A GEOLOGICAL EXCURSION INTO SOUTHWESTERN PENNSYLVANIA:

The Masontown Kimberlite Intrusion
and
The Bedrock and Surficial Geology of the Carmichaels Area

Guidebook for the

Pittsburgh Geological Society
Field Trip

April 20, 2013

Guidebook for the

PITTSBURGH GEOLOGICAL SOCIETY

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Saturday, April 20, 2013

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Field Trip Leaders

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* With apologies to James Taylor.

Pittsburgh adopts a new theme song.

GREAT MOMENTS IN GEOLOGIC HISTORY

Part 9 - The Pennsylvanian

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

A GEOLOGICAL EXCURSION INTO SOUTHWESTERN PENNSYLVANIA

John A. Harper
Pennsylvania Geological Survey

INTRODUCTION

The first references to geologic topics in southwestern Pennsylvania (Figure 1) 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, folios, and county reports by Campbell (1902, 1903), Munn (1910, 1911a, 1911b), Shaw and Munn (1911), Johnson (1925, 1929), Stone (1932a), Hughes (1933), and Hickock and Moyer (1940) among many others, that stand, for the most part, as a solid foundation for later economic, geologic, geotechnical, and environmental investigations.

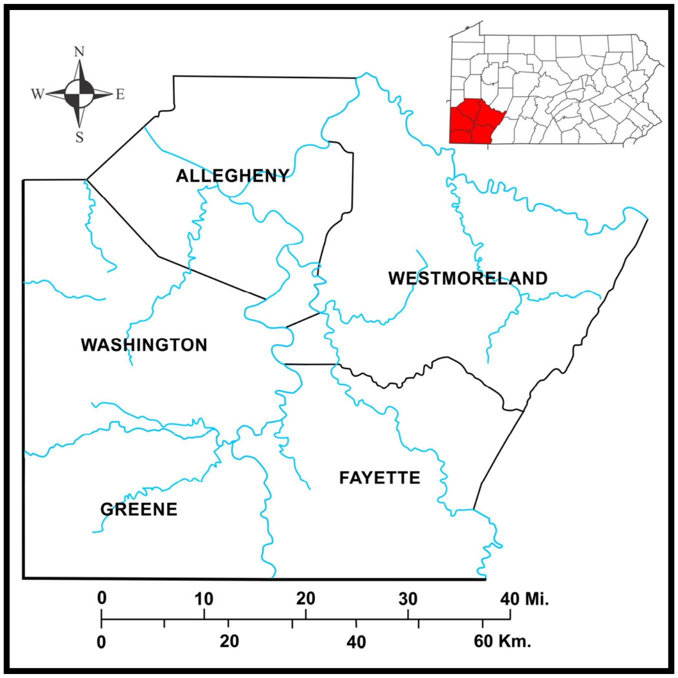


Figure 1. Base map of southwestern Pennsylvania, showing the counties and major streams. Based on

PHYSIOGRAPHY

Southwestern Pennsylvania lies within the Appalachian Plateaus physiographic province (Figure 2), an area having a generally level surface at an altitude great enough to permit erosion of deep valleys by streams. This relatively level surface results from the essentially flat-lying nature of the bedrock near the earth's surface. The Appalachian Plateaus Province in southwestern Pennsylvania is further subdivided into three sections, the Pittsburgh Low Plateau

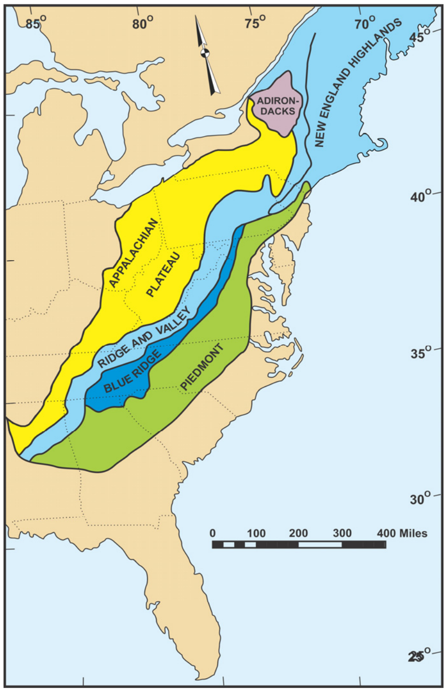


Figure 2. Map of the Appalachian physiographic provinces.

Section, Allegheny Mountain Section, and Waynesburg Hills Section (Figure 3). The topography in the Pittsburgh Low Plateau Section is characterized by a relatively small amount of relief (Sevon, 2000). 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 that 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 major streams of southwestern Pennsylvania are shown in Figure 1.

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 et al., 1970; Harper, 1997, 2000; and Kaktins and Delano, 1999). Suffice it to say that, prior to the first glacial advance into

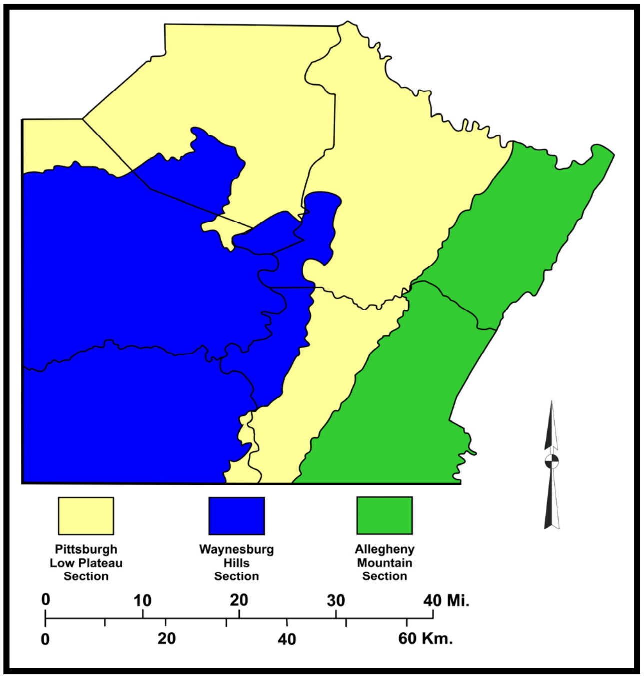


Figure 3. Sections of the Appalachian Plateaus Province in southwestern Pennsylvania. Based on Sevon, 2000)

North America during the Pleistocene, all of the major rivers in western Pennsylvania drained northward into what is now the Great Lakes. The change to the current drainage probably occurred early during the Pleistocene, perhaps during the first known glacial advance into northwestern Pennsylvania (>770 ka BP) (Sevon, 2000).

The process of downcutting and lateral erosion by western Pennsylvania'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 4). 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 glacial outwash that flooded the Allegheny and Ohio valleys, built up their channels with sediments derived from their watersheds to the south.

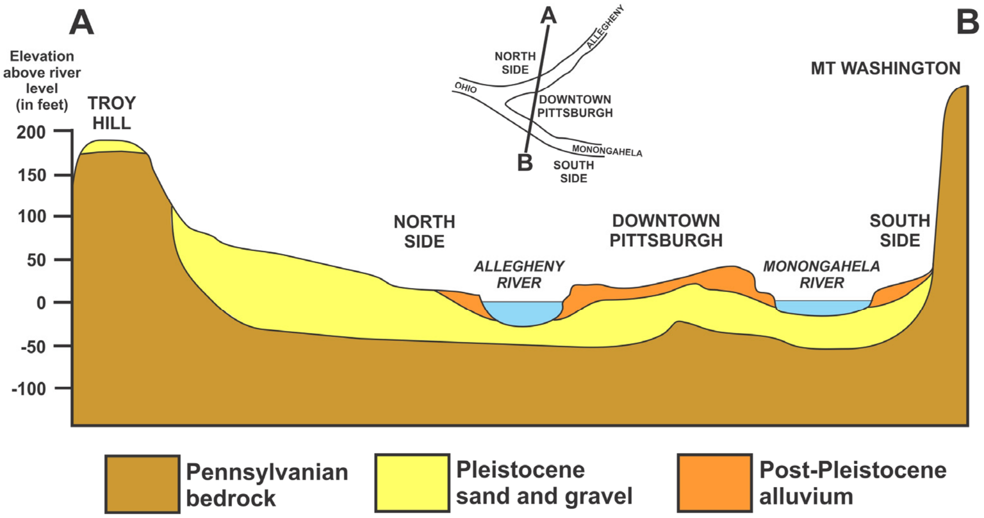


Figure 4. Cross section of the Pittsburgh area illustrating the valleys carved by the Allegheny and Monongahela rivers. The Allegheny and Ohio rivers are filled with glacially-derived outwash deposits from northwestern Pennsylvania, whereas the Monongahela and Youghiogheny (not shown) are filled with sediment derived from sources in Maryland, West Virginia and southwestern Pennsylvania. Pre– and early Pleistocene sediments commonly are found on high terraces above the rivers, such as Troy Hill on the left of the diagram, indicating that the rivers once flowed in channels high above their present channels.

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.

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.

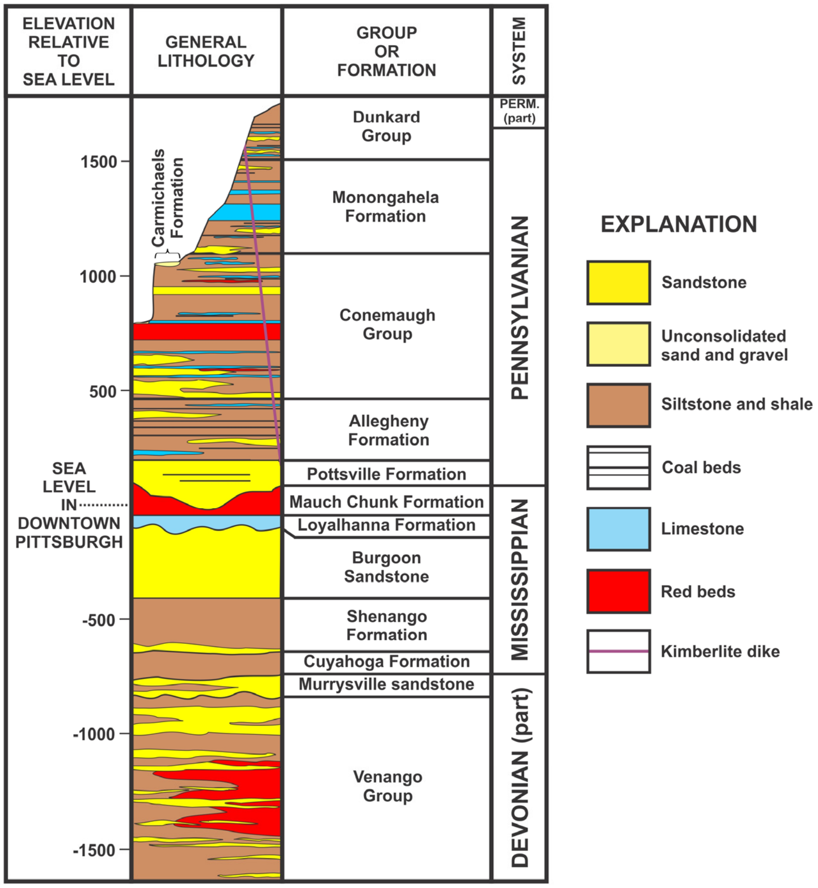


Figure 5. Generalized stratigraphic column of the rocks that are exposed in southwestern Pennsylvania. Devonian Venango Group rocks crop out only in the deepest river gorges through Chestnut Ridge and Laurel Hill.

STRATIGRAPHY

Figure 5 represents a very generalized columnar section of the formations exposed in southwestern Pennsylvania and Figure 6 is a highly generalized geologic map of the area. Strata traversed during this field trip include the Conemaugh Group and Monongahela Formation (late Pennsylvanian-age), the Dunkard Group (Pennsylvanian- and Permian-age), Jurassic-age intrusives (see Stop 1), and Quaternary-age surficial deposits. In addition, Mississippian-age rocks are exposed along the ridges of the Allegheny Mountain Section, and a few exposures of late Devonian-age rocks occur in the gorges where northwest-flowing streams have eroded deeply into the ridges.

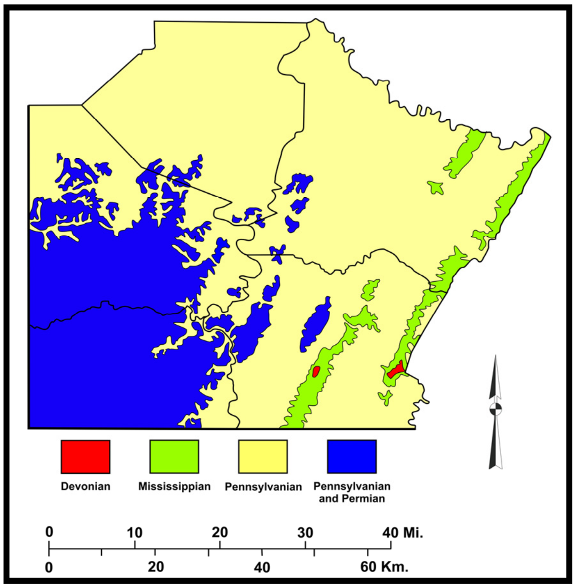


Figure 6. Generalized geologic map of southwestern Pennsylvania. Modified from Bureau of Topographic and Geological Survey (2007).

For the sake of brevity, only the rocks encountered along this field trip route are discussed further.

Pennsylvanian

Allegheny Formation

The Allegheny Formation (or Group, depending on who you talk to) (Figure 7) crops out only in the northern part of Allegheny County and on the flanks of Chestnut Ridge and Laurel Hill. The Upper Freeport coal, the boundary between the Allegheny Formation and Conemaugh Group, lies at a depth of approximately 600 to 1,000 ft (182 to 304 m) near the border between Allegheny and Washington Counties and gets gradually deeper as you go farther southwest.

Conemaugh Group

The Conemaugh Group (Figure 7) 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 (Figure 7). Flint (1965) divided the Conemaugh into two formations, the older Glenshaw Formation and younger Casselman Formation, with the top of the Ames Limestone as the boundary. Each of these formations is about 300 ft (90 m) thick, dividing the group into two roughly equal subdivisions.

The Glenshaw Formation underlies most of the area north of the Ohio River, but it also crops out at various places on the flanks of the structures in Westmoreland and Fayette Counties. It contains up to six marine units in the tri-state area, but only four are exposed well enough in southwestern Pennsylvania to be readily recognized. These units range from thin argillaceous limestones sandwiched between organic-rich shale layers to even thinner calcareous siltstones and shales containing sparse faunas.

The Casselman Formation is well exposed south and east of the Ohio River in Fayette, Washington, and Westmoreland counties. It typically contains no marine units, consisting instead of thick sandstones, red beds, shales, and thin coals. The upper part of the Casselman Formation can be seen in roadcuts and hillside cuts behind the stores along PA 51 from Century III Mall to Large on this field trip (see Road Log, mile 2.4). Approximately 1.3 mi (2.9 km) north of Large, the Connellsville sandstone crops out. It thickens from a few feet (a meter) to more than 20 ft (6 m) and then become thin again across the outcrop.

Probably the most recognizable part of the Conemaugh Group is the middle section spanning the boundary between the Glenshaw and Casselman formations. This is the section that includes the landslide-prone Pittsburgh red beds and the highly fossiliferous Ames Limestone at the bottom. The former has caused considerable damage throughout western Pennsylvania, whereas the latter has provided a wealth of entertainment and education to generations of hobbyists.

Monongahela Formation

The Monongahela Formation (Figure 7) lies almost entirely south of the Allegheny and Ohio Rivers, with a few erosional remnants crowning some high hills north of the Ohio River. It crops out in an irregular pattern that results from stream erosion cutting deep valleys

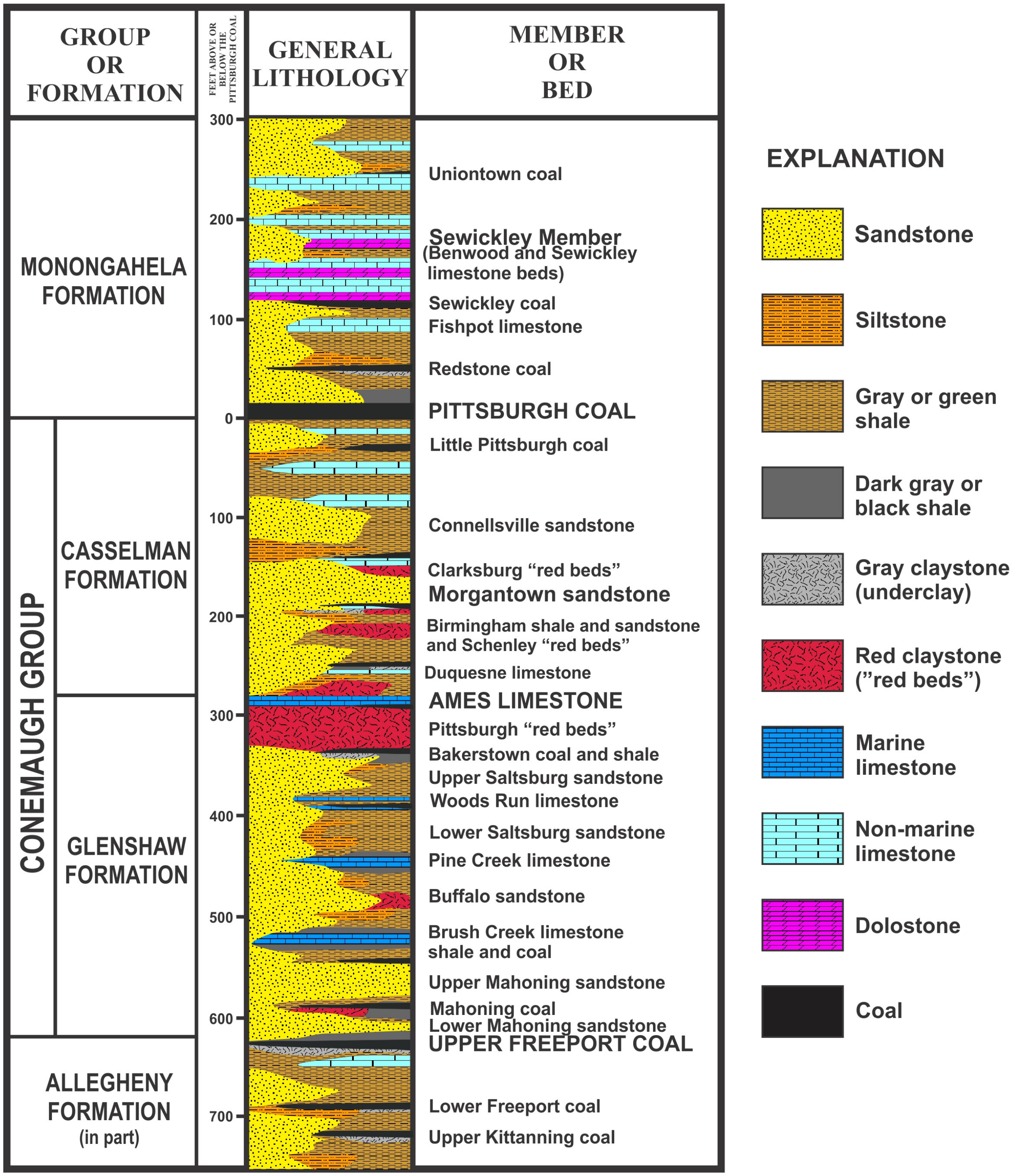


Figure 7. Stratigraphic column of Allegheny through Monongahela Formation rocks in southwestern Pennsylvania. Modified from Harper (2000).

completely through the formation and into the underlying Conemaugh. The formation is characterized by an abundance of nonmarine carbonate rocks, few red beds, and a relative lack of sandstone. While thick sandstones dominate the Conemaugh Group they are relatively rare in the Monongahela replaced instead by thin, discontinuous sandstones. Thicker sandstone units are not unknown, however. In Washington County, the Pittsburgh sandstone thickens greatly and replaces the Pittsburgh coal in large areas. All in all, the Monongahela Formation is about 300 ft (90 m) thick.

The lower Monongahela Formation contains three mineable coals, the Pittsburgh, Redstone, and Sewickley seams. The thick, mineable Pittsburgh coal occurs throughout most of southwestern Pennsylvania, and is deep-mined extensively in Greene and Washington counties by longwall mining.

