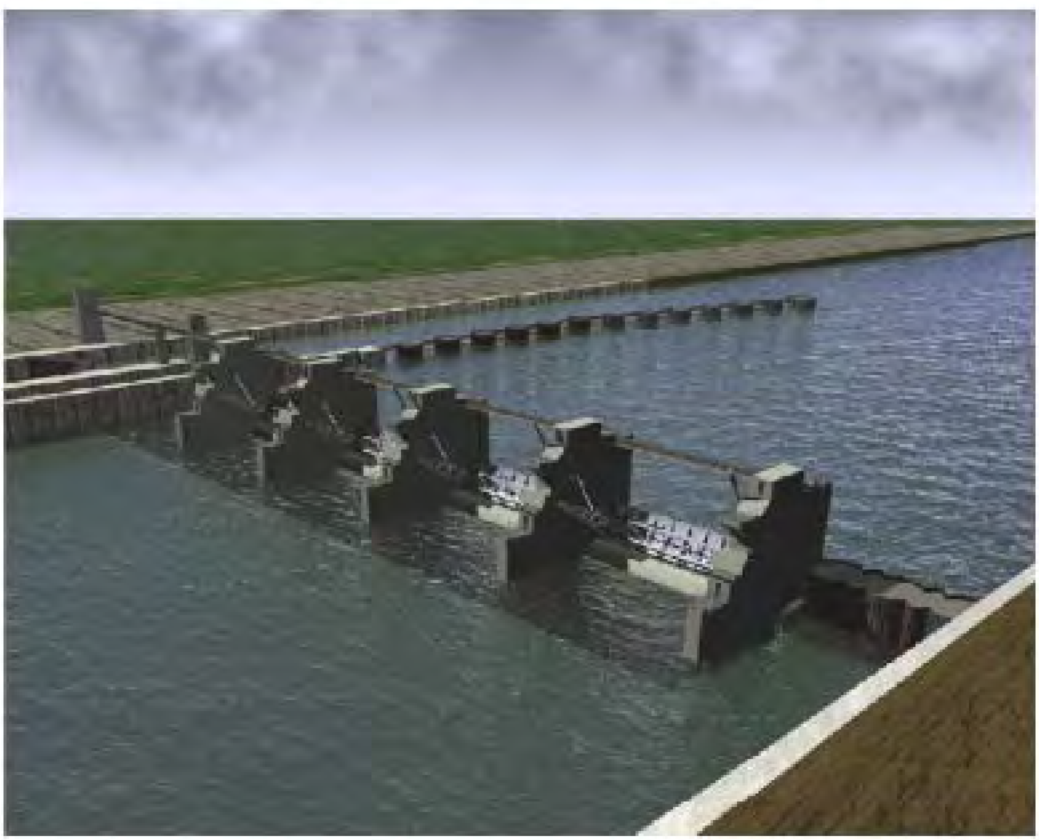
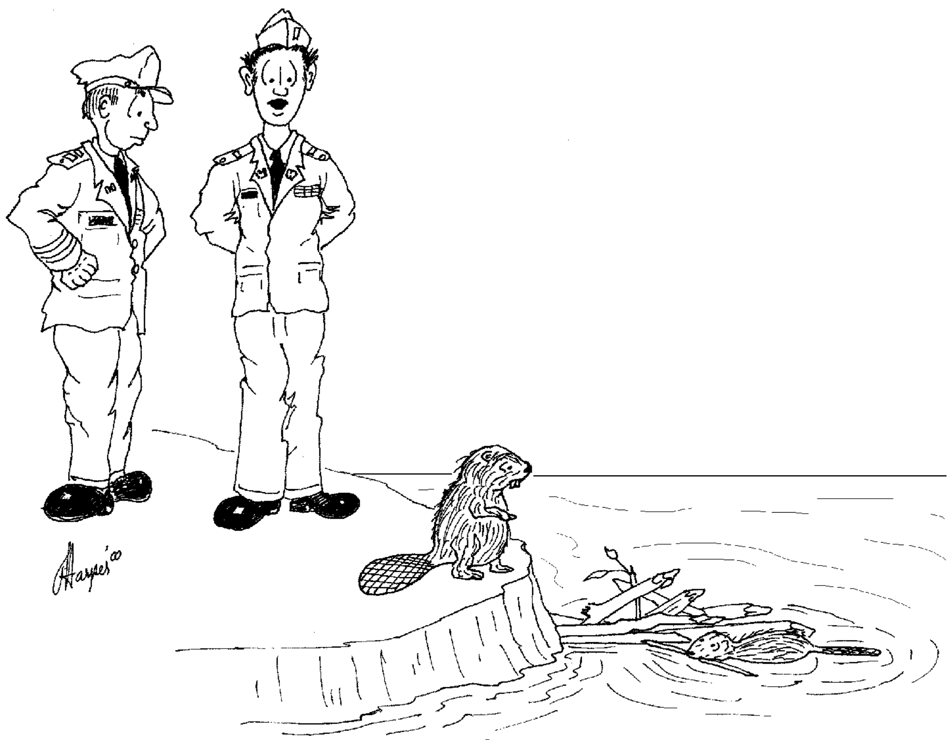


Figure 51. Top – Artist's depiction of a float-in dam segment set down. Bottom – Artist's depiction of the completed Braddock Dam.

precisely located using a pile-anchored two-level floating guide template. The casing will be refilled and the top of each casing will be cut-off to its final elevation using reotely controlled cutting tools. Two rows of 14-in (36-cm) H-piles will be driven within the footprint of the tailrace. Piles will be spaced on 8-ft (2.4-m) centers and will be driven to the clayshale rock layer. The tops of these piles will extend up into the first tremie concrete placement below the tailrace slabs.

Once the two float-in dam segments have been successfully set down and tremie concrete infilling placed, conventional methods will be used to finish construction of the remaining portions of the dam above water. The area beneath the segments will be filled with underbase grout. An artist's rendering of what the completed dam structure will look like is shown on Figure 51B. Following completion of Braddock Dam, the existing older Dam 2 will be removed by means of blasting and/or mechanical excavation. Additionally, the 2nd row of rock anchors will be installed in the new abutment wall to provide for long-term stability.



Well, actually Sir, they're the best dam engineers we've ever had. And they work dirt cheap!

Int	River Miles	Description
0.0	11.00	**Leave Lock No. 2** and move downstream toward Pittsburgh.
1.0	10.00	The flat area developed above the downtown Braddock area on the **right**. This is a representative section of the old Monongahela River terrace, similar to that at Kennywood Park.

0.3 9.70 Pass under the Rankin Bridge. The borough of Rankin to the **right** also has a flat surface. This is considered to be the entrance to a great meander loop in the old Monongahela River that passed through the present communities of Swissvale, Edgewood, Wilkinsburg, Homewood, East Liberty, Shadyside, and Oakland before exiting into the current drainage valley south of Oakland (Figure 41).

0.6 9.10 To the **left** is the beginning of The Waterfront, former site of the historic US Steel Homestead Works, now a major redevelopment area. This is a brownfield, an urban industrial site containing some level of contamination, that is being used to revitalize the depressed Monongahela valley. The numerous stores, restaurants, and other service industries that will eventually clutter this site offer jobs and hope to communities such as Homestead.

The original Homestead plant was owned and built by Pittsburgh Bessemer Steel Company in 1880. Andrew Carnegie purchased it in 1883, installed open hearth converters in1886, installed huge forge and rolling presses in 1890, and installed more Bessemer furnaces after 1892. Carnegie electrified the Works, installing 300 arc lights and 2,200 incandescent lamps in the 1890s. The Homestead Works made steel rails for the railroad boom, steel girders, beams, and braces for railroad bridges and skyscrapers, and steel armor plating for the nation's new steel battleship fleet.

The Homestead Works also represented the 19th century's struggle between capital and labor in its most brutal form. Skilled labor at Homestead Works was organized and represented by the Amalgamated Association of Iron and Steel Workers (AAISW). In 1892, Henry Clay Frick, the chief executive officer of Carnegie's steel company, decided to break the union. He closed the plant and locked out the employees. Then he brought in non-union laborers under protection from the brutal Pinkerton Detective Agency. Workers seized the plant and fought off the Pinkertons until they were ejected from the mills by state militia, brought in at Carnegie's request. It was a crushing blow to organized labor, and it wasn't until Roosevelt's New Deal era that unions became powerful in the steel industry.

1.4 7.60 To the **right** are the mouth of Nine Mile Run and the little community of Duck Hollow.

STOP 4. NINE MILE RUN SLAG DUMP

Leader: Henry S. Prellwitz

THE MINERALOGY AND GEOCHEMISTRY OF THE NINE MILE RUN SLAG AREA

The Nine Mile Run Slag Area, located in the Squirrel Hill section of the City of Pittsburgh, Pennsylvania (Figure 52), is an industrial brownfield site that is being developed for residential housing use. This 235-acre (95 ha) property was purchased by the City of Pittsburgh Urban Redevelopment Authority (URA) to increase upscale residential housing within the City limits, and to increase the City's real estate tax base.

Before this site could be developed, environmental assessments had to be performed to determine if the slag was chemically and physically stable, and if there were any toxicity problems

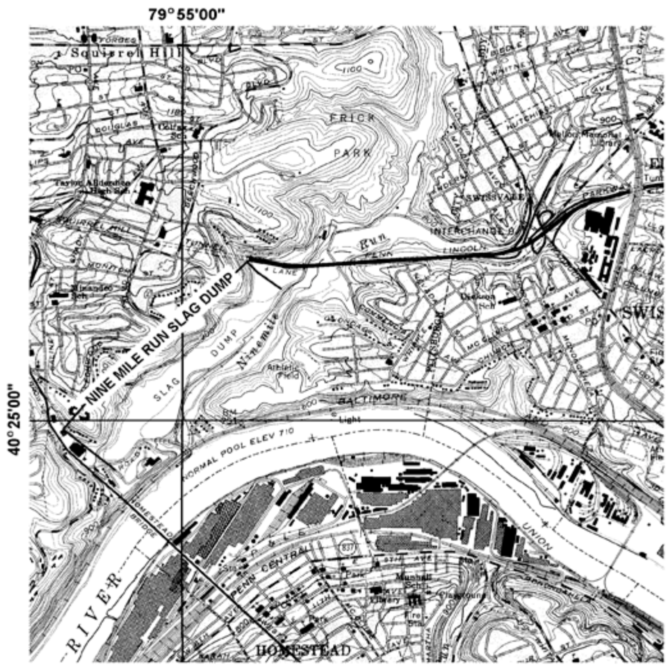


Figure 52. Location of the Nine Mile Run slag dump at Stop 4 on the Pittsburgh East quadrangle.

with the slag runoff into Nine Mile Run. Three environmental studies were contracted by the URA (Torbert, 1995, McGuire and others, 1995, and Veri, 1997). Another earlier assessment was performed by the US Army Corps of Engineers (1989). This summary is an overview of a mineralogical and geochemical study that was done by Prellwitz (1998).

Many questions arose when the initial environmental assessments were performed, such as: (1) What is the geological context of the site? (2) What is the mineralogy of the slag? (3) What is the origin of the hot steam vents? (4) How reactive is the slag with groundwater? (5) How long will any chemical reactions continue? The Prellwitz (1998) study was an attempt at answering these questions.

SITE HISTORY

Slag dumping at the Nine Mile Run site commenced in 1922. Before this time, the area was an open, wooded valley. Frederick Law Olmstead, the noted planner and designer of Central Park in New York City, was appointed by the City of Pittsburgh in 1911 to assess the site's potential for recreational use, since it shared a common boundary with Frick Park. A Citizen's Committee on City Planning recommended in 1920 that the City of Pittsburgh purchase the site. However, the Duquesne Slag Company bought the first parcels of the site in 1922.

Slag was dumped continuously from 1922 to 1972 from the blast furnaces and open-hearth furnaces of United States Steel's Homestead Works and Carrie Furnace in Rankin, PA, and Jones & Laughlin Steel Company in the Southside section of Pittsburgh. Starting in 1973, the Buncher Company had an iron and steel recovery operation at the Nine Mile Run site, which ended in 1976. The property remained vacant until purchased by the URA. Figure 53 shows what the site looked like before redevelopment began. As of this Field Conference (October 2000), grading operations are underway for the first portion of residential housing development.

SLAG TYPES AND COMPOSITIONS

Two major slag types are found at the Nine Mile Run site: (1) blast furnace, and (2) open hearth furnace. Over 90% of the slag at Nine Mile Run is of open hearth furnace origin. The chemical compositions of these two slag types are quite different, due to the steelmaking processes that produced them.

Blast furnace slag is a product of the reduction of iron from its oxide ores. There are three major ingredients in a blast furnace charge: (1) iron ore, usually a mixture of hematite and quartz

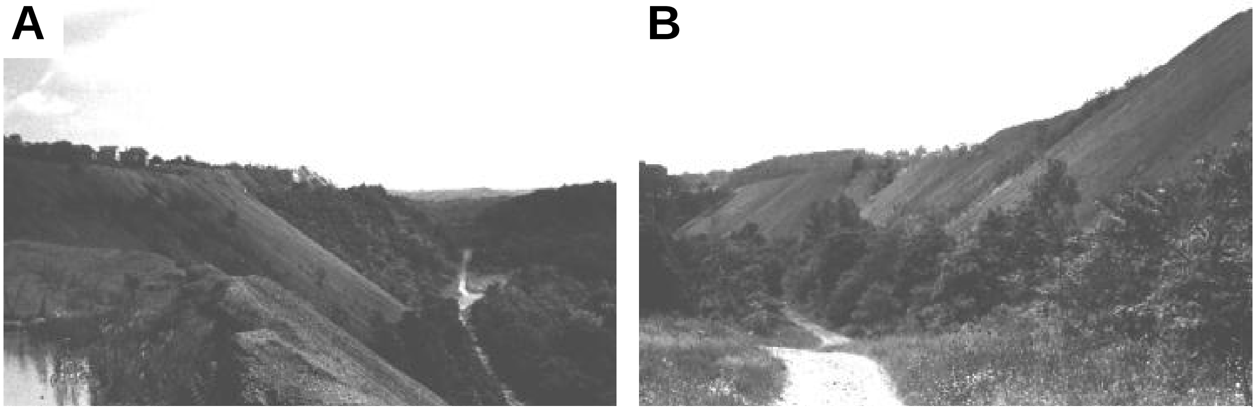


Figure 53. Photos of the undeveloped Nine Mile Run slag area. A. View looking northeast. B. View looking southeast.

(Fe_2O_3 and SiO_2); (2) limestone, used as a flux ($CaCO_3$); and (3) coke (carbon), which acts as a reducing agent and a fuel. Since the smelting process is a reducing one, very little iron remains in the slag. The blast furnace slag consists mostly of calcium silicates (calcium from the limestone, and silica from the ore).

In the basic open hearth steelmaking process, an oxidizing environment, one is trying to remove a certain amount of carbon, and other impurities (including phosphorus, and sulfur) to render iron into useable steel. The resulting slag contains a large amount of FeO, a lesser percentage of SiO_2 than blast furnace slag, usually a high concentration of CaO, from the dolomite furnace floor bricks, and added lime (CaO). The furnace is charged with lime to keep the slag pH high, and increasing its ability to remove detrimental oxides from the steel. Table 5 shows chemical composition limits of blast furnace and open hearth slags.

Table 5. Chemical composition limits in weight % of blast furnace and open hearth slags (from Josephson and others, 1949; Muan and Osborn, 1965; McGannon, 1964)

Oxides	Blast Furnace Slag	Open Hearth Slag
SiO_2	33 - 42	5 - 25
Al_2O_3	10 - 16	0 - 4
CaO	36 - 45	14 - 55
MgO	3 - 12	3 - 12
Fe_2O_3	---------	1 - 10
FeO	.3 - 2	5 - 40
MnO	.2 - 1.5	4 - 15
P_2O_5	.1 - 1.1	1 - 4
S	.5 - 2.5	.05 - .3

SLAG MINERALOGY

Prellwitz (1998) determined slag mineralogy from surface and borehole samples by petrographic and X-ray powder diffraction techniques. Two major mineral assemblages were recognized, corresponding with the blast furnace and open hearth slag types.

The blast furnace slags from Nine Mile Run consist mostly of akermanite ($Ca_2MgSi_2O_7$) and lime (CaO). The akermanite formed from the reaction of silica (from the ore), and CaO from the limestone flux. An excess of limestone is added to the blast furnace charge to insure all of the free silica is removed from the iron. This results in the remaining lime (CaO) left over when all available silica was used up.

Table 6. Averaged groundwater analytical results from the Nine Mile Run slag area. All results are reported in ppm concentrations (from Prellwitz, 1998).

Sample Location	Mg	Ca	Na	S	Si	K
Stream (under I-376 bridge)	16.2	76.4	70.7	37.8	5.6	4.9
Stream (middle of slag area)	12.5	65.2	52.5	34.9	5.3	8.0
Stream (near Mon river)	3.7	106	123.9	156.1	11.1	89.8
Seep 1	<.3	101.6	116.2	82.8	10.9	85.8
Seep 2	<.3	161.9	172	195.8	14.2	121.6
Monitoring Well 1	<.3	179.7	193.3	245.2	16.7	139.1
Monitoring Well 2	2.4	117.4	111.4	123	9.5	65
Monitoring Well 3	1	156.9	194	271.4	11.5	>150

The open hearth slags vary more in their composition, depending on the type and grade of steel wanted from the furnace, and when during the "heat" the furnace was tapped. The resulting slags contain calcium and iron oxide minerals, along with Ca-Mg-Fe orthosilicate minerals. Magnesium minerals are also present, from the magnesite and dolomite bricks that are the furnace floor. The more common open hearth slag minerals are lime (CaO), larnite (Ca_2SiO_4), wollastonite ($CaSiO_3$), wustite (FeO), fayalite $(Fe, Mg)_2SiO_4$, and merwinite $Ca_3Mg(SiO_4)_2$.

GROUNDWATER GEOCHEMISTRY

Groundwater samples were collected from three deep monitoring wells, two areas along Nine Mile Run where groundwater from the slag pile was seeping into the stream, and from the surface of Nine Mile Run. The monitoring wells and the seeps probably best represent the water baseflow under the slag pile.

High concentrations of calcium, sodium, sulfur, and potassium were found in the wells, seeps, and the surface of Nine Mile Run; values for heavy metals, such as lead, chromium, cadmium, and others were all below 1 part per million (ppm). Table 6 summarizes groundwater analytical results.

In general, concentrations of Mg, Ca, Na, S, Si, and K from samples taken from the surface of Nine Mile Run increased downstream from the I-376 (Parkway East) bridge to the confluence with the Monongahela River, due to the increased contribution of these elements from the water flowing out of the slag pile. The seeps and the monitoring well water samples are representatives of undiluted flow from under the slag pile, and have pH values of up to 11.2.

High concentrations of Ca were expected, since the lime in the slag is reacting with groundwater to produce portlandite (Figure 54). The reaction is: CaO (lime) + H_2O = $Ca(OH)_2$ (portlandite) + liberated heat. The temperatures in test boreholes had values up to 70°C, which indicates the interior of the slag pile is hot, the heat source being the above chemical reaction. This also explains the hot steam vents visible during cold weather. Prellwitz (1998) calculated that this reaction (assuming a normal amount of rainfall) will continue for at least 500 years.

High sulfur values were also expected, from trapped SO_2 gas in the slag vesicles. When a hand sample of slag is broken, a strong smell from the SO_2 is usually emitted.

The high levels of sodium and potassium seem anomalous, as the mineral makeup of the slag

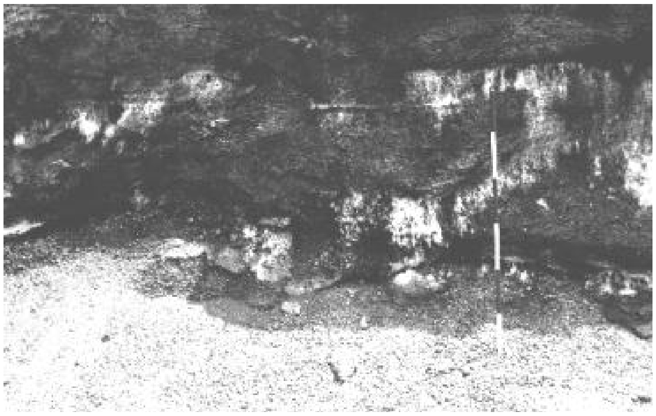


Figure 54. Photo of portlandite (white) leaching from the slag pile. Scale pole has 1 ft (0.3 m) intervals.

does not include these elements. One explanation could be road salt contamination.

The silicon values are from the breakdown of silicate minerals in the slag, and from silica bricks (used for furnace lining) dumped along with the slag.

CONCLUSIONS

The results of the Prellwitz (1998) study of the Nine Mile Run slag area arrive at four major conclusions: (1) concentrations of "toxic" heavy metals in the groundwater are almost nil; (2) the heat in the pile, and the steam vents, are both caused by the hydration of lime to portlandite; (3) this chemical reaction will continue in the future, assuming there will be water inflow into the pile; and (4) silicate slag minerals are relatively stable, compared with the reactivity of lime.

0.3	7.30	Pass under the Homestead Highlevel Bridge.
1.3	6.00	Pass under the Glenwood Bridge. Notice the delta on the **left** just upstream from the bridge. This is the mouth of Streets Run. It would be fascinating to do a sedimentological study of this delta. Also to the left is the Pittsburgh neighborhood of Hays, which, on August 6 and 7, was devastated by a flash flood following more than 5 inches of rain within one hour. Hays is situated in the valley of Streets Run.
1.0	5.00	The community to the **right** is Glenwood.
0.6	4.40	To the **left** is the mouth of Becks Run. To the **right** is the Pittsburgh neighborhood of Hazelwood, once home to LTV steel's Pittsburgh coke works.
1.3	3.10	Pass under the Hot Metal Bridge. Originally a RR bridge connecting J&L Steel's Hazelwood Works on the **right** with their South Side Works to the **left**, the bridge was refurbished in 2000 to carry road traffic between East Carson Street on the South Side and PA 885 (Second Ave.). Notice the absence of steel works. Both plants are gone and their brownfields sites are being redeveloped. The former Hazelwood Works site on the right is now the Pittsburgh Technology Center. The former South Side Works on the left is currently being developed as a combination of residential, commercial, entertainment, light industrial, and research and development facilities.
0.1	3.00	To the **right** the flat area above the river represents the western end of the great meander loop that took the preglacial Monongahela River out through East Liberty and Oakland.
0.7	2.30	Pass under the Birmingham Bridge.
0.3	2.00	On the right is Duquesne Bluff, capped by the Boulevard of the Allies, Duquesne University, Mercy Hospital, and a portion of the uptown section of Pittsburgh.

STOP 5. DUQUESNE BLUFF
Leader: John W. Kovacs, P.E.

A HISTORY OF CURRENT SLOPE CONDITIONS

Through long term erosional processes, the Monongahela River has carved a valley as it flows from the south towards the city of Pittsburgh, Pennsylvania. The river meanders to the east at the southern boundary of the city's downtown business district. As a result of the meander, the river has deposited a low terrace on the opposite bank of the city, the South Side, and erosional valley down cutting has developed a near vertical rock slope at the southern limit of downtown Pittsburgh (Figure 55). The approximately 115-ft (35-m) high rock slope is known locally as the Duquesne Bluff and consists of rock strata primarily within the Birmingham unit (Figure 56). Inspired by the spectacular view of Birmingham, now the South Side, situated on the opposite bank of the river, J. J. Stevenson named the unit accordingly in 1876 (Price, 1970).

Expansion of the city southward forced the construction of the Boulevard of the Allies at the crest of the bluff. This major state roadway (PA Route 885) links the central business district of downtown Pittsburgh to Oakland, a community east of Pittsburgh, and other nearby towns. The presence of four major educational institutions and several hospitals in and around Oakland contribute to the approximate 35,500 vehicles that travel the roadway daily. In spite of early critics claiming that a roadway built atop this rock slope would be dangerous, original construction of the roadway was completed in the 1920s. The roadway proved to be safe and remained unchanged until the mid 1950s when the Pennsylvania Department of Highways, now the Pennsylvania Department of Transportation (PennDOT), designed and constructed a widened roadway. The presence of Duquesne University, Mercy Hospital and established businesses adjacent to the inbound, westward, lanes of the Boulevard of the Allies forced the designers to extend the four lane roadway to the slope crest and, at places, cantilever beyond. Concurrent with the Boulevard of the Allies-widening activities, I-376 (the Parkway East) was under construction at the base of the Duquesne Bluff. The Parkway East, bounded by the Duquesne Bluff and the Monongahela River, was constructed on alluvial and colluvial deposits as well as fill material. The Parkway East currently facilitates the travel of approximately 70,000 vehicles daily.

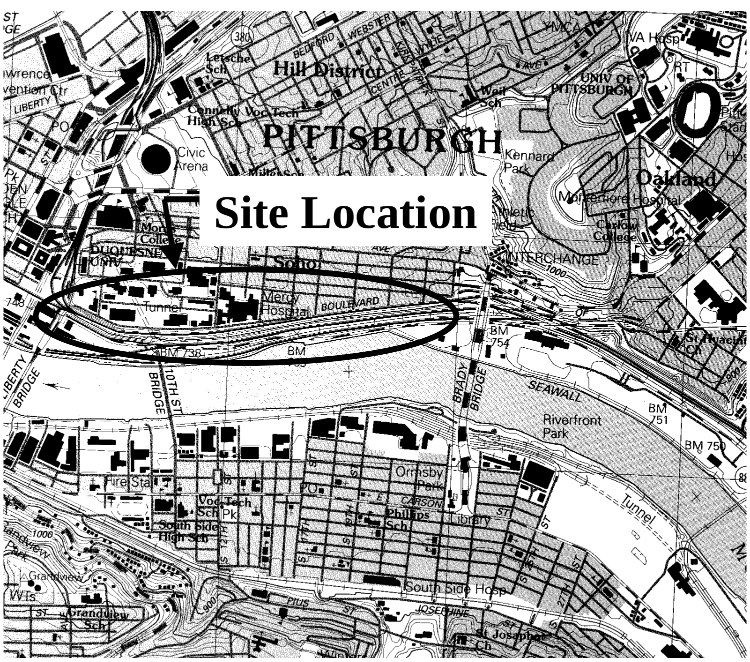


Figure 55. Location of the Duquesne Bluff project area at Stop 5 on the Pittsburgh East quadrangle.

