GEOLOGY OF OHIOPYLE STATE PARK

and the LAUREL HIGHLANDS *of Southwestern Pennsylvania*

85TH ANNUAL
Field Conference of Pennsylvania Geologists

TRIP LEADERS

Jim Shaulis, Pennsylvania Geological Survey

Frank Pazzaglia, Lehigh University

Steve Lindberg, University of Pittsburgh—Johnstown

PRE-CONFERENCE
Field Trips & Registration
Thursday, October 7, 2021

WHEN
October 7 — 9, 2021

WHERE
Ohiopyle, PA

HEADQUARTERS: Seven Springs Mountain Resort
777 Water Wheel Drive, Champion, PA 15622

ROCK SWAP

Silent Auction
BENEFITING
Student scholarship fund

FEATURING • Meadow Run Slides knickpoint • Turtlehead Rock Bog • Ferncliff • Ohiopyle Falls • Baughman Rock • Carmichaels Fm • Laurel Caverns • Jumonville Rocks • Great Allegheny Passage • Robinson Falls

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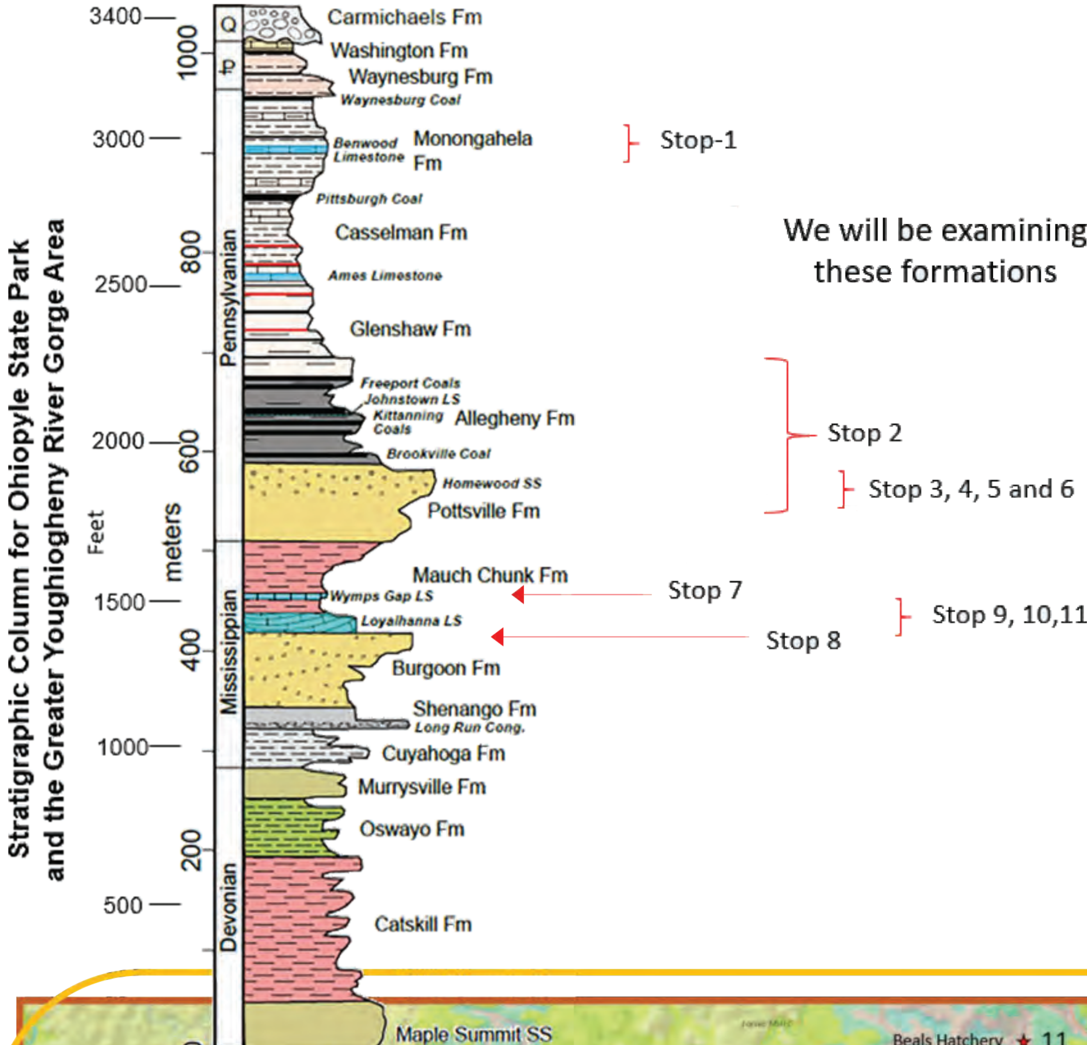
Stratigraphic Column for Ohiopyle State Park
and the Greater Youghiogheny River Gorge Area
Feet
meters
3400
3000
2500
2000
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Q
Pennsylvanian
Mississippian
Devonian
Carmichaels Fm
Washington Fm
Waynesburg Fm
Waynesburg Coal
Benwood Limestone
Monongahela Fm
Pittsburgh Coal
Casselman Fm
Ames Limestone
Glenshaw Fm
Freeport Coals
Johnstown LS
Kittanning Coals
Allegheny Fm
Brookville Coal
Homewood SS
Pottsville Fm
Mauch Chunk Fm
Wymps Gap LS
Loyalhanna LS
Burgoon Fm
Shenango Fm
Long Run Cong.
Cuyahoga Fm
Murrysville Fm
Oswayo Fm
Catskill Fm
Maple Summit SS
Stop-1
We will be examining these formations
Stop 2
Stop 3, 4, 5 and 6
Stop 7
Stop 8
Stop 9, 10,11