The middle Monongahela Formation is dominated by fresh-water carbonate rock. A sequence of dolostones and limestones called the Benwood carbonates commonly reaches 40 ft (12 m) in thickness. This sequence constitutes the major part of the Sewickley Member of Berryhill and Swanson (1962). The base of this sequence is recognized easily in many places where the thick carbonates sit directly on darker colored shales and claystones. It can be quite valuable as an accessory marker bed.

The upper Monongahela Formation ranges from approximately 40 to 80 ft (12 to 24 m) in thickness. It is bounded by thin coal seams—the base of the Uniontown coal forms the base of the formation and the base of the Waynesburg coal forms the top. The Uniontown coal is not considered to be a major economic resource, but it has been mined locally in several areas in southwestern Pennsylvania. Sandwiched between these coals is a sequence of sandstones, siltstones, shales, and nonmarine carbonate rocks typical of the remainder of the Monongahela Formation.

Pennsylvanian and Permian

Dunkard Group

The Dunkard Group (Figure 8) contains the youngest consolidated sedimentary rocks in western Pennsylvania. It includes all the strata from the base of the Waynesburg coal bed or its stratigraphic equivalent to the top of the highest bedrock exposures in southwestern Pennsylvania, southeastern Ohio, and western West Virginia (Berryhill and Swanson, 1962; Fedorko and Skema, 2011). Berryhill and Swanson (1962) divided the Dunkard into, from bottom to top, the Waynesburg, Washington, and Greene Formations (Figure 8). However, only the Waynesburg and part of the Washington are present in the area of this field trip, so the Greene Formation will not be discussed further. The Waynesburg Formation, with the Waynesburg coal at its base, consists of about 180 ft (55 m) 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 ft (61 m) of mostly claystones and shales with minor amounts of other rock types.

The Dunkard Group, which spans the Pennsylvanian/Permian boundary, is preserved in a wide area straddling the axis of the Pittsburgh-Huntington synclinorium in eastern Ohio, southwestern Pennsylvania, and western West Virginia (Figure 9). The Dunkard attains its maximum thickness in Wetzel County, West Virginia, where it is approximately 1,190 ft (363 m) thick, and in Greene County, Pennsylvania, where it is approximately 1,125 ft (343 m) thick

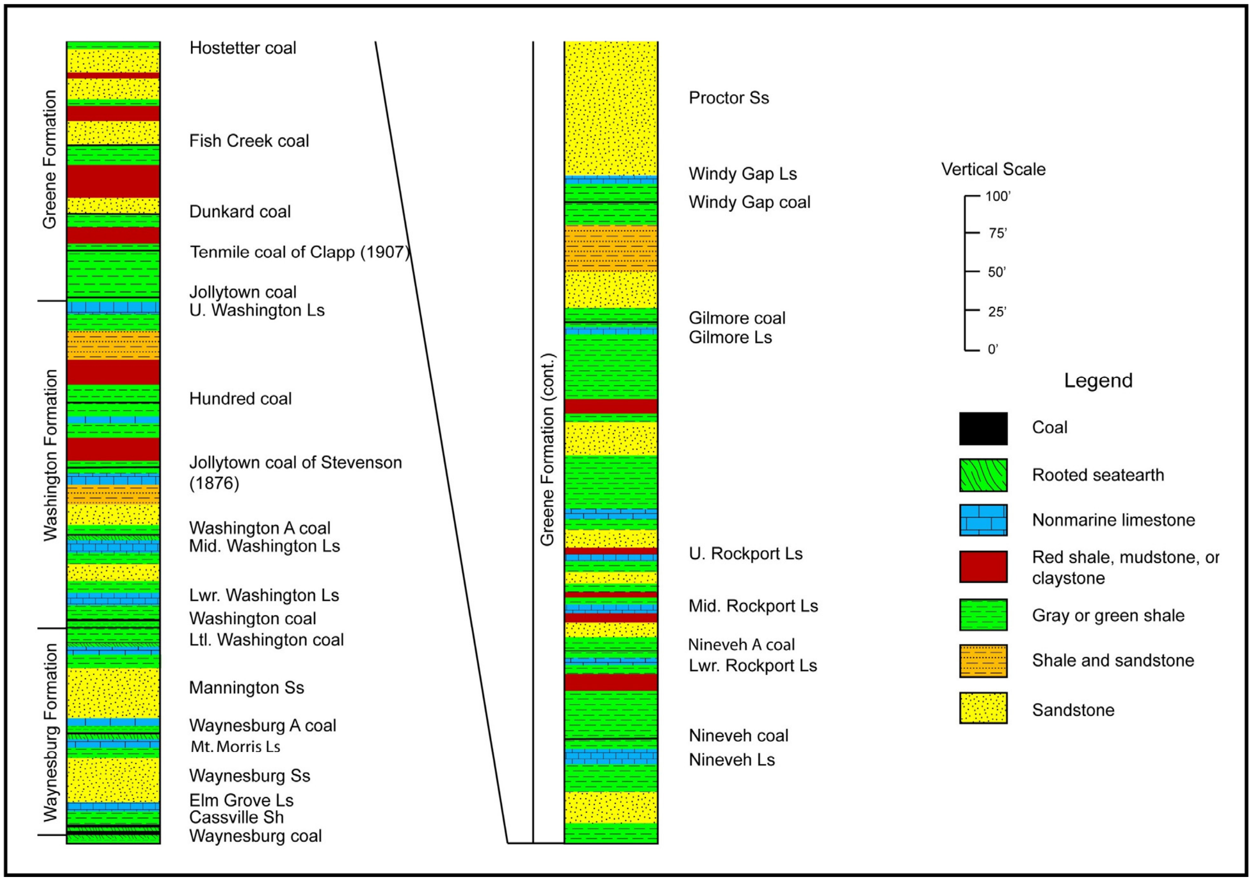


Figure 8. Generalized section of the Dunkard Group in southwestern Pennsylvania and northern West Virgina (modified slightly from Fedorko and Skema, 2011).

(Fedorko and Skema, 2011). Fedorko and Skema (2011) estimated the thickness of the underlying Pennsylvanian strata (Pottsville to Monongahela) in this area to be about 1,350 ft (412 m) thick, indicating that the Dunkard Group alone is almost as thick as all of the other post-Mississippian rocks in the Appalachian basin.

Strata tend to be an interbedded mix of black, gray, green, and red shale; gray, green, and red claystone and mudstone; gray and green siltstone; gray and green sandstone; nonmarine limestone; and thin coal beds that are generally less than 3 ft (0.9 m) thick. Much, if not all of the Dunkard Group may have been

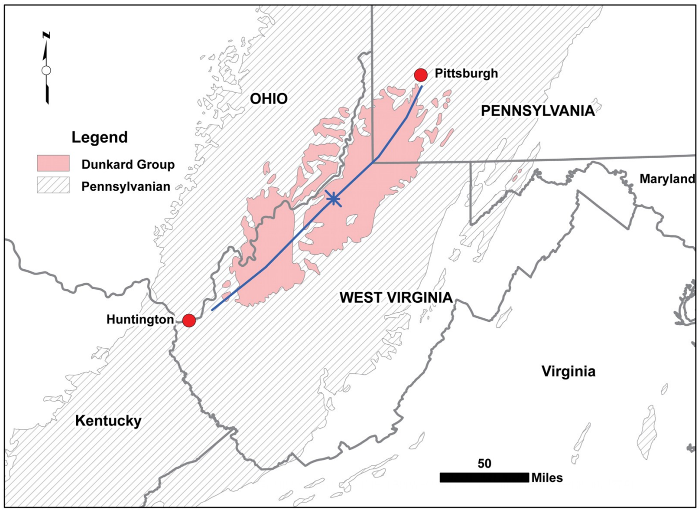


Figure 9. The area underlain by the Dunkard Group rocks in the northern Appalachian basin, showing the axis of the Pittsburgh-Huntington synclinorium (from Fedorko and Skema, 2011).

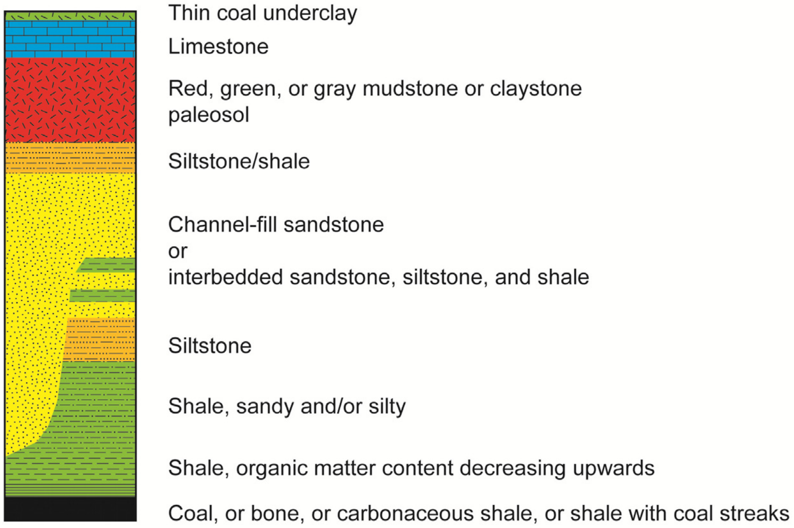


Figure 10. Idealized depositional cycle of the Dunkard Group (from Fedorko and Skema, 2011 as modified from Beerbower, 1961).

deposited during a time of global polar ice fluctuations (Rygel et al., 2008), and there is evidence in the Dunkard of fluctuating depositional conditions driven by allocyclic factors (external to the basin) (Beerbower, 1961; Cecil et al., 2011; Eble et al., 2011) resulting in strata deposited as cyclothems. Beerbower (1961) described the typical Dunkard cyclothem (Figure 10), which is similar to the "ideal" cyclothem of the Pennsylvanian (Wanless and Weller, 1932), but with a coal bed marking the base of the cycle. Thick sandstone bodies typically have undulating bases that eroded into the underlying strata, indicating their origin as stream channels. They often directly overlie coal beds or their roof shales. Sandstones associated with meandering channel systems often grade upward into siltstone and/or shale as their energy gradients wane. Paleosols, commonly with calcareous nodules, may develop in this alluvium. Micritic, nonmarine, lacustrine limestones, rarely more than 5 ft (1.5 m) thick, may overlie the paleosols and tend to exhibit desiccation cracks, fractures, and nodular or brecciated fabrics, indicating subaerial exposure (Fedorko and Skema, 2011). The limestones, then, are overlain by thin and poorly developed mudstone or claystone seat earths. Then the next cycle starts with another coal bed. Variability in these cyclothems are obvious when examined throughout the basin, as they were undoubtedly induced by local changes in depositional environments.

For more information on the general stratigraphy and nomenclatural history of the Dunkard Group, see Fedorko and Skema (2011).

Mesozoic

The only Mesozoic-age rocks known from southwestern Pennsylvania are those of the Masontown kimberlite dike, which we will examine at Stop 1. Please see the discussion of that stop on p. 25 for information.

Cenozoic

Cenozoic-age deposits in southwestern Pennsylvania are represented by fluvial and lacustrine deposits of Pleistocene age and soils. The soils include post-Pleistocene soils derived from Paleozoic bedrock or Pleistocene and Holocene deposits, and soils that are classified as artificial land (i.e., soils that have been disturbed by commercial, industrial, and residential activity, including urban land, landfills and garbage dumps, mine tailings, and slag dumps).

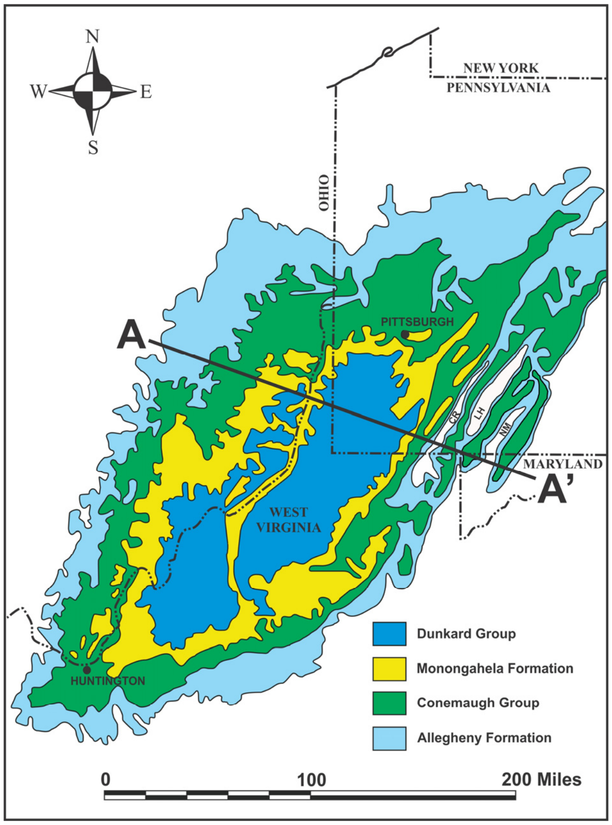


Figure 11. Geologic map of the Pittsburgh-Huntington synclinorium and other structures in southwestern Pennsylvania and adjacent areas. CR – Chestnut Ridge anticline. LH – Laurel Hill anticline. NM – Negro Mountain anticline. See Figure 12 for cross section A-A'. Modified from Wagner et al.,

The primary Pleistocene deposit in southwestern Pennsylvania is the Carmichaels Formation, named by Campbell (1902) for primarily lacustrine deposits preserved in the abandoned meander channel at Carmichaels (see Stop 2). The name is often, incorrectly, used for all Pleistocene terrace deposits in western Pennsylvania. Many of the sediments in the Allegheny-Ohio drainage are glacial outwash deposits that are distinctly different from the sediments of the Carmichaels.

For more information on the Carmichaels Formation, see Stop 2 on p. 31.

STRUCTURE

The regional structure of southwestern Pennsylvania is shown in Figures 11 and 12. Much of the field trip area lies within or on the flank of the Pittsburgh-Huntingdon Synclinorium (also called the Dunkard Basin). The Dunkard Group occupies the center of the basin, and progressively older rocks crop out towards the basin margins.

The strata of southwestern Pennsylvania are very gently folded, with axes trending approximately N35°E, although there are numerous exceptions (Figure 13). 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 (Figures 11 and 12).

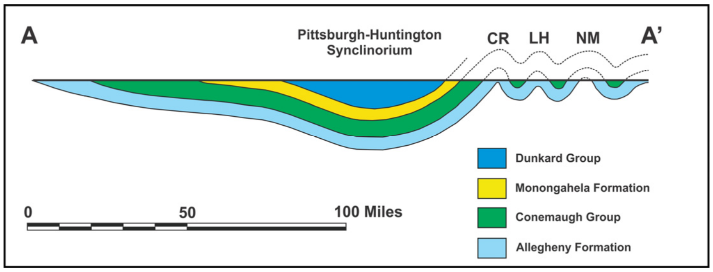
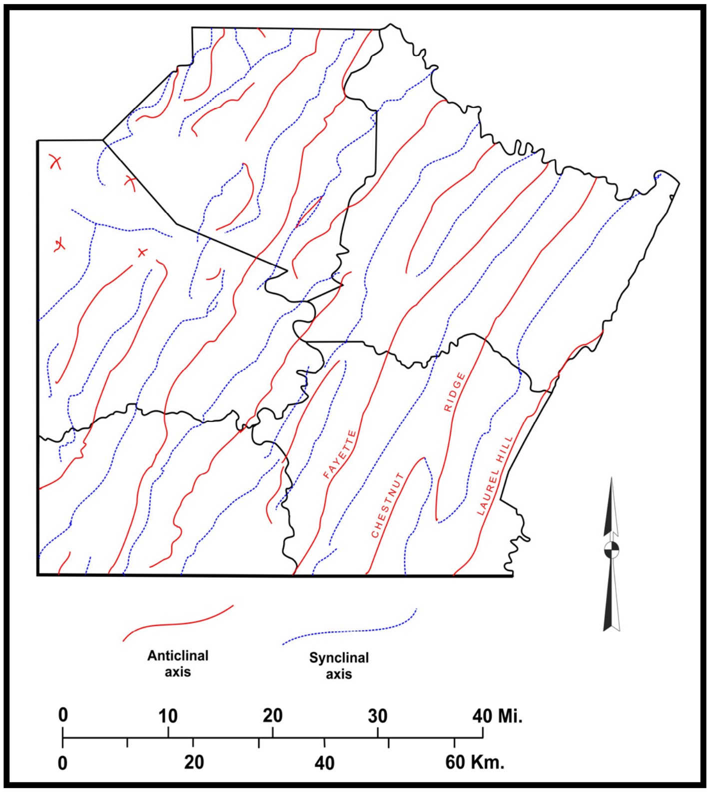


Figure 12. Highly generalized cross section along line A-A' (see Figure 11) showing the geologic structure of the Pittsburgh-Huntington synclinorium and the three most complex anticlines of the Appalachian Plateau. CR – Chesnut Ridge anticline. LH – Laurel Hill anticline. NM – Negro Mountain anticline. Modified from Wagner et al., 1970.

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°E to

Figure 13. Structural axes of southwestern Pennsylvania (modified from Faill, 2011).



N40°E and N50°W to N80°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 (see Stone, 1932a for a discussion). 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 in the western part of southwestern Pennsylvania. 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 contribute to the plethora of landslide problems encountered in western Pennsylvania (see Hamel and Adams, 2000).

Faulting is not a common feature of the surface rocks of southwestern Pennsylvania, but faults do occur. Normal faults are the most common type present in the field trip area. Most, if not all, occurred penecontemporaneously with deposition as glide planes of slump blocks associated with stream-bank landslides. Reverse faults are far less common than normal faults in this area, but they can be observed at various locations on the flanks of Chestnut Ridge and Laurel Hill, as well as in the river gorges that cut deeply into them.

GEOLOGIC RESOURCES

Geologic resources in southwestern Pennsylvania 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 30 years.

Fossil Fuels

Coal

Coal, historically the most important mineral resource to the southwestern Pennsylvania's economy, has been mined throughout the entire area, except on and near the crests of the major anticlines where they are absent as a result of erosion. Southwestern Pennsylvania's coals are all bituminous, although they have varying ranks (Figure 14).

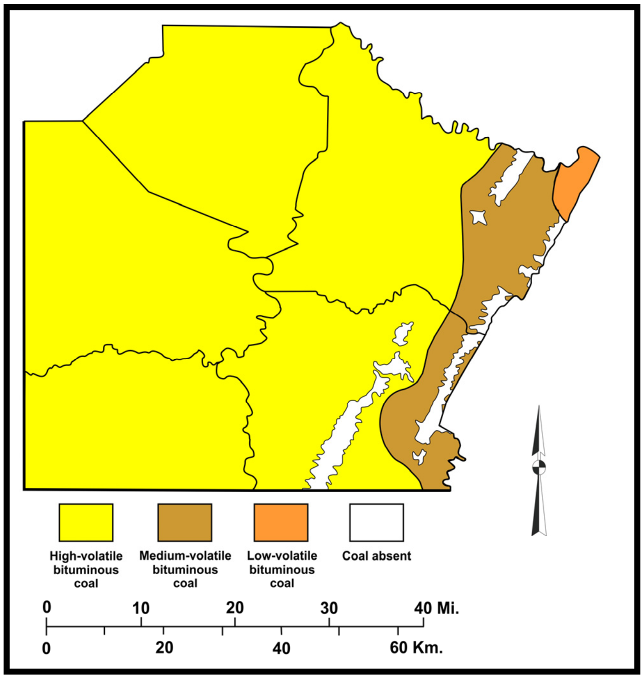


Figure 14. Generalized distribution of coal by rank in southwestern Pennsylvania (modified from Bureau of

The Pittsburgh coal, the basal unit of the Monongahela Formation, is one of the world's major economic resources. It is the best known and one of the most valuable of all the bituminous coal beds of the Appalachian basin, and has been since it was first mined on Coal Hill (now Mount Washington) in 1759. By comparison to most coals, the Pittsburgh seems to be uniformly present and of relatively constant thickness. In reality, however, it ranges from 0 to more than 12 ft (3.6 m) thick. There are a few places where the overlying Pittsburgh sandstone thickens and cuts out the coal completely, the result of a large stream traversing the ancient swamp in which the coal formed. The Pittsburgh coal is a high quality coal, suitable for almost every use, but is especially valuable for coking. From 1759 to 1804, the total bituminous coal output of Pennsylvania was derived from this seam. From then until 1940 it usually supplied over half of the total output. In 1956, the Pittsburgh seam contributed 40 percent of the total US production, but by 1985 it supplied only 2.2 percent.