Slope failures in the late 1970s prompted PennDOT to initiate slope-remedial studies. Investigation of remedial alternatives began in 1980 with work performed to identify and recommend remedial alternatives for rock-slope stabilization and the protection of traffic on the Parkway East. As a result of these evaluations, several concepts for stabilization were identified. These included: 1) trimming of overhanging or potentially unstable rock masses; 2) construction of a reinforced concrete slope protection to protect weaker rocks from weathering and to provide stabilization of overhangs above; and 3) constructing a drop zone to contain rock debris from the upper slope. These recommendations were constructed in the mid-1980s.

GEOLOGIC SETTING

The Duquesne Bluff is located within the Appalachian Plateaus Province in the Appalachian Highlands. The Appalachian Plateaus consists of gently folded, relatively flat lying rock units dipping regionally to the southwest at a rate of approximately 1 ft per 100 ft (0.3 m per 30.5 m) (Johnson, 1929). The topography within the region consists of steep hillsides and deep river and stream valleys with magnitudes of vertical relief typically ranging between 200 and 400 ft (61 and 122 m). Specifically, the 115-ft (35-m) maximum vertical relief of the Duquesne Bluff was formed as the result of long term erosion processes of the Monongahela River and the accompanying valley wall stress relief (Ferguson, 1967; Ferguson and Hamel, 1981).

Stratigraphically, the Duquesne Bluff reveals exposures of rock units within the Conemaugh Group of the Pennsylvanian system with geologic units in the lower Casselman and upper Glenshaw Formations. The main lithologic types are shale, claystone, marine and freshwater limestone, sandstone, siltstone, and coal. Definitive contacts can be observed between the stratigraphic units exposed on the bluff with the apparent dip being from east to west. The following subsections discuss the stratigraphic units exposed on the bluff (Figure 56).

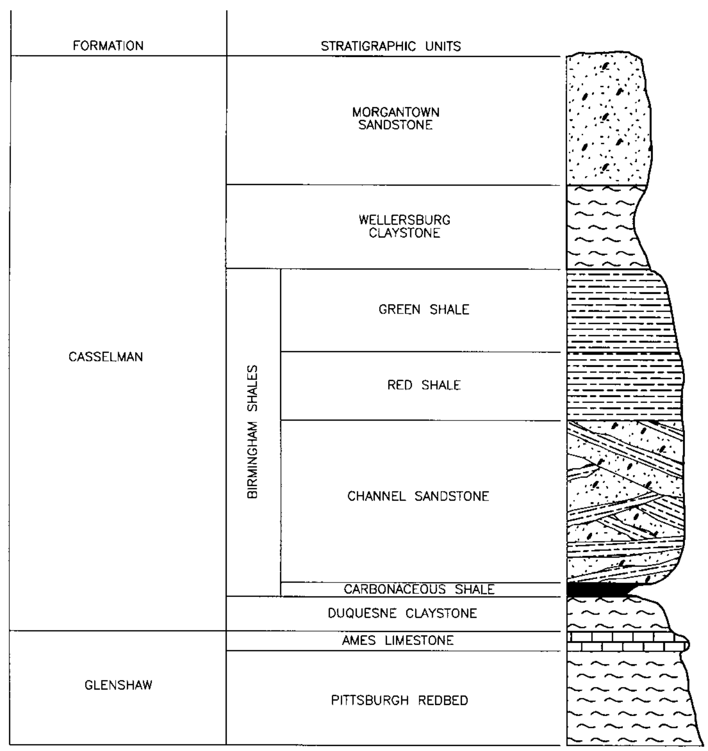


Figure 56. Generalized stratigraphic section illustrating the lithologic units of the Duquesne Bluff slope.

The Morgantown Sandstone

The Morgantown sandstone is a tan, cross-bedded, medium to fine grained sandstone with some interbedded shale. The sandstone is observed at the slope crest within the western portion of the site and measures between 10 and 25 ft (3 and 7.6 m) in thickness. The Morgantown is a durable sandstone and not typically susceptible to weathering.

The Wellersburg Claystone

The Wellersburg claystone lies directly beneath the Morgantown sandstone and is observed to be approximately 10 to 15 ft (3 to 4.6 m) in thickness. The Wellersburg is typically olive in color in an unweathered state and turns dull red as pyrites oxidize during weathering (Johnson, 1929). The Wellersburg is susceptible to weathering, a trait that lends itself to overhanging conditions of the Morgantown Sandstone.

The Birmingham Shale

The Birmingham shale is the predominant unit visible on the slope and ranges in thickness from 45 to 70 ft (14 to 21 m), but typically is 50 ft (15 m) thick. Within the Birmingham are several subunits, including the green shale, the red shale, and the channel sandstone. The green shale is located in the upper portion of the Birmingham unit and is not visible in the eastern region of the site. The red shale underlies the green shale and is observed throughout the slope. The red shale is poorly fissile and highly jointed. Channel sandstone is visible for a limited length, approximately 600 ft (183 m), and represents the exposure of a traverse cross section of a meandering stream and flanking floodplain deposits (Price, 1970). Investigators of this stratigraphic unit have concluded that the color variations within the shale have been the result of environments of deposition transgressing from freshwater to brackish. Marine fossils have been identified in the Birmingham shale, suggesting that this is the ighest stratigraphic unit in western Pennsylvania to contain such fossils. Recent field investigations have indicated that the red and green shale is somewhat susceptible to weathering, but more resistant than the Wellersburg claystone present directly above. The lowest subunit within the Birmingham shale is an approximately 2-ft (0.6 m) thick, highly weatherable basal, black carbonaceous shale.

The Duquesne Claystone

The Duquesne claystone is observed along approximately two thirds of the length of the slope and measures, typically, 7 to 15 ft (2 to 4.6 m) in thickness. The claystone is a very weatherable unit and, along with the basal black shale, has led to serious overhanging conditions of the Birmingham shale unit.

The Ames Limestone

The Ames Limestone was observed along a 100-ft (30.5 m) long section of the slope. The Ames measured approximately 3 ft (0.9 m) in thickness and is intermittently present on the slope. The Ames has not been observed to contribute to adverse slope conditions.

The Pittsburgh Red beds

The Pittsburgh red beds are composed of claystone and are persistent throughout the Pittsburgh vicinity, and are largely responsible for many unstable slope conditions within the region. The Pittsburgh red beds at this location are entirely covered by a talus slope protecting it from weathering effects. Unlike many other locations within the Pittsburgh region, it does not appear as though this stratigraphic unit is presently contributing to adverse slope conditions along the Duquesne Bluff.

STRUCTURAL GEOLOGY

In addition to the alternating sequences of durable and less durable rock units along the slope, jointing is readily observed on the bluff face and has been instrumental in the development of current slope conditions and instabilities. Many of the joints exposed on the slope are observed to be closed; however, several joints are open, as much as 6 in (15 cm) at one location. Primary jointing types, including tectonic and valley stress relief, have resulted in the formation of rock wedges and the potential for rock fall conditions. Tectonic joints, formed by the lateral compressive deformation of the earth's crust, are found to be systematically perpendicular and intersect the slope face at angles ranging between 30^{o} and 60^{o}. Stress relief joints are also present along the slope face and have formed by the relief of stresses with the valley down cutting by the Monongahela River (Ferguson, 1967; Ferguson and Hamel, 1981). These joints are curvilinear but generally parallel to the slope face and have been measured at $10^{o}\pm$, of due east. Jointing conditions, as described, have promoted slope instabilities leading to wedge and toppling failures. It is anticipated that these failures may have been initiated by geomorphic processes, including root pry and frost wedging. Additionally, seepage can be observed within the Birmingham shale and Duquesne claystone units.

Discontinuity data gathered from the slope face and evaluated using stereonet analyses have identified five principal joint sets within the Duquesne Bluff. These include (A) N78^{o}E, (B) N78^{o}W, (C) N41^{o}E, (D) N59^{o}W, and (E) N6^{o}E. Dip directions were recorded to be 82^{o}S, 80^{o}S, 81^{o}SE, 79^{o}SW, and 85^{o}E, respectively. Joint sets A and B are interpreted to be valley stress relief joints, and strike directions in adjacent quadrants confirms the undulating, curvilinear, surface observed in the field. These joints were also identified to be spaced approximately 5 ft (1.5 m) apart into the slope based on field observations (Figure 57A). Joint sets C, D, and E are anticipated to be tectonically induced. The bedding orientation identified in this region was measured to strike N56^{o}W and dip 5^{o}S. The strike of the slope surface beneath PA 885 was, on average, N80^{o}E, with an approximate dip of 80^{o}. All readings were adjusted for a declination of 7.5^{o} based on the City of Pittsburgh mapping dated 1984.

PREVIOUS SLOPE MODIFICATIONS

As discussed, the presence of alternating sequences of durable and less durable rock strata has historically resulted in differential weathering and the formation of precarious overhangs. Perpendicular and sub-perpendicular joints have led to unstable rock wedges and rock fall potential. The remedial program completed in the mid-1980s aimed to remove these overhangs and to stabilize the slope against future degradation. Primary construction activities included: trimming of the entire slope face; removal of overhanging rock masses; installation of dental concrete-rock buttresses in support of rock overhangs; placement of a shotcrete slope face treatment to prevent continued weathering of the less durable rock exposures; and installation of rock bolts to stabilize rock blocks formed by adverse tectonic and stress relief joints. In addition, limited areas were fitted with wire

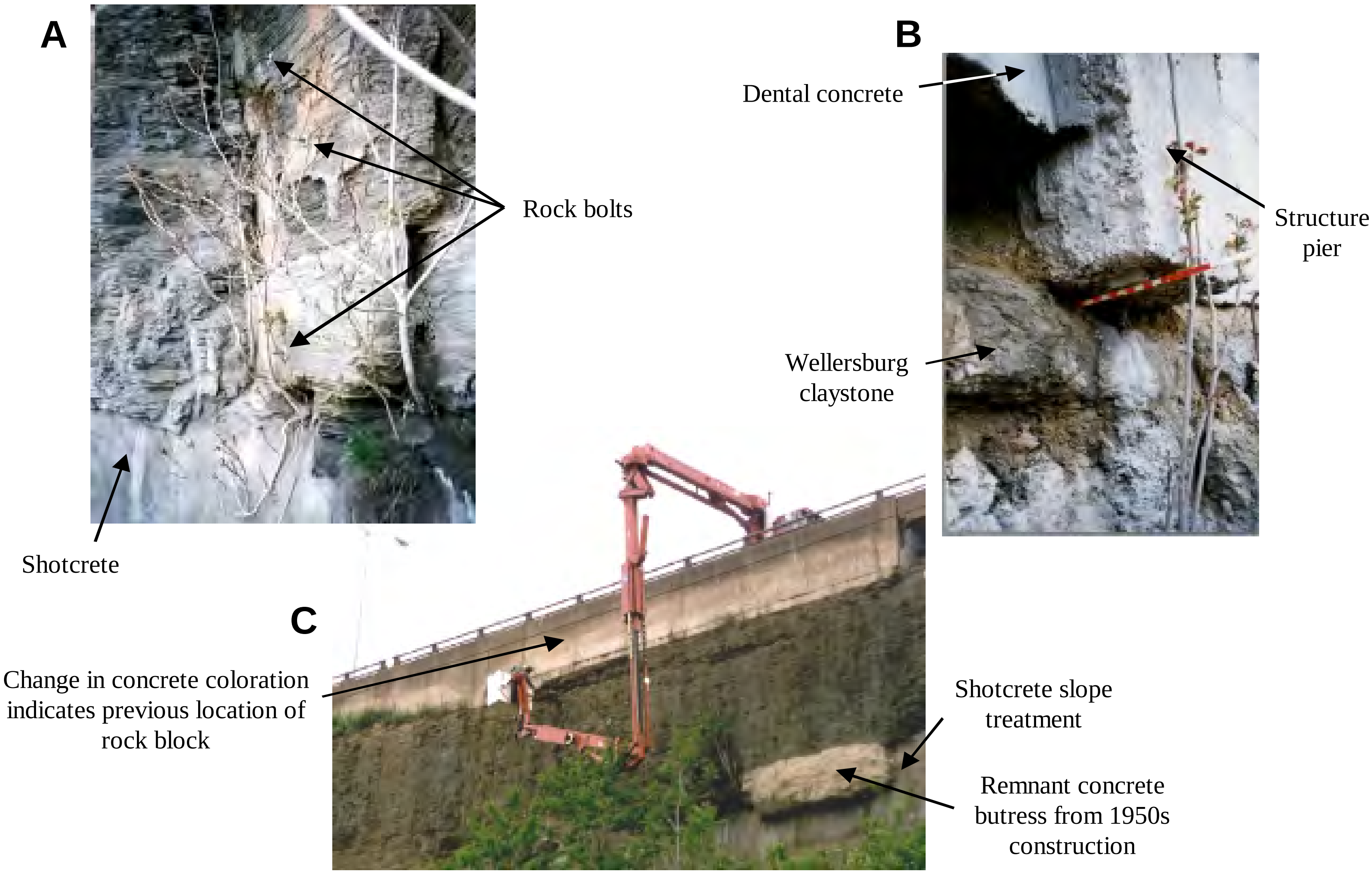
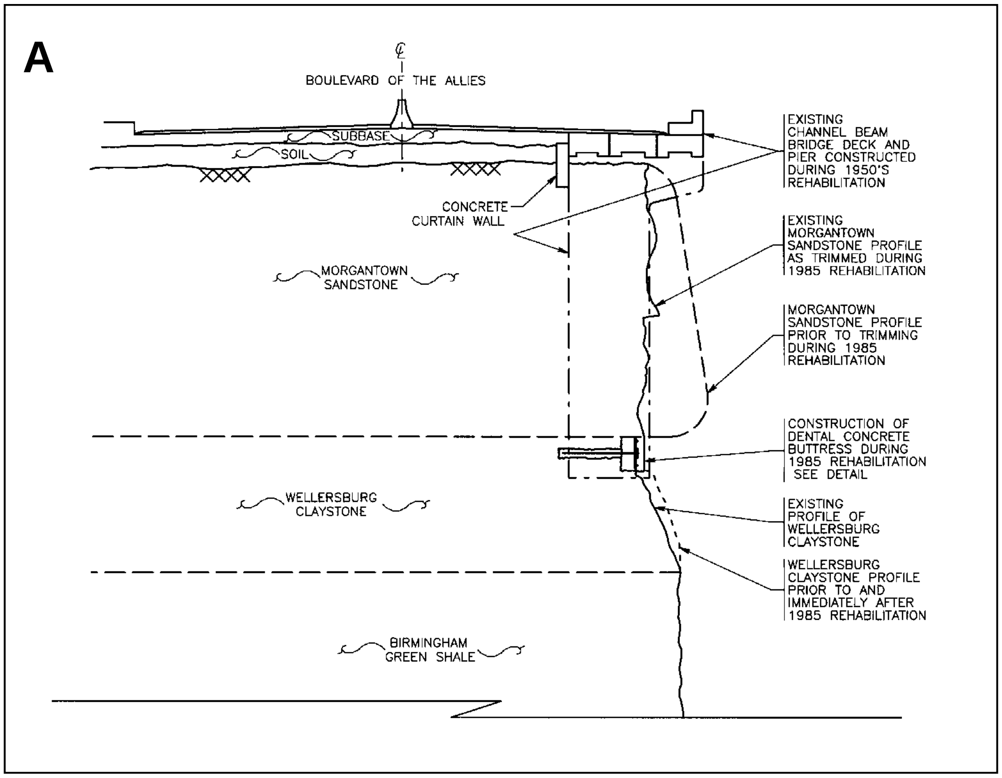


Figure 57. Photographs of the Duquesne Bluffs project. A. Valley stress relief joints in the Birmingham shale. Note the rock bolts in the Birmingham unit and shotcrete covering the Duquesne claystone below. B. Detail of undercutting from loss of the Wellersburg claystone beneath the structure pier (see Figure 58A for cross sectional diagram). Maximum undercut measured was 18 in (46 cm). C. Location of large rock block removed during 1985 slope scaling operations (see Figure 58B for cross sectional diagram). The engineering geologist and operator are investigating concrete that has been undercut due to removal of the rock block and subsequent weathering. This undercut is above an open tectonic joint (not visible).



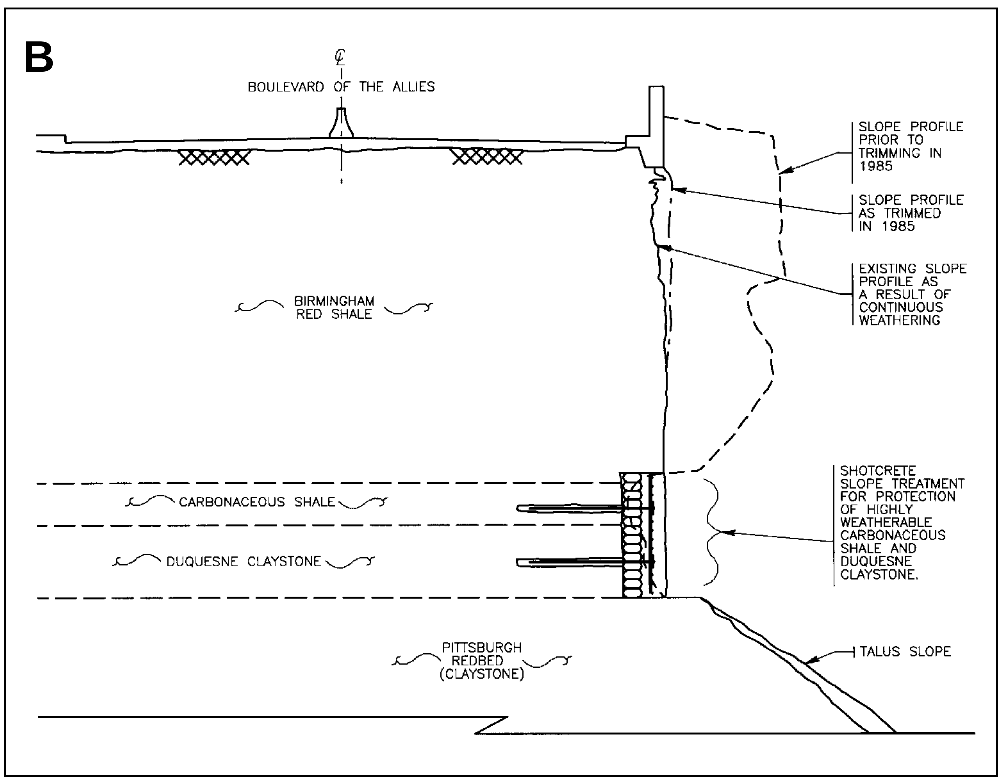


Figure 58. Cross sections of the Duquesne Bluffs project looking east. A. Location of the undercut shown in Figure 57B. B. Location of the large rock block removed in 1985, shown in Figure 57C.

mesh rock netting and localized catchment basins were constructed. However, cutting into the Pittsburgh red beds was not desired, thereby limiting the effective width of these basins. Overall slope trimming was performed by a relatively innovative method. In an attempt to facilitate the slope face trimming in areas of difficult access, the contractor fabricated a crane boom attachment that would allow the cutting head of a continuous longwall miner to be attached. Uniform vertical striations from the cutting head are still visible within areas of the Birmingham shale that have not weathered rapidly since the time of construction activities in the mid-1980s. Large rock masses were removed by conventional equipment to produce the desired cross sectional slope profile.

Subsequent to the rock removal and trimming activities, dental concrete buttresses were constructed within the upper Wellersburg claystone unit to provide support under the Morgantown sandstone overhangs. However, the dental concrete buttress has become a victim of the continuous weathering and mass wasting of the underlying Wellersburg claystone. Undercutting by as much as 1.5 ft (0.46 m) suggests a potential for instability (Figure 57B). Elsewhere on the slope, a layer of shotcrete slope protection was installed within the basal carbonaceous shale of the Birmingham unit and the Duquesne claystone. The concrete slope protection served to prevent continued weathering of these less durable units.

The most prominent slope alteration included the removal of a massive rock block measuring 70 by 30 ft (21 by 9 m) by approximately 15 ft (4.6 m) in depth. This rock block was a large overhang that had been supported with a concrete buttress. The buttress was installed prior to the remedial construction of 1985, possibly during the 1950s widening. Removal of the rock mass has exposed a large, open tectonic joint. Areas at the base of the Boulevard of the Allies roadway have weathered rapidly, likely due to continuous freezing and thawing within the shale laminations, and have created a precarious undercut of the structure. Removal of the large rock mass was undoubtedly in the interest of motorist safety from rock fall; however, these trimming activities have resulted in accelerated slope degradation and potential instabilities of the Boulevard of the Allies structures (Figure 57C).

SUMMARY

Geologic conditions of the Duquesne Bluff consist of alternating layers of durable and non durable rock units that are prone to differential weathering and the formation of rock overhangs. In addition, valley stress relief joints formed parallel to the bluff face and systematically perpendicular tectonic joints have resulted in unstable rock wedges. In 1985, a major rehabilitation construction project was implemented to correct many of the potential rock fall hazards present on the slope face. Current observation of the support buttressing and slope weathering protection alternatives constructed during the remedial project indicate that the designs are effective. However, aggressive slope trimming operations conducted during the remedial project may have led to weathering and mass wasting of the less durable rock units and the undercutting of the dental concrete buttressing and of roadway structures at various locations. Although localized removal of large rock masses may have been warranted given the pecarious rock overhangs, aggressive overall slope trimming may have promoted the conditions currently observed on the slope.

0.5 1.50 Pass under the 10th St. Bridge.
0.4 1.10 Pass under the Liberty Bridge.

HARPER'S GEOLOGICAL DICTIONARY

GENTLE DIP - A semi-idiot who loves children and animals.

0.1 1.00 Pass under the Panhandle Bridge. Formerly a RR bridge, this span now carries the T, Pittsburgh's light rail transit system (LRT), to the South Hills.

0.2 0.80 Pass under the Smithfield St. Bridge. On the **left** is Station Square, the former P&LE RR station and freight houses. These have been converted to office, retail, and restaurant/tavern space, making the area a popular attraction for both visitors and residents. Behind Station Square is the Monongahela Incline, which carries commuters and sightseers up and down the Mt. Washington slope.

STOP 6. MT. WASHINGTON SLOPE

Leader: James V. Hamel, P.G.

MT. WASHINGTON SLOPE - DUQUESNE INCLINE TO SMITHFIELD STREET BRIDGE

The Mt. Washington Slope, across from the "Point" of Downtown Pittsburgh, will be viewed from the Corps of Engineers barge while we cruise the Monongahela and Ohio Rivers. The slope segment of interest here extends from the Duquesne Incline up the Monongahela River past the Fort Pitt Tunnel and Bridge to the Monongahela Incline and Smithfield Street Bridge at Station Square (Figure 59). The Monongahela Incline, which opened in 1870, is the oldest incline in the United States. The Monongahela Incline and the Duquesne Incline, which opened in 1877, are still used extensively by commuters and tourists. Both of these inclines are National Historic Landmarks as are the Smithfield Street Bridge constructed in 1883 and the former Pittsburgh and Lake Erie Railroad Station completed in 1901 at what is now Station Square.

The Mt. Washington Slope forms part of the famous Pittsburgh skyline. This slope extends from river level (normal pool elevation 710 ft [216.4 m], controlled by the Emsworth Dam 6 mi [9.6 km] down the Ohio River from the "Point") up to approximately elevation 1150 ft (350 m)

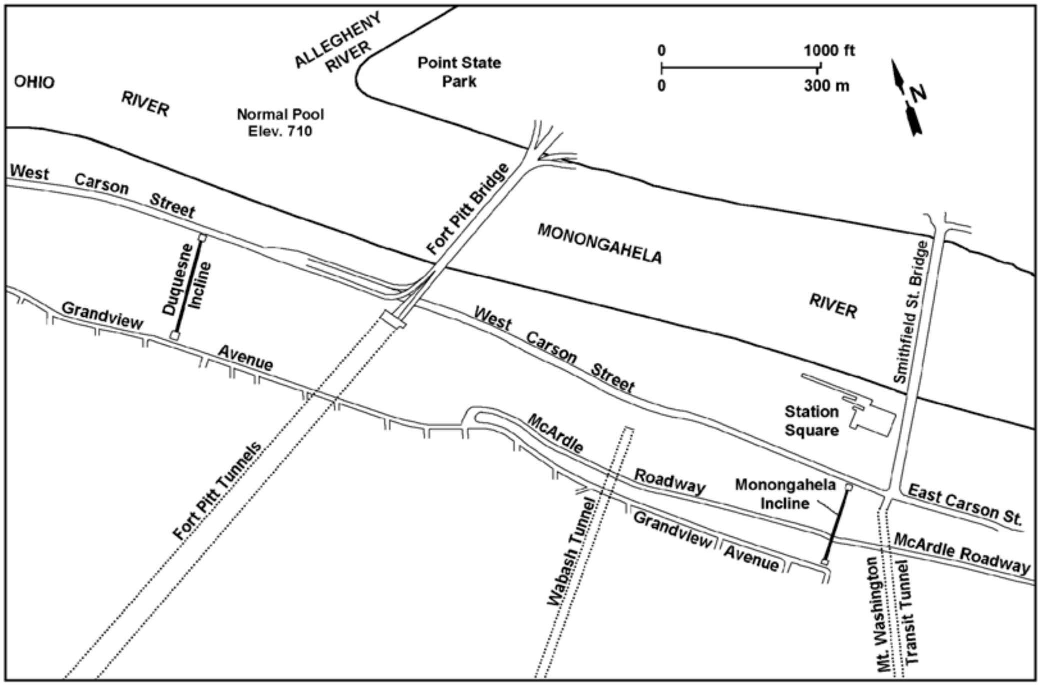


Figure 59. Map of Mt. Washington Slope - Duquesne Incline to Smithfield Street Bridge.

along Grandview Avenue (Figures 59-62). Rocks in the slope belong to the Pennsylvanian age Conemaugh and Monongahela Groups. These rocks are flat-lying with a dip of about 1% southerly or into the Mt. Washington Slope (Figure 61). The Ames Limestone at the top of the Lower Conemaugh Glenshaw Formation lies at nominal elevation 750 ft (229 m) while the Pittsburgh coal at the base of the overlying Monongahela Group lies at nominal elevation 1050 ft (320 m) (Figures 61 and 62). The first known mining of the Pittsburgh coal occurred on Mt. Washington, then known as Coal Hill, circa 1760 (Stop 1; Adams and oothers, 1980; Delano, 1985).