Beals Hatchery 11
New Enterprise Quarry 10
Chestnut Ridge
Seven Springs Resort
1 Robinson Falls
Uniontown syncline
2 Rail-Trail Pennsylvanian and Carmichaels
Ohiopyle &
Laurel Highlands
85th Annual FCOPG
Laurel Ridge
8 Jumonville Rocks
3 Ohiopyle Falls
4 Meadow Run slides and Cucumber Falls
7 Wymps Gap Quarry
5 Baughman Rock
Ridge
Chestnut
6 Turtlehead Rock Bog
9
Laurel Caverns
LEGEND
Permian
Pennsylvanian
Mississippian
Devonian
Pg
Pw
PPw
Pm
Pcc
Pcg
Pa
Pp
Mmc
Mb
MDso
MDr
Dck
Df
Ds
Scale

Guidebook for the

85th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

October 7 — 9, 2021

GEOLOGY OF OHIOPYLE STATE PARK — and the Laurel Highlands of Southwestern Pennsylvania

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Cover: Ohiopyle Falls in Winter

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- Big tip of the hat to Frank Pazzaglia who helped to create, organize, and bring to life the Day 1 Road Log and introduction section for the guidebook.
- Thanks to all the conference and pre-conference stop leaders for all their hard work and a special shout out to Steven Bill who made several trips down from New Hampshire to commune with the rocks.
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- Many immeasurably large thank-yous to Mr. John Joseph who purchased and donated the land containing the Robinson Falls historic site to Dunbar Township and the Dunbar Township Board of Supervisors: Keith Fordyce, George Stash, and J.R. Romanko for providing us the opportunity to visit it. And a special thanks to Mr. John Trimba who working as a volunteer, has helped to oversee the design and direct the maintenance of this site. And even more special thanks to Laura Means who just recently gifted the old Pennsylvania R.R. Opossum Run branch right-of-way, formerly the Catawba Indian War Path, and Braddock Trail which runs along the northwestern edge of the falls to Dunbar Township.
- Special thanks to Ohiopyle State Park for their hospitality – providing lodging, personnel, and use of facilities to individuals involved in stop descriptions, as well as letting us congregate at geologically significant, heavily visited, and sensitive park sites for conference stops.
- New Enterprise Stone and Lime Company for providing personnel and use of their quarry for conference stops and preparatory visits.
- Park manager Mike Mumau of Laurel Hill State Park and Mr. Beals for use of Beals Hatchery site.
- The Fort Necessity Battlefield National Monument park interpretive guide for providing much needed services to help us understand the history behind the geology at the Jumonville Rocks site.
- Thanks to the management of Laurel Caverns for making it possible for a "special" large group visit of Laurel Caverns.

- Thanks to Penn Dot for adjusting their work schedule and allowing us to visit and collect from their U.S. Route 40 quarry.
- Thanks to Steve Lindberg, Chris Coughenour and University of Pittsburgh Johnstown campus for helping to sponsor the conference and arranging for student support.
- Thanks to Frank Pazzaglia and Robert Booth at Lehigh University for sharing with us the results of complex and time consuming geologically focused research in Ohiopyle State Park done by those numerous students of theirs over the last 5 years.
- Many thanks to our loyal sponsors in these difficult times. And to Rachel Sager for stepping forward to be our banquet speaker.

SPEAKER

Rachel Sager
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Rachel Sager, *the forager mosaicist*, works on the cutting edge of the contemporary mosaic fine art movement. Her innovative work has been represented in cities throughout the U.S. and internationally and has been awarded multiple bests of show in juried exhibitions. Her *Marcellus Shale Series* stands as a true Pittsburgh success story and her work is collected with passion by private clients and corporations all over the world. Rachel's commitment to the classical language of mosaic paired with her intuitive andamento style has shaped a strong voice in the mosaic world. She brings these classical techniques home to the here and now of the present American mosaic movement. Rachel proudly hails from the foothills of Appalachia and passionately preserves her storytelling, hillbilly roots as she weaves the colorful tales of family, nature, self-reliance, humor, and the legacy of coal through the lens of mosaic. Whether she is digging into the earth of her native Pennsylvania, traveling the world as a teacher and speaker, or working as the pioneer of **The Ruins Project**, her mission to *build the line* continues to inspire new generations of mosaicists.