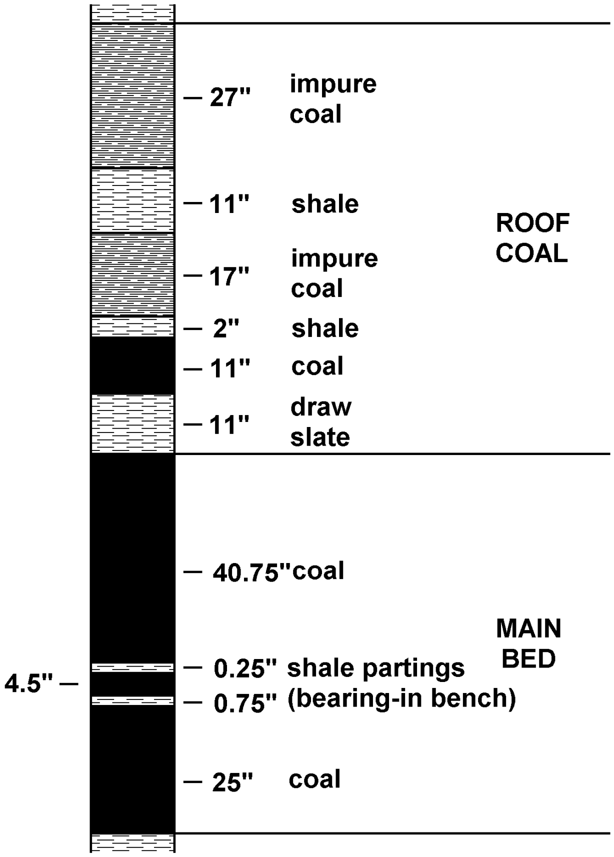


Figure 15. Detailed layering of the Pittsburgh coal seam. Adapted from Johnson, 1929.

In general, the Pittsburgh seam consists of a roof coal and a main coal, separated by a claystone parting up to 3 ft (0.9 m) thick (Figure 15). The upper, or roof coal has a high ash content, and typically is left in the mine. The lower coal ranges from 3.5 to 9 ft (1.1 to 2.7 m) thick, averaging about 5.5 ft (1.7 m), and is subdivided into four distinct benches. From top to bottom, these are the upper or "breast", about 3 to 4 ft (0.9 to 1.2 m) of good coal; the "bearing-in", about 4 in (10 cm) of soft crumbly coal; the "brick bench", up to 3 ft (0.9 m) of excellent blocky coal; and the "bottom coal" which is thin and dirty and is usually left in the mine.

The Redstone coal occurs about 50 ft (15 m) above the Pittsburgh seam. It is of good quality in various areas of the southwestern Pennsylvania. However, it is extremely irregular in thickness, ranging from only a few inches to 5 ft (1.5 m). The general range of thickness in the best areas is 2.4 to 4 ft (0.7 to 1.3 m). Subsidence caused by mine collapse in the Pittsburgh seam may create mostly unmineable conditions in places where the Redstone would otherwise be economically recoverable.

The Sewickley coal, like the Redstone, is highly variable in thickness and quality. It is especially thick and commercially viable in southwestern Fayette County, where it is known locally as the “5-foot” bed (Hickock and Moyer, 1940).

Crude Oil and Natural Gas

Crude oil was far more important in southwestern Pennsylvania 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, which runs from Neville Island in Allegheny County south into northern Washington County, was discovered in 1890 and is second in volume of production only to the famous "giant" Bradford oil field in McKean County in northwestern Pennsylvania. Most of the oil comes from the Upper Devonian Venango Group sandstones (Figure 5), although some significant early (late 1800s-early 1900s) production came from Pennsylvanian sandstones of the Conemaugh Group and Pottsville Formation (Figure 5). Today few companies operate the old wells and only a few new wells have been drilled since the mid-1980s.

In contrast to crude oil, natural gas production increased significantly through the 1900s, primarily from sandstone reservoirs in the Upper Devonian Venango Group (Figure 5). Many new wells were drilled in southwestern Pennsylvania during the 1980s and 1990s, particularly in Fayette, Greene, Washington, and Westmoreland counties, to siltstone and fine-grained sandstone reservoirs of the Upper Devonian Brallier Formation (Figure 16). Coalbed methane, natural gas from coal, began to be developed in earnest in all but Allegheny County in the 1980s and 1990s. Production comes from the

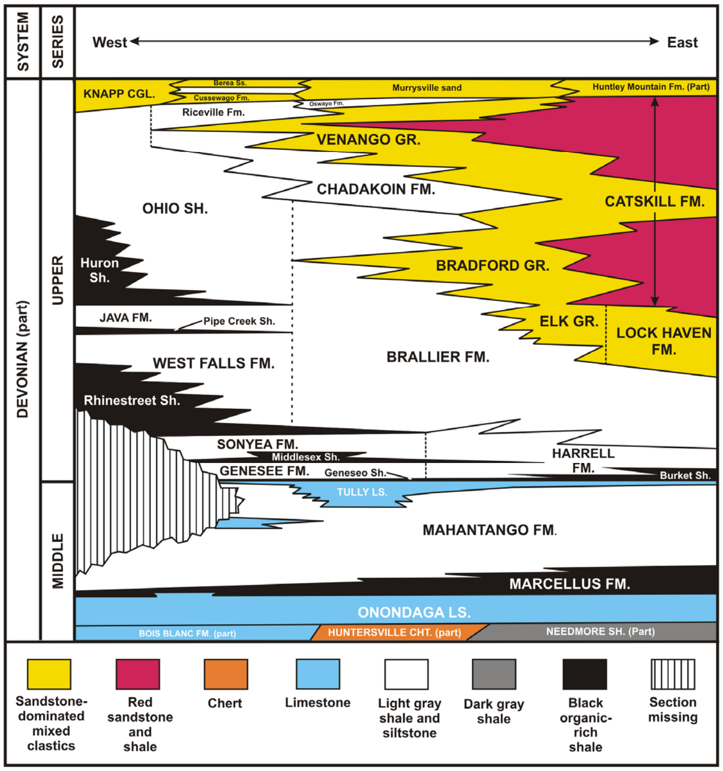


Figure 16. Correlation diagram of Middle and Upper Devonian formations in the Appalachian Plateau of Pennsylvania (from Carter, et al. 2011).

Pittsburgh seam and all of the coal seams that occur in the area in the Allegheny and Pottsville Formations. Subsequently, with the discovery of large quantities of gas in the Marcellus shale (Figure 16) in 2004, the natural gas industry has expanded even more. The value of natural gas as a clean, environmentally "friendly" fuel that is beginning to replace coal in electric power generation will continue to make it a viable geologic resource in the region for many years to come.

Non-Fuel Mineral Resources

Iron Ore

Iron ore was mined and smelted in Pennsylvania from the early Colonial days. The industry grew rapidly, Pennsylvania taking and maintaining the lead in iron ore mining and in the production of pig iron until 1880. By 1880 Pennsylvania was importing iron ores from other regions, particularly the great deposits in Michigan and Minnesota. This led to the abandoning of much of the iron ore mining in Pennsylvania, with the exception of the magnetite ores of Cornwall, French Creek, and a few other localities which continued to be mined into the second half of the 20th century. Iron manufacturing in the early 1800s was a relatively simple affair, with a small stone furnace for smelting ores (Figure 17) built where the most important resources, including iron ore, limestone, wood, and running water, could be found in sufficient quantity to assure many years of production. Iron ore generally was of low quality, especially in western Pennsylvania, consisting primarily of siderite nodules and bog iron. Siderite ($FeCO_3$) is a common, if not abundant, iron ore typically associated with marine limestones and shales in western Pennsylvania. It typically contains only 40 or 50% iron, and so is considered to be a very low grade ore. Still, it was the primary source for most iron furnaces in western Pennsylvania for decades. Siderite was mined from numerous Mississippian and Pennsylvanian formations, including the Mauch Chunk Formation, Pottsville Formation, Allegheny Formation, and Glenshaw Formation. One of the most valuable ores was the Buhrstone ore, a layer of bedded and/or nodular siderite typically capping the Vanport Limestone of the lower Allegheny Formation. This occurs only north of Allegheny County, but it provided the primary source of ore throughout northwestern Pennsylvania for many years. Limestone was necessary in the iron industry as flux. Since siderite was often associated with limestone, obtaining a good supply was not a problem. Wood was necessary for creating charcoal, which was used exclusively as a fuel and for carbon until the iron masters began using coke made from bituminous coal (Swank, 1878). As a result, much of western Pennsylvania was denuded of trees by the mid-1800s. Running water was used to generate the power needed to keep the blast machine operating. The old iron furnaces of western Pennsylvania commonly were situated along a small or moderate sized stream having a steady flow of water.

By the 1850s, 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 with them the coke manufacturing and coal mines that dominated the Monongahela River valley for generations.

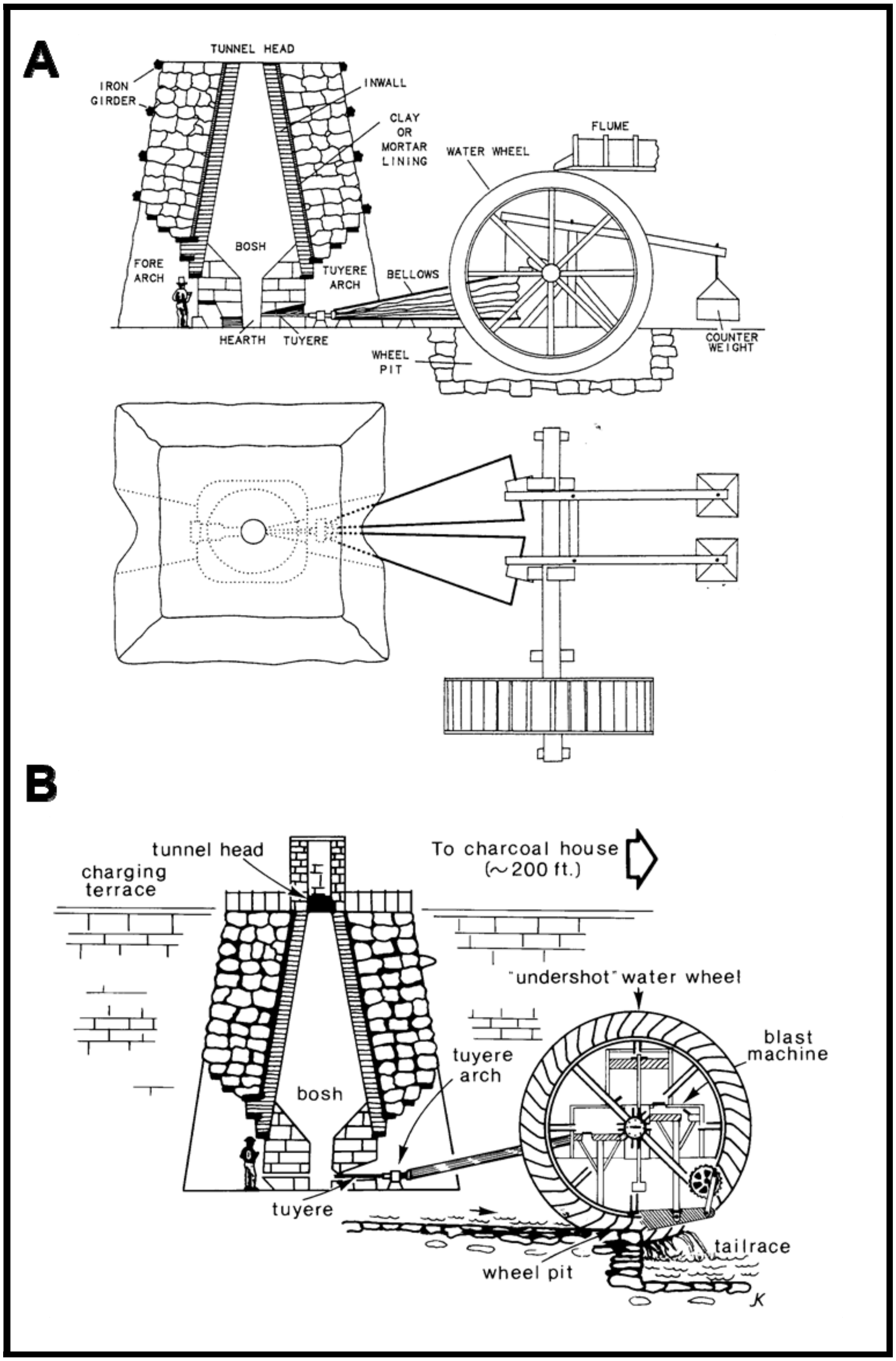


Figure 17. **Generalized plans of early American iron furnaces. The earliest (A) furnaces were equipped with bellows to provide the blast (modified from Bining, 1938). In the 1800s, however, iron manufactures developed a different kind of blast machine (B) consisting of pistons and cylinders (from Inners, 1986).**

Non-Metallic Resources

The quantity of non-fuel, non-metallic resources such as sandstone and limestone remains high in southwestern Pennsylvania, but 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 land-use 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, sand and gravel, and clay quarries around the region, now there are very few or none at all.

Sand and gravel of both Pleistocene and Holocene age are available in large supply in the beds of the Allegheny and Ohio rivers, and from the Pleistocene Carmichaels Formation in high-level terraces above the Monongahela and Youghiogheny river valleys. Ohio and Allegheny river deposits are largely reworked glacial material containing durable rock, so they are most suitable as 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 from the Carmichaels Formation also was used for glass manufacturing, and as molding sand. Sand and gravel occurring on the river terraces along the Ohio and Allegheny rivers contain a somewhat higher proportion of weathered pebbles than the deposits in the rivers and are, therefore, less useful and less valuable.

Local Pennsylvanian-age 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, such as the Mather Sandstone of the Dunkard Group (see Stop 2), 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 southwestern Pennsylvania are impure, thin to nodular bedded, and irregularly distributed. The exception to this is the Mississippian Wymps Gap Limestone, which is still being quarried on Chestnut Ridge and Laurel Hill. The Sewickley Member of the Pittsburgh Formation (commonly called “Benwood limestone”) is the thickest and, arguably, most useful of the lesser quality Pennsylvanian and Permian carbonates. An average analysis for the thicker usable limestones shows calcium 75% to 85%, magnesium carbonate 2.3% to 6.8%, silica 5% to 11%, and combined alumina and iron oxide 2.4% to 10.8% percent (Johnson, 1929; Hickock and Moyer, 1940). When southwestern Pennsylvania was almost all 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 southwestern Pennsytlvania, currently are considered of minor consequence. This is due more to the steadily shrinking area 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 “Benwood limestone” crops out close to the tops of broad, flat-topped hills, but these areas commonly are more valuable as farmland or housing developments.

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 now boasts Century III 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, 2011). But, according to Hamel and Adams (2000), the District 11-0 office of PennDOT 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 has been developed into an upscale townhouse community.

From about 1815 to 1870, the salt industry played a major role in the economy of southwestern Pennsyvlania. 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. Tarentum, north of Pittsburgh on the Allegheny River, was the first place in western Pennsylvania where salt was produced from brine, and later became one of the more important salt producing areas of the country. Similarly, in western Fayette County, wells produced brine from which an excellent table salt was recovered. Most of the brine came from sandstones of the Pottsville Formation; 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 along the three rivers depend primarily on the rivers for their water supplies. Many of them draw their drinking water directly from the 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.

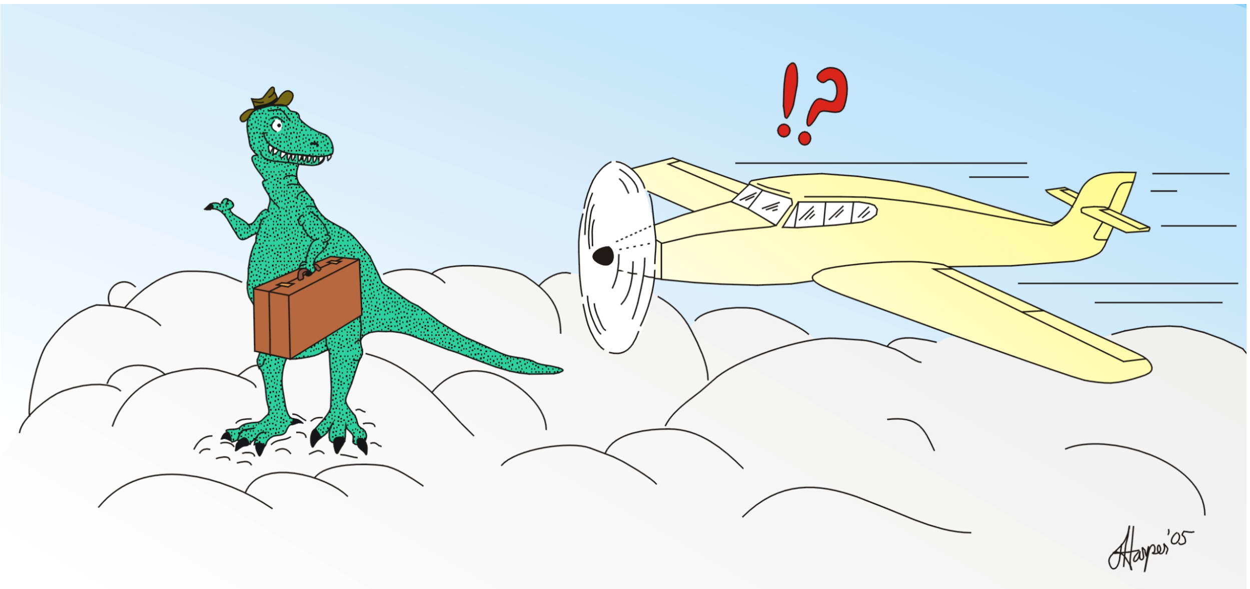
The Allegheny and Ohio valley-fill deposits consist of clay, silt, sand, and gravel containing scattered cobbles and rare boulders. The Monongahela valley-fill is chiefly locally-derived fine sand, silt, and clay with scattered large clasts of bedrock. The permeability of all these deposits can vary 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 consumption. Unfortunately, this groundwater is harder and contains more iron and manganese than does the surface water.

The greatest proportion of groundwater used throughout southwestern Pennsylvania comes from the rivers because this is where the population is mainly concentrated. But much of the groundwater comes from bedrock aquifers, typically a sandstone or limestone within 500 ft (152 m) of the surface. The better bedrock yields come from the sandstones, of which the Morgantown sandstone (Conemaugh Group, Casselman Formation) (Figure 7) is probably the best for consistent supply. The "Benwood limestone" (Sewickley Member of the Pittsburgh Formation) (Figure 7) 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.

Southwestern Pennsylvania was once blessed with an abundance of springs. The best tasting spring water came from the base of the Ames Limestone (Conemaugh Group, Glenshaw Formation), the "Benwood limestone" (Sewickley Member of the Pittsburgh Formation), and the Morgantown sandstone (Figure 7). The spread of residential areas following World War II, and mine subsidence problems, have led to local disruption and pollution of many springs.



There are no dinosaur remains to be found anywhere in western Pennsylvania's rock layers. Why? Western Pennsylvania was once covered by more than one mile (1.6 kilometers) of rock and sediment, including the bedrock and soil the dinosaurs trod upon. But, because that ground they walked on, and the rock layers their fossilized remains would have been encased in, have long since been eroded and washed away, no remains exist anywhere in western Pennsylvania except the collections in the Carnegie Museum of Natural History, and they all came from somewhere else. But . . .