This area is generally thought to have been eroded to the ridgetop level of Mt. Washington (nominal elevation 1200 ft [365 m]) (Figures 59 and 61) by the end of Tertiary time (Johnson, 1929; Leighton, 1947; Wagner and others, 1970). Erosion of river channels in bedrock down to the Parker Strath, nominal elevation 900 ft (274 m), is generally thought to have occurred by the Illinoian period of Pleisttocene time when glacial outwash was deposited up to nominal elevation 1000 ft (305 m) (Figure 61). Further erosion of river channels in bedrock down to nominal elevation 660 ft (200 m)

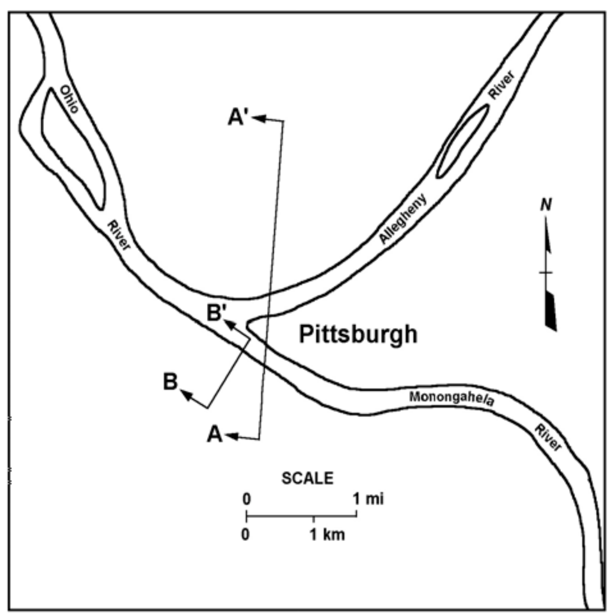


Figure 60. Map of Pittsburgh with cross-sections A – A' and B – B' (modified from Hamel, 1998).

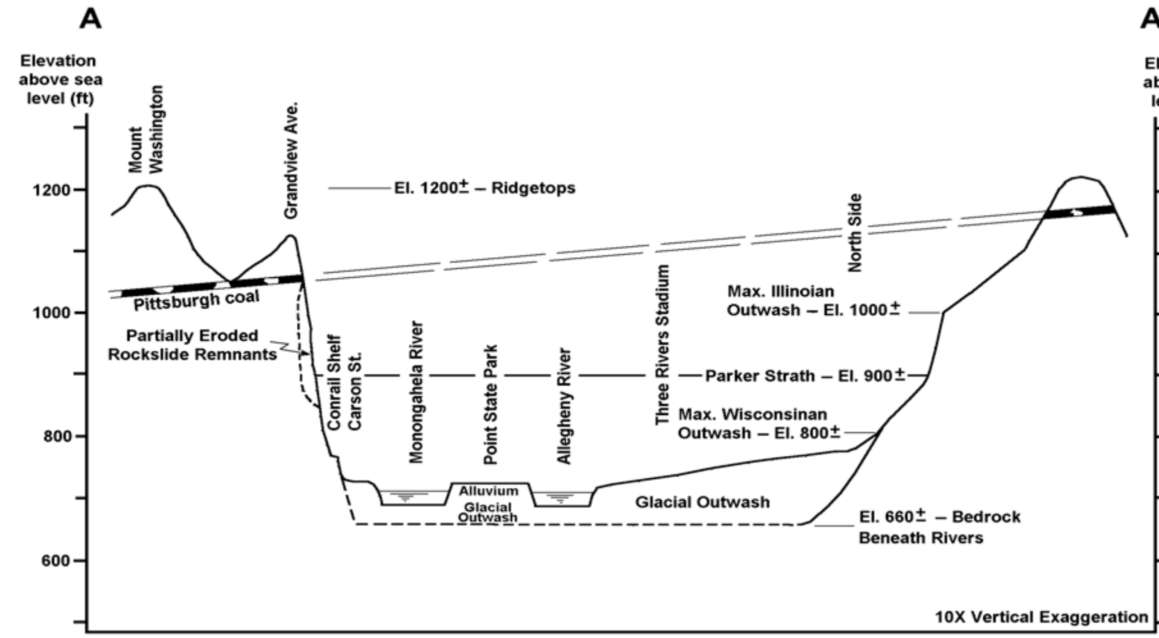


Figure 61. Cross-section A – A' (modified slightly from Hamel, 1998). See Figure 60 for location.

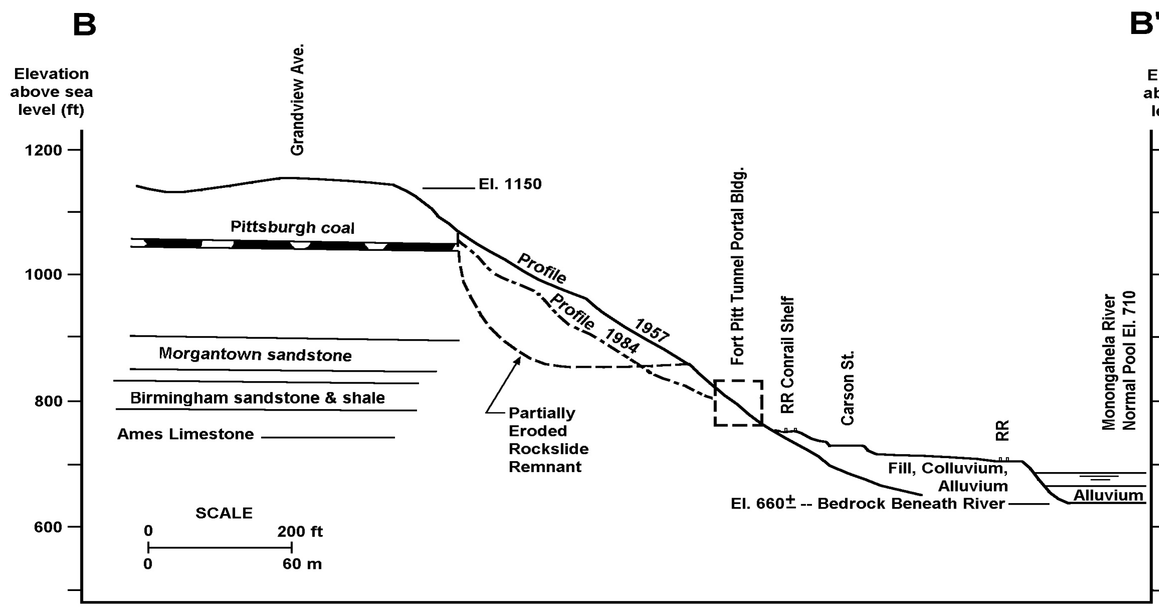


Figure 62. Cross-section B – B' (modified slightly from Hamel, 1998). See Figure 60 for location.

(Figures 61 and 62) is generally considered to have occurred in Late Illinoian time. During the later Wisconsinan period, little, if any, additional bedrock erosion of river channels is thought to have occurred. Extensive Wisconsinan outwash was deposited and reworked in the Pittsburgh area, with remnants existing up to nominal elevation 800 ft (244 m) (Figure 61).

Further information on the fascinating history of Pittsburgh's rivers during Pleistocene time is given by Leverett (1902, 1934), Wagner and others (1970), Adams and others (1980), Jacobson and others (1988), Harper (1997), and Hamel (1998) (also, see p. 28). It should be noted that the chronology of river erosion and deposition in the Pittsburgh area is not well constrained and some events may, in fact, have occurred earlier than generally believed. Additional details of this chronology are yet to be discovered through meticulous geologic field work, combined with the latest laboratory dating techniques, at key areas like the Mt. Washington Slope.

As Pittsburgh grew over the past two centuries, extensive development occurred in flatter areas along the toe and top of the Mt. Washington Slope. Of particular importance was initial railroad construction along the slope toe ca. 1850, as the railroads extended westward, and railroad expansion further into the slope toe ca. 1900, as Pittsburgh industries grew (Conrail Shelf, Figures 61 and 62). The slope itself, with a height of 300 to 400 ft (90 to 120 m) and an overall inclination of 1.5H:1V (34^{o}) with some steeper segments, remained, for the most part, undeveloped. This lack of development on the slope resulted from generally difficult access as well as geotechnical problems, mainly slope instability. Numerous landslides and rockfalls have come down onto the railroad over the past 150 years.

Until the 1990s, the Mt. Washington Slope received little attention from geologists and engineers, other than that related to construction and rehabilitation of several tunnels through the ridge in the 19th and 20th centuries, construction of McArdle Roadway up the slope from the Liberty Bridge in the 1920s, and re-construction of McArdle Roadway in the 1980s. Ackenheil (1958, 1959, and 1987) described rock slides and their treatment at the North Portal of the Fort Pitt Tunnel (Figures 59 and 62). Voytko and others (1987) described stabilization measures for the rock slope at the North Portal of the Mt. Washington Transit Tunnel southwest of the Smithfield Street Bridge at Station Square (Figure 59). I have not yet found any publications on the Wabash Railroad Tunnel or McArdle Roadway (Figure 59). Ackenheil (1954) tabulated some historic landslides and rockfalls along Mt. Washington and Ackenheil (1958) provided additional historical information on slope instability along the railroad.

Geologic and engineering attention was focused on the Mt. Washington Slope in the 1990s when a busway was proposed to be constructed along the slope toe on the Conrail Shelf (Hamel and others, 1998a and 1998b). Preliminary geotechnical investigations for the busway from 1991 to 1993 identified significant rockfall hazards. Detailed geotechnical investigations during 1994 and 1995 developed further information on slope geology and landslide and rockfall hazards, and produced designs for hazard reduction measures. Construction of these measures (which included cable lashing, scaling, rockbolts, and buttresses along the Mt. Washington Slope) began in late 1996 and was terminated prior to completion in early 1997 when the busway project was cut back as a result of cost and political considerations. There are some indications that this project may re-activate in the 21st century.

The 1994-1995 busway slope investigations included review of technical literature and historical records as well as analysis of historical (vertical) aerial photographs and low-level oblique aerial photographs taken for this project. The Mt. Washington Slope was virtually

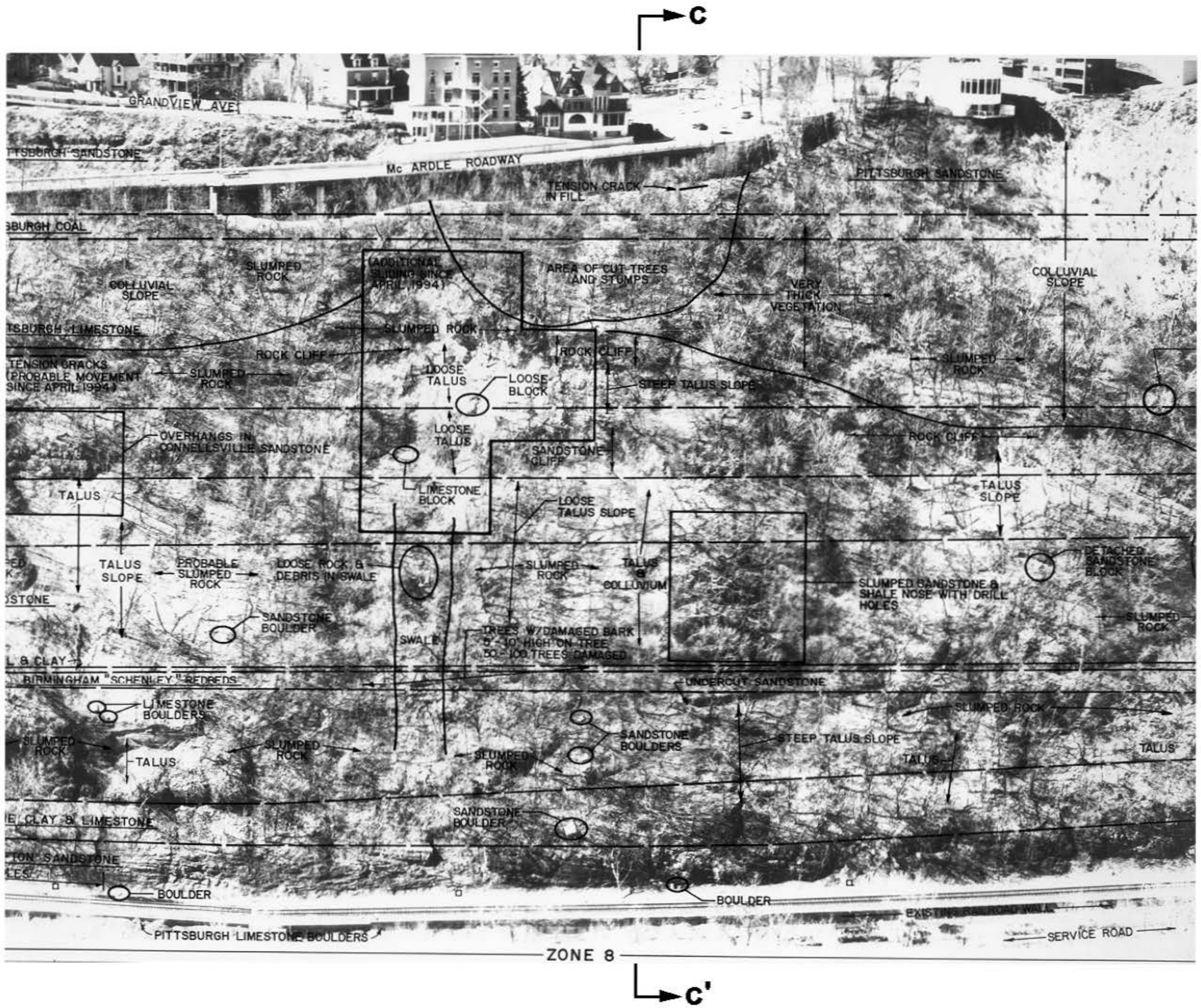


Figure 63. Aerial mosaic strip with cross-section C – C' (modified from Hamel and others, 1998b).

inaccessible to drill rigs and environmental and safety concerns essentially precluded drilling there. Field work consisted mainly of reconnaissance and mapping on large-sale (1:360) oblique aerial mosaics (Figures 63 and 64).

This field work along the Mt. Washington Slope revealed many of the slope failure types and processes of Varnes (1978). Rockfalls and rock topples are ubiquitous. Some of these failures are related to lateral rock spreads, rock slides, and rock slumps associated with valley stress relief (Ferguson, 1967; Ferguson and Hamel, 1981; Hamel, 1998). Debris slumps, debris slides, and slump-earthflows, all colluvial slope failures typical of the region (Hamel and Hamel, 1985; Hamel and Ferguson, 1999), are common along the Mt. Washington Slope. Debris slides, debris flows, and debris avalanches, which involve movement of colluvium and/or talus down chutes or ravines, are also common there (Hamel and others, 1998b).

The most significant geologic finding along the Mt. Washington Slope was the previously hypothesized (Hamel and Adams, 1981; Hamel and Hamel, 1985; Hamel and Ferguson, 1999), but hitherto relatively undocumented presence of numerous remnants of deep-seated, slump and translational landslides in bedrock. Slumped rock masses are recognized in the field by the appreciable dip of their beds back into the slope (Figure 65). Field recognition of translational rock slides is more difficult.

TThese rock slides are believed to have occurred during Pleistocene time when the rivers were actively eroding their valleys and climatic and hydrogeologic conditions were much more

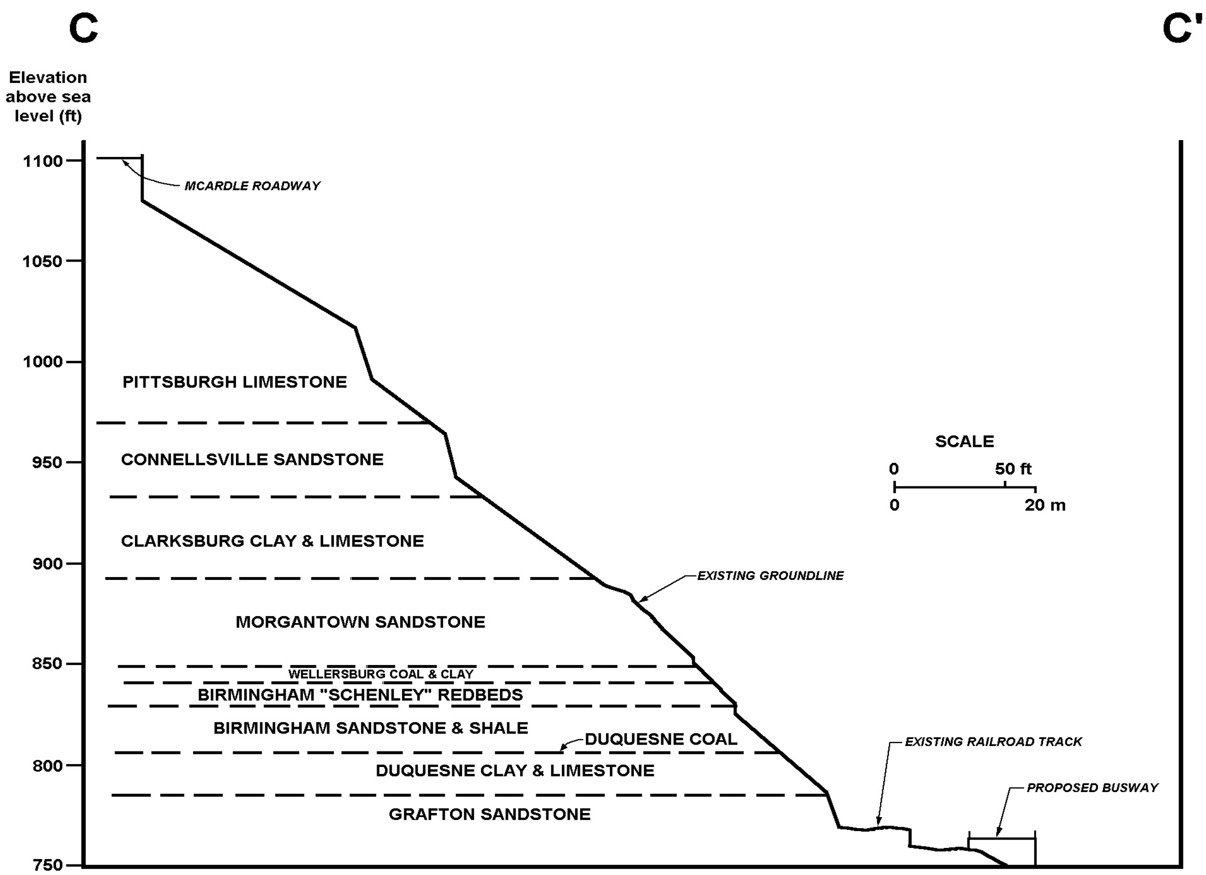


Figure 64. Cross-section C – C' (modified from Hamel and others, 1998b). See Figure 63 for location.

Figure 65. A. Slumped Morgantown sandstone blocks on slope 500 ft (150 m) upriver from Duquesne Incline (July 21, 1994). B. Slumped sandstone (30° dip into slope along 3-ft segment of 3 X 1-ft rule) in Pittsburgh limestone unit on slope 1000 ft (300 m) upriver from Fort Pitt Tunnel (July 28, 1995).

severe than at present (Hamel, 1998). Portions of these rock slide masses were eroded during later Pleistocene time and additional portions were excavated during the two major phases of railroad construction ca. 1850 and 1900.

The Pleistocene rock slide remnants, along with the numerous colluvial landslide features along the Mt. Washington Slope, are considered to be at least marginally stable under presently prevailing climatic, fluvial, and hydrogeologic conditions as long as they are not disturbed by construction activities. Loosened rocks from the rock slide remnants will continue to fall and/or slide onto the railroad along the slope toe, however, as they have for the past 150 years (Ruppen, 1999).

Discovery and documentation of numerous, deep-seated rock slide remnants along the Mt. Washington Slope lead to review of previously noted but seemingly rare and widely scattered rock slides in the region (Hamel, 1998). These rock slides have significant geologic implications regarding the Pleistocene history of the region, specifically processes of valley formation and colluvial slope development. They also have significant engineering implications relative to continuing rockfall and rock slide problems along transportation corridors, e.g., the Conrail Shelf, and future construction activities, particularly along slopes like the Mt. Washington Slope, which comprise much of the open space remaining in the Greater Pittsburgh area (Hamel, 1998).

The 1994-1995 busway slope investigation, which included the Mt. Washington Slope, was performed by Michael Baker, Jr., Inc. for the Port Authority of Allegheny County under FTA Project PA-03-0227. The work was financed in part through a grant from the US Department of Transportation, Federal Transit Administration, under the Urban Mass Transportation Act of 1964, as amended. John D. Lasko, Christopher A. Ruppen, and Donald V. Gaffney (all Professional Geologists) of Michael Baker, Jr., Inc., contributed substantially to this work for which the writer served as a consultant.

0.6	0.20	Pass under the Fort Pitt Bridge.
0.2	0.00	Confluence of the Monongahela River and Allegheny River to form the Ohio River.
0.3	0.30	The oddly shaped gray building to the **right** with the submarine USS Requin in front of it is the Carnegie Science Center. Next to it downstream are docked Voyager and Discovery, two surplus naval vessels that serve as Pittsburgh's floating classrooms. Pittsburgh Voyager takes groups of school children and their teachers on the water during the school year to teach them about the biology, chemistry, geology, and engineering of Pittsburgh rivers.
0.4	0.70	Pass under the West End Bridge. There used to be a salt works on the south shore to the **left** where Saw Mill Run drains into the river (Figure 66).
0.8	1.50	Upstream end of Brunot Island on the **left**. The island was named for the Brunot family who once lived there. Brunot Island is a six-unit, oil-fired, electric-generation facility. Formerly a coal-fired plant, it was converted by Duquesne Light Company in 1972. It has a demonstrated net capacity of 234 megawatts. Orion Power, a Baltimore-based corporation, recently acquired Brunot Island from Duquesne Light and plans to refurbish the facility, converting the old oil-fired plant to an efficient, environmentally preferred combined-cycle power plant fueled with natural gas. Orion Power expects to begin construction in November 2000, with full commercial operation

Figure 66. This painting, ca. 1832-34 by Russell Smith, shows a saltworks situated at the mouth of Saw Mill Run (below West End Circle).

beginning in 2002.

0.8	2.30	Pass under RR bridge.
0.4	2.70	To the **right** is Western State Penitentiary in the Woods Run neighborhood. Woods Run is the type locality of the Woods Run limestone, one of the cyclical marine units of the Glenshaw Formation, Conemaugh Group (see Figure 2). To the **left**, on the far side of Brunot Island, Chartiers Creek flows into the Ohio on the western shore. Chartiers Creek is one of the Ohio's major tributaries in this area. It is an old stream, as evidenced by the numerous remnant terraces found along the valley walls (see Figure 25).
0.5	3.20	To the **right** is ALCOSAN, the Allegheny County Sanitary Authority. This plant currently treats 225 million gallons per day.
0.1	3.30	Pass under the McKees Rocks Bridge.
0.2	3.50	The sandstone cliffs to the **right** are Buffalo sandstone, middle Glenshaw Formation (Figure 2).
0.2	3.70	Jacks Run enters the Ohio on the **right**. You should be able to make out the well-developed honeycomb weathering in the Buffalo sandstone above the RR tracks here.
0.9	4.60	The small island on the left is Davis Island.
0.4	5.00	Upstream end of Neville Island on the **left**. This is the home of the West View Water Authority, which takes its water supply from wells in the Wisconsinan gravels beneath the river. Neville Island has been home to many industrial companies and their disposal sites over the decades. According to the Neville Island Good Neighbor Committee, a local watchdog group, the island’s industry generates over 3 million pounds of toxic chemical waste, including 900,000 pounds that are released to the air and water every year (over one ton a day). An additional 600,000 pounds are incinerated or treated on Neville Island, and

		1.5 million pounds are shipped to other sites. Over 25% of all toxic chemical releases for Allegheny County comes from industry on Neville Island, according to the group.
1.1	6.10	Emsworth Locks and Dam. The dam helps maintain a standard pool elevation of 710 feet above sea level in the Pittsburgh area. We will leave the barge at this point and reboard the buses for the ride back to the hotel.