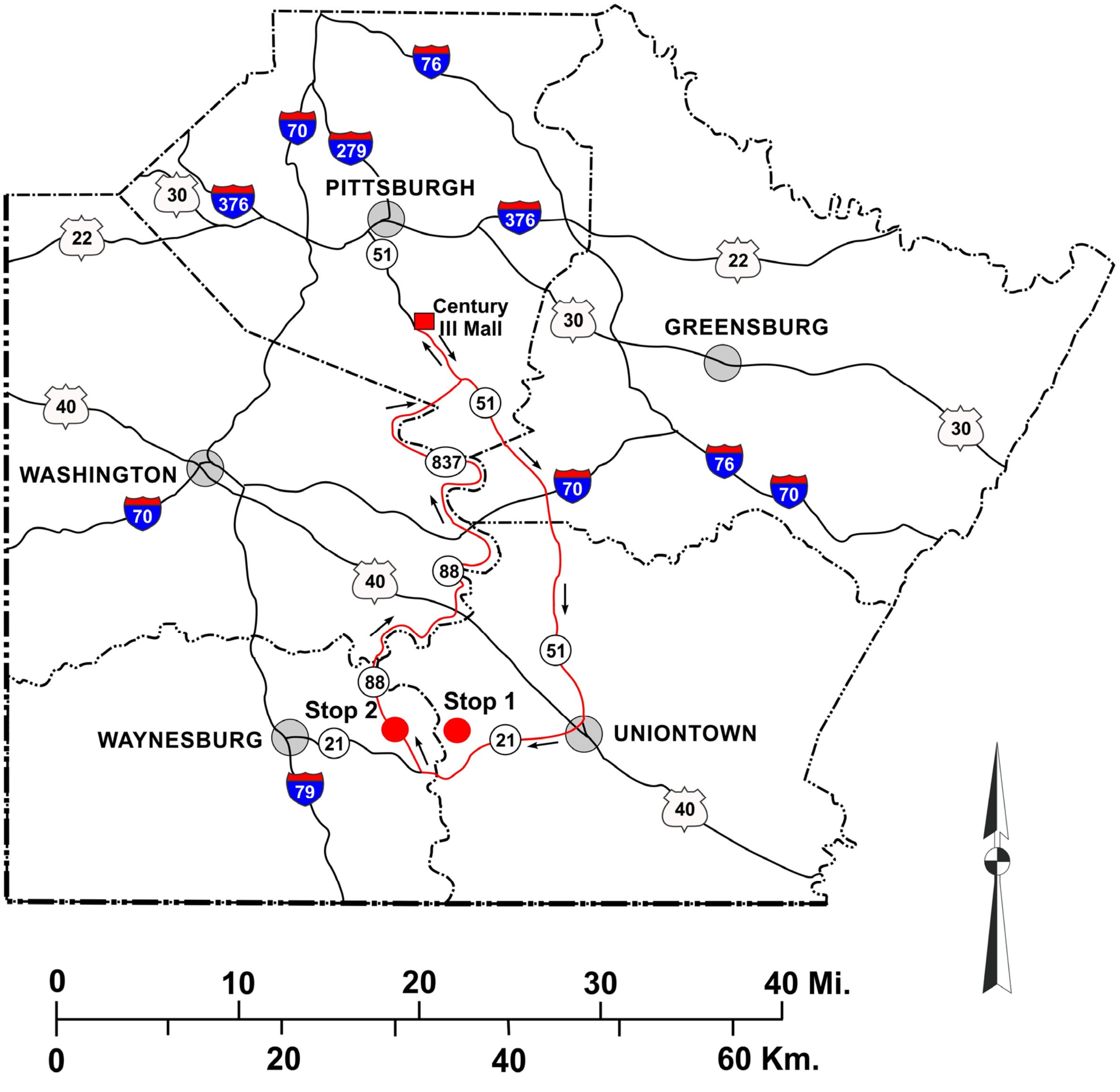


Figure 18. Map of southwestern Pennsylvania showing Century III Mall (the start and stop location—red rectangle), field trip route as laid out in the road log (red line—arrows indicate the direction of travel), and the locations of the two field trip stops (red circles).

ROAD LOG

Mileage		
Int.	Cum.	Description
0	0	Leave Park & Ride parking lot at Century III Mall. Follow mall perimeter road W to stop sign. See Figure 18 for route map.
0.2	0.2	STOP SIGN. Turn left and follow road to PA 51.
0.1	0.3	Turn left onto PA 51 southbound.
0.2	0.5	Southland shopping center on the left. The hills behind the shops on both sides of the highway have been affected by mine subsidence. Collapse features can be seen behind the northernmost shops at Southland, and mine collapse weakened the rocks behind the shops on the left enough that a large rockfall in the 1980s destroyed a couple of cars parked in the parking lot of a Ponderosa restaurant that was also damaged. The restaurant is no longer there. Figure 19 is a cross section approximately paralleling PA 51 from Pleasant Hills near Century III Mall on the left (NW) to past Elizabeth on the right (SE). The Pittsburgh coal, a good marker bed, illustrates the relationship of structure and topography as the road winds down the Lewis Run valley. Elevations range from720 ft (220 m) on the Monongahela River to over 1,200 ft 366 m) at the highest elevations, indicating that relief just along this stretch of highway is >400 ft (122 m). The coal is folded into two broad, gentle anticlines, the Amity and Murrysville, and a syncline, the Duquesne. The structural relief on the coal, measured vertically from the trough of the syncline to the crest of the anticline, is about 150 ft (46 m).
1.9	2.4	Outcrop of a the Connellsville sandstone on right. Notice the geometry of this sandstone body.
0.8	3.2	Exit to PA 43, the Mon-Fayette Expressway to the right. Continue south on PA 51.

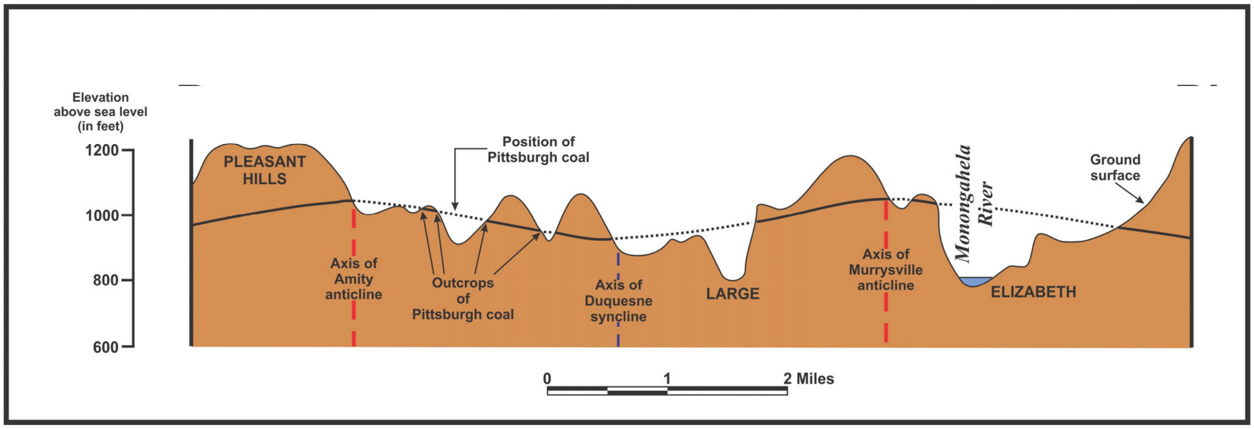


Figure 19. Cross section along Route 51 from Pleasant Hills to past Elizabeth. The section crosses the Amity and Murrysville anticlines and the Duquesne syncline, and shows the structural relief based on the Pittsburgh coal.

0.5	3.7	Cross Peters Creek in Large, PA, a community within the Borough of Jefferson Hills. Peters Creek starts in Nottingham Township, Washington County, and flows 16.8 mi (27 km) to the Monongahela River at Clairton, Allegheny County.
0.1	3.8	Cross Norfolk Southern Railroad tracks.
		Cross the Monongahela River and enter the Borough of Elizabeth. Elizabeth was founded in 1787 by Samuel Mackay, Stephen Bayard, and Bayard’s wife Elizabeth Mackay Bayard, and they named the place Elizabeth Town in honor of Bayard’s wife. Elizabeth supposedly is the site where the keelboat used for the historic Lewis and Clark Expedition was built in 1803, although the City of Pittsburgh disputes that. The town was incorporated as a borough in 1834. Elizabeth also lends its name to one of the deepest oil and gas producing sandstones of the Upper Devonian Venango Group.
3.3	7.1	Above PA 51 in this area are some flattened hilltops at elevations around 900 ft (274 m), or about 200 ft (61 m) lower than the elevation of the Appalachian Plateaus. These flattened areas are remnant terraces of the old pre-glacial Monongahela River.
1.5	8.6	The semi-circular expression of the hillside on the left is all that remains of a major landslide that occurred here in 1973.
2.2	10.8	Intersection with PA 48, Scenery Drive, to the left. Continue south on PA 51. Round Hill Park, one of Allegheny County's numerous parks, is about half a mile to the left. The park has a working farm that helps supplement the park's expenses.
1.2	12.0	Exit to PA 136 to the right. Continue south on PA 51.
0.8	12.8	Enter Westmoreland County. Westmoreland County was formed in 1773 from part of Bedford County that lay to the west of Laurel Hill. Following the tradition of the time, the county was named for a county in England. One historian waggishly said the name was very appropriate because it lay to the **west** and had **more land** than had been occupied up to that time.
0.3	13.1	Rostraver Airport lies off to the left.
2.4	15.5	Exit to PA 201 on the right. Continue south on PA 51.
0.1	15.6	Cross over PA 201.
1.2	16.8	Cedar Creek Park, called the premiere access point to the Youghiogheny River Trail for Westmoreland County residents, is off the the left.
1.1	17.9	Exit to I-70 W. Continue south on PA 51.
0.1	18.0	Cross I-70.
0.3	18.3	Intersection with PA 981 on left. Continue south on PA 51.
1.7	20.0	Enter Fayette County. Fayette County was created from the southern portion of Westmoreland County in September 1783 and named for the Marquis de la Fayette (Lafayette), the famous Frenchman who assisted George Washington during the American Revolution.
2.5	22.5	Enter the Borough of Perryopolis. This town has a lot of social and geologic history. George Washington bought some land here when it

first became available. In 1770, he declared it "as fine a land as I have ever seen, a great deal of rich meadow; it is well watered and has a valuable mill seat." The mill was completed in 1776 and encouraged other businesses to follow. Eventually, the town of New Boston sprung up. Washington drew up plans for the streets to be laid out in the shape of a wagon-wheel, but he never saw his dream come to fruition. After he died, his estate sold the land and, in 1814, the town was laid out using Washington's plans, and named for Admiral Oliver Hazard Perry, who won the famous victory of Lake Erie during the War of 1812. The main part of the borough is to the west of PA 51, but you can see the wagon-wheel shape of the town center in aerial photography (Figure 20).

Figure 20. Aerial photograph of Perryopolis, showing the wagon-wheel-shaped town center, as laid out by George Washington who originally owned the land. From Google Maps.

Geologically, Perryopolis and its environs lie within a cut-off meander of the Youghiogheny River. This meander was abandoned sometime before or during the early Pleistocene. The Carmichaels Formation (see Stop 2) consists mostly of alluvial and lacustrine deposits. The lowest material is coarse, because it was deposited by an active stream. Above and often interbedded with this are large clasts of rock that can be identified as bedrock the Youghiogheny River encountered in its trip through the Allegheny Mountain Section. Fine, laminar clays indicate deposition in quiet water, probably Lake Monongahela (see Stop 2).

The Carmichaels Formation is about 35 feet thick in Perryopolis, or at least it was before development of the area disturbed much of the land. In the late 1800s and early 1900s, the sand was being used to make glass, and the clays for brick. Campbell (1903) reported that Pleistocene plant fossils had been found in the clays here, but none of the fossils had been preserved for examination.

1.7	24.2	Historical marker on right reads: *COKE OVENS - The bee-hive ovens nearby are typical of the region. Coke was first made from coal near Connellsville in this type oven about 1840. Since 1870 use of coke has been vital to steel making.*
0.9	25.1	Enter Village of Star Junction. This village was founded when the Washington No. 2 Mine was opened by the Washington Coal and Coke Company in 1893. The name derives from its origin as the railroad depot at the end of the line for the Washington Run Railroad. As in Perryopolis, Star Junction had its own coke oven business (Figure 21).

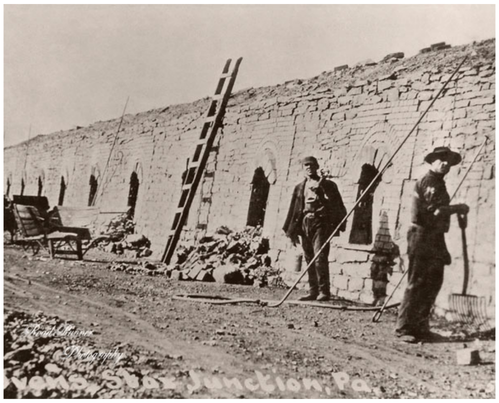


Figure 21. Bee hive coke ovens operated in Star Junction. The coke ovens were in Stickel Hollow on the Washington Run Railroad, which later was owned by the P&LE Railroad. It appears that the rail bed became the 4 lane PA 51. From Allison PA, 2013.

0.6	25.7	Exit to PA 201 on the right. Continue south on PA 51.
0.1	25.8	Cross under PA 201.
4.3	30.1	The fossiliferous Ames marine zone crops out just above the level of the bench along the hillside to the left. This is actually a pretty good place to go fossil collecting.
0.3	30.4	Enter the Village of Waltersburg. Waltersburg is home to the Coal Miners Memorial at the Park Hill Mine & Coke Works. The Park Hill Mine & Coke Works opened in 1905 on the Pennsylvania Railroad and the P. V. & C. Railroad at Waltersburg. Besides the mines, Park Hill also operated 58 coke ovens (Washlaski et al., 2010). The Waltersburg gas field, one of the larger Upper Devonian gas fields in Fayette County, was discovered in 1910 along the axis of the Fayette anticline (Figure 13).
0.2	30.6	The Waltersburg Mine to the left is a coal strip mine in the Lower Bakerstown coal that was operated by Piccolomini Contractors Inc. Donahue et al. (1972) descibed and discussed the asymmetrical transgressive-regressive nature of the Woods Run marine zone found at this mine (Figure 22).
0.9	31.5	Cross Redstone Creek. This is the creek that lent its name to the Redstone coal of the Monongahela Group. Redstone Creek runs from the western slope of Chestnut Ridge near Uniontown to the Monongahela River at Brownsville. The creek was so named because the exposures of coal on the hillsides near Brownsville sometimes became ignited and burned much as modern bone shale piles burn or smolder, turning the overlying shale a bright red color (called "clinker" or "red dog").

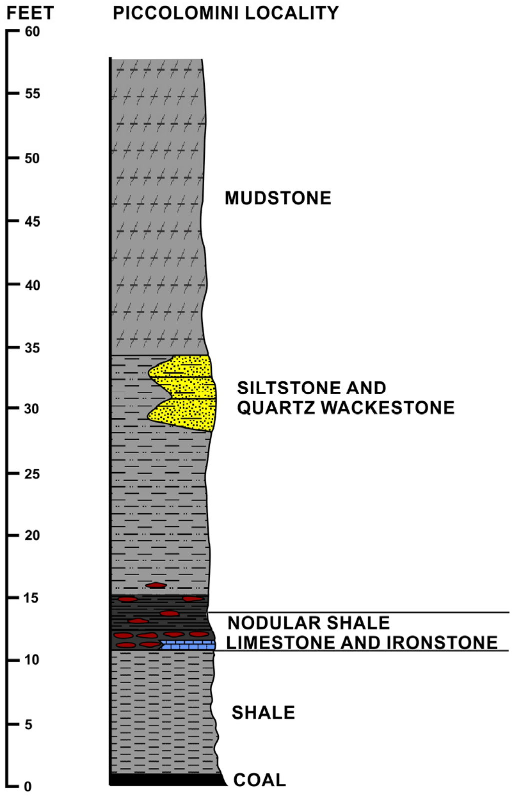


Figure 22. Stratigraphic section of the Woods Run marine zone and adjacent rocks at the Piccolomini coal mine at Waltersburg, Fayette County. Modified from Shaak, 1975.

0.5	32.0	Enter the Village of Upper Middletown.
2.8	34.8	Good view of Chestnut Ridge and Uniontown ahead.
1.0	35.8	Exit to PA 43, the Mon-Fayette Expressway. Continue south on PA 51.
0.2	36.0	Cross under PA 43.
0.1	36.1	Bear right onto exit ramp for US 119 S and merge with traffic.
0.8	36.9	Exit to US 40 on right. Continue south on US 119
0.8	37.7	Bear right onto exit ramp toward PA 21, McClellandtown Road, and merge with traffic.
0.5	38.2	Turn left onto PA 21 W.
1.9	40.1	Enter Village of Revere.
0.8	40.9	Enter Village of Balsinger.
1.8	42.7	Enter Village of Messmore.
		Enter the Village of McClellandtown. McClellandtown was founded by William McClelland, who was granted a license to open a tavern there in 1798.
1.3	44.0	The McClellandtown area was the first area in Fayette County to produce natural gas. The Ryder and Mack wells were drilled about one mile southeast of McClellandtown in, respectively, 1887 and 1888 (Hickock and Moyer, 1940).
2.2	46.2	Intersection with PA 166 N. Turn right and travel to Stop 1. Because of the sensitive nature of the outcrop, the exact route will not be shown.

STOP 1—MASONTOWN, FAYETTE COUNTY, PA : The Masontown (Gates-Adah) Kimberlite Intrusion*

Stop leader: Henry S. Prellwitz

INTRODUCTION

The Masontown kimberlite intrusion (also known as the Gates-Adah dike because of exposures in coal mines and at the surface near Gates, Fayette County, and Adah, Greene County, across the river) cuts through late Pennsylvanian sedimentary strata in the eastern portion of Fayette County, Pennsylvania near the village of_Adah (Figure 23). 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.

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 1,022 to 1,112° F (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).

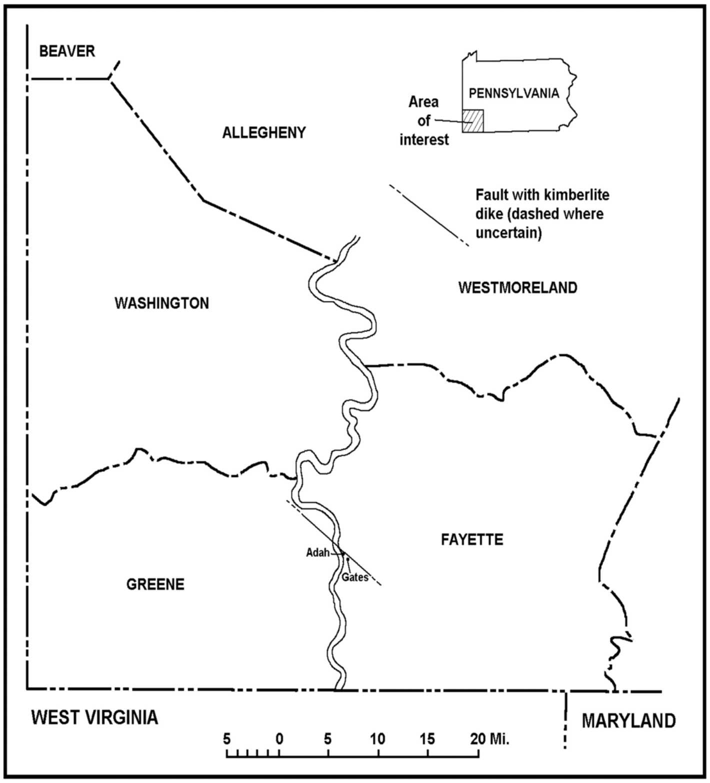


Figure 23. Map of southwestern Pennsylvania showing the general location of the Masontown (Gates-Adah) kimberlite

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*Modified from Prellwitz and Bikerman, 2011.

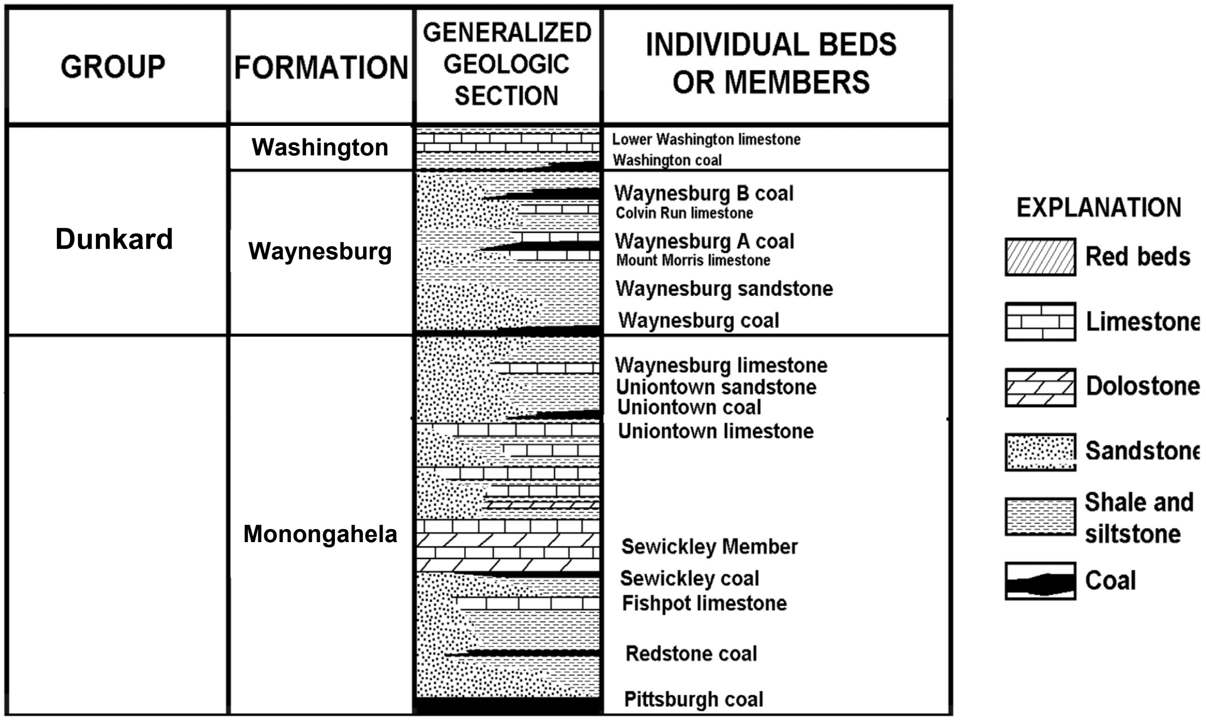

Figure 24. Generalized geologic column of the country rock exposed in the area of the Masontown kimberlite dike.

GEOLOGICAL SETTING

The Masontown kimberlite intrudes through sedimentary rocks of the Upper Pennsylvanian Monongahela and Waynesburg formations (Figure 24). 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 25). 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.

Figure 25. Photograph of an unaltered portion of the kimberlite dike in outcrop. Rock hammer for scale.

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 25). Occasional surface outcrops have been traced for more than 1.9 mi (3 km) (Prellwitz 1994), and over 3 mi (5 km) in 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

Age determination on igneous rocks from a deep-seated origin is a tricky proposition. The parent isotopes incorporated in the deep source generated significant daughter isotopes during the lengthy pre-eruption residence time. Depending on the nature of the host material - mineral, magma, or gas - the daughter isotopes may be retained entirely in their host which, for a robust mineral, would later give an apparent age of first formation of the mineral rather than the eruption or emplacement age. Alternatively source materials open to migration of parent and/or daughter *in the magma chamber* but not after eruption may be datable for the eruption time. To have a valid date any carry over daughter would either have to have expelled in the eruption, or be accounted for in the analysis and calculation of the date. Finally any true age would not have had any change in isotope composition post emplacement. Of course many intermediate possibilities exist often without a ready way of identifying them. The results of the many dating attempts summarized below suggest that this was true to some degree.

K-Ar on phlogopite	Dates in Ma		References
Two coarse	368+/-18	408 +/- 20	Zartman et al., 1967
fine	184+/- 10		Pimental et al., 1975
Coarse / very fine	353 +/- 2.2	147 +/- 1.5	Prellwitz, 1994
^{40}Ar/^{39}Ar on fine phlogopites – laser step heating		161 to 176	Bikerman & Phillips, 2000
^{40}Ar/^{39}Ar on fine phlogopites – laser spots		149 to 167	

Rb-Sr dating - phlogopite	149 +/- 5		Alibert & Albarede, 1988
Coarse/fine	188 +/-0.7	170 +/- 1.3	Bikerman et al., 1997

Sm-Nd scatterchron [garnet, calcite, whole rock]	145+/- 11	Bikerman et al., 1997

Since the emplacement age must postdate the Early Permian or about 280 Ma the 147 +/- 5 average of K-Ar, ^{40}Ar/^{39}Ar, Rb-Sr and Sm-Nd is possibly the best estimate of the actual final emplacement of the dike. Possibly the concentration of dates in the 160 to 180 Ma range reflects incomplete purging or closure of some isotopic systems prior to and during eruption, or as Bikerman and Phillips (2000) have postulated there might have been two eruptions – one around 180 Ma and the other at 147 Ma with some partial resetting of systems in the interim. For most purposes the latter date may be used as the emplacement age.

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 26A 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 Formation – see Figure 24) 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

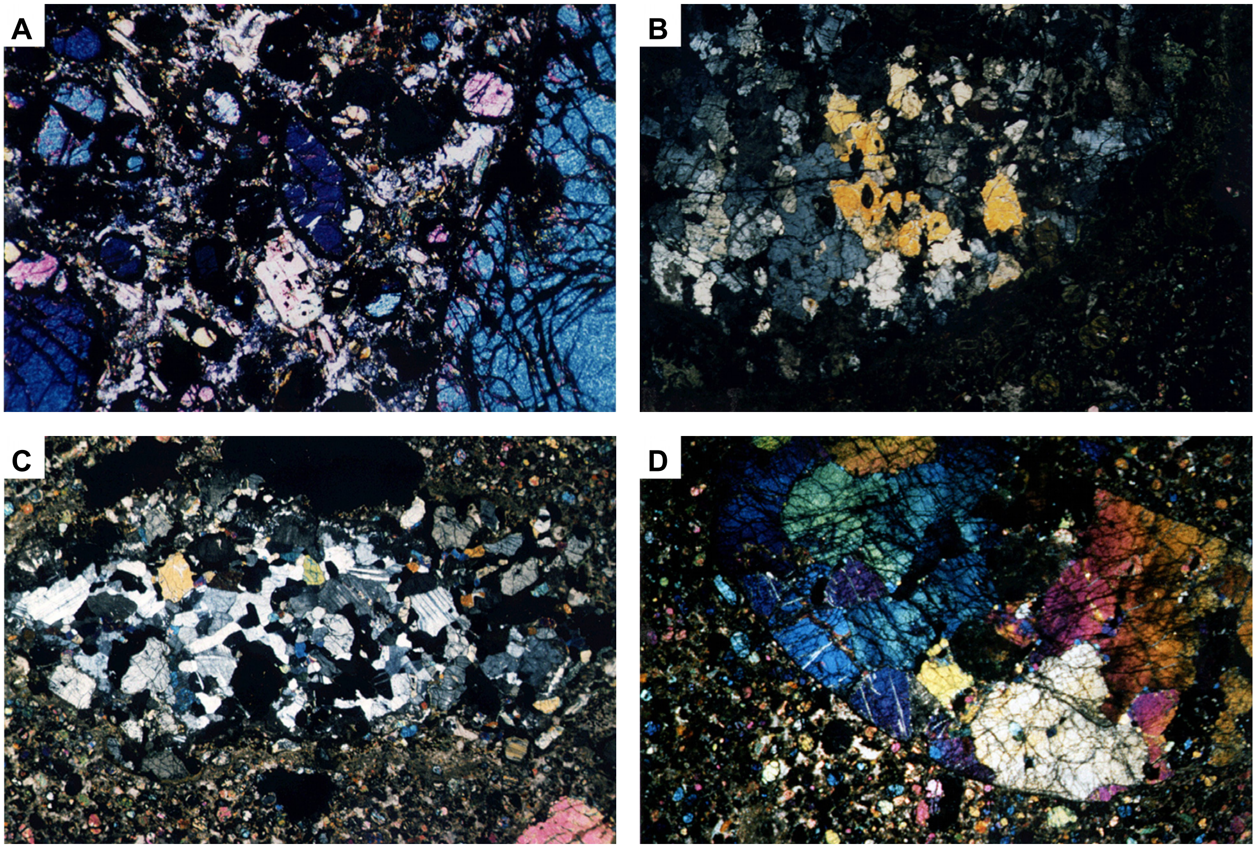

Figure 26. Photomicrographs of the Masontown kimberlite, all under cross polarizers. A – Unaltered kimberlite. Field of view = 4 mm. B – Granitic gneiss xenoliths in the kimberlite. Xenolith is 2 cm (0.8 in) long, and the quartz grains have an anomalous yellow color due to an overly thick slide. Field of view = 4 mm. C – Eclogite xenoliths in kimberlite. Field of view = 4 mm. D – Spinel dunite xenoliths in kimberlite. Field of view = 3 cm.

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 26B**,** are quartz, albite, biotite, and minor microcline. The sample from which the thin section was made clearly shows typical gneissic banding, and most probably represents the Grenville basement that is buried at least 5 km (3 mi) deep in southwestern Pennsylvania.

Another xenolith type commonly encountered in the kimberlite is eclogite. The minerals in Figure 26C 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 26D 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.

		Leave Stop 1 and return to PA 21. Turn right and head W.
0.9	47.1	Enter the Borough of Masontown. The town was founded by Johanias Mansonge and his wife Apalonia who erected a fort. Johanias and Apalonia were better known among their English-speaking neighbors as John and Abigale Mason, and their fort was called Fort Mason. John Mason laid out a town plan where he sold the lots, each 66 X 165 ft (20 X 50 m), for a Spanish half-dollar. Masontown was incorporated in 1876 after many years as a village. Masontown, like so many other of the larger towns between the Monongahela and Youghiogheny rivers, was built on an abandoned pre-glacial meander, floored by Carmichaels Formation clay, silt, sand, and gravel (Campbell, 1902; Kent, 1973).
0.3	47.4	Intersection with PA 166 S to the left. Continue west on PA 21.
1.0	48.4	Duke Energy power plant to the right. This is a 620-megawatt natural gas -fired, combined-cycle plant. The plant went into commercial operation in May 2003. The facility consists of two natural gas-fired combustion turbines, two heat recovery steam generators, and one steam turbine operating in combined-cycle mode.
0.4	48.8	Cross the Monongahela River and enter Greene County. Allegheny Energy's Hatfields Ferry power plant to the right. This power station has an installed capacity of 1,710 megawatts . It is considered to be one of most polluting power plants in the country. A Greenpeace activist got in and scaled the smokestack in 2004 in order to draw attention to this. This plant and one in Maidsville, West Virginia, together released 4,110 pounds of arsenic, 277 pounds of beryllium, 69 million pounds of nitrogen oxides (NOx), and nearly 500 million pounds of sulfur dioxide (SO2) into the atmosphere in 2002, according to a report by the National Resources Defense Fund (Environmental News Service, 2004).
0.2	49.0	From the Monongahela River to the intersection with PA 88, PA 21 runs along an old cut-off meander terrace of the ancient Pittsburgh River. This abandoned meander now carries Little Whiteley Creek to the river.
1.3	50.3	Enter Village of Paisley.
0.2	50.5	Turn right onto PA 88 N and cross Little Whiteley Creek.
1.3	51.8	Enter Borough of Carmichaels. From here, the road descends to the old pre-glacial cut-off meander of the Pittsburgh River we traversed from the Monongahela to PA 88. If you pay attention, you will notice that there

		seems to be more than one level of terrace here.
1.6	53.4	Turn right onto George Street.
0.1	53.5	“Roundabout”—bear around to left onto Market Street.
0.2	53.7	Greene Academy—1790-1810 on right (this building is on the National Registry of Historic Places.)
0.1	53.8	Turn right onto McCann Lane into Laurel Point Cemetery.
0.1	53.9	Bear left onto gravel road and drive through gate if it's open. Otherwise, park along cemetary access road and walk past the gate into Laurel Point Falls Park.

STOP 2—CARMICHAELS, GREENE COUNTY, PA: Cassville shale (Late Pennsylvanian Dunkard Group) and Carmichaels Formation (Pleistocene)*

Stop leader: John A. Harper

INTRODUCTION

At this stop, we will examine the basal Dunkard rocks and collect some nice plant fossils from the lower beds of the Waynesburg Formation, the fossiliferous Cassville Shale. These rocks are exposed on both sides of Muddy Creek, which can be accessed via a series of trails descending the steep cliffs from near the picnic shelter in Laurel Point Falls Park, which is located adjacent to Laurel Point Cemetary on McCann Lane in northern Carmichaels Borough (Figure 27). Descent along the trail at the fence will allow you to arrive at Muddy Creek just downstream of Laurel Point Falls, a small but prominent waterfall near the bridge that carries Market Street across the creek (Figure 28).

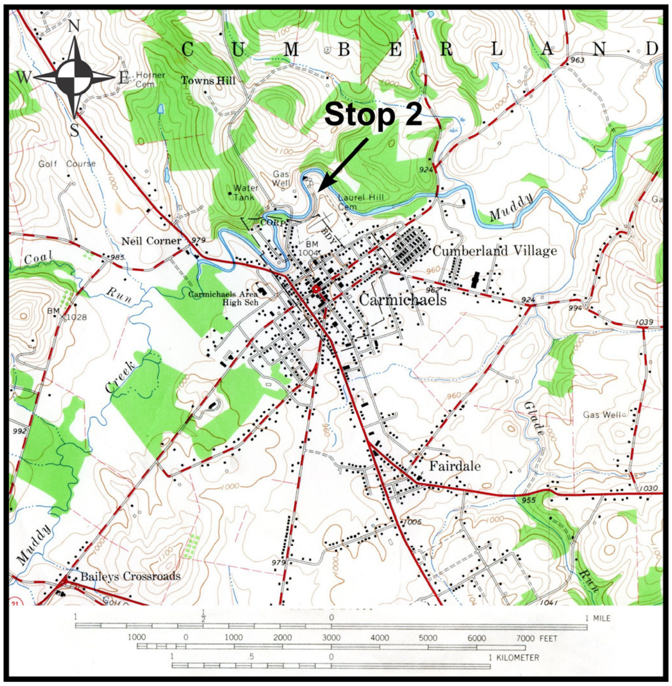

Figure 27. Map of the Carmichaels Borough area, showing the location of Stop 2 (Laurel Point Falls Park).

Figure 28. Photograph of Laurel Point Falls on Muddy Creek in Carmichaels, Greene County, PA. The falls is formed on a resistant lower layer of Mather Sandstone (Waynesburg sandstone of earlier authors).

WARNING: **Use extreme caution descending the paths into the deep**

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* Revised and expanded from Harper and Kite, 2011.

Muddy Creek gully. The hill is steep and covered with tangling vegetation, including poison ivy, and rocks capable of causing serious injury. Some of the worn paths are better than others, but be certain to watch the path and your feet on the way down and while exploring the creek banks.

We will also discuss the Carmichaels cut-off meander of the ancient Pittsburgh River, and the Pleistocene lacustrine sediments found as terrace deposits in abandoned meanders of the preglacial Monongahela River. Carmichaels is the type locality of these sedimentary deposits, called, not surprisingly, the Carmichaels Formation.

CARMICHAELS BOROUGH

Carmichaels Borough (Figure 27) was settled in 1768, laid out by Major James Carmichael, and incorporated from Cumberland Township, Greene County, in 1855. The first post office in Carmichaels began operating in 1822 (Anonymous, 2011).

James Carmichaels was a scout under Colonel Henry Enochs of the Second Battalion, Washington County Militia and, according to local history, was originally awarded a tract of land on Tenmile Creek in what is now the borough of Jefferson. He is supposed to have traded that tract with Thomas Hughes for Hughes' land on Muddy Creek. Carmichaels died in 1796 (Leckey, 1977).

Among the borough's claims to fame are the historic Greene Academy (1790-1810, which is on the National Registry of Historic Places), the Carmichaels Covered Bridge over Muddy Creek, the annual Covered Bridge Festival, the Bituminous Coal Show/Festival, and unfortunately, one of the worst coal-mining disasters in Pennsylvania history. Two gas and coal -dust explosions occurred within minutes of each other on December 6, 1962 in the Frosty Run shaft of Robena No. 3 mine, operated by U.S. Steel Corp. beneath Carmichaels. Thirty-seven men died 680 ft (207 m) below ground as a result of the first explosion; two other men were knocked down but not injured by the force of the second explosion. The remaining 133 miners in the mine that night escaped without mishap (Beitler, 2008; United States Mine Rescue Association, 2011).

GEOLOGIC OVERVIEW

The Dunkard Group

Dunkard Coals

Dunkard coals typically are thin and high in both ash (averaging 26.8%) and sulfur (averaging 5.1%) (Figure 29), and as such they have little or no economic value. These coal beds frequently degrade laterally into thin bone coals, carbonaceous shales, shales with coal streaks, or dark gray to black shale; despite this, these horizons can be traced regionally. Shales, characteristically darkened by organic matter and containing plant fossils, commonly overlie Dunkard coal beds. Plant fossils can also be found in shales not associated with coal beds. For additional information on Dunkard plant fossils and their significance, see Blake and Gillespie (2011).

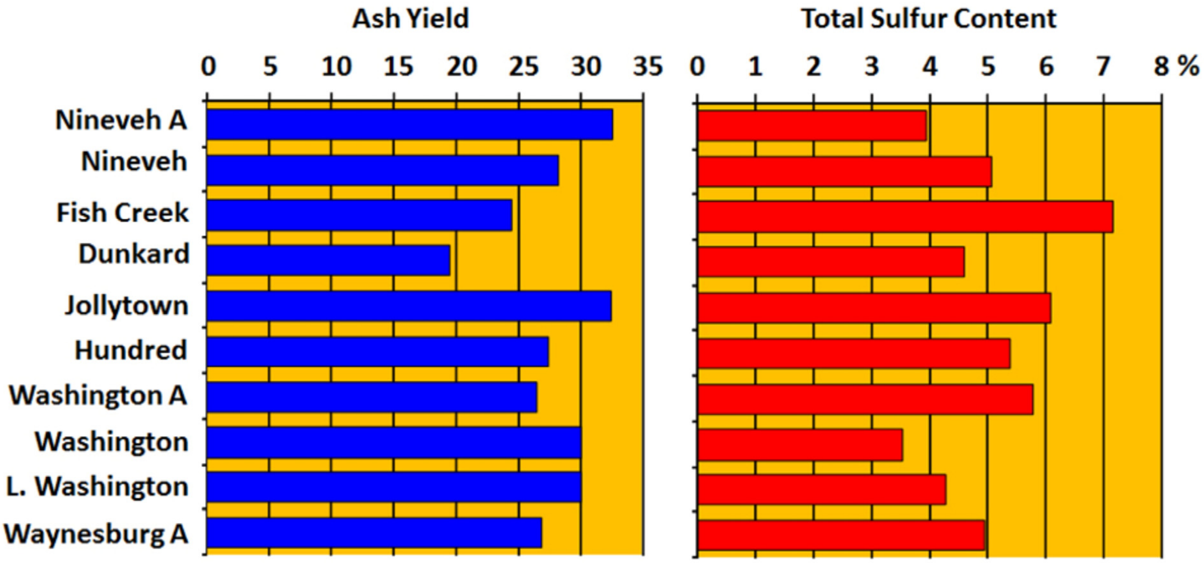

Figure 29. Average ash yield and total sulfur contents of Dunkard coal beds. From Eble et al. (2011).

Waynesburg Coal

The Waynesburg coal, which occurs in outcrop around Carmichaels, traditionally had been considered to be the top of the Monongahela Formation. Berryhill and Swanson (1962), however, revised the stratigraphy of the Dunkard Group to include the Waynesburg coal at the base, and named all of the rocks from the base of the Waynesburg coal to the base of the Washington coal (Figure 8).