Mileage		Description
Int	Cum	
0.00	46.85	Leave Emsworth Lock and Dam. **Turn right** at the old Dickson House log cabin.
0.10	46.95	Crossing the PA 65 (Ohio River Blvd.).
0.05	47.00	**Turn right** at the first stop sign.
0.10	47.10	At the traffic light **turn right** onto the PA 65 (Ohio River Blvd.).
0.35	47.45	Entering Emsworth. Atlantic Ave., access road to Emsworth Lock and Dam, to the left. **Continue** on PA 65.
0.25	47.70	Crossing Lowries Run.
0.05	47.75	Traffic light at intersection of PA 65 (Ohio River Blvd.) and Camp Horne Rd. **Continue** on PA 65.
0.65	48.40	On the right for the next 1.3 miles are exposures of the Buffalo sandstone, Glenshaw Formation, Conemaugh Group (Figure 2).
0.65	49.05	The buildings on the right are part of the former Dixmont State Hospital.
0.60	49.65	**Bear right** onto the ramp to I-79 South and follow the road under the expressway.
0.65	50.30	**Merge with traffic** on I-79 South and cross the bridge over the Ohio River.
0.35	50.65	Exit to Neville Island. **Continue** on I-79 South.
0.20	50.85	Crossing the back channel of the Ohio River. To the right is Coraopolis, childhood home of your friendly neighborhood guidebook editor.
4.70	55.55	Exit 16A to PA 60 north, Moon Run, and the Greater Pittsburgh International Airport. **Continue** on I-79.
0.50	56.05	Exit 16B to PA 60 south and Crafton. **Continue** on I-79.
0.95	57.00	Notice the acid mine drainage on the hillside to the left. The Pittsburgh coal has been deep mined extensively in this area.
0.75	57.75	**Bear right** at Exit 14 to I-279 North toward Pittsburgh. The large cuts directly ahead and to the right expose strata of the Pittsburgh Fm. in the Monongahela Gp.
0.65	58.40	**Merge with traffic** on I-279 North and head east toward Pittsburgh.
0.65	59.05	The concrete embankment to the left covers open mine entrances of the room-and-pillar mined Pittsburgh coal.
0.70	59.75	Crossing bridge over Chartiers Creek and borough of Carnegie.
0.20	59.95	Exit 3 to Carnegie and PA 50. **Continue** on the Parkway West (I-279 and US 22 & 30).
0.20	60.15	Passing under the Norfolk and Western RR trestle. Get into the **right lane**.
1.55	61.70	**Bear right** at Exit 4 to Green Tree and Mt. Lebanon.
0.15	61.85	At the traffic light at the top of the ramp **turn left** onto Green Tree Rd. (PA

		121).
0.30	62.15	Traffic light at intersection of Green Tree Rd. and Parkway Center Dr. **Turn right** onto Parkway Center Dr.
0.10	62.25	**Turn left** into the Parkway Center Inn parking lot. **End of Day 1**.

Remember: Social Hour at 6:30 p.m. and Annual Banquet at 7:30 p.m.

ALTERNATE ROAD LOG

There is always a remote possibility that the Corps of Engineers' boat and barge cannot be made available for the Day 1 Field Trip (e.g. mechanical failure). In addition, future geologists might like to follow this road log. We, therefore, offer this alternate road log from Stop 3, Braddock Dam, to the Parkway Center Inn.

Mileage		Description
Int	Cum	
0.00	46.85	Leave Stop 3.
0.35	47.20	**Turn right** onto 11th St.
0.30	47.50	**Turn left** onto Braddock Ave. Notice the historical marker on the left commemorating the Great Steel Strike of 1912.
0.95	48.45	Approach ramp to the Rankin Bridge.
0.00	48.45	**Go up** the approach to the Rankin Bridge, cross the intersection and **bear right** under the bridge and onto the entrance ramp.
0.20	48.65	**Merge with traffic** on the bridge at the stop sign.
0.50	49.15	**Turn right** off the bridge at the traffic light. Go down the ramp and **merge with traffic** on PA 837.
0.45	49.60	Traffic light at the entrance to the Waterfront development on the right. **Continue** straight on PA 837.
0.75	50.35	Entering the City of Homestead.
0.40	50.75	Traffic light at the intersection of Eighth Ave. (PA 837) and Amity St. **Turn right** onto Amity St.
0.10	50.85	Cross two sets of railroad tracks.
0.05	50.90	**Turn right** on circular drive. To the left is a ramp to the Homestead High Level Bridge.
0.20	51.10	At the traffic light **turn right**.
0.05	51.15	**Turn right** into the large parking area of the Target superstore.

STOP 4. NINE MILE RUN SLAG DUMP

Leader: Henry S. Prellwitz

The slag dump can be viewed across the Monongahela River from this stop. See p. 86-90 for the description.

0.90	52.05	Return to Amity St. and PA 837 (Eighth Ave.). **Turn right** on PA 837 at the traffic light.
0.10	52.15	Intersection at PA 837 (Eighth Ave.) and the Homestead High-Level Bridge.

Get in the **left lane** and **continue** straight on PA 837.

0.30 52.45 **Bear right** following PA 837.

0.60 53.05 Sandcastle Water Park on the right.

0.35 53.40 Pass under CSX RR trestle. The valley to the left is Hays, a neighborhood of Pittsburgh. Hays is built on the floodplain of Streets Run. On August 7, 2000, a rainstorm dropped more than 5 inches of rain in the Streets Run drainage area in less than 24 hours. There were no casualties, but there was a considerable amount of property damage from the resulting flash flood.

0.15 53.55 Get in the **right lane** and **bear right** onto the ramp to PA 837 (East Carson St.)

0.10 53.65 Go under CSX RR bridge and Glenwood Bridge.

0.30 53.95 The flat area to the right used to be an Amoco tank farm for storing oil products. Shipments came across country via pipeline down over the steep hillside to the left, and were loaded in trucks and in barges on the river. Amoco abandoned the site and demolished the tanks several years ago.

0.40 54.35 The community across the river is Hazelwood and Glenwood, neighborhoods of Pittsburgh that thrived on coke and steel. Both are now depressed areas.

1.10 55.45 Traffic light at Becks Run Rd. and PA 837 (East Carson St.). **Continue** on PA 837.

0.70 56.15 The area on the right for the next 0.8 mi. used to be the Jones & Laughlin South Side Works. There is almost no trace of these great steel mills remaining. Instead, this brownfield site is currently being developed as a combination of residential, commercial, entertainment, light industrial, and research and development facilities.

0.20 56.35 On horizon ahead across the Monongahela is the Cathedral of Learning of the University of Pittsburgh in the Oakland section of the city.

0.30 56.65 Traffic light at Hot Metal St. and PA 837 (East Carson St.). Hot Metal St. is named for the Hot Metal Bridge to the right. This former railroad bridge used to transport steel products between Jones & Laughlin's Hazelwood Works on the north side of the river and their South Side works. The bridge was converted to road traffic in 2000 in order to help alleviate traffic congestion at the Birmingham Bridge. **Continue** on PA 837.

0.50 57.15 Birmingham Bridge on right. **Continue** straight on PA 837.

0.80 57.95 Traffic light at intersection of 10th St. and PA 837 (East Carson St.). The 10th St. Bridge is just to right. **Continue** straight on PA 837.

0.15 58.10 **Turn right** onto South 8th St.

0.15 58.25 **Turn right** at the end of South 8th St. onto the gravel area. Across the river are

the Duquesne bluffs with the Boulevard of the Allies, Duquesne University, Mercy Hospital, and a portion of uptown Pittsburgh above them.

STOP 5. DUQUESNE BLUFF

Leader: John W. Kovacs, P.E.

The Duquesne Bluff can be viewed across the Monongahela River from this site. See p. 91-97 for the description of this stop.

0.05	58.30	**Turn right** onto South 9th St.
0.15	58.45	**Turn right** onto PA 837 (East Carson St.).
0.60	59.05	Pass under Liberty Bridge. Arlington Ave. intersects on the left at the traffic light.
0.15	59.20	Station Square station of the T, Pittsburgh's subway/LRT, on the left.
0.05	59.25	Traffic light at intersection of Smithfield St. and PA 837 (East Carson St.). **Turn right** onto Smithfield St. and cross the Smithfield St. Bridge.
0.10	59.35	The buildings to the left are former P&LE RR station, freight house, and administration buildings. They were converted to the Station Square shopping mall, Grand Concourse Restaurant, and office complexes in the early 1980s.
0.25	59.60	Smithfield St. crosses over the Parkway East (I-376 and US 22 & 30). Get in the **left lane**. At the traffic light, **turn left** onto Fort Pitt Blvd.
0.25	59.85	Traffic light at intersection of Fort Pitt Blvd. and Stanwix St. **Turn right** onto Stanwix St. On the left is a pier of the old Wabash RR.
0.05	59.90	Traffic light at intersection of Stanwix St. and Blvd. of the Allies. **Turn left** onto Blvd. of the Allies.
0.10	60.00	Traffic light at intersection of Blvd. Of the Allies and Commonwealth Place. **Turn left** onto Commonwealth Place.
0.05	60.05	On the left is the parking area for Point State Park. Buses will drop conferees off here and return in approximately one hour. Walk to the Monongahela edge for a view of the face of Mount Washington and McArdle Roadway

STOP 6. MT. WASHINGTON SLOPE

Leader: James V. Hamel, P.G.

The shore of the Monongahela River at Point State Park offers a great view of the Mt. Washington slope. See p. 98-105 for the description of this site. Following the discussion, we will walk back to the parking area and reboard the buses.

0.00	60.05	**Turn left** onto Commonwealth Place.
0.10	60.15	**Bear right** onto Liberty Ave.
0.10	60.25	Get in **left lane** approaching intersection with Stanwix St.
0.05	60.30	Traffic light at intersection of Liberty Ave. and Stanwix St. The oddly shaped building on the corner to the right is the entrance to the Gateway Center station of the T, Pittsburgh's subway/LRT. **Turn left** onto Stanwix St.
0.05	60.35	Traffic light at intersection of Stanwix St. and Penn Ave. **Continue** on Stanwix St.
0.10	60.45	Traffic light at intersection of Stanwix St. and Fort Duquesne Blvd. PNC Park, the Pittsburgh Pirates baseball stadium is directly ahead across the Allegheny River. **Turn left** onto Fort Duquesne Blvd.
0.10	60.55	Get in the **right lane** and head toward the Fort Pitt Bridge (I-279 and US 22 & 30).
0.10	60.65	Pass under the approach ramps to the Fort Duquesne Bridge. **Stay in the** right lane.
0.20	60.85	**Merge with traffic** and cross the Fort Pitt Bridge. Get into one of the two **left**

		lanes.
0.30	61.15	Enter the Fort Pitt Tunnels. The tunnels were constructed in the softer shales, siltstones, and claystones of the Birmingham unit. Above is the Morgantown sandstone.
0.70	61.85	Exit the Fort Pitt Tunnels.
0.50	62.35	Runaway truck "sand pile" (actually, gravel) on the left. This safety feature saves lives every year by stopping big trucks that have lost their brakes coming down the hill toward the tunnels.
0.60	62.95	Get in the **right lane** and **bear right** onto Exit 5, Parkway Center Drive.
0.50	63.45	**Turn right** into the parking lot at the Parkway Center Inn. End of Day 1 field trip.
		Remember: Social Hour at 6:30 p.m. and Annual Banquet at 7:30 p.m.

ROAD LOG – DAY 2

Mileage		Description
Int	Cum	
0.00	0.00	**Leave** the Parkway Center Inn and **turn right** onto Parkway Center Dr.
0.05	0.05	Traffic light at intersection with Green Tree Rd. **Turn right** onto Green Tree Rd.
0.95	1.00	Stop sign at intersection with Woodville Ave. **Continue** straight ahead on Woodville Ave.
0.40	1.40	Traffic light at intersection with Neptune St. West End Branch of Carnegie Library on the right. **Turn right** onto Neptune St.
0.05	1.45	**Turn left** onto Alexander St.
0.05	1.50	Traffic light at intersection with South Main St. **Turn right** onto South Main St.
0.35	1.85	**Merge with traffic** into the West End Circle. Follow the signs to I-279 North.
0.10	1.95	**Turn right** onto the West End Bridge. Stay in the **left lane**. There is a spectacular view of Pittsburgh and the Point to the right.
0.30	2.25	**Bear right** and follow the signs to I-279 North.
0.40	2.65	The oddly shaped gray building on the right with the even odder funnel-like gizmo on the roof is the Carnegie Science Center. The new Three Rivers Stadium is right across the street. This will be the home of the Pittsburgh Steelers football team starting in 2001. Just beyond it is the old Three Rivers Stadium. It is scheduled to be demolished in 2001. Stay in the **left lane**.
0.20	2.85	Follow the signs for PA 28 and I-279 North. The Fort Duquesne Bridge is to the right.
0.40	3.25	On the right is Pittsburgh's new Pirates baseball stadium, PNC Park. Get in the **right lane**.
0.20	3.45	**Bear right** at Exit 13 to PA 28.
0.40	3.85	**Merge with traffic** on PA 28. Get in either the **left or center lane**.
0.40	4.25	On the right is the H.J. Heinz plant, and on the left is the Penn Brewery, maker of Penn Dark, voted the best dark beer in the world by a panel of international taste testers.
0.90	5.15	Traffic light at the 31st St. Bridge. This bridge crosses Washington's Landing, formerly known as Herr's Island. One of Pittsburgh's early reclaimed "brownfield sites, the island is now home to the Pittsburgh offices of the Pennsylvania Geological Survey and Pennsylvania Department of Environmental Protection. NOTE: Although the city insists on calling the island "Washington's Landing," the actual site of George's ignominious plunge into the icy Allegheny, and subsequent camp-out, was about 0.25 miles upstream and close to the far shore. It no longer exists. Troy Hill, at the top of the cliffs on the left, is a classic example of the Parker Strath. The community exists on the flat surface that used to be the pre-glacial Allegheny River (see Figure 40). The hillside from here to Millvale has been plagued by landsliding for a long time. Notice the number of abandoned building foundations at and just above road level over the next 1.5 miles.

0.40	5.55	Entering the Borough of Millvale.
0.30	5.85	**Bear right** and pass under the 40th St. Bridge. **Continue** north on Route 28.
0.40	6.25	Exit 3 to Millvale. **Continue** north on Route 28.
0.20	6.45	The reinforced retaining wall on left covers the beginning of a 0.8 mi. stretch in which the Pittsburgh and Schenley red beds and intervening strata, including the Ames Limestone, are exposed in the hillside on the left. Colluvial soils, derived from the red claystones, have a long history of earthflow-type landsliding in southwestern Pennsylvania, causing a great deal of damage and expense annually. This exposure seemed to be more trouble than usual over the years, and in the late 1980s and early 1990s, the highway department had to remove a sizable amount of soil and deeply weathered bedrock while attempting to widen the highway. The retaining wall is literally screwed into the hillside.
0.90	7.35	Shaler Waterworks on the left supplies groundwater to the North Hills areas from alluvial sand and gravel of the present Allegheny River valley.
0.20	7.55	Exit to Etna. **Continue** on PA 28 but get in the **left lane**.
0.50	8.05	**Bear left** onto the exit ramp at Exit 5 toward Butler and **merge with traffic** on PA 8. The cliffs on the right expose rocks of the upper Glenshaw Formation to upper Casselman Formation, from the Upper Saltsburg sandstone near road level to the Connellsville sandstone at the top. Can you tell where the Ames Limestone is in this section?
0.60	8.65	The roadcut on the right exposes a beautiful little cut-and-full channel sandstone in the Lower Saltsburg sandstone (middle Glenshaw Formation).
0.10	8.75	Traffic light at intersection with Kittanning St. **Continue** on PA 8.
0.20	8.95	Exposure of the Pine Creek limestone on the right, adjacent to the intersection of PA 8 and Catherine Street in Etna. The Pine Creek lies at an elevation of 760 feet above sea level here but rises in elevation as you travel north toward the axis of the Kellersburg anticline at Allison Park. The underlying shales and siltstones grade northward into sandstone (Buffalo) along the length of this outcrop. One historical note: I. C. White, who did the original field work and mapping of this portion of Allegheny County during the Second Geological Survey of Pennsylvania (White, 1878), called the limestone bed at this spot the Brush Creek. What is especially fascinating about this is that White was the author who first described and named both the Brush Creek and Pine Creek limestones. **Continue** on Pa. PA 8.
0.50	9.45	On the left is a flood control project in Pine Creek. The state Bureau of Flood Protection removed a thick spur of Buffalo sandstone that was responsible for a large meander loop in Pine Creek (it crosses beneath PA 8 near the Burger King restaurant, curls around Shaler Plaza to the right and crosses beneath PA 8 again about 100 yards south of this position. The spur and loop blocked water flow during times of high runoff, creating floods in this part of Shaler Township. The sides of the flood control channel south of the excavation are lined with grouted riprap for erosion control. In addition, the streamflow to the meander loop was sustained to accommodate the biological habitat of the stream critters living in the meander. Only floodwater comes over the weir. For more information, see Harper (1995b). **Continue** on PA 8.

0.10	9.55	Traffic light at intersection with Saxonburg Blvd. **Continue** on PA 8.
0.30	9.85	Excavation on the right exposes the Buffalo sandstone overlying shales of the Pine Creek interval.
0.50	10.35	Glenshaw Glass Factory on the left.
0.60	10.95	Traffic light at Fall Run Rd. Penalty Box ahead on the right. **Turn right** onto Fall Run Rd.
0.05	11.00	Cross Pine Creek.
0.05	11.05	**Turn left** to Fall Run Park and at the fork, **bear right** into the park.
0.20	11.25	Drive to the circle at the end of the access road and disembark from the bus.

STOP 7. FALL RUN PARK

Leaders: Chuck Shultz and John Harper

We will disembark at the lower end of Stop 7 (Figures 67 and 68) and proceed north up the walking path through the park.

STRATIGRAPHY, GEOMORPHOLOGY, LANDSLIDING, AND THE EFFECTS OF URBAN FLASH-FLOODING IN FALL RUN PARK

It is essential that you bring your field guild with you on this stop. We will provide a general overview after we disembark, but the trip is principally self-guided. We have marked eight substops (A to H) on the hike upstream, each of which is described in your guide. Stop locations are shown on the detailed topographic map of the Fall Fun drainage (Figure 68). The hike is about one mile long with a 220-foot rise in elevation. There is one steep climb of 40 feet to get to the top of the falls; steps have been excavated into landslide debris to ease the climb.

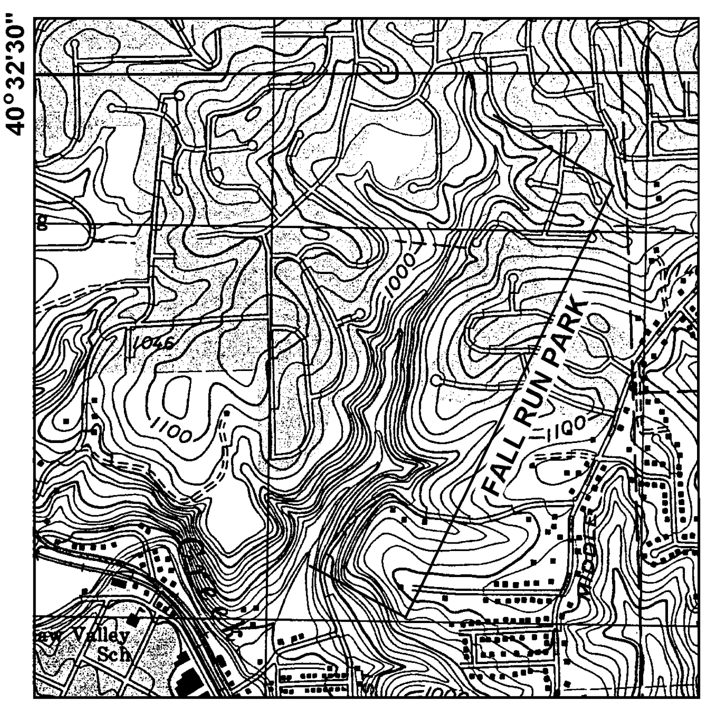


Figure 67. Location of Stop 6 on the Glenshaw quadrangle.

OVERVIEW

How do Cleveland, Columbus, Indianapolis, and Chicago differ from Pittsburgh? The former are built on flat lands, so a block system was utilized and virtually all land was developed. But, in the Pittsburgh area, "Mother Nature" presented deep slot valleys, rugged hills, and steeply wooded river-valley walls that could not be developed (without some problems). Thus, by default, Pittsburgh is splashed and sprinkled with green zones that have changed little since the time when Europeans first arrived (early 1700s). Fall Run valley is one of these preserved relict green spaces. Well, almost. Of

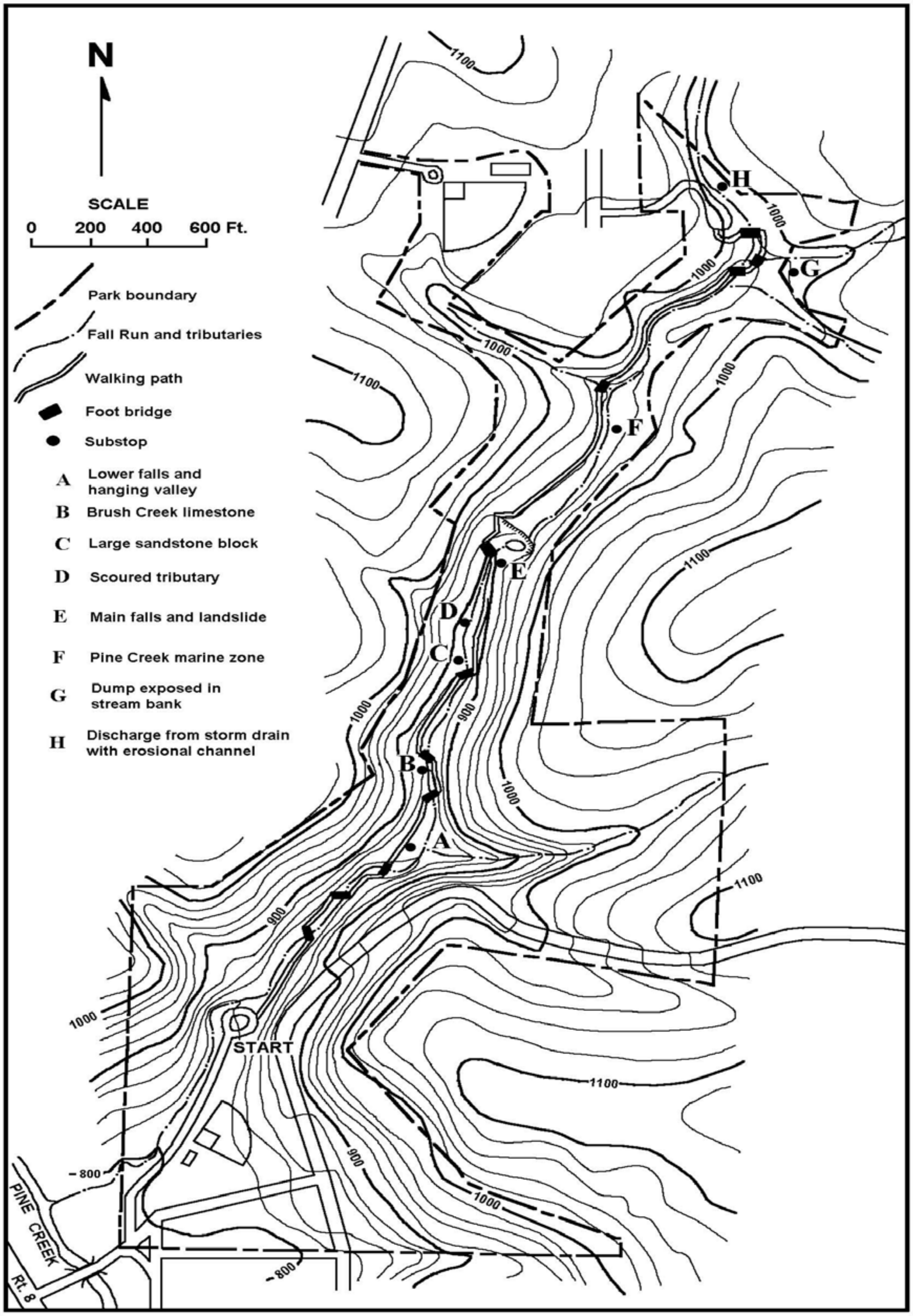


Figure 68. Topographic map of Fall Run Park showing the locations of substops (modified from Shultz and others, 1995).

course, a major sewer trunkline rruns down its spine. This is standard operating procedure around here. And then, in the summer of 1997, owing to ignorance and indifference in the late 1960s, a massive landslide spewed into Fall Run valley, marring its namesake. This was followed in the summer of 1998 by a microburst or tornado from a severe thunderstorm that splintered and flattened many grand trees. But don't dspair. The area is still pleasant and green, as you will see. Recovery will come. Humans still can't plant houses and hotels in this antique valley. In the end, "Mother Nature" will eventually win in spite of us.

So what is Fall Run eroded into? Well, mainly it is the Glenshaw Formation. Almost all of it (Figure 69). The Upper Freeport coal bed at the top of the underlying Freeport Formation of the Allegheny Group is just a wee bit out of the Park, updip to the north on PA Route 8. The housing developments that surround the Park are built on the uppermost part of the Glenshaw (including the Pittsburgh red beds and the Ames limestone) and lower members of the Casselman Formation. Pity. Think of the runoff and instability. On your hike upstream, you will see mostly shaley Glenshaw mudrocks. But, in ascending order, these are punctuated by 1) the Brush Creek limestone; 2) the Buffalo channel sandstone (upholds the main falls, but is a mere vestige of its glorious self a mile or so to the south); and 3) the Pine Creek marine zone with associated micaceous siltstone.

Consider the whole valley. Where you start, it is a narrow V-shaped slot with slopes exceeding 45°. But uphill beyond the falls, it becomes a gentle, broad, U-shaped valley. Cool. Look at the details. Where we start, there is a dissected alluvial fan (Pleistocene?) built by a tributary. The depth of entrenchment of other fans decreases upstream. At Substop A, a tributary has developed into a hanging valley, and a small waterfall on the main stream just upvalley is a knickpoint. Fall Run has four perennial tributaries and several intermittent ones. It discharges into Pine Creek a short distance south of our starting point. Relief in this part of the valley is in excess of 200 ft (61m), but average relief is about 130 ft (40m).

What of urban development? The Fall Run drainage is virtually surrounded by housing developments. Roofs, driveways, and roadways lead to very rapid runoff, ripping and eroding tributaries to Fall Run. During large thunderstorms, catastrophic increase in discharge of Fall Run threatens and engulfs the sewer trunkline sometimes. Messy! At the head of the valley you will see a fine example of the Appalachian solution to waste disposal – dump it over the nearest hillside into a local creek. And the *pièce de résistance* of the whole Stop is the Stone Ridge-Fall Run landslide at the main Falls. Now, go take a hike!

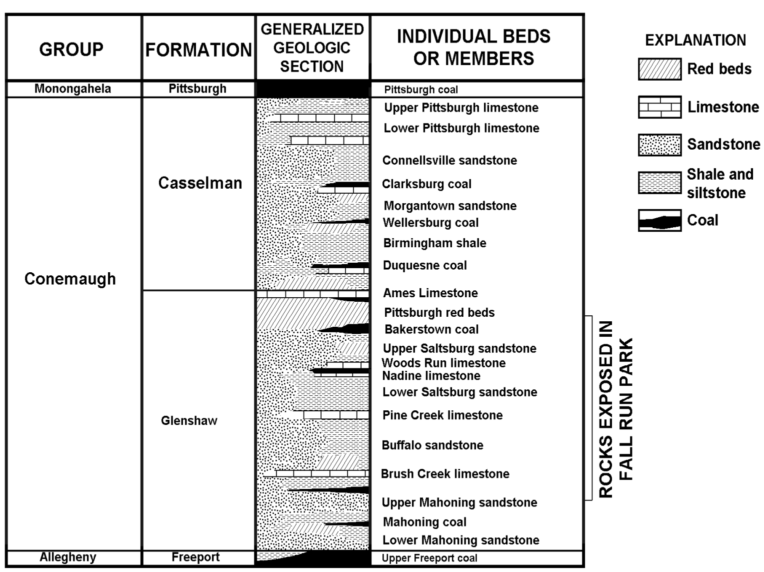


Figure 69. Generalized geologic column of the exposed rocks in Fall Run Park (from Harper and Neelan, 1996).

Segue Start to Substop A

Note shingling of platy rock

fragments in the stream alluvium. Generally the stream flows on bedrock, but after the landslide, alluvium has become more prominent. Note that the shale outcrop in the stream apparently dips downstream and is gently warped. There are abundant shale outcrops in the steep valley walls here.

SUBSTOP A - LOWER-FALLS KNICKPOINT AND HANGING VALLEY

Directly across Fall Run to the east is a tributary valley that appears to be in pristine condition. It was saved because the contractor that built the homes at the head of the valley installed a flood-runoff and sediment retention basin. The tributary does not meet Fall Run at a common level but rather flows over an 8 to 10 ft (2.5 to 3 m) bedrock falls. This was left stranded as a knickpoint progressed upstream, now visible as the "lower falls" 100 ft (30.5 m) to your left. The discharge of the tributary is too small to erode down to the channel level in Fall Run. The "lower falls" is not caused by resistant rock since the lithology there is little different than that above or below the falls. Note that the sewer trunkline, sheathed in concrete, climbs tastefully(?) over the trail side of the falls.

Segue Substop A to B

After you cross the bridge just before Substop B, there is a small outcrop of the Brush Creek limestone to your right. Turn and look back at the bridge. The decrepit stone piers underneath the new bridge within the channel were for the original bridge. Flash flooding undermined these piers owing to channel constriction. All bridges on the trail were of this design and have now been replaced with new bridges that leap the whole channel.

SUBSTOP B - BRUSH CREEK LIMESTONE

Fall Run flows over bare bedrock here. The most prominent riffle is the Brush Creek limestone (Figure 69), about 12 in (30.5 cm) thick. It contains invertebrate fossils. **WARNING: wet, algae-covered rock can be very slippery!** Note the orthogonal joint sets that trap small amounts of alluvium. Bedding is virtually flat-lying.

For all intents and purposes, the Brush Creek limestone and shales comprise the lowest of the Conemaugh marine zones in Pennsylvania (see Busch, 1984 for earlier Conemaugh marine zones in Ohio and West Virginia). White (1878) named the Brush Creek limestone for an exposure in a small coal mine along Brush Creek in Cranberry Township, Butler County about 3 mi (4.8 km) upstream from the Beaver County line. White recognized the variable lithology of this unit, from black calcareous shale to argillaceous, often ferruginous, limestone. In places it has so much iron in it that is was used as ore. As is typical of Conemaugh marine zones, the Brush Creek commonly consists of a limestone sandwiched between black shales. The upper black shale sequence often contains numerous siderite nodules. The entire marine unit is almost always extremely fossiliferous with rugose corals, brachiopods, bivalves, gastropods, and cephalopods dominating. Although the Brush Creek is one of the more fossiliferous marine units in the Appalachian basin, you might not find many fossils in the limestone here, but you might get lucky.

Segue Substop B to C and D

Severe storm damage to trees is visible here. Note abundant outcrop high up on the valley wall. This is common throughout the valley, but is generally obscured by foliage. Trees with curved trunks lean into the valley or have already fallen.

SUBSTOP C - A BIG ROCK

A large block of sandstone has fallen - well, probably not actually fallen, but slid or "mooshed" its way downslope through soil and colluvium. It is probably Buffalo sandstone, the same unit that holds up the main waterfall. The block shows cross bedding. Is it right-side up? Note just downstream that tree debris has blocked the stream, causing a build-up of alluvium behind the dam.

SUBSTOP D - RIPPED TRIBUTARY

To your left in a northwest direction is a tributary that has been severely scoured by urban runoff. Downspouts, storm sewers, etc. are simply piped to the head of this tributary and discharged. The tributary has been stripped clean down to bedrock, leaving a residue of large rocks. Near its mouth, the tributary bifurcates around a remnant of a former alluvial form. We have seen this tributary when it looked like a little Niagara. Ah, urban flash flooding – a sight to behold!

Segue Substop D to E

Just before you arrive at the bridge at Substop E, there is an outcrop of Glenshaw mudrocks to your right. Note that there are steep joints that dip about parallel to the valley wall. These are stress-release fractures. Any questions about why steep slopes are unstable in this area? Also notice the well-developed example of spheroidal weathering in these mudrocks and the production of "pencil shale."

SUBSTOP E - MAIN FALLS AT FALL RUN AND THE STONE RIDGE-FALL RUN LANDSLIDE

You're standing at the end of a partially destroyed foot bridge with *en echelon* boards. A late-stage mudflow "sheared" the bridge; eroded remnants of the flow cover the lower end of the bridge. The pile of "dirt" in front of you is the toe of a debris-flow fan that butted against the shale outcrop to your right. This blocked Fall Run creating a landslide lake in what used to be the plunge pool of the falls. The water level rose approximately 10 ft (3 m) to about the stratigraphic break in the lower part of the falls. The lake became a sewage lagoon when the debris flow ruptured the sewage trunkline. Subsequently, with the help of Shaler Township equipment, Fall Run trenched through the toe, spreading alluvium downstream to Pine Creek and draining the lake. The plunge pool has been reconstituted, albeit a mere vestige of its former elegant self (Figure 70). Look up ahead to the northeast skyline. This was once dense forest, all swept away by the slide. Bare ground then, it is partially revegetated now. Look carefully at mid-slope, you

Figure 70. Photograph of the main waterfall at Fall Run Park. The waterfall is developed on the Buffalo sandstone (see Figure 69).

will see a bedrock channel. This was the chute that channeled the debris flow to your feet; so, the 75^{o} slope in front of you is only veneered with slide debris. That channel was a perennial stream fed by springs emitting from beneath the landfill mass that failed. This stream cheerfully flows today on the left side of the trail as you cross over the bridge.

So what was the Stone Ridge-Fall Run landslide? It resulted from the failure of an unengineered fill, emplaced on a 15^{o}-20^{o} colluvial slope underlain by springs, that was constructed for a housing project developed in the late 1960s. It damaged four private properties, threatened two homes, and as you see, caused serious destruction in Fall Run Park. Catastrophic failure began about noon on June 17, 1997, but there had been a years-long history of premonitory events. The preceding May was one of the wettest on record (6.33 in); a major rainfall (2.07 in) on June 12-13 triggered the event. The landslide is about 425 ft (130 m) long, 150 to 200 ft (46 to 61 m) wide, and has a vertical drop of 175 ft (53 m). Damage wrought by the slide is shown in Figure 71. It occurred in three phases (Figure 72). Initially it was a standard combination slump and earthflow. Twenty-four hours later, when the toe reached the 50^{o}-75^{o} bedrock, lower-valley wall, debris cascaded about 100 ft (30.5 m) into the valley bottom, forming a debris-flow fan. It damaged the sewer trunkline and dammed Fall Run, creating a landslide lake. In mid-August, after a 2.5 in rain event, unstable slide debris was mobilized, forming a gooey mudflow. This built a second fan below the landslide dam partially reblocking Fall Run. Downstream aggradation of the stream bed caused the channel to become braided.

Now cross the debris-flow fan and climb the steps we cut up the steep slope to the top of the falls. Careful! Note the “new” wetland at the top filled with cattails and bullfrogs. Step to your right to the falls to see the relatively fine-grained, thin Buffalo sandstone (Figure 69); this is the hard rock that holds up the falls, which is about 35 ft (11 m) high. The best view of the debris-flow fan and the entrenchment channel is from this vantage point.

Segue Substop E to F

You are now in the nearly flat-bottomed, grass-carpeted, U-shaped part of Fall Run valley. Note the old landslide to your left covered with mature trees. Well off to your right is a new, scoured, hanging tributary valley. The large fallen slab of rock is Pine Creek limestone, which is also exposed in the tributary to the left as you cross the footbridge. Notice the short undermined bridge to your right that is now abandoned.

Figure 71. Selected views of the Stone Ridge-Fall Run landslide. A. The pool and bathhouse at the McAdams residence before the slide. B. The same view as A from the same viewpoint taken 24 hours after the slide began (June 18, 1997). C. The curving crown scarp tangent to the McAdams house (right) and the Noel House (upper right) (June 18, 1997). D. View uphill from within the slide mass toward the Noel (left) and McAdams (right) houses. Remnants of the McAdams pool in the lower right (June 27, 1997). E. A landslide lake, filled with raw sewage, was created by the debris flow. The edge of the main falls (Buffalo sandstone) can be seen in the lower part of the photograph. The plunge pool was inundated to a depth of about 10 ft (3 m). The blue pipe is a temporary by-pass installed by Shaler Township to carry effluent around the blocked sewage trunkline (June 23, 1997). F. A mudflow fan downstream from the original debris-flow dam. Runoff from a very heavy thunderstorm (2.5 inches) remobilized he landslide debris (August 21, 1997).

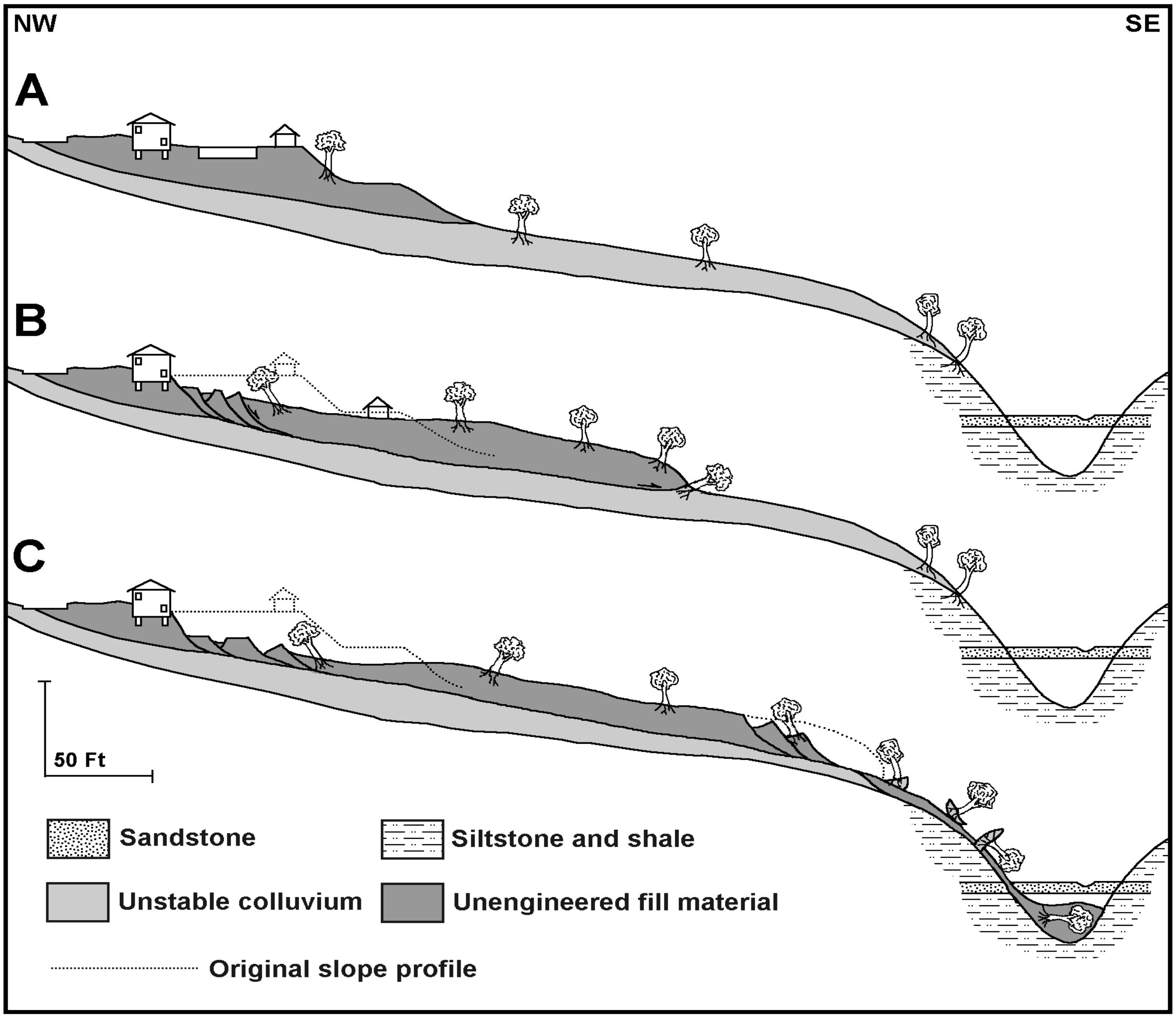


Figure 72. Cross-sectional cartoons showing the evolution of the Stone Ridge-Fall Run landslide observed at substop E. A. The situation before sliding began, with the house, pool, and bathhouse sitting on artificial fill emplaced on the original land surface above colluvial soils. Springs and seeps were buried by fill. B. The afternoon of June 17, 1997, approximately eight hours after movement began. A debris flow began slowly "mooshing" through the dense forest. Slump blocks develop at the crown of the slide. The crown scarp is tangent to the building foundation. The pool (previously drained) was destroyed and the bathhouse moved downslope (the dotted line shows the original profile). C. The morning of June 18, 1997. Overnight, the toe of the debris flow reached the steep inner valley and cascaded into the gorge, damming Fall Run and forming a landslide lake.

SUBSTOP F - PINE CREEK MARINE ZONE

White (1878) named the Pine Creek limestone for a “somewhat persistent limestone at 120 to 140 feet below the Crinoidal [Ames Limestone Member]” that occurs in the valley of Pine Creek in Hampton Township, Allegheny County. The type locality often is mistaken for a good exposure along PA Route 8 in Etna (e.g. Busch, 1984), but actually White's (1878) type locality was on a hillside above Pine Creek in what is now Allison Park, just a few miles north of here. Stevenson (1906) thought that the Pine Creek was correlative with the Cambridge Limestone of Ohio, and the name Cambridge had priority. However, Busch (1984) has shown that the Cambridge Limestone is correlative with the Nadine marine unit in Pennsylvania and the Pine Creek correlates with Ohio's Upper Brush Creek limestone.

At the type locality the Pine Creek consists of an approximately 2 ft (0.6 m) thick, somewhat sandy and argillaceous limestone containing abundant fossils and fragments of rugose corals, brachiopods, cephalopods, and crinoids. The limestone is 10 in (25.4 cm) thick here, but maintains its fossil and detrital content. Curiously, the limestone changes appearance quickly from one place to another. In many places it is a buff-colored limestone sandwiched between similarly colored shales, whereas at other places it looks very much like the Brush Creek limestone and shale.

Carothers (1976) in his regional study of the Pine Creek marine unit, recognized lithoclastic-rich wackestones and packstones containing basal conglomerates, fossiliferous wackestones, and fossiliferous mudstones associated with redbeds. He found the lithoclastic wackestones common in southwestern Pennsylvania and interpreted them as carbonate banks deposited during a transgression over abandoned delta lobes. The fossiliferous wackestones, which are common in the Pittsburgh area, were deposited near abandoned deltaic facies. The fossiliferous mudstones are common in Somerset County and in Maryland where they have been interpreted as low-relief tidal mudflats rich in oxygenated iron-stained clay sediments.

Boulders of Pine Creek limestone can be found in the bed of Fall Run downstream from the main falls for several hundred feet. They can be recognized by their buff coloration and the presence of invertebrate fossils and numerous occurrences of *Zoophycos* (Figure 30) and other trace fossils.

Perhaps the most interesting aspect of the Pine Creek marine zone is the presence of a highly micaceous shale or siltstone beneath the limestone. Vik Skema (personal communication, 1995) discovered large euhedral crystals of mica in a siltstone beneath the Pine Creek Limestone in Westmoreland County. The crystals were identified by Bob Smith of the Pennsylvania Geological Survey as probably being associated with a volcanic ashfall. When we discovered the mica below the Pine Creek here, John Harper and Bill Kochanov (also of the Pennsylvania Geological Survey) began to look for it, and find it, in other known Pine Creek localities. So far the mica bed has been documented in Westmoreland County in outcrops along PA 66 near the intersection with PA 130, at the BY Park in Trafford, and in Allegheny County at the intersection of Logan Ferry Road and Barking Hill Road a few miles south of New Kensington and at this locality. The prospect of this mica bed being representative of an unknown ashfall event is exciting. Further study is warrnted. In fact, this would make an excellent thesis topic for some aspiring young geochemist. Any takers?

***Segue* Substop F to G**

The shale outcrop to your left contains a zone of very large ironstone concretions. This is probably the upper shale of the Pine Creek marine zone. Note that the valley is getting shallower and homes are visible at the edge of the valley. We are near the head. After crossing the first bridge, proceed straight ahead to Substop G.

SUBSTOP G - OUTFALL PIPE CREATES A RAVINE IN COLLUVIUM

Developers building in this area prior to the passage of the Stormwater management Act of 1974 simply funneled stormwater into drainpipes that discharged into the upper reaches of the tributaries to Fall Run. At this substop you will see the result. An urban stormwater drain has been directed onto an unprotected colluvial slope rather than into existing tributary channels. The result is an unnatural, ugly gully sprinkled with municipal-waste artifacts. Note that the concrete box formerly connected to the outfall pipe has now collapsed, owing to headward erosion.

Segue Substop G to H

Return to the main trail. Cross two more bridges. Walk to the right of the crushed-stone piles and follow the bank of stream channel.

SUBSTOP H - STREAM-BANK DUMP

In the past it wasn't an uncommon practice to dispose of municipal waste by dumping it over a stream embankment. Here we see the results. Observe old tires, a water heater, a drier, an old garbage can, rusty-brown leachate, etc. This material was probably dumped here decades ago, but we don't know exactly when. Fortunately, this doesn't happen anymore. Does it?

Return to the bottom of the park and reboard the buses and return to PA 8.

Pittsburgh adopts a new theme song!

0.35	11.60	**Turn right** onto PA 8.
0.20	11.80	To the right, the Upper Freeport coal dips into the stream. North of this point, the coal is above stream level. South of this point, it is below stream level. Where the coal interfaces with the stream, there are a couple of little mine openings where acid mine drainage flows into Pine Creek.
0.15	11.95	Roadcuts on both sides of the road expose the Mahoning sandstone (lower Glenshaw Formation**). Continue** on PA 8.
0.20	12.15	Traffic light at Spencer Ln. Ext. Upper reaches of Fall Run Park may be accessed from this road. **Continue** on PA 8.
0.30	12.45	Upper Freeport sandstone and shale (upper Allegheny Group) are exposed in the roadcut on the right. The Upper Freeport coal, which is about halfway up the hillside, is only a few inches thick here. The sandstones and shales represent stream channel and floodplain deposits.
0.10	12.55	Traffic light at intersection with Old Butler Plank Rd. The hillside on the north side of the warehouse to the left contains a small exposure of the Upper Freeport coal and adjacent shale. The Upper Freeport is 3 feet thick here, and the rocks represented by the Upper Freeport sandstone and shale at the last outcrop have been replaced by limestones and shales representative of a lake environment.
0.60	13.15	Traffic light at Burchfield Rd. The upper reaches of Fall Run Park may be accessed from this road. **Continue** on PA 8.
0.80	13.95	Just before the bridge over Pine Creek, a dirt access road to the left used to lead to the Allison Park railroad station. The railroad cut here also exposes the Upper Freeport coal and adjacent rock, and the coal has returned to its thickness of only a few inches. The coal is just above road level because the axis of the Kellersburg anticline passes close to Allison Park.
0.20	14.15	Traffic light at the intersection with Duncan Ave., the Green Belt, in Allison Park. The type locality of the Pine Creek limestone is on the hillside up the Pine Creek valley to the left. **Continue** on PA 8.
0.40	14.55	The Upper Freeport sandstone is exposed in the roadcut on the right. Over the next mile, the road rises through the upper Allegheny and lower Conemaugh groups. PA 8 in northern Allegheny County is so heavily developed that few exposures exist north of Talley Cavey.
0.40	14.95	Traffic light at intersection with Harts Run Rd. The Upper Freeport limestone is exposed in the excavation and roadcut on the left. **Continue** on PA 8.
1.50	16.45	Traffic light at intersection with Wildwood Rd, the Yellow Belt, in Talley Cavey. **Continue** on PA 8.
0.10	16.55	On the right, a former shopping center was destroyed by mine subsidence. Mining of the Upper Freeport coal caused an extensive loss of groundwater in local wells.
1.20	17.75	Cross under the Pennsylvania Turnpike. The Turnpike entrance is to the right.
0.70	18.45	Exposure of Pittsburgh redbeds part way up the slope on the right behind Tesones parking lot.
1.10	19.55	Traffic light at intersection with PA 910, the Orange Belt. **Continue** on PA 8.
1.00	20.55	**Bear right** onto the exit to Bakerstown Rd.
0.20	20.75	Entering Bakerstown, purported type locality of the Bakerstown coal.

0.10 20.85 Stop sign at intersection with Bakerstown Rd., the Red Belt. **Turn left** onto Bakerstown Rd.
0.10 20.95 Cross under PA 8.
1.10 22.05 Pittsburgh North Golf Club on right. Bakerstown Rd. follows the crest of the drainage divide separating the Connoquenessing Creek watershed to the north and the Pine Creek watershed to the sought. Continue on Bakerstown Rd.
0.20 22.25 Richland Elementary School on left.
0.65 22.90 **Turn left** onto Station Hill Rd.
0.30 23.20 Pull over to the right.

STOP 8. BAKERSTOWN STATION RAILROAD CUT
Leaders: Chuck Shultz and John Harper

When you get off the bus, move to the railroad grade and walk to your right (north) toward the railroad cut bridged by Bakerstown Road (Figure 73). The buses can turn around 0.15 mi. down the road.

We will present the data and our interpretations at three substops. After the discussions are complete, you will have adequate time to explore, climb to outcrops, take photographs, and collect samples. Permission to enter this property is courtesy of CSX. Please be alert for trains and follow any directions given by CSX employees.

FOSSIL LANDSLIDE PRESERVED IN LOWER CASSELMAN FORMATION, BAKERSTOWN STATION RAILROAD CUT

This is the most structurally complex area in the exposed surface rocks of the Pittsburgh Low Plateau section of the Appalachian Plateau province. We will observe numerous examples of listric-normal faults, tilted blocks (Toreva), an angular unconformity, soft-sediment deformation, and a textbook example of a conjugate joint (fault) set.

The Baltimore and Ohio Railroad excavated this cut around 1915 (Ross, 1933) to bypass an unstable tunnel still visible to the west, adjacent to the cut. Richardson (1932) was the first to mention tilting and faulting at Bakerstown Station, but offered no explanation. Ross (1933) suggested that the structures were a result of ancient landsliding. Wagner and others (1970) presented a cross section of the west wall of the cut and suggested that a meandering stream north of the cut was involved with the failure. Shultz reinvestigated the site in 1994 and, with John Harper, presented preliminary results during the Golden Anniversary

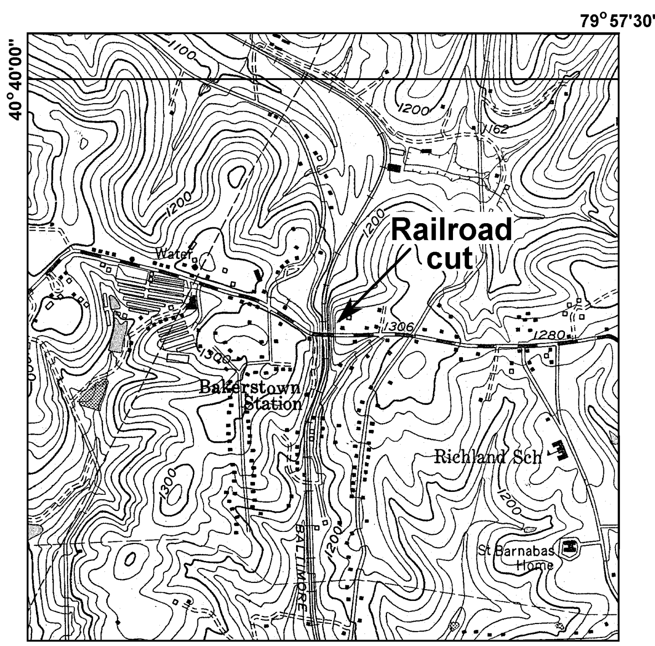


Figure 73. Location of the Bakerstown Station railroad cut at Stop 8 on the Valencia quadrangle.

field trip of the Pittsburgh Geological Society (Hutchinson, 1995). Final results were presented at the 8th International Conference and Field Trip on Landslides, Granada, Spain (Shultz and Harper, 1996), where participants declared the Bakerstown Station site to be the oldest known preserved landslide on Earth (ca. 310 million years).