The Waynesburg is the most prominent coal bed in Greene County (Campbell, 1902; Stone, 1932a). It typically varies in thickness from 5 to 9 ft (1.5 to 2.7 m), includes many thin or a few thick shale partings (Figure 30), and often contains some pyrite (Stone, 1932a). Fontaine and White (1880) found that the shale partings varied greatly over a short distance, suddenly thickening from 5 or 6 in (13 or 15 cm) up to 6 ft (1.8 m) or more. The coal crops out in the valleys of the larger creeks in eastern Greene County, as well as in Wheeling Creek near the western boundary with West Virginia. Although there are places in the county where the coal is very thin, or even absent, it typically disappears only where it is cut out by the overlying Mather Sandstone (Waynesburg sandstone of Stevenson, 1876, and most later authors). As a resource, it has been most important in Greene County and adjacent parts of West Virginia where, historically, it was mined at many small

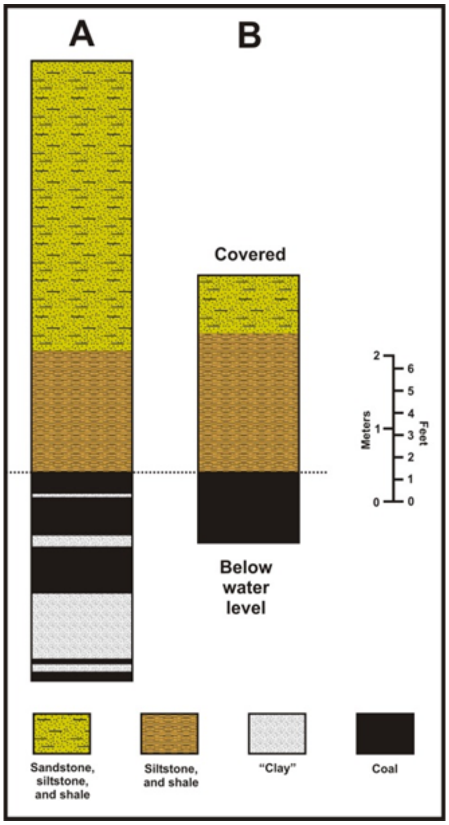

Figure 30. Stratigraphic sections of the lower Waynesburg Formation along Muddy Creek. A – Composite based on Stevenson (1876, p. 57). Notice the number of "clay" partings in the coal. B – Section measured by Harper on the north side of Muddy Creek opposite the most easily accessed fossil collecting site.

country banks for local use. Stevenson (1876) found numerous such coal banks along Muddy Creek from Carmichaels to about 1 mi (1. 6 km) from its mouth in the Monongahela River.

Cassville Shale

The Cassville Shale (type locality – Cassville, Monongalia County, WV) forms the "roof" of the Waynesburg coal seam. It attains a thickness of up to 12 ft (3.7 m) in parts of Greene County (Stevenson, 1876; Stone, 1932a), although in the exposures at this stop, it is only about 3 to 5 ft (1.2 to 1.5 m) thick (Figure 30). It is, perhaps, best known as the unit containing the most abundant and diverse plant fossils in the Dunkard Group (see below). At Carmichaels, these usually are found within 2 ft (0.6 m) of the top of the coal. The shale disintegrates readily upon exposure to the elements, and so is difficult to obtain and preserve good specimens. Historically, the best material in the Carmichaels area was found in spoil piles associated with coal mining in the Muddy Creek valley.

Mather Sandstone Lentil

Figure 31. Photograph of overhang of Mather Sandstone above the Cassville Shale a few meters east of Laurel Point Falls.

Where the Cassville Shale is absent, the overlying sandstone lies directly on top of, and sometimes cuts out, the Waynesburg coal. Stevenson (1876) originally named this Waynesburg sandstone, but Martin and Henninger (1969) renamed it the Mather Sandstone Lentil (also, see discussion and reply by Roen et al., 1970). This is the most conspicuous sandstone in Greene County, ranging from 40 to 70 ft (12 to 21 m) thick. It is coarse grained, light gray to light tan, and can be thin bedded or massive (Stone, 1932b). There are usually two nearly equal sections of sandstone separated by shale and/or fissile siltstone. The lower of the two is most often massive and forms cliffs and waterfalls where exposed, such as Laurel Point Falls (Figure 28). In some places, however, it tends to be soft and easily eroded, producing large cavities and honeycomb weathering patterns (Stevenson, 1876). The upper section of the sandstone typically is cross-bedded and flaggy. Although not exactly the best building stone in Greene County, it has been used in numerous localities for foundations, road metal, and even dimension stone. Good examples of the latter include several buildings in Waynesburg (Stone, 1932b) and the abutments of the two bridges at Carmichaels, including the famous 1889 Carmichaels Covered Bridge on Old Town Road (Stone, 1932a; Anonymous, 2011). The older section of the Greene Academy in Carmichaels probably is built from Mather Sandstone as well. Several quarries existed in the early 1900s in the vicinity that supplied much of the building stone and aggregate used in the town. At one time Cumberland Township operated a quarry on the bank of Muddy Creek where the Mather Sandstone is 40 ft (12 m) thick. Stone (1932a) reported that the rock was blasted down and hauled away without the need for crushing because it broke into chunks less than 1 ft (0.3 m) in diameter. At Stop 2, the Mather is mostly covered along the slopes of Muddy Creek, but where exposed is very hard

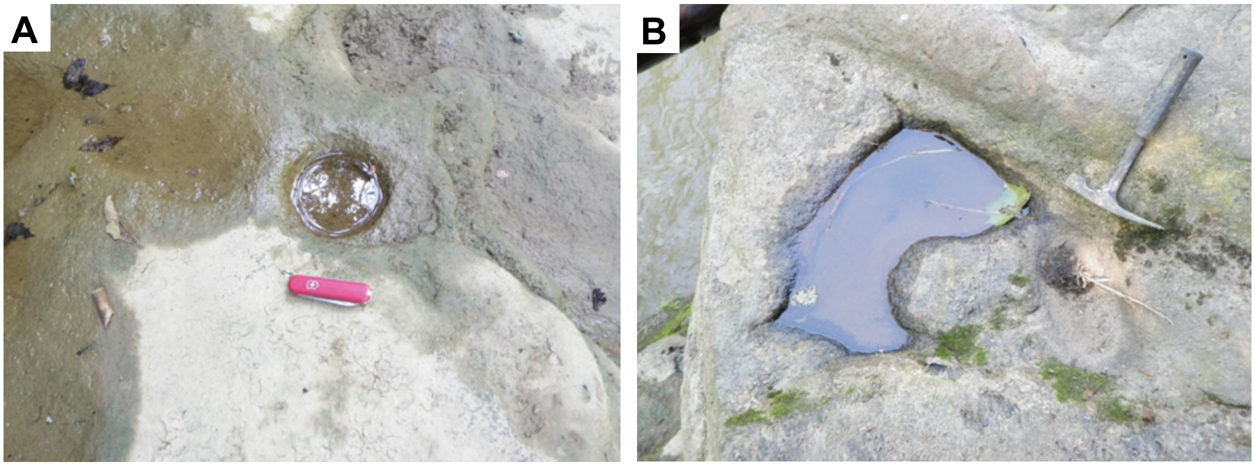

Figure 32. Small potholes in the bed of Muddy Creek at Laurel Point Falls. A—Small circular pothole reminiscent of a drill hole. B—Somewhat larger, irregularly shaped pothole.

and resistant. It forms the 11-ft (3.4-m) high Laurel Point Falls (Figure 28), and also forms a broad overhang of the Waynesburg coal and Cassville Shale just upstream from where the trail descends to the creek (Figure 31). Where the sandstone forms the bed of Muddy Creek just before the falls, it exhibits small potholes ranging in shape from circular to highly irregular (Figure 32).

Dunkard Fossils

Dunkard Group fossils are mostly nonmarine in origin. Plants, including trees, ferns, seed ferns, conifers, shrubs, and scouring rushes (Figure 33), dominate but both vertebrate and invertebrate fossils can be quite common to abundant if the right strata are encountered. Ostracodes are arguably the most common invertebrates (see, for example Figure 34), but other relatively common invertebrates that can be found in the shales and limestones include conchostracans (bivalve shrimp), tiny gastropods and bivalves, and spirorbid worm tubes (Figure 35A-E). "*Lingula*" (Figure 35F), an undoubted marine or brackish-water inarticulate brachiopod, occurs in the shales associated with the Washington coal bed in eastern Ohio and northern panhandle of West Virginia, indicating that there was some marine influence within the Dunkard at least that high in the section as the lower Washington Formation (Figure 8). The Cassville shale is well known for its wealth of insect fossils (see below). Vertebrate fossils consist mainly of fish remains, such as teeth, scales and bones. Stevenson (1876), for example, documented the occurrence of "fish beds", thin carbonaceous shales containing abundant fossil fish remains, that sometimes are so carbonaceous that they are more correctly considered to be thin coal beds. Remains of amphibians and reptiles, although rare, have been found and described from the Dunkard (Figure 36). Vertebrate tracks have also been found (Cross and Schemel, 1956).

Cassville Invertebrate Fossils

The Cassville Shale is also well known for its fossil insect fauna (Scudder, 1895), although these elusive fossils are much more difficult to find and identify. No fossil insects have been described or officially reported from Carmichaels, but it wouldn't surprise me to learn that many wing impressions from this locality occur in private collections, and possibly even in

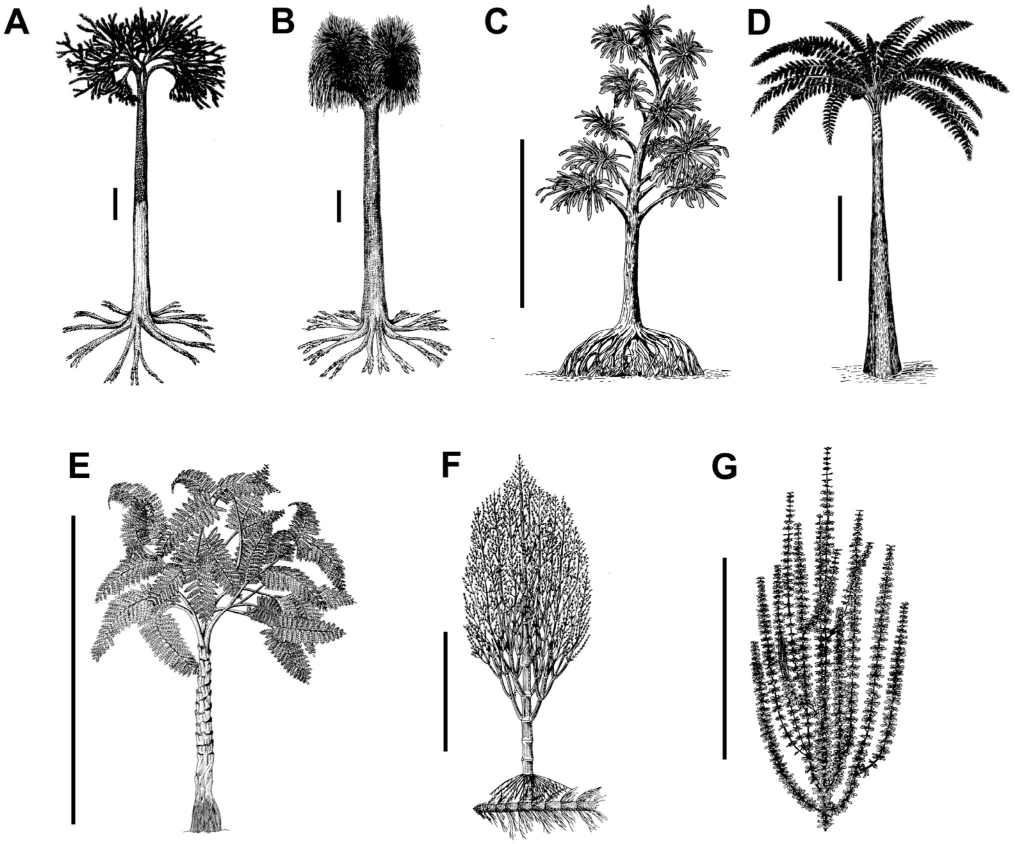

Figure 33. Reconstructions of some representative Pennsylvanian and Permian plants found as fossils in the Dunkard Group. A – *Lepidodendron* (scale tree)*; B –* *Sigillaria* (scale tree); C – *Pennsylvanioxylon (*primitive conifer that bore *Cordaites* leaves); D - Psaronius (primitive fern that bore *Pecopteris* leaves); E – Medullosa (seed fern that bore leaves such as *Neuropteris* and *Odontopteris*); F – *Sphenophyllum* (scrambling shrub); and E – *Calamites* (scouring rush, related to modern-day horsetails). Scale bars = 10 ft (3 m).

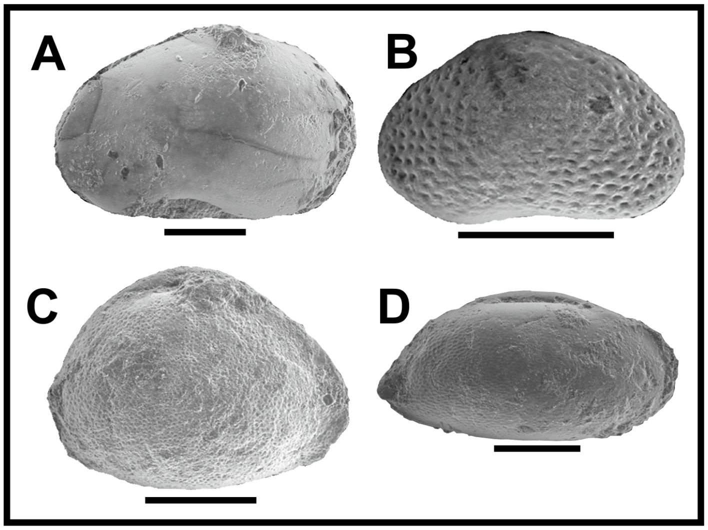

Figure 34. Some common ostracodes from the Dunkard Group. A—*Whipplella parvula*; B—*Whiplella cuneiformis*; C—*Gutschickia deltoidea;* and D—*Hilboldtina magnitata*. Bar scales = 100um. Modified from Tibert, 2011.

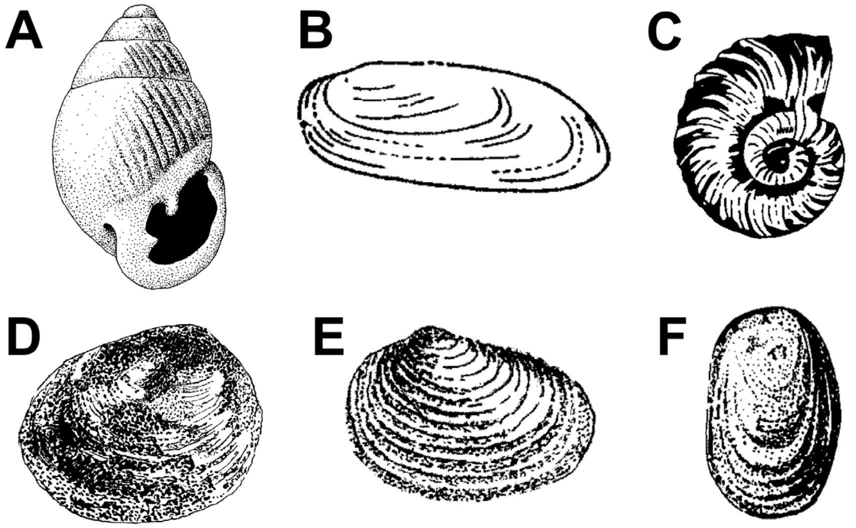

Figure 35. Common Dunkard invertebrate fossils. A—*Anthracopupa*, a gastropod. B—*Anthraconaia*, a bivalve. C—*Spirorbis*, a worm tube. D—*Cyzicus* (*Lioestheria*), and E—*Cyzicus* (*Euestheria*), both conchostracans. F—"*Lingula*", an inarticulate

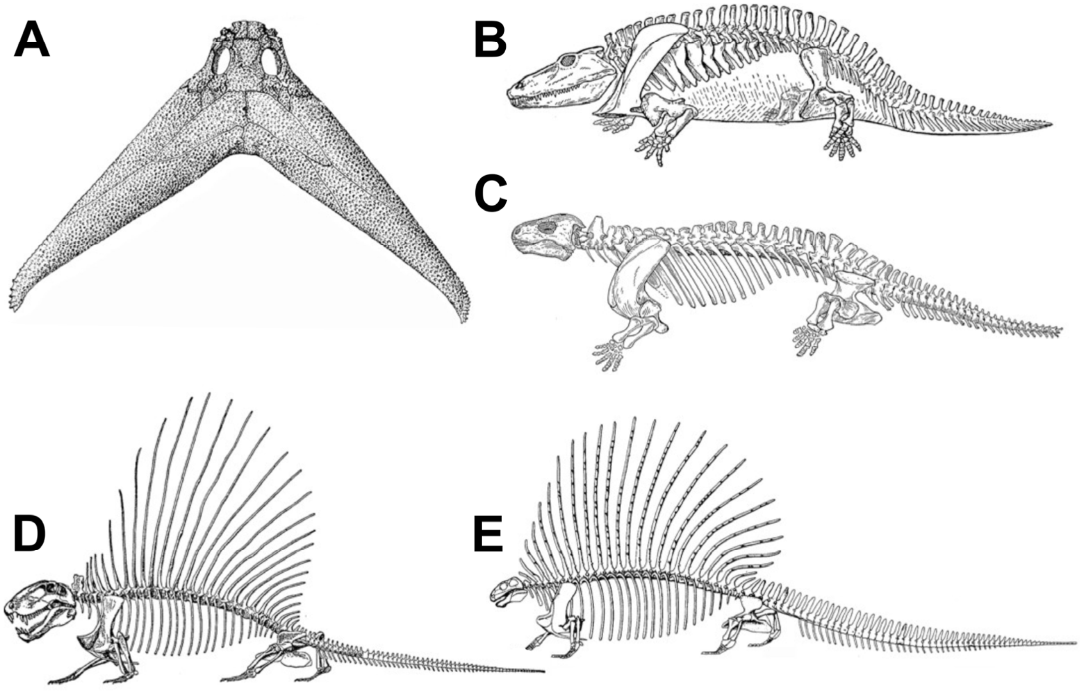

Figure 36. Some typical Dunkard fossil vertebrates (modified from Lucas, 2011). A—Skull of *Diploceraspis.* B—Skeleton of *Eryops.* C—Skeleton of *Diadectes.* D—Skeleton of *Dimetrodon.* E—Skeleton of *Edaphosaurus.* Dunkard vertebrate fossils typically do not include complete skeletons.

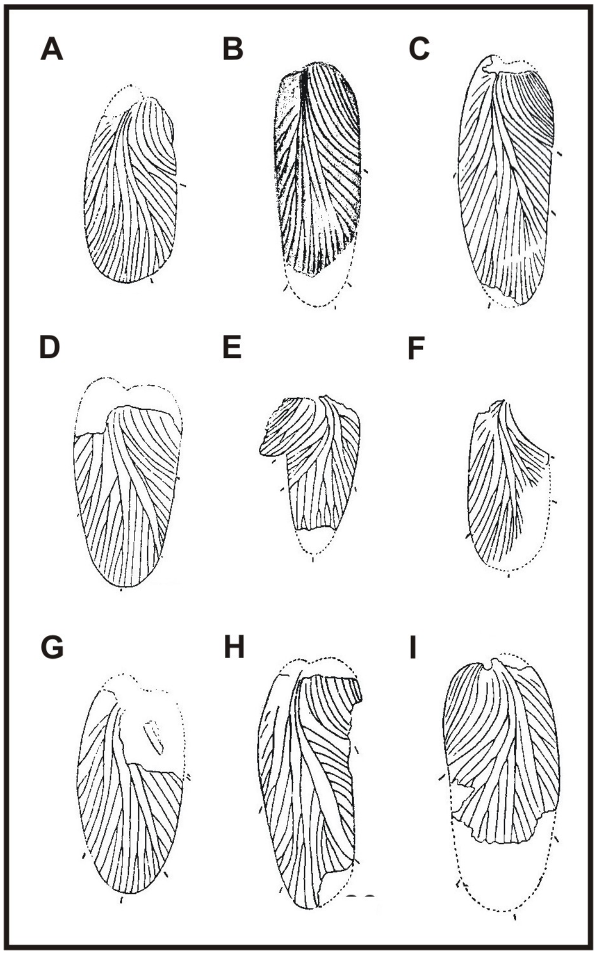

Figure 37. Representative fossil cockroach wings from the Cassville shale (reproduced from Scudder, 1895). A – *Amblyblatta lata* (Scudder). B – *Amoeboblatta permanenta* (Scudder). C – *Apempherus complexinervis* (Scudder). D – *Bradyblatta sagittaria* (Scudder). E – *Exochoblatta hastate* (Scudder). F – *Penetoblatta virginiensis* (Scudder). G – *Petrablattina ovata* (Scudder). H – *Spiloblattina aperta* (Scudder). I – *Symphyoblatta debilis* (Scudder). All drawings X2.