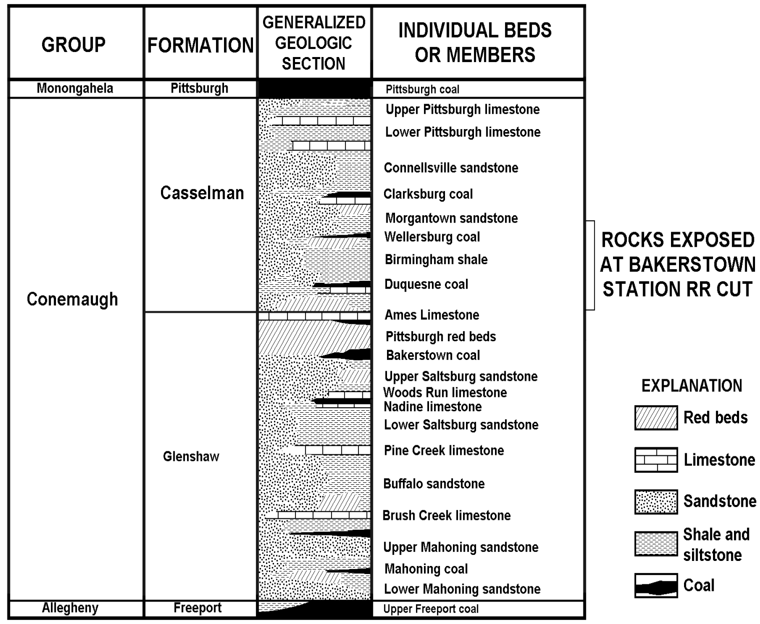


Figure 74. Generalized geologic column of the exposed rocks in the Bakerstown Station railroad cut.

STRATIGRAPHY

The lower Casselman Formation of the Conemaugh Group (Figure 74) is exposed in the railroad cut. The contact with the underlying Glenshaw Formation is present just below railroad grade. The Ames Limestone and underlying Pittsburgh red beds are not visible today, but apparently were observable when Ross did his work in 1933. A few pieces of Ames float were found along the north side of the cut and the red beds are clearly present 1220 ft (372 m) north of the last outcrop of the railroad cut in an excavation for an industrial building. In descending stratigraphic order, lower members of the Casselman Formation exposed in the cut (Figure 74) are:

- Morgantown sandstone
- Birmingham shale
- Duquesne coal bed
- Duquesne silty shale and claystone
- Grafton sandstone
- Ames Limestone Member of the Glenshaw Formation (unexposed)

The thickest and most prominent units are Birmingham and Morgantown.

The Duquesne coal is laminated, strongly cleated, and 8 to 12 in (20 to 30 cm) thick. In ascending order, subunits of the Birmingham consist of laminated gray shale, carbonaceous shale with abundant siderite concretions ("ironstone"), claystone, and laminated silty shale. The basal Morgantown contains siderite-concretion lag deposits, mudclasts, and other channel trash. About a meter above the base is a discontinuous coal bed (Wellersburg?). Floating mats of plant debris may explain the discontinuous nature, but horizontal extension related to landsliding is an additional or alternate interpretation. The main body of Morgantown sandstone is a resistant, fine- to coarse-grained, prominently cross-bedded, channel sandstone.

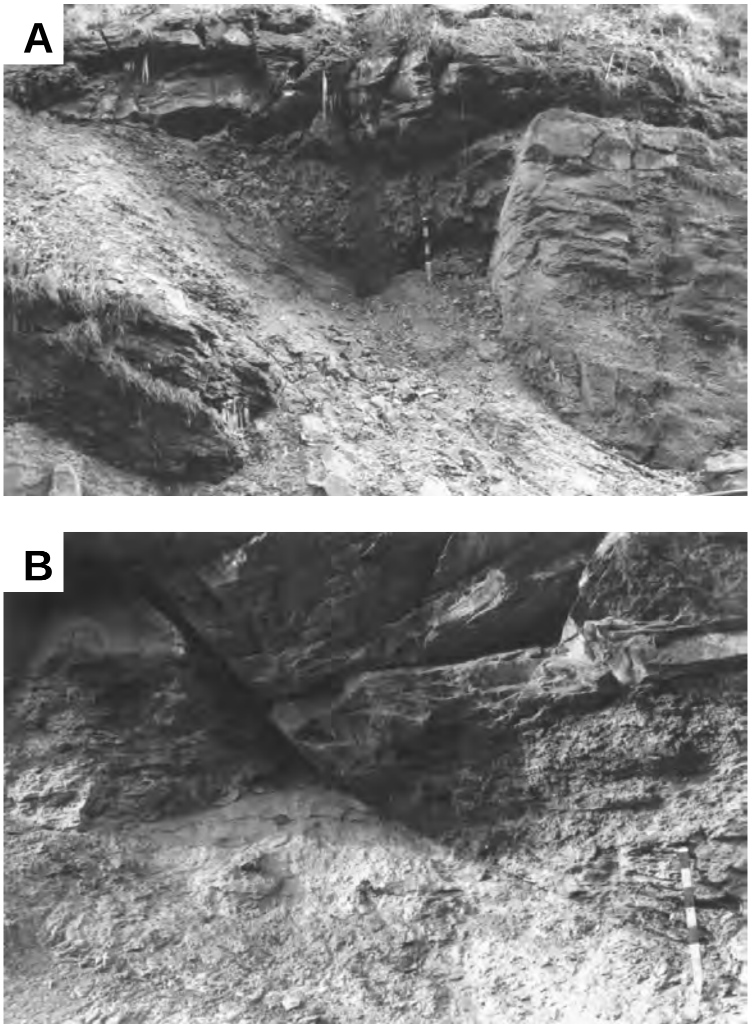


Figure 75. A. *En echelon* Toreva blocks of Birmingham shale and sandstone dipping south (right) on the east wall at the deepest part of the Bakerstown Station railroad cut. Upper part of a steeply dipping listric-normal fault is exposed to the right of 1-meter scale stick. Note the infill sediment in the swale between blocks and the angular unconformity created by the horizontal Morgantown sandstone at the top of the photograph. B. Lower part of a listric-normal fault showing the concave-upward curve. The fault presumably becomes bedding-parallel to the right, but is obscured. The blocky sandstone in the upper third of the photo is basal Morgantown sandstone, which has been offset about 7 ft (2 m). Scale is 1 m (3.3 ft). The view is to the west at the deepest part of the cut beneath the Bakerstown and Valencia Road overpass.

STRUCTURE

Normal structure in northern Allegheny County consists of virtually flat-lying sedimentary strata. Brittle units show an orthogonal set of vertical joints striking N10°-40°E and N50°-80°W (Nickelson and Hough, 1967). Listric-normal faults and an inclined conjugate joint set exposed here bear no relationship to regional structure. The faults, which bound about eight Toreva blocks, formed first. Fault dip is to the north and nearly vertical at the crown of the blocks (Figure 75A). With depth, the dip flattens and presumably becomes bedding-parallel. Thus, the fault planes are concave upward (Figure 75B). Strike varies but is about east-west in well-exposed faults. In places, there are numerous, small, south-dipping normal faults (and even small reverse faults); these are probably antithetic in character and represent local adjustments within the slide complex. Throw on the listric faults is in the order of 16 to 33 ft (5 to 10 m) in the Birmingham shale section, but only 3 to 7 ft (1 to 2 m) in basal Morgantown. The main body of Morgantown sandstone above shows horizontal stratification and is unaffected by faulting. Dip of bedding in Toreva blocks ranges up to 45°S (Figure 76), but is generally less. Between the upper Morgantown and the fault-block complex there is a prominent angular unconformity. Concave, lens-shaped bodies of sandy sediment (commonly with a breccia-like aspect) have infilled the swale between Toreva blocks

(Figure 76).

At the south end of the railroad cut, a less prominent but very significant set of structures formed after the main listric faulting in that portion of basal Morgantown affected by reactivated listric faulting. These consist of conjugate fractures intersecting at about 60°, forming rhomboid blocks oriented east-west. Most of these are joints, but where liquefaction of sand or soft-sediment deformation has occurred, they are normal faults with small displacements defining grabens (Figure 77). This difference in mechanical behavior indicates that the conjugate fractures are penecontemporaneous with deposition

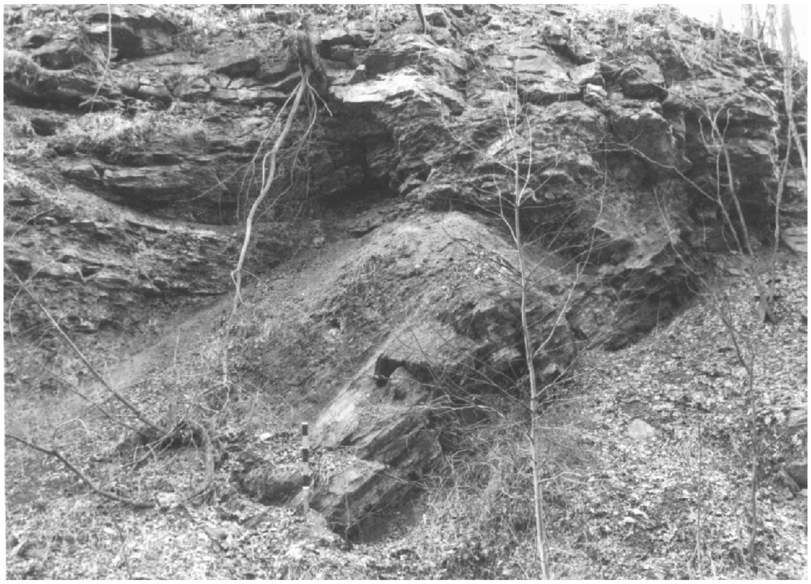


Figure 76. A Toreva block composed of Birmingham shale with the underlying Duquesne coal at the top of the colluvial slope to the right. Dip is about 45°. Note the horizontal Morgantown sandstone above is in angular unconformity with the slide complex below and the lensoid infill of sediment on the down-dropped backside of the Toreva block. The view is to the west; scale is 1 m (3.3 ft).

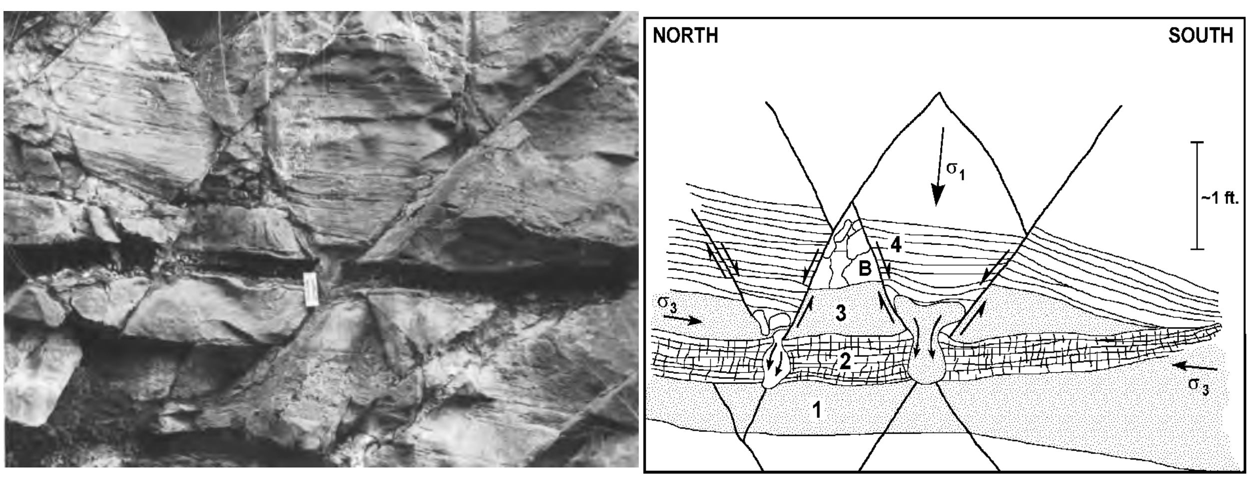


Figure 77. Left – photo from the southeast end of the cut showing soft-sediment deformation and conjugate joints/faults at about 60° that form rhomboid blocks in the basal Morgantown sandstone. At the intersection of two normal (shear) faults where the scale card is placed, note the sand injected downward and laterally into the Wellersburg (?) coal bed. The unconformity is at the bottom of the photo. Length of the scale card is 16.5 cm (5 in). Right – an interpretive sketch shows σ_1 (maximum principal stress gravity and overburden pressure; compressional) and σ_3 (least principal stress; extensional). Note that σ_1 is not vertical, owing to reactivation of the landslide along pre-existing listric faults. B = breccia. Mechanical behavior of the lithic units 1-4 is shown in Table 7.

Table 7. Description of lithologic units showing in Figure 77 and the approximate mechanical characteristics at the time of deformation.

Unit	Lithology	Mechanical Character
4	thin-bedded sandstone	brittle
3	massive sandstone	fluid
2	highly cleated coal (Wellersburg?)	ductile
1	massive sandstone	brittle

and formed before complete lithification had occurred. Some sands were sufficiently cemented to behave in a brittle fashion and thus supported fractures. Other sands were less well lithified, and when stressed, underwent granular failure or liquefaction. Such material was mobilized and injected downward into other lithologies (sediment?), in particular coal (Wellersburg?), which apparently behaved in ductile or plastic fashion (Figure 77).

The conjugate fractures coincide with the circular sections of the triaxial stress ellipsoid. The bisectrix of the conjugate fractures is σ_1, or maximum principal stress, which in this case is gravity augmented by overburden weight. It should be vertical but is tilted a few degrees toward the south. Reactivation of the listric-normal faults caused this rotation and a 3 to 7 ft (1-2 m) offset of lower Morgantown beds.

INTERPRETATION

Figure 78 is a cartoon showing the hypothetical sequence of events to explain the features observed at the Bakerstown Station cut. In late "Birmingham time," a great meandering river lay north of the site, its channel was eroded through the Ames Limestone and into the Pittsburgh red beds (Figure 78A). The cut bank was to the south, so a thick accumulation of semi-consolidated sediment was unbuttressed toward the north. Catastrophic failure occurred, possibly beginning as a block glide with a breakaway scarp as a south margin. Sliding was a decollement on or within the Pittsburgh red beds. The slab rapidly segmented along listric-normal faults into a series of nested, curved Toreva blocks (Figure 78B). This scene possibly resembled the Turnagain Heights slide following the Good Friday earthquake in Alaska, 1964 (see Grantz and others, 1964, fig. 17). The cause of the grand-scale failure at Bakerstown Station is unknown, but since the Alleghanian Orogeny was underway 250 to 300 mi (400 to 500 km) to the east, seismic activity is a possible explanation. After the catastrophe, the river was partially reestablished. High ridges on Toreva blocks were eroded, and the depressions between the tilted original land surfaces and slump scarps were infilled (Figure 78C). This differential sediment loading on an inherently unstable foundation caused reactivation of the listric faults, perhaps again triggered by earthquake activity. Extension, as a precursor to this second event, created the conjugate-fracture sets, and listric faults propagated upward into the lower Morgantown (Figure 78D). Finally, the great river reestablished itself above the slide complex in later "Morgantown time," depositing a thick mass of undeformed channel sand unconformably above the slide complex.

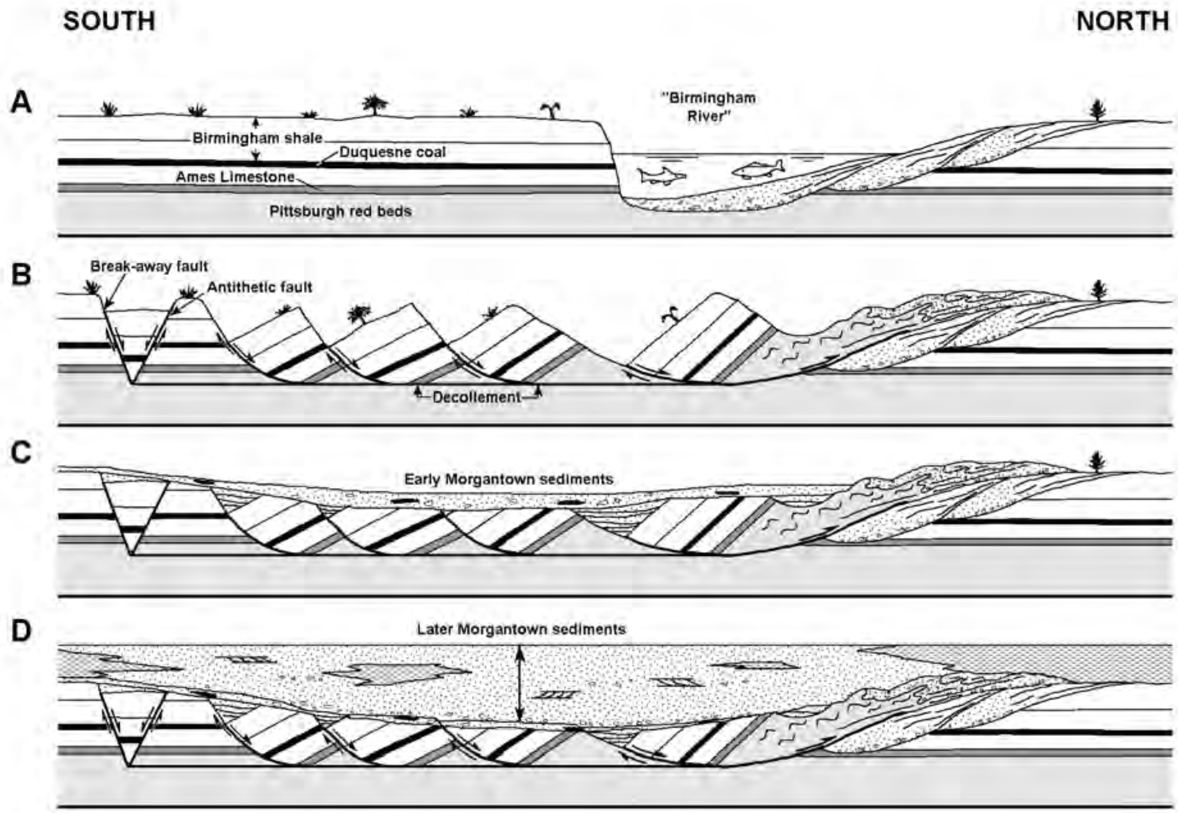


Figure 78. Diagrammatic sections of a hypothetical sequence of events in the development and preservation of the tilted blocks at Bakerstown Station. Modified from Shultz and others (1995). A. The Birmingham River meandering north of this site carves a cut-bank into semi-consolidated sediments. B. A disaster, possibly an earthquake, triggers a massive landslide. Toreva blocks rotate and slide along a decollement on or in the underlying Pittsburgh red beds. C. The crowns of the blocks are eroded and sediment is deposited in the swales between the blocks, causing differential loading. D. Renewed movement on the listric faults causes displacement of early Morgantown sediments. The entire complex is subsequently buried by later Morgantown channel sediments creating an angular unconformity.

AN IRONY

About 1220 ft (372 m) north of the last Paleozoic landslide outcrop at the base of a steep wooded slope, the notorious Pittsburgh red beds are present at the surface. The toe of this slope was excavated in 1980 to make way for a large industrial building. Within a year or two, the red beds began to move. An earthflow developed that gradually deformed and damaged the building. By 1996, remedial action was required to save the building. The Pittsburgh red beds are mechanically very unstable and will not support a load if an unbuttressed face is created, whether by the “Birmingham River” in late Pennsylvanian time 310 Ma ago or by humans in the Holocene Epoch today. You can’t change the spots on a leopard!

After reloading the buses, return to Bakerstown Rd.

0.55	23.75	**Turn left** onto Bakerstown Rd.
0.15	23.90	Cross over CSX RR tracks at Stop 8.
1.85	25.75	Stop sign at intersection with SR 4031. **Continue** straight on Bakerstown Rd., the Red Belt.
0.30	26.05	Stop sign at the intersection with Babcock Blvd. The Red Belt bears to the right. **Continue** straight on Babcock Blvd.
1.35	27.40	Cross the Pennsylvania Turnpike.
0.60	28.00	Four-way stop sign at the intersection with PA 910, the Orange Belt. **Continue** straight on Babcock Blvd.
0.95	28.95	Nice scenic view of western Pennsylvania to the left.
1.60	30.55	Entering North Park.
2.75	33.30	**Turn right** at the bottom of the hill onto Pearce Mill Rd. and cross North Park Lake.
0.75	34.05	Boat House entrance is on the left.
0.45	34.50	Tennis courts on the left at the bottom of the hill.
0.60	35.10	**Turn left** onto Walter Rd.
0.10	35.20	**Bear left** onto Lakeshore Dr.
1.25	36.45	Pull over to the side of the road across from the Point pavilion and picnic area and disembark.

LUNCH. POINT PAVILLION AT NORTH PARK

Through the persistence and vision of one man, County Commissioner E. V. Babcock, North Park was dedicated as a recreational area for all citizens of Allegheny County in 1927. The park covers 2,900 acres (1,174 ha), most of it forested. These forests comprise a combination of mature hardwoods and plantations of evergreens planted by the WPA and CCC in the 1930s.

The centerpiece of North Park is North Park Lake, the largest man-made body of water in Allegheny County. It covers 72 acres (19 ha) and has 4.5 mi (7.2 km) of shoreline. The lake formed as a result of the damming of Pine Creek at its junction with the North Fork of Pine Creek. Most of the lake lies within the North Fork valley. North Park Lake is stocked annually with game fish, and so has been called "The Fisherman's Paradise of Allegheny County." A smaller, 17-acre (7-ha) lake called Lake Marshall lies about 0.75 mi (1.2 km) north of North Park Lake along the North Fork. Lake Marshall is a waterfowl refuge.

North Park has many amenities, and is used year around by many citizens, particularly from the North Hills area. The park boasts a nature center, walking, biking, and nature trails, a swimming pool, playgrounds, an 18-hole public golf course, ice skating rink, Girl Scout and Boy Scout cabins, horse show rink and exercise areas, tennis and basketball courts, boathouse complex, softball and baseball fields, and many other features of interest. In addition, there are 121 groves and shelters that can be reserved for picnics, parties, and other events.

PLEASE BE AWARE

Do not pick any flowers, collect any rocks, or molest any animals. Do not go in the lake. Please separate recyclable materials from other trash and dispose of all waste in appropriate receptacles.

Reboard the buses after lunch and continue on Lakeshore Dr.

1.00	37.45	Stop sign at intersection with Kummer Rd. **Turn left** onto Kummer Rd.
0.05	37.50	Stop sign at intersection with the Ingomar Rd., the Yellow Belt. **Turn right** onto Ingomar Rd.
1.05	38.55	Crossing under McKnight Rd. Get in the **left lane**.
0.45	39.00	Traffic light at intersection with US 19. **Continue** straight on West Ingomar Rd., the Yellow Belt.
1.00	40.00	Entering the Borough of Ingomar.
0.40	40.40	At the intersection, the Yellow Belt continues straight. **Bear right** and **continue** on West. Ingomar Rd.
0.25	40.65	Ingomar United Methodist Church on the right, site of many Pittsburgh Concert Chorale concerts.
0.10	40.75	West Ingomar Rd. turns left. **Continue** straight on Brandt School Rd.
2.10	42.85	Orchard Hill Chapel on the left is the site of your friendly neighborhood guidebook editor's chorale practices (Tuesdays, September to May). Just thought you'd want to know!!
0.50	43.35	Soergel's Farm Market on the left. A mostly yuppie establishment, but has a lot of good home-grown produce. Get in the **left lane**.
0.20	43.55	Traffic light at the intersection of Brandt School Rd. and PA 910, the Orange Belt. **Turn left** onto PA 910.
0.10	43.65	Crossing I-79.
0.20	43.85	**Turn left** onto the southbound ramp of I-79 toward Washington.
0.40	44.25	**Merge with traffic** on I-79 South.
1.00	45.25	Outcrop of Connellsville sandstone (upper Casselman Fm.) on the right.
0.85	46.10	The roadcut on the right exposes a small, gentle anticline and syncline in the Clarksburg limestone and overlying Connellsville sandstone. The Clarksburg limestone here contains numerous nonmarine fossils, mostly ostracodes and *Spirobis* worm tubes (see Figure 31). The folds seen here are not tectonic in origin. They represent draping caused by differential compaction of mudrocks and sandstone.
0.15	46.25	Junction of I-279 and I-79. **Continue** on I-79 South.
2.90	49.15	Exit 20 to Mt. Nebo Rd., the Yellow Belt. **Continue** on I-79 South.
0.80	49.95	**Bear right** onto exit ramp at Exit 19 to Sewickley and Emsworth. The outcrop on left exposes the Pittsburgh red beds, which has been involved in extensive landsliding all over western Pennsylvania.
1.30	51.25	**Turn left** onto Glenfield Rd.
0.10	51.35	Crossing under I-79.
0.15	51.50	Entering Glenfield.
0.80	52.30	Entrance ramp to PA 65. **Turn right** toward Sewickley.
0.35	52.65	**Merge with traffic** on PA 65, the Ohio River Blvd. The Ohio River is on your left. On the right for the next 0.5 mi. are extensive outcrops of middle Glenshaw sandstones and shales.

1.25 53.90 Traffic light in Haysville. **Continue** on PA 65.
1.05 54.95 Entering the Borough of Sewickley.
0.20 55.15 Quaker Valley Middle School on the right. Get in the **left lane**.
0.45 55.60 **Turn left** at the second traffic light.
0.25 55.85 Crossing the Ohio River on the Sewickley Bridge.
0.20 56.05 Traffic light at the intersection with PA 51. To the left is Coraopolis, childhood home of your friendly neighborhood guidebook editor. Ahead and to the left is a large 0.6-mile long roadcut exposing the Brush Creek limestone and shale (lower Glenshaw Fm. - the oldest of the Conemaugh marine zones in western PA) at road level up through the Morgantown sandstone (middle Casselman Fm.) at the top of the hill.

Notice the large ice cream cone-shaped rock in the outcrop directly ahead (Figure 79). This is a large biogenic mound. Although no burrowing organism has been found in any of these large mounds in western Pennsylvania, the most likely candidate is some form of malacostracan crustacean (Norton, 1974). The size and complexity are similar to those of modern crustacean burrows where worms, clams, sea urchins, and other burrowers are excluded. A single or breeding pair of modern eumalacostracan crustaceans is capable of producing a structure of this size.

The small listric normal fault in Figure 7A is about 0.1 mile to the right of the bridge. The Pine Creek limestone is exposed on the first bench above the road, and the Ames Limestone can be found above that, but not in place. Landsliding in the Pittsburgh reds near top of hill has affected the overlying rocks and caused slumping over the lower ones.

This used to be an excellent fossil collecting locality (Hoskins and others, 1983), but because of ongoing rockfalls, the local police won't let anyone onto

Figure 79. A biogenic mound in the Brush Creek limestone on PA 51 at the south end of the Sewickley Bridge.

the site anymore.

Turn right onto PA 51 (Narrows Run Rd.).

0.50	56.55	Entering Stoops Ferry. The exposure of sandstone ahead and on the right is an abandoned Mahoning sandstone (lower Glenshaw Formation) quarry. Get in the **right lane**.
0.25	56.80	**Bear right** and **continue** on PA 51, Stoops Ferry and Shousetown Rd. Notice the Brush Creek marine limestone and black shales about half way up the cliff on the right, separating the lower Mahoning sandstone from the upper Buffalo sandstone.
1.15	57.95	Stop sign at the intersection with Flaugherty Run Rd. The outcrop ahead across the intersection exposes either Brush Creek or Pine Creek limestone. **Turn left** onto Flaugherty Run Rd.
0.90	58.85	Four-way stop at the intersection with Broadhead Rd. **Continue** on Flaugherty Run Rd.
1.20	60.05	Pittsburgh red beds are exposed along the road on the right. Prehistoric and historic landsliding, including some new ones behind The Hanger, has created a great deal of hummocky terrain along this stretch of the road.
0.65	60.70	The small outcrop of on the right near the fire hydrant is Ames Limestone. It is very fossiliferous here. You can literally grab handfuls of brachiopods, crinoid stems and calyx plates, and horn corals from the loose material on the top of the rocks.
0.80	61.50	Stop sign at the intersection with Hookstown Grade Rd. on the right and Moon-Clinton Rd. on the left and ahead. The large indoor parking facility on the left was built following excavation of a hillock where a number of open Pittsburgh coal mine rooms and pillars were exposed. **Continue** straight on Moon-Clinton Rd.
0.10	61.60	**Bear right** onto the entrance ramp to Business Route PA 60 North.
0.35	61.95	**Merge with traffic** on Business Route PA 60 North.
0.65	62.60	**Merge with traffic** on PA 60 North.
1.70	64.30	Entering Beaver County.
1.00	65.30	Exit 9 to PA 151 and Hopewell. **Continue** on PA 60 North.
3.65	68.95	The outcrop on the right is middle Conemaugh Gr. The blocks of rock are very fossiliferous Ames Limestone (for a description, see Harper, 1986).
0.35	69.30	Exit 10 to Aliquippa. **Continue** on PA 60 North.
0.60	69.90	Bridge over Raccoon Creek. USAir Flight 427 crashed a mile west of here in September 1994 killing 132 people.
0.80	70.70	Bridge over Raccoon Creek.
2.60	73.30	Exit 11 to Center Township. **Continue** on PA 60 North.
2.20	75.50	**Bear right** onto the exit ramp at Exit 12 to PA 18, Monaca, and Shippingport. **Bear left** at the end of the ramp to the stop sign.
0.40	75.90	Stop sign at intersection with PA 18. **Turn left** onto PA 18 toward Shippingport.
0.10	76.00	Crossing under PA 60.
0.70	76.70	Traffic light. On the right is the Zinc Corp. of America, situated on the floodplain of the Ohio River. **Continue** straight on PA 18.

0.65	77.35	BASF Corporation Refinery on the right.
0.55	77.90	Crossing Raccoon Creek just upstream from its confluence with the Ohio River.
0.30	78.20	The road to the right leads to the US Army Corps of Engineers Montgomery Lock & Dam on the Ohio. **Continue** straight on PA 18.
3.95	82.15	Kennedy's Corners. **Turn right** toward Shippingport. The upland surface in this area is relatively flat with a general elevation of 1,100 to 1,160 feet. This is our old friend the Parker Strath.
0.65	82.80	The 950-foot stack of the Bruce Mansfield Power Plant is visible straight ahead.
0.15	82.95	Entering Shippingport.
1.00	83.95	**Turn right** onto Ferry Hill Rd. at entrance to Penn Power's Bruce Mansfield Plant. **Turn right** at the stop sign and follow the signs to the main entrance.
0.20	84.15	Plant visitor's center. We will pick up Joe Smith from Penn Power here and return to the highway.
0.20	84.35	Stop sign at the highway. **Turn right**.
0.90	85.25	Intersection with PA 168 from the north. **Continue** straight on 168 South. On the right hand side just after the intersection is the old Beaver Valley Nuclear Power Plant of Duquesne Light.
1.60	86.85	Gabion wall stream stabilization for support of PA 168.
0.10	86.95	In the valley to the right was the former Peggs Run underground mine in the Upper Freeport coal, here about 42 inches thick. Ahead on the left the coal bed has been strip mined.
1.45	88.40	Stop sign in Hookstown. PA 168 turns left. **Continue** straight on Georgetown Road.
0.50	88.90	Sandstone in the Kittanning Formation of the Allegheny Group exposed in the Mill Creek valley.
1.80	90.70	**Turn left**, with caution, onto the gravel road where the paved road curves to the right. Go about 50 yards to a T-intersection and turn left on an abandoned right of way of the former Penn Central Railroad. On the right are extensive inactive sand and gravel pits in the Ohio River flood plain and on the left, the lower Mill Creek valley.
0.30	91.00	Gate to the Penn Power gypsum impoundment reservation.
0.50	91.50	Intersection with a gravel road heading uphill on the right. **Continue** straight across the former railroad embankment crossing Little Blue Run. Below us on the right is the confluence of Mill Creek and Little Blue Run, and beyond is the Ohio River. At the end of the embankment turn left.
0.50	92.00	Base of Little Blue Run Dam

STOP 9. LITTLE BLUE RUN DAM

Leaders: Joe Smith and Chris Ruppen

Park below the dam and walk a short distance to the north then turn left and walk 100 yards out onto the crest of the dam (Figure 80). This is **substop A**.

GEOLOGY AND ENGINEERING OF LITTLE BLUE RUN DAM AND RESERVOIR

The Little Blue Run Dam was constructed to contain the scrubber sludge from the Bruce

Mansfield power station on the Ohio River at Shippingport, PA. The Bruce Mansfield power plant clean air disposal system includes four positive displacement pumps each with a capacity to pump 1,200 gpm of waste slurry from the mixing tank through four 7-mi (11-km) long pipelines into Little Blue Run Dam (Figure 81).

The Little Blue Run Dam was constructed between July 1, 1974 and July 1, 1977. The design cross-section is shown in Figure 82. The dam is 420 ft (128 m) high, 1,700 ft (518 m) thick at the base and 2,200 ft (671 m) along its crest. It contains 9,000,000 yd^3 (6,885,000 m^3) of earth and rock and is reputed to be the largest earth and rock fill dam in the eastern US. All materials used in dam construction were mined locally in the Little Blue Run drainage area.

Reboard the buses

0.50 92.50 **Turn right** uphill, climbing the east side of the valley of Little Blue Run.
0.80 93.30 Blue Run Dam pump and maintenance station near the east abutment of the dam. This is **substop B** (Figure 80).

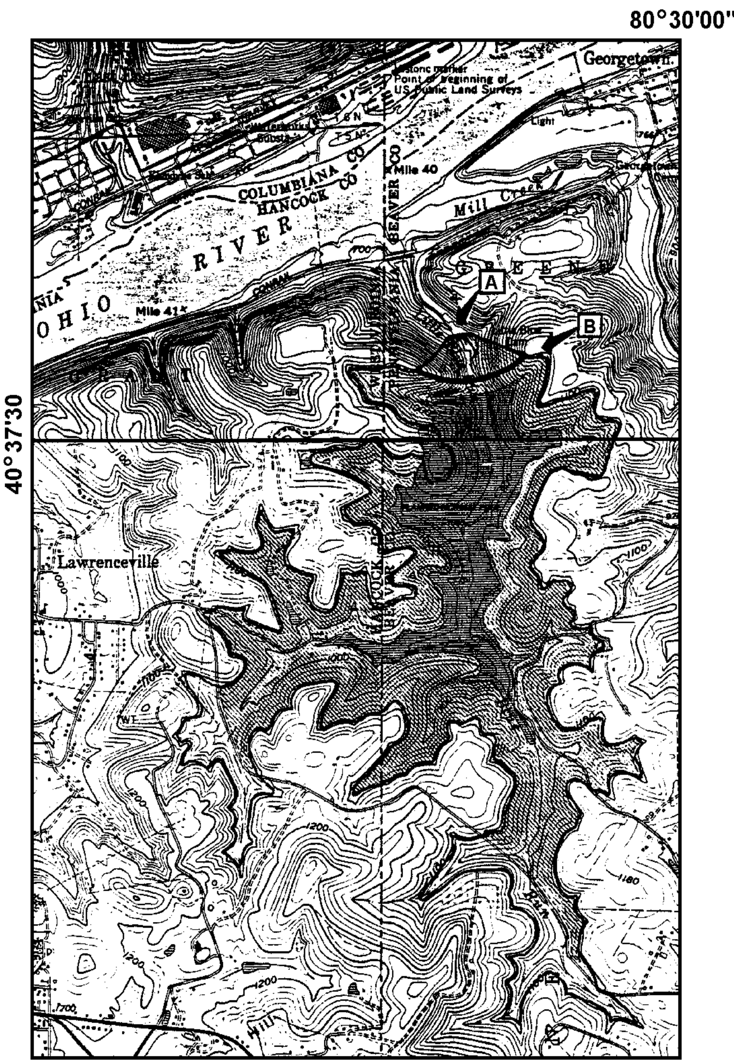


Figure 80. Location of Little Blue Run Dam and reservoir, Stop 9 on the East Liverpool North and East Liverpool South quadrangles.

Borings and test pits provided much of the data on soils and bedrock at the dam site (Thiers and others, 1976). Soil depths ranged from 3 to 30 ft (0.9 to 9 m). A relatively thin veneer of fine-grained colluvial soils (primarily sandy and clayey silt with some silty clay) occurred on the valley walls, whereas the valley bottom contained thicker deposits of silty sand and gravel with occasional thin lenses of clay. Bedrock in the valley comprises flat-lying sandstone, siltstone, shale, coal, claystone, and minor limestone varying in thickness from less than 1 in (2.54 cm) to 60 ft (18 m) (Figure 83). For reference, the carbonaceous shale and coal layer at 1000 ft (305 m) elevation in Figure 83 is the Upper Freeport coal, the top of which is the boundary between the Conemaugh and Allegheny groups. Most of the jointing encountered during boring was from valley stress relief (as per Ferguson, 1967).

Much of the bedrock in the Little Blue Run valley is relatively impermeable. Packer permeability tests indicated that the extent of

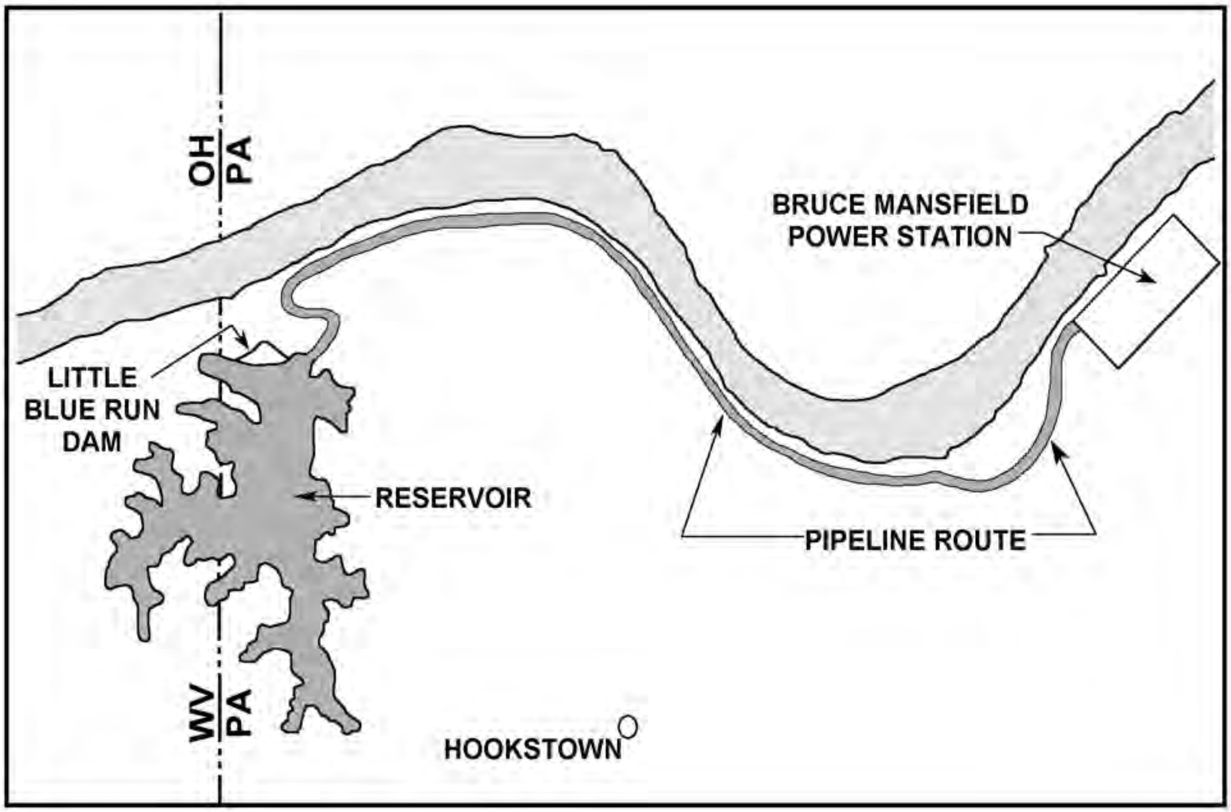


Figure 81. Location of the slurry pipeline route from the Bruce Mansfield power plant to Little Blue Run reservoir (modified slightly from Thiers and others, 1976).

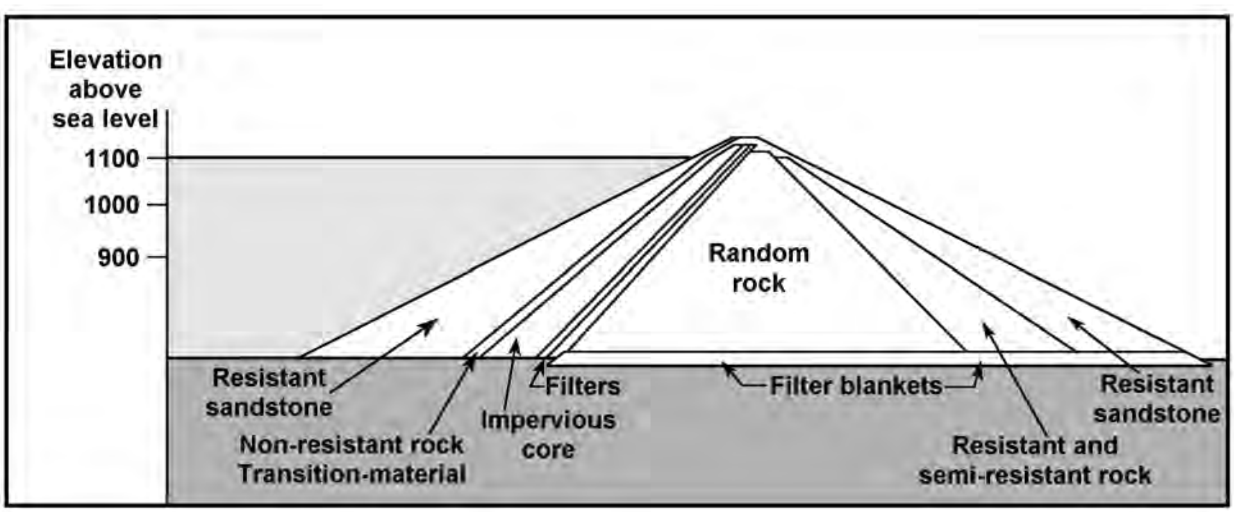


Figure 82. Cross sectional diagram of Little Blue Run Dam from south (left) to north (right). Modified from Ruppen and Briggs, 1995.

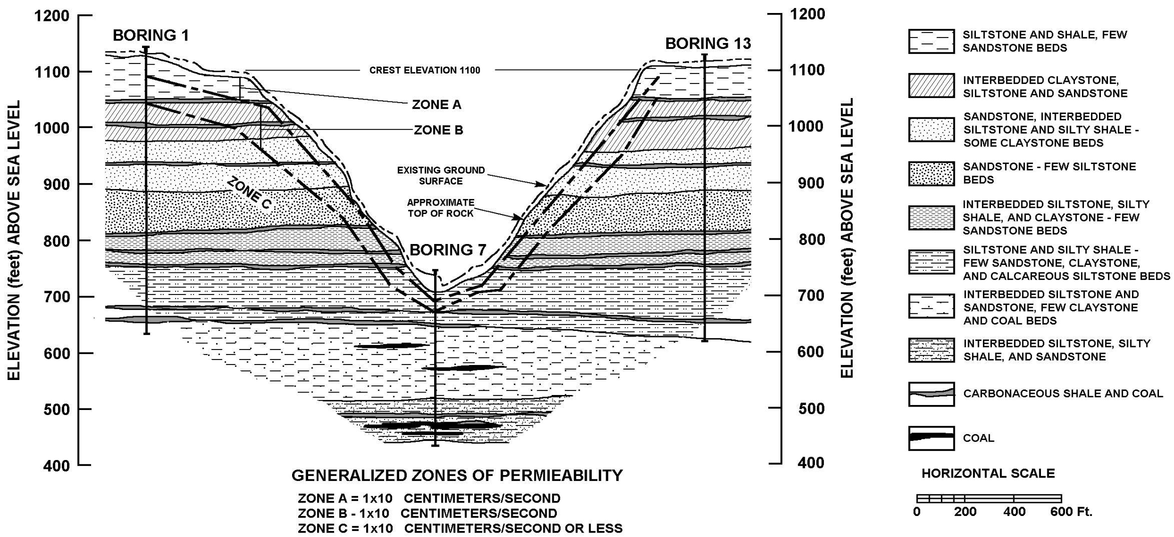


Figure 83. Generalized geologic cross section of the Little Blue Run valley (modified from Thiers and others, 1976).

jointing and brokenness of the strata was more important to rock permeability than was rock type. Permeability decreased with depth as fracturing decreased (Thiers and others, 1976) (Figure 83).

Some country-bank coal mines were discovered in the abutments during dam construction. Most of these extended only 25 to 30 ft (8 to 9 m), but one mine extended 110 ft (34 m) into the hillside. Those mines encountered downstream of the dam core were filled with filter material to insure good drainage, and the small mines upstream of the core were either backfilled with concrete or pressure grouted. After the entrances of the large mine were sealed, it was backfilled by injecting a mixture of fly ash, cement and water through holes drilled from the surface (Thiers and others, 1976).

The dam and its reservoir cover ground on the west edge of the Hookstown field, which produced oil from the Upper Devonian Berea Sandstone starting in about 1889. Oil and gas wells in the area were plugged.

Sixteen monitoring wells surround the site. The dam is designed to contain the heaviest 24-hr rainstorm expectable in a 100-year period. Note targets painted on some of the riprap boulders. Presumably these are used for periodic monitoring of possible movement in the face of the dam. A weir for measuring seepage flow occurs on the east side of the face of the dam. The gypsum sludge has a high pH, and if the pH exceeds a certain limit, acid is added to the runoff in the small impoundment below.

The total site includes 1,300 acres (527 ha), just over 2 mi^2 (5 km^2), and eventually the 860-acre (348 ha) lake will cover 92,000,000 yd^3 (70,380,000 m^3) of scrubber waste. When the power plant is in full operation, the impoundment receives about 3,000,000 gal (11,355,000 l) of sludge per day. The first sludge was pumped to the impoundment on December 5, 1975, during the power plant run-up trials and before the dam had been topped off. The floats you see carry the sludge piping out into the lake. The pipes can be moved to allow even deposition of the sludge. Particularly when viewed from the air, the impoundment has a striking blue color, much like the blue seen over sandbars and near beaches in tropical seas.

Depending on operational variables, the sludge capacity of the impoundment will be reached between the years 2007 and 2015. To handle sludge once the impoundment is full, Penn Power is considering conversion to a dry system, with the sludge still piped to here, where it will be dewatered with the water returned to the power plant. The damp sludge will be stacked on the full impoundment, below the level of the rim of the drainage basin. Tests have shown that the sludge can be compacted to a bearing capacity of 4.5 tons/ft^2 (43.9 metric tons/m^2).

The crest of the dam is at the approximate elevation 1,100 ft (335 m). Here the Upper Freeport coal bed horizon is at approximately 940 ft (287 m) elevation, so the base of the dam rests on Allegheny Group strata while the crest is at a level about half way up in the Glenshaw Formation. Below us the normal pool elevation of the Ohio River is 665 ft (203 m), so the crest of the dam is about 435 ft (133 m) above the river.

Reboard the buses and return to Georgetown Rd.

2.60 95.90 **Turn right** and return to the Bruce Mansfield Power Plant.
6.55 102.45 **Turn left** onto Ferry Hill Rd. and follow signs to the main entrance.
0.20 102.65 **Turn right** and park at the visitor's center.

STOP 10. BRUCE MANSFIELD POWER STATION
Leaders: Joe Smith and Chris Ruppen

INTRODUCTION

The Bruce Mansfield power plant, operated by Penn Power, a wholly-owned subsidiary of FirstEnergy, is located approximately 25 mi (40 km) northwest of Pittsburgh along the Ohio River at Shippingport, PA (Figure 84). The plant operates three coal-fired units that produce a total of 2,505 megawatts (MW) of electricity. Unit 1 went on line in 1976, Unit 2 in 1977, and Unit 3 in 1980. Each generates 835 MW of electricity. At full capacity, the plant is capable of producing 56 million kilowatt-hours daily.

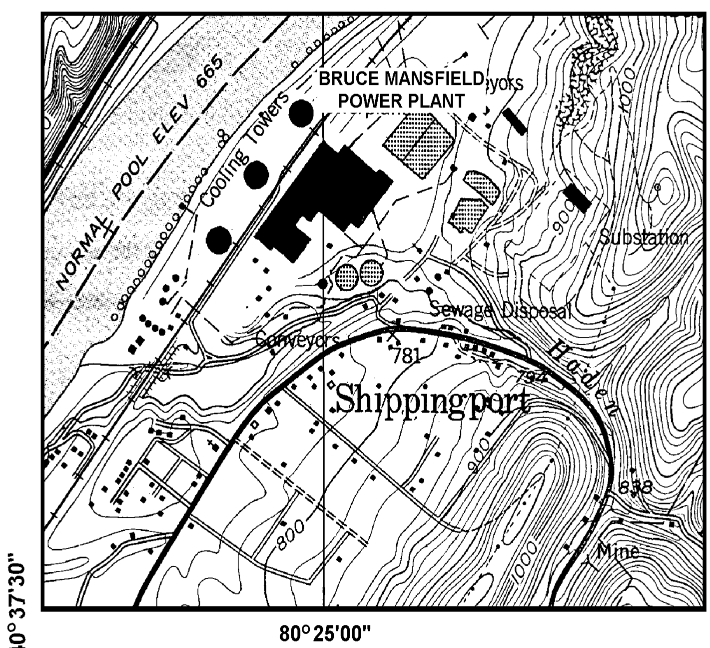


Figure 84. Location of the Bruce Mansfield power plant, Stop 10 on the Midland and Hookstown quadrangles.