Figure 38. *Adelophthalmus mansfieldi* (C. E. Hall). From J. Hall (1884), pl. IV, fig.2.

local area university collections. Anyone collecting plant fossils from the Cassville should be on the lookout for insects. Don't be fooled – they might look like tiny plant leaflets, but the veination is significantly different.

Cassville insects all belong to the Order Blattoidea – the cockroaches (Figure 37). Non-blattoids occur in some Pennsylvanian formations, but none are known from the Cassville Shale. Scudder (1895) and Handlirsch (1906) originally described the Cassville insects, but more recent revision has reduced the number of species considered valid (Durden, 1969).

In addition to insects, the Cassville Shale also is known to contain at least one other invertebrate fossil. Scott (1971) documented two specimens of the eurypterid, *Adelophthalmus mansfieldi* (C. E. Hall) (Figure 38), from a 10-ft (3-m) thick section of the Cassville Shale in a road cut about 4.5 mi (7.2 km) east of Waynesburg, PA. Hall (1877) originally described *A. mansfieldi* from the shale below the Darlington coal of the Allegheny Formation near Cannelton, Beaver County, Pennsylvania. As with insects, nothing of this sort has been recorded from Carmichaels, but avid collectors should keep a close eye on their finds.

Cassville Plant Fossils

Many different varieties of plant fossils have been documented from the Cassville Shales, particularly in West Virginia near the type locality of the formation, and at West Union in Doddridge County, WV (Fontaine and White (1880; D. White, 1913; Darrah, 1969). Stevenson (1876, p.59), in discussing the Cassville Shale at Carmichaels, wrote:

> The best locality for making collections is on Muddy creek, near Carmichaels, in Greene county, where, for almost half a mile, the shale and coal are finely exposed along the stream, and the very numerous openings give ready access to the roof. Mr. White [I. C. White, Stevenson's field assistant], who has given some attention to the study of fossil plants, has made out the following partial list of genera occur-ring at this locality and its vicinity:—*Neuropteris, Pecopteris, Alethopteris, Sphenopteris, Anotopteris*?, *Goniopteris?, Sphenophyllum, Annularia, Pinnularia,* and *Hymenophyllites.*

Stevenson (1876, p. 131) also reported that a 6-ft (1.8-m) long stem of *Calamodendron* (*Calamites* stem) that had been found in the roof of a coal mine along the bank of Muddy Creek near Carmichaels.

Fontaine and White (1880) described 104 genera and species of plants from the Cassville at numerous localities in southwestern Pennsylvania, northern West Virginia, and western Maryland. D. White (1913) added 5 more. Of these, 81 species were obtained from Cassville itself, 41 from West Union, 8 from Carmichaels, and 13 from various other localities in West Virginia and Maryland (Fontaine and White, 1880; D. White, 1913). The flora Fontaine and White (1880) found at Carmichaels included (their identifications):

*Macroneuropteris scheuchzeri (*Hoffman)
Neuropteris auriculata Brongniart
Neuropteris ovata Hoffman
Pecopteris arborescens (Schlotheim)
Nemejcopteris (Pecopteris) feminaeformis (Schlotheim)
Pecopteris germari (Weiss)
Pecopteris stellataini
Callipteridium sp.
Annularia cf. stellataini
Callipteridium sp.
Annularia cf. stellata Schlotheim

Darrah (1969) collected 225 specimens from the Cassville Shale at Carmichaels, which he identified as:

Rhacophyllum lactuca (Sternberg)
Rhacophyllum speciocissimum Schimper
Pecopteris merianiopteroides Fontaine & White
Pecopteris pluckeneti Brongiart
Pecopteris pteroides Brongiart
Pecopteris miltoni Artis
Pecopteris arborescens (Schlotheim)
Sphenophyllum filiculmis Lesquereaux

He found the most common forms included *Macroneuropteris scheuchzeri*, the two species of *Neuropteris,* and *Pecopteris arborescens*. He thought this established the Carmichaels flora as being closer to the flora from West Union than to that from Cassville.

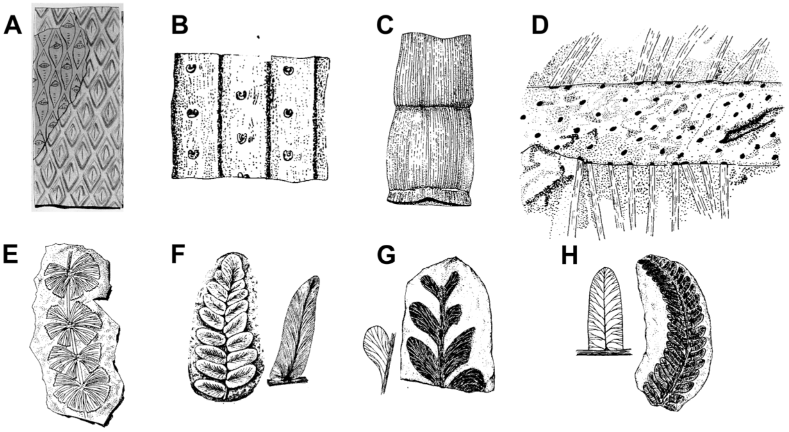

Figure 39. Common types of plant fossils found in southwestern Pennsylvania, including the Cassville Shale. A—*Lepidodendron*. B—*Sigillaria*. C—*Calamites*. D—*Stigmaria*. E—*Sphenophyllum*. F—*Neuropteris*. G—*Odontopteris*. H—*Pecopteris*.

Hoskins et al. (1983), based on limited collecting over 20 years, found the genera *Sphenophyllum*, *Neuropteris*, *Odontopteris*, *Sigillaria*, and *Stigmaria* from the Cassville at Carmichaels, but didn't attempt to identify them to species. My own quick collections while researching this stop included very commonly occurring *Macroneuropteris scheuchzeri* and *Sphenophyllum* sp. The avid collector should be able to find more than a few forms. The shale has been hacked at and broken from the bank walls by many collectors over the years, and has collapsed from undercutting in some places. This provides much easily collected material. Figure 39 illustrates some of the types of plants that you might be able to find in the Cassville Shale at Carmichaels.

BE AWARE: The shale breaks very easily, so that good fossils can be lost if you are not cautious about carefully collecting, wrapping, and preserving your finds. It is highly recommended that collectors bring plenty of newspaper or paper towels, collecting bags (plastic zipper bags are ideal, and you can write on them with a permanent marking pen like a Sharpie), and one or more boxes. Try not to pile too much shale into a bag or box. The better you take care of your specimens the more valuable they will be to you. If you do happen to find some good identifiable specimens, we will have some high-powered expertise on the field trip who should be able to tell you what you found.

CARMICHAELS CUT-OFF MEANDER AND THE CARMICHAELS FORMATION

The Monongahela River between Greene and Fayette counties flows in a steep-walled channel that is about 150 ft (46 m) deeper than the surrounding country side. The river did not always occupy that particular channel, however. At one time, before Pleistocene glaciation occurred to the north, the ancestral Monongahela (Pittsburgh River of Stout et al., 1943) wound in a far more circuitous route than the present day river (Figure 40), and at a substantially higher elevation. At some point since the first glacier advanced into northwestern Pennsylvania and blocked the predominantly northwestward drainage, most of the meanders were abandoned and the current channel was cut, leaving numerous old channel segments high-and-dry. One of the more prominent of these abandoned meanders occurs at Carmichaels (Figure 41), although it is difficult to recognize from ground level. Other than the broad, flat topography atypical of southwestern Pennsylvania, the town of Carmichaels would not seem to be much different than any other small community in Greene County. The flatness of the topography, of course, would have attracted many settlers and businesses, and excavation of basements would have exposed an extensive deposit of unconsolidated sediment resembling that found in the floodplain of the

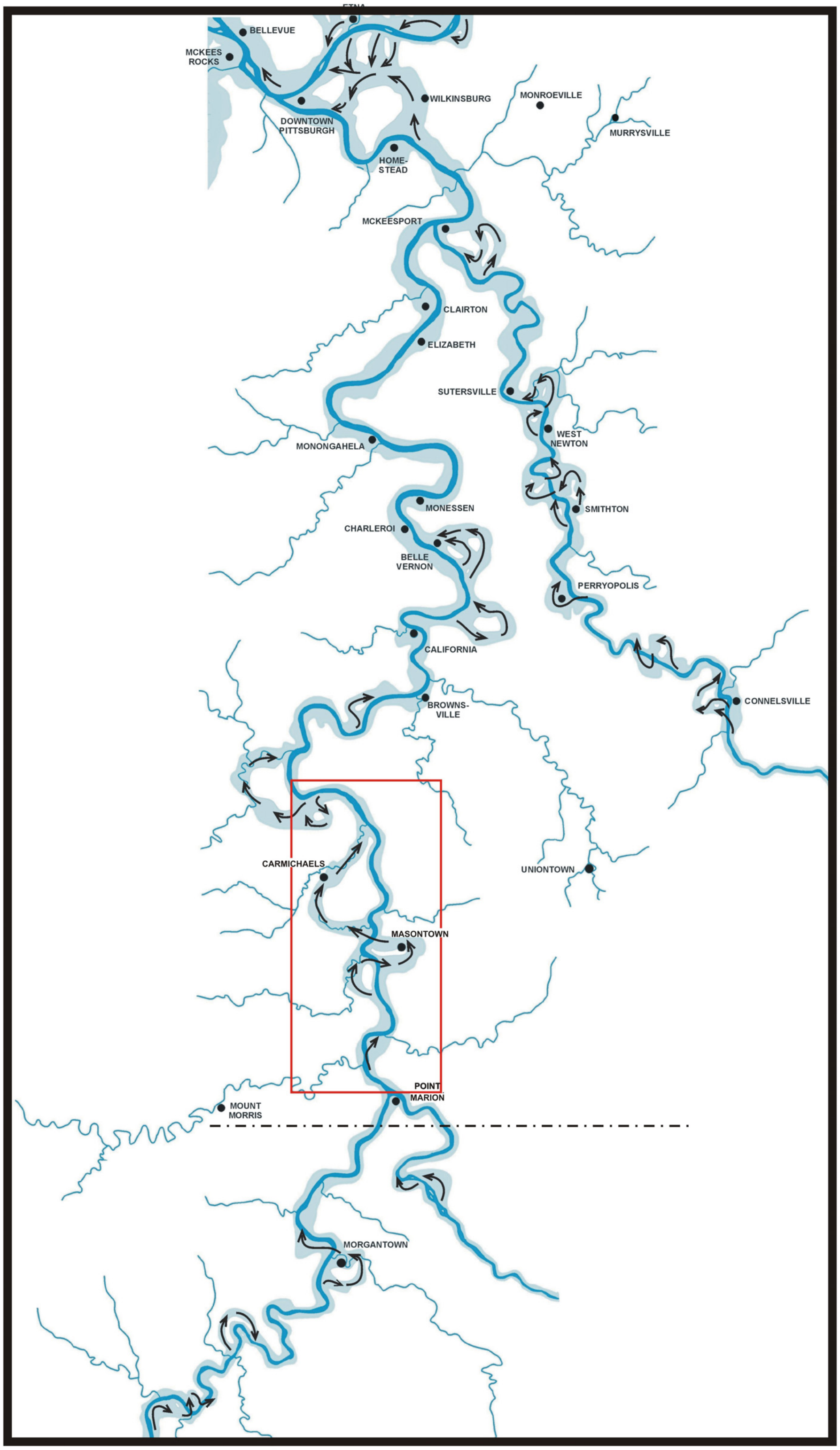

Figure 40 The modern Monongahela River drainage, including larger tributaries in darker blue, with approximate traces of abandoned pre-glacial meanders (terraces) in lighter blue. Town names for orientation. Arrows indicate directions of flow. The red rectangle indicates the area shown in Figure 41.

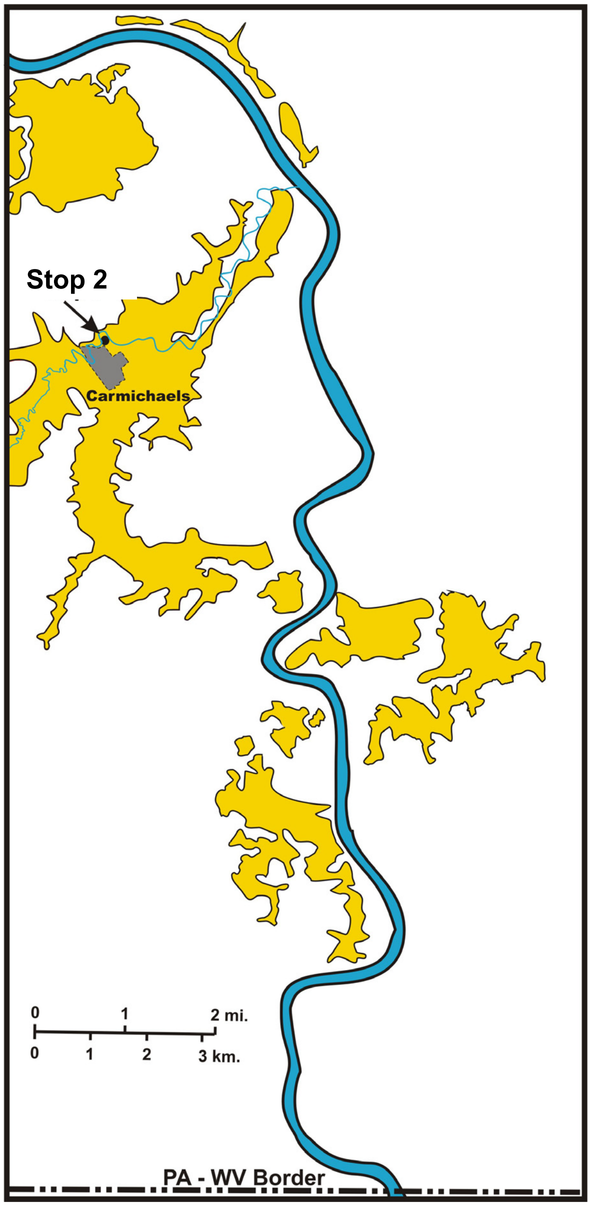

Figure 41. Extent of the existing Carmichaels Formation at Carmichaels (redrawn from Campbell, 1902).

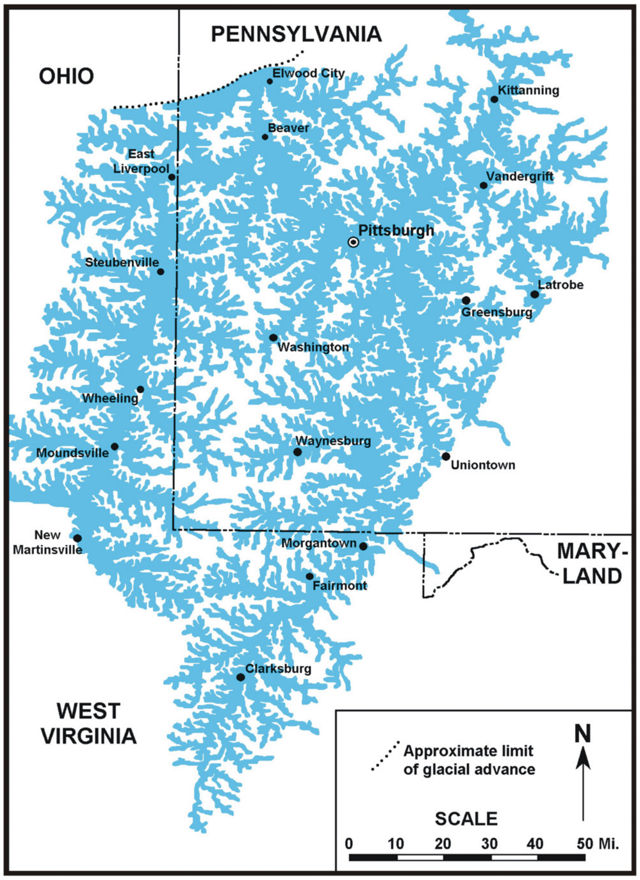

Figure 42. Reconstruction of the possible configuration of Lake Monongahela based on the 335 m (1,100 ft) maximum lake elevation (modified from Marine, 1997).

Monongahela. Today, we call such a flat area above the river a terrace.

White (1896) was probably the first to recognize that there actually are several terraces, containing varying thicknesses of clay, sand, and gravel, at various levels in the valleys of the Monongahela, Allegheny, and Ohio rivers and their tributaries. He suggested that these were deposited during the Pleistocene in a vast lake-like reservoir that he called Lake Monongahela. He suggested that the north-flowing river system had been blocked by advancing glacial ice, impounding the river waters, and raising the level of Lake Monongahela to an elevation of 1,100 ft (335 m).

Much of what is currently known about Lake Monongahela comes from studies of the terrace 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). Modern reconstructions of Lake Monongahela (Figure 42) indicate that the lake's boundaries extended into the upper Ohio and the lower Allegheny drainages as well as throughout the Monongahela drainage (Gillespie and Clendening, 1968; Morgan, 1994; Marine, 1997; Marine and Donahue, 2000).

Figure 43. Photograph of Carmichaels Formation at Speers, Washington County. Notice the red coloration and the large range of clast size.

As the ponded water in Lake Monongahela rose, it eventually overtopped drainage divides, and the water spilling over them eroded cols in the divides and formed new drainage channels paralleling the ice margin. Because these outlets were now at lower elevations, ponding during the next glacial advance never reached the level of the first ponding. Subsequent pondings occurred at progressively lower elevations as the outlets were eroded and the river channels became entrenched. And as each ponding occurred, newly formed lacustrine sediment was deposited in the lake bottom and sides.

Because the Monongahela River system was impounded several times, leaving different lacustrine remnants at different elevations (Leverett, 1934; Fullerton, 1986; Jacobson, 1987), there are complications. Depositional events from repeated glacial advances and retreats have overprinted each other stratigraphically, making it difficult to decipher the drift boundaries of individual glacial events (Marine and Donahue, 2000). Campbell (1902) named these Lake Monongahela lacustrine deposits found throughout northern West Virginia and southwestern Pennsylvania Carmichaels Formation for deposits preserved in the abandoned meander channel at Carmichaels (Figure 41). The name is often used for all Pleistocene terrace deposits, even though many of the sediments in the Allegheny-Ohio drainage are distinctly different glacial outwash deposits.

Unfortunately, we probably will not see any exposures of the Carmichaels. As Donahue and Kirchner (1998) indicated, one of the more frustrating aspects of doing field work on the Carmichaels is the lack of good exposures. Rare exceptions include building excavations, road construction, and dug but unfilled grave sites. Carmichaels deposits typically consist of clay, silt, and sand, generally ranging in color from reddish-orange to tan, and containing subangular to well-rounded, cobbles and boulders of local bedrock, typically sandstone (Marine, 1997; Donahue and Kirchner, 1998; Marine and Donahue, 2000) (Figure 43). The clays tend to be highly plastic (Carmichaels clay was used in the early pottery industry in western Pennsylvania). Donahue and Kirchner (1998) speculated that the red clays might be derived from soils developed during the interglacial intervals. Carmichaels Formation deposits occur on the upper two terrace levels (Jacobson et al., 1988).

White (1896; also Jacobson, et al., 1988; Morgan, 1996; Marine, 1997) recognized that Carmichaels Formation terraces within the Monongahela drainage can be grouped by elevation above sea level into three distinct levels representing three different glacial damming events (Table 1): 1) ~1,050-1,100 ft (~320-335 m) representing one pre-Illinoian stage of glaciation; 2) ~1,000 ft (~305 m) representing a second pre-Illinoian stage of glaciation; and 3) ~920-970 ft (~280-296 m) representing Illinoian glaciation. These elevations represent the upper limits of Lake Monongahela deposition. The glacial ages are based primarily on correlation with outwash

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

Terrace	M (Ft) Above River Level	M (Ft) Above Sea Level
First	9-12 (30-40)	~253 (~830)
Second	23-24 (75-80)	~267 (~875)
Third	38-53 (125-175)	280-296 (920-970)
Fourth	~61 (~200)	305 (1,000)
Fifth	84-91 (275-300)	320-335 (1,050-1,100)

gravel trains and drift, and on remanent paleomagnetism measurements at widely scattered localities (Marine, 1997). Two lower terraces, occuring at ~830 ft (~253 m) and ~875 ft (~267 m) (Table 1) represent Wisconsinan glaciation (White, 1896; Marine, 1997), and are not composed of Carmichaels Formation sediment. Marine (1997) could find no geomorphic evidence of lake-cut terraces or discernible paleoshorelines, at least in the lower Allegheny drainage. In most cases the lacustrine silts and clays associated with Lake Monongahela rest directly on 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. Also, the time duration of the ponded waters in the lower Allegheny and Monongahela valleys was not sufficient to cut terraces in the local bedrock.