The Bruce Mansfield plant (Figure 85) is a showcase for environmental technology. A schematic diagram is shown in Figure 86. The plant is equipped with full-scale air quality control systems designed to remove virtually all particulates and 92% of the sulfur dioxide (SO_2) from boiler flue gases. Units 1 and 2 are equipped with massive ductwork "scrubber trains" that are large enough for a tractor-trailer assembly to pass through. This

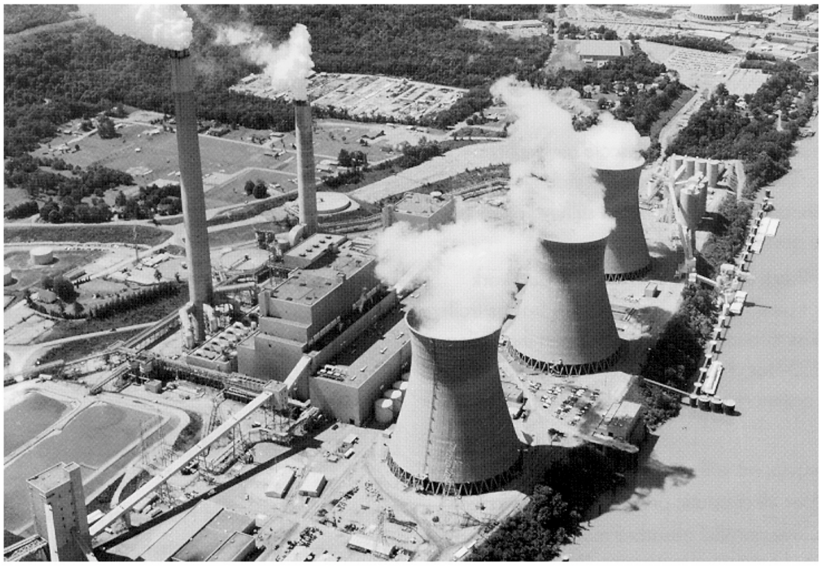


Figure 85. Aerial view of the Bruce Mansfield power plant at Shippingport, PA. The site covers 473 acres.

is located between the boilers and the 950-ft (290-m) stack. It is a two-stage scrubber/absorber system. Unit 3 is equipped with a precipitator/absorber system – four electrostatic precipitators (see below), four induced draft fans, five parallel absorber modules, and a 600-ft (183-m) stack (Figure 87). The air quality control systems require about 175,000 tons (159,000 metric tons) of limestone per unit each year, or one ton (0.907 metric ton) of limestone for every 11 tons (10 metric tons) of coal burned. As a result, more than 400,000 tons (363,000 metric tons) of SO_2 are removed from plant emissions every year.

At full capacity, each unit's air quality control system can produce up to 4,000,000 gal. (15,000,000 l) of scrubber slurry daily. A separate pollution control system is used to dispose of this slurry. It includes a treatment and pumping facility at the plant site, seven miles of underground pipeline, and a 1,300-acre (527 hectare) disposal site, complete with the largest earth and rockfill embankment dam in the eastern US (see Stop 9).

The plant uses 70,000,000 gal. (265,000,000 l) of water daily. The water is taken from the

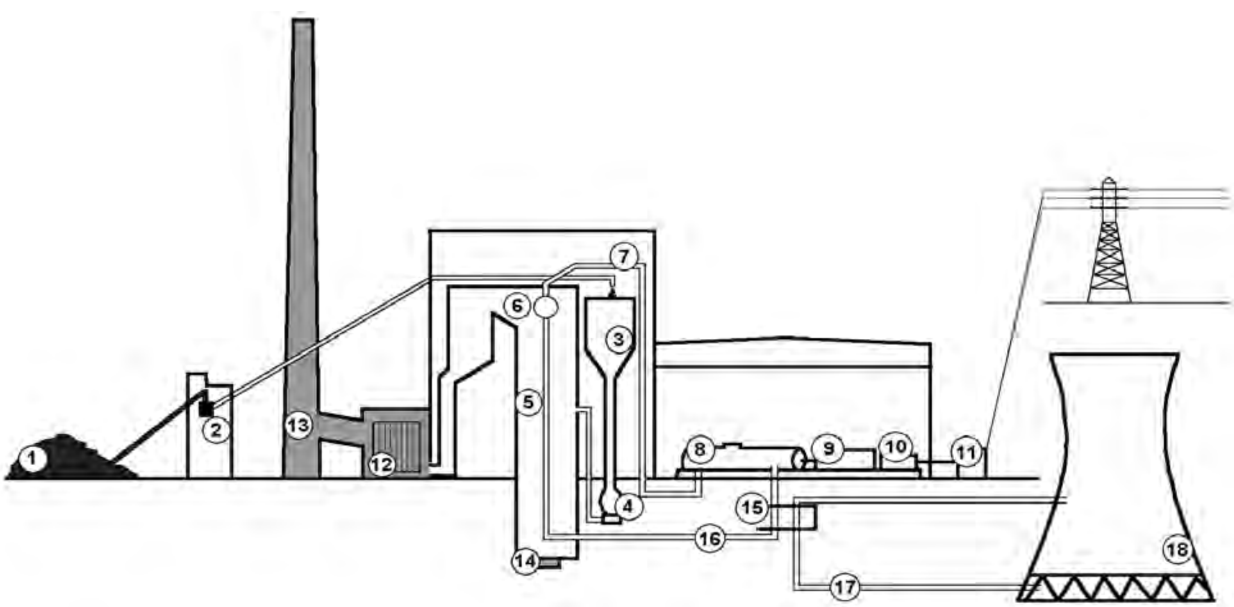


Figure 86. Schematic diagram of a coal-fired electrical generation plant. Numbered items are described in Table 8. The environmental controls are shaded.

Table 8. Items of interest shown in Figure 86. Shaded items are the environmental controls.

No.	Item	Description
1	Coal pile	Storage of approximately 45-60 days supply
2	Crusher house	Coal crushed to < 1 in (2.54 cm)
3	Coal bunker	Storage of 24-48 hour supply
4	Coal pulverizer	Coal is ground into powder and blown into the furnace
5	Boiler	Water-filled tubes generate steam
6	Steam drum	Heat in the boiler produces steam in the top of the drum
7	High pressure steam main	Steam passes to the turbine
8	Turbine	Steam causes the turbine blades to rotate
9	Generator	Produces electricity
10	Exciter	Produces the electric field of the generator
11	Step-up transformer	Increases produced voltage to transmission voltage
12	Electrostatic precipitators	Electronically removes particulates from boiler gases
13	Chimney	Disperses emissions high into the atmosphere
14	Ash hopper	Collects heavy ash from the combustion process
15	Condenser	Cools and condenses steam
16	Water recycling	Pumps condensed steam back to boiler for reuse
17	Cooling water	Water for steam condensing from base of cooling tower
18	Cooling tower	Cools water for steam condensing by evaporation

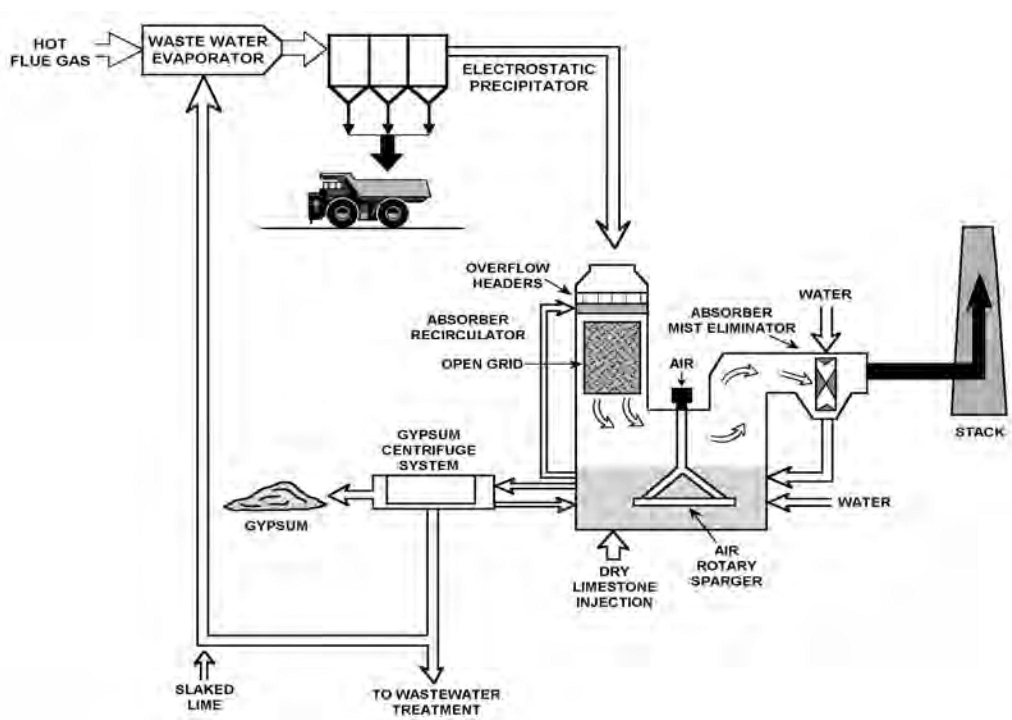


Figure 87. Schematic diagram of wet flue gas desulfurization (FGD) technology.

Ohio River and returned in a quality equal to, or cleaner, than its original condition. Three 410-ft (125-m) natural-draft cooling towers reduce the temperature of approximately 310,000 gal. (1,173,000 l) of water per minute by 27°F. A plume of water vapor leaves the top of the tower while cooled water collects at the base where it is mixed with water pumped from the Ohio River tto make up for evaporation.

WET FLUE GAS DESULFURIZATION (FGD)

Combustion of coal in power plants creates flue gases containing sulfur oxides, particularly sulfur dioxide (SO_2). Many Appalachian coals have sufficiently high sulfur content to cause SO_2 emissions exceeding environmental standards. To overcome this problem, power plants have adopted clean coal technologies. One approach in reducing SO_2 and particulate emissions is a process called *flue gas desulfurization*, or FGD. FGD is categorized as either dry or wet, depending on the state of the reagent as it leaves the absorber. The Bruce Mansfield plant uses a wet FGD process. The Bruce Mansfield wet FGD uses a limestone slurry to absorb SO_2 in the flue gas. This process produces calcium-sulfur compounds – calcium sulfite at this plant.

Generally, in wet FGD systems the flue gas passes through a slurry consisting of a sorbent in an aqueous medium, where the flue gas is cooled to the adiabatic saturation temperature. Particulates, SO_2, and other sulfur oxides are removed by precipitation, absorption, or chemical reaction.

The Bruce Mansfield plant utilizes electrostatic precipitators for removing suspended matter, such as dust, fly ash, fumes, or mist, from air or other gases. Electrostatic precipitators are particularly effective in removing very fine particles. The gas moves through passages that are either bundles of tubes or sets of parallel plates. A series of discharge electrodes are suspended in the passage centers, insulated electrically from the rest of the precipitator. The electrodes are supplied with direct current at negative voltages ranging from 30,000 to 75,000 volts. The tubes or plates, which serve as collectors, act as grounded electrodes. The high-voltage current applied to the discharge electrodes ionizes the gases. This ionization charges the suspended particles, causing them to move toward the collecting electrodes. These electrodes are then rapped to loosen the collected dust, which then falls into hoppers; if liquids are separated out, they flow to the bottom by gravity.

The byproduct slurry ("scrubber sludge") from this process then is removed to a holding pond (such as Little Blue Run reservoir), dewatered for disposal, sold commercially, or, as we will see at the Bruce Mansfield plant, recycled for use as building material.

Wet FGD systems consist of three main processing areas: sorbent handling, SO_2 scrubbing, and by-product handling. The type of sorbent used, typically lime, limestone (as at the Bruce Mansfield plant), sodium carbonate, or magnesium oxide, affects the sorbent handling process. Additives can improve efficiency; for example, the addition of organic acid in limestone systems improves SO_2 efficiencies, reduces the liquid-to-gas ratio, improves sorbent utilization, reduces scaling, and improves waste-handling characteristics. In addition, sorbent particle size can be an important consideration. With limestone, for example, reducing particle size below 74 μm significantly increases absorber reliability and reduces waste in non-regenerable systems (see below).

Wet FGD systems that use lime or limestone continually discharge a scrubber slurry from the absorber that is generally more than 90% water. The slurry can be dewatered using a number of processes including thickeners, ponds, hydrocyclones, centrifuges, and vacuum filters. In such systems, the dried sludge would be mixed with fly ash to create a fairly impermeable fill or handled simply as a dry material and placed in a landfill. The Bruce Mansfield plant sent the wet slurry to Little Blue Run reservoir for disposal, but with the impending filling of the reservoir, this has become a less acceptable solution.

Regenerable FGD Systems

FGD systems frequently are classified according to whether they produce a saleable by-product (regenerable) or a discarded (typically landfilled) by-product (non-regenerable). In the US during the 1980s approximately 70% of the retrofit FGD technology was non-regenerable. Utilities typically favored the non-regenerable systems because design complexity, maintenance and operating costs, and market conditions for saleable by-products was not cost effective. However, in the US, recent advances in regenerable wet FGD systems became more attractive where a market for sulfuric acid, elemental sulfur, or gypsum opened. Wet regenerable FGD systems have numerous advantages over non-regenerable systems, including 95% or higher sulfur-removal efficiency, minimal wastewater discharges, and the production of a salable sulfur product. In addition, wet regenerable FGD systems do not require space for waste disposal.

Some systems use an aqueous solution of sodium sulfite to remove SO_2. The scrubbing solution is then thermally regenerated using the sodium bisulfite waste stream, which produces a concentrated SO_2 gas stream that can be used to make elemental sulfur or sulfuric acid.

Magnesium oxide systems use a magnesium oxide or magnesium hydroxide slurry as the alkaline reagent. When the SO_2 in the flue gas comes in contact with the magnesium compounds it reacts, producing solid sulfite trihydrate and/or hexahydrate precipitates. A centrifuge then separates the sulfite solids from the scrubbing slurry where they are dried and calcined (thermally decomposed). The calcining process produces regenerated magnesium oxide and an off-gas of concentrated SO_2. Finally, the regenerated magnesium oxide is recycled to the absorber, where the SO_2 is used to produce a salable byproduct of sulfuric acid or elemental sulfur.

The new system used at the Bruce Mansfield plant uses forced oxygen technology to treat the slurry. Because of the composition of the wet slurry (calcium sulfite), it was determined that it could be purified to hydrous calcium sulfate – $CaSO_4.2H_2O$ – a commercial grade of gypsum.

FOG PLANT

Calcium sulfite hemihydrate ($CaSO_3{\bullet}½H_2O$) comprises the majority of waste by-product produced at the Bruce Mansfield power plant during the wet FGD process. Fly ash is separated from the calcium sulfite hemihydrate using electrostatic precipitators (see above). Synthetic gypsum in the form of calcium sulfate dihydrate ($CaSO_4{\bullet}2H_2O$) is then produced using a patented oxidation process called Forced Oxygen to Gypsum (FOG) developed by Ohio Edison and Dravo Lime Company (now part of Carmeuse). In this technology, air is forced (bubbled) through the calcium sulfite solution, oxidizing it to form a gypsum slurry, which is then dewatered in a hydroseparator. The gypsum solids settle out of the stack by gravity, leaving the clear water at the top that flows to a retention pond and, eventually is recycled.

The gypsum needs to be purified to over 96% purity for commercial use. In fact, the gypsum resulting from the FOG plant is purer than mined, natural gypsum. This FOG plant is the first full-scale FOG facility. It produces up to 70 tons (63.5 metric tons) of wallboard-quality gypsum per hour, sending it all by enclosed conveyor belt system to National Gypsum's plant across the street.

The Process

In FGD systems, thickeners are used to thicken calcium sulfite and gypsum slurries prior to final dewatering. Calcium sulfite slurries normally require a thickener to increase their concentration to 25-40 wt.% solids prior to vacuum filtration (see below). Thickener underflows from units 1 and 2 at the Bruce Mansfield power plant are routed to the FOG plant as a water slurry. A hydroclone removes undesirable coarse fly ash in the underflow. Then hydroclone overflow, and thickener underflow from Bruce Mansfield’s unit 3, are pumped to acid mix tanks where the pH and density are adjusted with sulfuric acid and filtrate. Acid mix tanks allow sufficient residence time for some carbonate neutralization and calcium sulfite dissolution. The adjusted slurry is then pumped to five oxidation columns. Compressors blow air into these columns, which allow the mixing of slurry and air at a residence time sufficient for the conversion of sulfite to sulfate. In addition to the slurry feed and air, diluted sulfuric acid is added to the tops of the columns to control pH. Gypsum slurry is finally pumped from the oxidizing columns to hydroseparators to concentrate the slurry and to separate product fines from contaminant fines.

Hydroseparators produce overflow water containing suspended solids. The amount of solids in the overflow varies with the flow rate and particle size distribution of the feed slurry. Hydroseparators have the additional flexibility of producing a clear overflow by adding polymer to the feed slurry. An added flocculant ties the finer particles to the larger particles so that they do not return to the scrubber system. Since the fines are not allowed to accumulate in the FGD system, the result is a slurry that can be more easily dewatered to higher concentrations.

Also, due to their larger particle size, gypsum slurries thicken much more rapidly than typical calcium sulfite sludges. Consequently, hydroseparators may produce the 30 to 60 wt.% solids required prior to further dewatering.

Hydroseparator underflow is pumped to vacuum belt feeder troughs. These feed the vacuum belt filters, where product is dewatered and washed with heated service water. A conveyor transfers material either to storage piles or to the gypsum wallboard plant. The resultant gypsum product contains about 10% moisture, and tends to crust, thereby reducing the likelihood of emissions to the environment.

Controls and Emissions

A model estimated uncontrolled SO_2 emissions from the oxidation columns to be 20 ppm, or a total of 6.16 lb (2.8 kg) per hour, 27 tons (24.5 metric tons) per year, from the five oxidation columns. In reality, actual stack tests indicate sulfur emissions are very low.

NATIONAL GYPSUM COMPANY WALLBOARD PLANT

The FOG plant will produce a minimum of 450,000 tons (408,000 metric tons) of commercial-grade gypsum annually. The resultant gypsum by-product is then sold to National Gypsum Company, which operates a wallboard manufacturing plant on 118 acres adjacent to the

Bruce Mansfield power plant. When this plant became operational in 1999, it was one of the world's largest single-line gypsum wallboard plants. Using the recycled gypsum from the scrubber system, the new plant produces more than 600,000,000 ft^2 (55,800,000 m^2) of high-quality gypsum wallboard "dry wall" annually, and utilizing 100% recycled materials. Besides the gypsum from the FOG plant, this plant also uses recycled paper, produced at the company's Milton, PA subsidiary near Harrisburg, for the wallboard facing and backing. In fact, most of the products utilized in the manufacturing process are made in Pennsylvania. And 100% of the excess material (production waste) is recycled back into manufacturing. In addition, the plant uses natural gas as its primary power source. All combustion sources (kilns) are equipped with ultra low NOx (nitrogen oxides) burners and all particulate emissions are controlled with state-of-the-art baghouses (basically, large boxes containing numerous bags that remove particulates between 0.01 to 100 μm in diameter.)

The Wallboard Process

When it arrives from the FOG plant, the gypsum is milled to a fine powder, called "land plaster." The land plaster is then fed into a calcine system where it is heated to remove three-quarters of the water in the gypsum lattice. This results in stucco, a very dry powder that, when mixed with water, will quickly rehydrate and "set up," or harden. The stucco is fed into large bins, which then feed it into the pin mixer.

Refer to Figure 88 for a schematic of the wallboard manufacturing process.

The pin mixer is the first step on the "wet end" of the manufacturing process. The stucco is blended with water and other ingredients (depending on the type of wallboard being made) to make a "slurry," or paste. The slurry is spread on a moving stream of cream-colored face paper

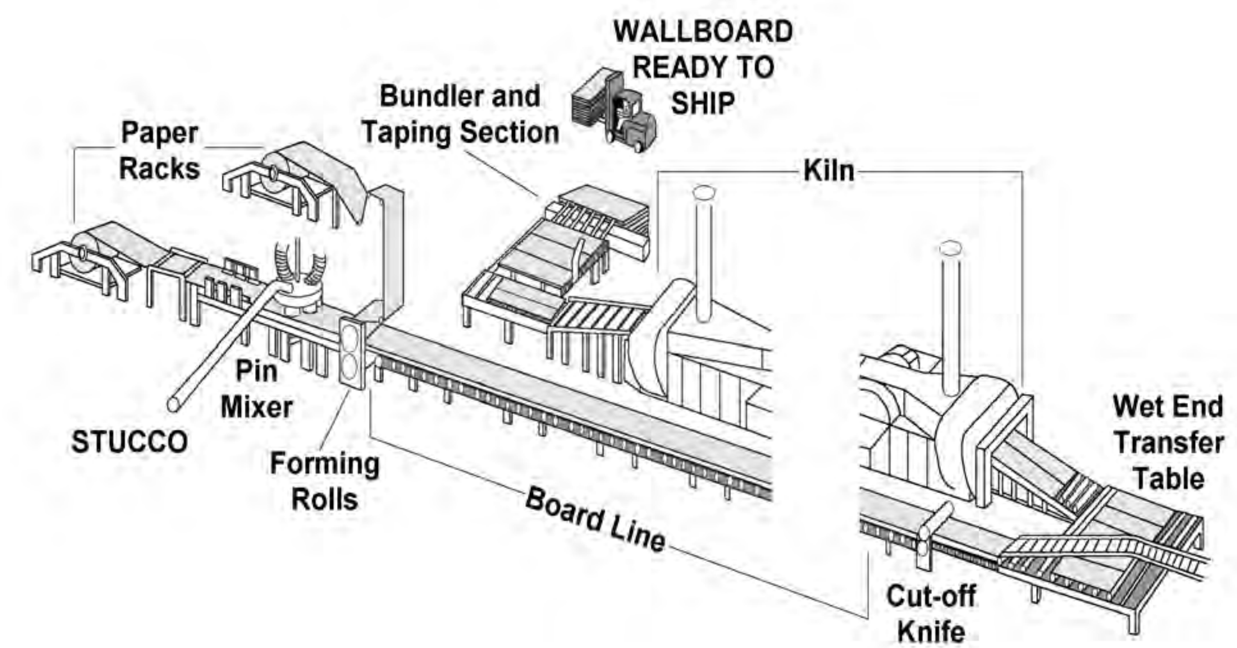


Figure 88. Schematic diagram of National Gypsum Company’s gypsum wallboard manufacturing process

and then covered, or sandwiched, with the top paper, or "grey back," to be formed into wallboard at the forming station.

The long, continuous sheet of wallboard now travels for about four minutes (to give it time to harden) down moving belts and roller conveyors to the knife, where it is cut into specified lengths. The cut wallboard panels are turned cream side up and sent into the kiln to dry. Once it leaves the kiln at the "dry end" of the process, the wallboard is sent to a bundler where it is trimmed to exact length, taped in two-panel bundles, stacked and moved to the warehouse to await shipment.

National Gypsum Company, manufacturer and supplier of Gold Bond® brand products, is a leading producer in this field, operating 18 plants that turn out a seemingly endless stream of gypsum board products.

Reboard the buses and return to the highway.

0.20 102.85 **Turn left** and head back to PA 60.
7.70 110.55 **Turn left** onto Route 60 south.
9.90 120.45 Entering Allegheny County.
1.05 121.50 Junction with Business Route PA 60. **Continue** on PA 60.
0.55 122.05 Crossing under Hookstown Grade Rd. The road cut exposes Clarksburg claystones through Pittsburgh limestone and claystone (upper Casselman Formation). The Clarksburg claystone is unusually thick in this area (up to 75 feet). In

We used to have a chimney sweep - before the scrubbers and the gypsum plant, and so forth - but he disappeared about the time the wallboard plant went in. Coincidentally, that's when I remodelled my office.

many places it is brick red and would be suitable for pottery and brick manufacturing.

1.40 123.45 Mine seal in the Pittsburgh coal on the right. This hill is the drainage divide between the Raccoon Creek watershed on the west and the Montour Run watershed on the east.

1.05 124.50 Entrance to Greater Pittsburgh International Airport. **Continue** straight on PA 60.

2.40 126.90 The bench in the road cut on the left is at the level of the Pittsburgh coal. Approximately 1.5 miles to the north is a mine fire in an isolated knoll.

0.50 127.40 McClaren Road exit. **Continue** straight on PA 60.

1.00 128.40 Cuts on the right expose the Morgantown sandstone. The Clarksburg claystone interval is missing at this locality. A basal conglomerate is present for the first 50 feet at the south end of the cut at ramp grade. Highly fractured Morgantown sandstone at the south end of the cut likely is due to stress relief adjacent to the small valley.

1.35 129.75 Montour Run exit. The bridge passes over Montour Run, Montour Run Rd., and the Montour Trail, a leg of the defunct Montour RR that has been converted to hiking and biking. **Continue** straight on PA 60.

1.60 131.35 Exit to US 22 and 30 west, and PA 60 north. **Continue** straight on US 22 and 30 east.

3.55 134.90 Crossing under I-79.

0.30 135.20 Traffic merging on the right from I-279.

0.65 135.85 The concrete embankment to the left covers open mine entrances of the room-and-pillar mined Pittsburgh coal.

0.70 136.55 Crossing bridge over Chartiers Creek and borough of Carnegie.

0.20 136.75 Exit 3 to Carnegie and PA 50. **Continue** on the Parkway West (I-279 and US22 & 30).

0.20 136.95 Passing under the Norfolk and Western RR trestle. Get into the **right lane**.

1.55 138.50 **Bear right** at Exit 4 to Green Tree and Mt. Lebanon.

0.15 138.65 At the traffic light at the top of the ramp **turn left** onto Green Tree Rd. (PA 121).

0.30 138.95 Traffic light at intersection of Green Tree Rd. and Parkway Center Dr. **Turn right** onto Parkway Center Dr.

0.10 139.05 **Turn left** into the Parkway Center Inn parking lot. End of Day 2 field trip and Y2K Field Conference of Pennsylvania Geologists.

Have a safe trip going home. Remember to attend next year's Field Conference on the Delaware River. See you there.

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