Campbell (1902) indicated that the rock floor of the meander channel at Carmichaels lies at an altitude of 920 ft (280 m), indicating that the type Carmichaels Formation is probably Illinoian in age. The deposit is as much as 60 to 70 ft (18 to 21 m) deep, and extends up the sides of the valley about 160 ft (49 m) above the floor of the meander. The bottom of the channel contains well-rounded boulders, and the material deposited upon this layer shows no regularity of deposition. As Campbell (1902) pointed out, at times the waters must have been still because of the abundance of clay; at other times there were fairly strong currents that brought sand and coarse material, including boulders, into the deposit. One can occasionally find wood and other organic debris in the matrix, such as a log that was reported to have been found in the clay about 40 ft (12 m) from the surface (Campbell, 1902).

		Turn around and drive back to Market Street.
0.1	54.0	Turn right onto Market Street and cross Muddy Creek.
0.1	54.1	Bear left onto Old Town Road. This is the original road from Carmichaels to points north. Cross historic Carmichaels Covered Bridge. The bridge is a 64-ft (20 m) long Queenpost truss bridge with a raised seam, tin-covered, gable roof. It was constructed in 1889 and listed on the National Register of Historic Places in 1979. It is one of nine historic covered bridges in Greene County. The abutments of this bridge were built from the Mather Sandstone (see Stop 2).
0.3	54.4	Turn right onto Market Street.

0.1	54.1	Bear left onto Old Town Road. This is the original road from Carmichaels to points north. Cross historic Carmichaels Covered Bridge. The bridge is a 64-ft (20 m) long Queenpost truss bridge with a raised seam, tin-covered, gable roof. It was constructed in 1889 and listed on the National Register of Historic Places in 1979. It is one of nine historic covered bridges in Greene County. The abutments of this bridge were built from the Mather Sandstone (see Stop 2).
0.3	54.4	Turn right onto Market Street.
0.2	54.6	Turn right onto George Street at the "roundabout". Then turn right onto PA 88 N, Vine Street.
0.1	54.7	Historical marker on right reads: *GREENE ACADEMY - Established in 1810 by Act of Legislature. Was aided by State grant of $2000 and public subscriptions. Until 1860, a leading academy west of the mountains. Old building, no longer used for a school, is northeast of here, on Market St.*
0.3	55.0	Cross Muddy Creek.
2.1	57.1	Good view of the topography associated with the Waynesburg Hills Section of the Appalachian Plateaus Province to the left.
1.2	58.3	Enter the Village of Dry Tavern. Bedrock in this town is lower Washington Formation (Kent, 1969).
0.2	58.5	Intersection with PA 188 W on the left. Continue north on PA 88.
1.6	60.1	Cross the deep valley of Rush Run.
0.9	61.0	Another good view of the local topography in this area.
0.9	61.9	Cross Ten Mile Creek into Washington County. Ten Mile Creek
0.7	62.6	Pass under railroad tressle and enter the Village of Millsboro. Notice that Ten Mile Creek flows into the Monongahela River here. Millsboro and the surrounding area are the former homes of bituminous coal mines. The topography has been somewhat altered by the addition of bony dumps on the river banks.
1.0	63.6	Enter Fredericktown.
0.7	64.3	Outcrop of Monongahela sandstone and shale to the left.
0.8	65.1	Outcrop of Pittsburgh coal on the left.
0.2	65.3	Enter the Borough of Centerville. A portion of this town is registered as the Centerville Historic District. For more information, see The Gombach Group (2008).
0.6	65.9	Monongahela outcrop to the left.
1.0	66.9	Enter the Village of Low Hill.
1.2	68.1	Entrance ramp to PA 43 S, the Mon-Fayette Expressway, to the right. Continue north on PA 88.
0.3	68.4	Entrance ramp to PA 43 N, the Mon-Fayette Expressway, to the left. Continue north on PA 88.
0.4	68.8	Outcrop of a lower Monongahela sandstone and shale to the left. These rocks lie between the Pittsburgh and Redstone coal seams according to Schweinfurth (1967).

1.6	70.4	Outcrop of crossbedded lower Monongahela sandstone to the left. It you look closely, you will see what appears to be a tufa flow covering part of the outcrop. This is probably the same sandstone unit as seen at mile 68.8.
0.4	70.8	Stop sign at intersection with Old National Pike. Continue north on PA 88.
0.1	70.9	Enter West Brownsville. Across the river is Brownsville where the Whiskey Rebellion started in 1791. The road cut on the left exposes the middle Monongahela Formation, with carbonates of the Sewickley Member (the "Benwood Limestone") especially prominent on the northern end.
0.5	71.4	Pass under US 40 bridge across the Monongahela River.
0.5	71.9	Exit ramp to US 40 on left. Continue north on PA 88.
0.9	72.8	Outcrop of upper Monongahela sandstone.
0.3	73.1	Enter the Borough of California. California University of Pennsylvania athletic fields on the left. California was founded in 1849. Besides being home to California University of Pennsylvania, the town once was home to the Vesta #4 mine, the largest bituminous coal mine in the world. The town was also home to the former Vigilant Mine, which produced the largest single lump of coal in the world.
1.1	74.2	Bear left and stay on PA 88 N.
0.5	74.7	Intersection with Third Street at traffic light. Turn left and continue north on PA 88.
0.7	75.4	Turn right onto PA 88 N.
0.1	75.5	Enter Borough of Coal Center. Notice the brickwork on the outcrop to the left. This is a spring.
0.8	76.3	Highpoint Restaurant and Lounge on the right. There is an incredible view of one of the entrenched meander loops of the Monongahela River from the parking lot. The town across the river is Newell (see Figure 44).

Figure 44. View of Newell, Fayette County, from the bluff above the Monongahela River. The river forms one of its tightest meanders here. This meander was incised into the bedrock when the river was rejuvenated during uplift in the Pleistocene, probably due to glacial rebound to the north, lowering of sea level, or both.

0.7	77.0	Stop sign at intersection with Dally Road. Continue north on PA 88.
0.3	77.3	Stop sign at T intersection with Elco Hill Road. Turn right and continue north on PA 88. As we go down the hill, we will be entering the realm of the Casselman Formation, which is the bedrock at river level in the Monongahela valley from here to Pittsburgh (the Ames Limestone, the uppermost member of the Glenshaw Formation, crops out at road level on Carson Street by the Duquesne Incline).

0.3	77.6	Enter the Borough of Elko.
0.1	77.7	Nice outcrop of the "Benwood Limestone" to the left.
0.9	78.6	Enter the Borough of Rosco. According to Wikipedia, "The Allenport & Roscoe Street Railway was formed in 1903 and was purchased by Pittsburgh Railways to form part of their interurban line to Pittsburgh in 1906. The 2.4 miles (3.9 km) extension to Roscoe was completed on June 20, 1910. The line was closed in 1953."
0.9	79.5	Enter the Borough of Stockdale.
0.9	80.4	Enter the Borough of Allenport. Someone with an axe to grind posted this on Wikipedia: "Allenport's local government is most known for corruption and deception. The city council is primarily composed of residents with special interests and with little community involvement. The townspeople are most represented by the local civic club which acts as a balancing power in the neighborhood. Many Allenport city council members seek to limit community involvement by promoting a strong anti-dog agenda; this agenda has been set back by the pro-dog civic club. Since the borough is constantly strapped for cash, they offer help in getting passports for a fee of 10.00, most of the residences feel they need a passport to visit Cedar Point in Ohio."
1.5	81.9	Enter the Borough of Dunlevy.
1.0	82.9	Enter the Borough of Speers. Speers was one of the stops on the 1999 PGS Spring field trip, led by Jack Donahue. Figure 43 is a photo taken at that stop.
0.5	83.4	Entrance ramp to I-70 E. Continue north on PA 88.
0.2	83.6	Pass under I-70.
0.3	83.9	Entrance ramp to I-70 W. Continue north on PA 88.
0.5	84.4	Enter City of Charleroi. The name Charleroi King Charles II of Spain. This city boasted one of the first movie theatres in the US—the Electric Theatre, which opened in October, 1905. Charleroi was once home to one of Pittsburgh Plate Glass's largest glass factories, as well as Corning Glass. Today, as home to World Kitchen, the city is the only place in the US to make Pyrex.
1.0	85.4	Outcrop of Casselman sandstone on the left.
0.9	86.3	Bear right and continue north on PA 88.
1.8	88.1	Turn right onto PA 837 N. We will follow PA 837 through the Monongahela valley all the way back to PA 51.
1.8	89.9	Turn right and continue north on PA 837.
1.1	91.0	Exit ramp to Donora Monessen Bridge on the right. Continue north on PA 837.
0.3	91.3	Pass under Donora Monessen Bridge.
0.2	91.5	Bear left and continue north on PA 837 into Donora. Donora is a combination of the names William Donner (one of the area's great steel magnates) and Nora Mellon (Andrew W. Mellon's wife). Donora's nickname is "The Home of Champions" mainly because it is the home town of baseball greats Stan Musial, Ken Griffey, and Ken Griffey, Jr.

Like most Monongahela valley towns, Donora had a long history of coal mining and manufacturing until the collapse of the steel industry in the 1980. But Donora's greatest legacy probably will be the calamity of the great smog that killed or sickened so many people in 1948 (see mile 92.3 for more information).

0.1	91.6	Stop sign. A historical marker near hear reads: *CEMENT CITY - Located four blocks to the west. Built 1916-17 as housing for employees at American Steel & Wire's Donora plant. A community of 100 units in 80 Prairie-style buildings, noted for the innovative use of poured-in-place concrete construction. One of several concrete communities built in the U.S. during this era, Cement City survived to house successive generations of families. A National Register Historic District.*
0.5	92.1	Turn right and continue north on PA 837 through the City of Donora.
0.1	92.2	Turn right at the traffic light on First Street. Continue north on PA 837.
0.1	92.3	Historical marker on right reads: *THE 1948 DONORA SMOG - Major federal clean air laws became a legacy of this environmental disaster that focused national attention on air pollution. In late October of 1948, a heavy fog blanketed this valley, and as the days passed, the fog became a thick, acrid smog that left about 20 people dead and thousands ill. Not until October 31 did the Donora Zinc Works shut down its furnaces - just hours before rain finally dispersed the smog.*
2.1	94.4	To the right is what is left of a railroad bed that was built up using slag. As you can see, at one point it has been breached, exposing a unique cross section that is reminiscent of a multicolored lava flow.
1.9	96.3	Acid mine drainage on the left is from the Pittsburgh coal, which has been largely depleted by mining (Roen et al., 1968).
0.4	96.7	Intersection with PA 88 and PA 136. Enter the City of Monongahela.
0.1	96.8	Cross railroad tracks.
0.1	96.9	Historical marker on right reads: *WHISKEY POINT - The bluff at Main St. and Park Ave. was the site on Aug. 14, 1794, of a meeting of 226 whiskey rebels. Albert Gallatin's eloquence turned the tide, resulting in peaceful ending of the Whiskey Rebellion and the possibility of civil strife.*
0.3	97.2	Historical marker on right reads: *MONONGAHELA - Oldest settlement in the valley and transportation center since the days of Devore's Ferry, chartered 1775 Laid out in 1796 as Williamsport. A city since 1873. Here thousands of pioneers began the journey to the West.*
0.8	98.0	Intersection with PA 136 W on left. Enter New Eagle, hometown of quarterback Joe Montana. Continue north on PA 837.
1.1	99.1	Intersection with PA 88 N on left. Continue north on PA 837.
0.5	99.6	Coal conveyor from the Mathies Mine crosses the road to the rail and barge loading facility on the river to the right. The Mathies Mine closed in 2002.
0.2	99.8	First Energy power plant to the right. Long (~ -.8 mi-long) outcrop of lower Monongahela Group on the left.
1.2	101.0	Outcrop of Pittsburgh coal on the left.

0.8	101.8	The hillside to the left is contaminated in places over the next 0.5 mi (0.8 km) by acid mine drainage from Pittsburgh coal mines on the hillside about 10 to 20 ft (3 to 6.1 m) above road level.
1.3	103.1	Norfolk Southern Railroad yard on the right.
0.6	103.7	Enter Elrama.
0.2	103.9	GenOn Energy power station to the right. Enter Allegheny County and the Borough of Jefferson Hills, named in honor of President Thomas Jefferson. The local community here is called Floreffe, apparently in honor of Floreffe in the Namur Province of Belgium, which is best known as the location of a 12th-century abbey.
0.5	104.4	Large storage tanks on both sides of the road In January 1988, one of these tanks containing more than 95,000 barrels of diesel oil owned by Ashland Oil Company, Inc. split apart and collapsed. while being filled after having been moved from an Ohio location and reassembled here. The containment dike was insufficient to contain the spilled diesel oil, which flowed into an uncapped storm drain that emptied directly into the river. A huge oil slick formed within minutes and moved down river, washing over Lock and Dam #3 1.1 mi (1.8 km) north and Braddock Lock & Dam below Kennywood Park. The oil was carried by the Monongahela River into the Ohio River, dispersing throughout the width and depth of the rivers. It temporarily contaminated drinking water sources for an estimated 1,000,000 people in Pennsylvania, West Virginia, and Ohio, contaminated ecosystems, killed wildlife, damaged private property, and adversely affected businesses throughout the area. Contractors hired by Ashland used booms, vacuum trucks, and other equipment to retrieve the spilled oil, but ultimately recovered only about 20% of the oil that flowed into the river. In September 1988, Ashland Oil Company was indicted by a federal grand jury for negligently discharging oil into the Monongahela River in violation of section 311(b)(3) of the Clean Water Act.
0.3	104.7	Historical marker on right reads: *YOHOGANIA COURTHOUSE - Governmental and judicial center for Yohogania, a county erected by Virginia in asserting its claim to western Pennsylvania from 1777 to 1780. The site is on the hilltop opposite.*
0.2	104.9	Eastman Chemical plant to the right. This plant has the capability to manufacture many chemicals (primarily resins), and has advanced operating capabilities, reliable support services and utilities, and a waste treatment for liquids.
0.5	105.4	Enter the Borough of West Elizabeth. This town, initially laid out in 1833 (incorporated in 1848), was best known for coal mining and boat building. Mined coal was carried from the mine to the river by inclines, then was transported down the Monongahela by barge to Pittsburgh.
0.5	105.9	Pass under PA 51.
0.1	106.0	Bear right onto PA 51 S and PA 837 N.
0.1	106.1	Exit to the left toward Pittsburgh and West Elizabeth.

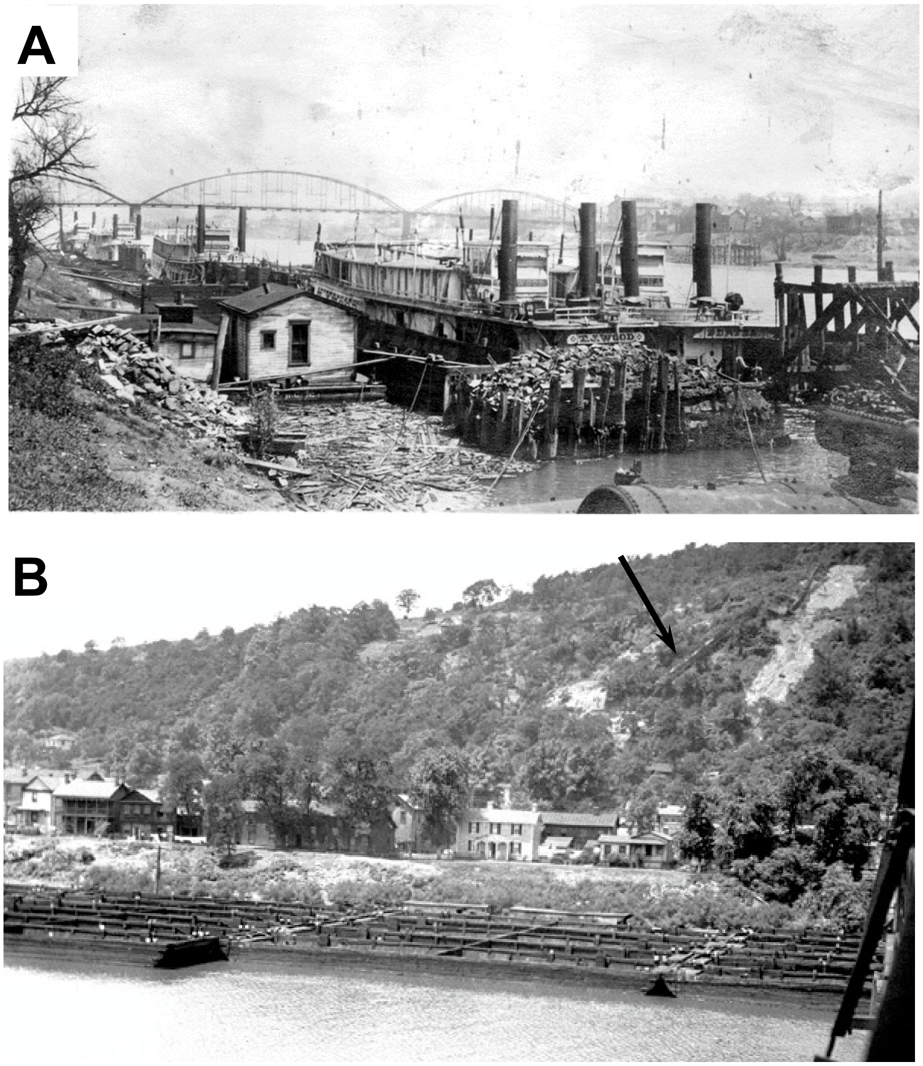

Figure 45. Early 20th Century photos of the West Elizabeth. A – West Elizabeth Boat Yard ca. 1919, by Robert Eberhart. The boat yard was located slightly up-river and opposite the Elizabeth Marine Ways. Boats in the photo include the T. J. Wood, the Bertha, and the Jim Brown. B – View of West Elizabeth from the bridge to Elizabeth, showing the coal barges at the Boat Yard, ca. 1920s or 1930, photographer unknown. Note the coal conveyor incline on the hillside to the left of the long bare patch (arrow). From Mohney (2013).

0.1	106.2	Stop sign at PA 51 N. Carefully merge with traffic and return to Century III Mall.
5.8	112.0	Turn right onto access road to Century III Mall at traffic light.
0.1	112.1	Turn right at T intersection and follow the mall perimeter road to the Park and Ride lot.
0.2	112.3	Century III Mall Park and Ride parking lot. End of field trip.

HAVE A SAFE TRIP HOME

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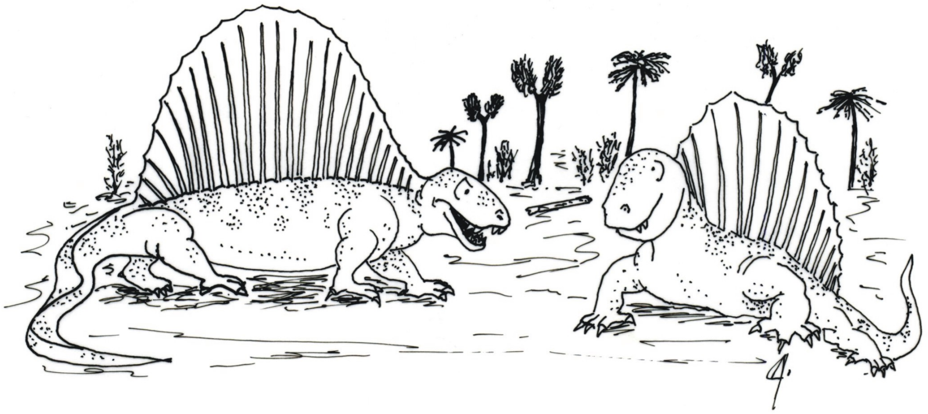
GREAT MOMENTS IN GEOLOGIC HISTORY
Part 12: The Permian



I'm tellin' ya, Sid, the way things have been goin' in the Paleozoic, I'm glad I won't be around for the Mesozoic!