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GUIDEBOOK

OHIOPYLE 2021

FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

FRANK J. PAZZAGLIA – LEHIGH UNIVERSITY
JIM SHAULIS – PENNSYLVANIA GEOLOGICAL SURVEY
STEPHEN R. LINDBERG – UNIVERSITY OF PITTSBURGH AT JOHNSTOWN

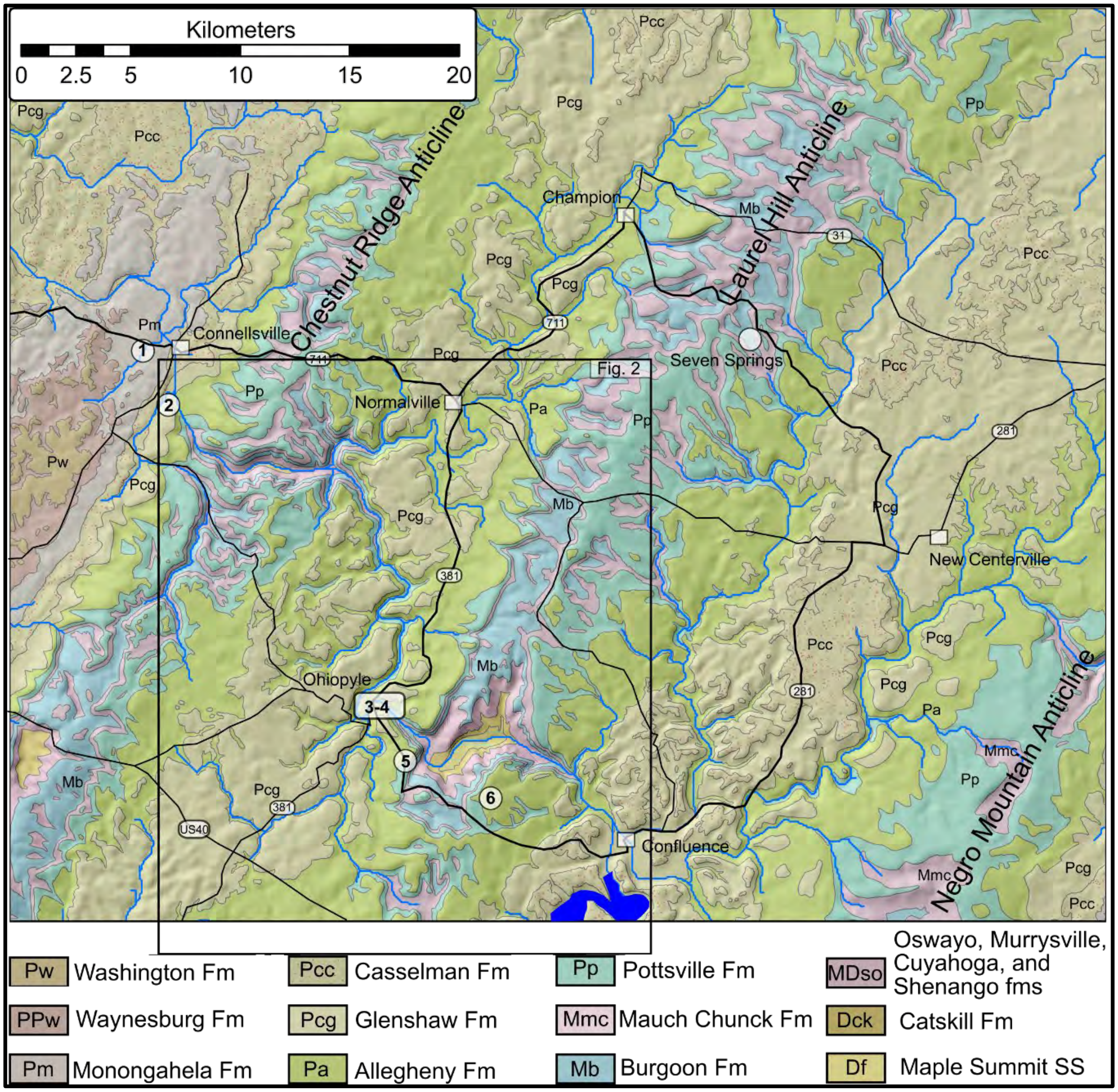


Figure 1. *Slope shaded geologic map of Ohiopyle, with rectangle outlining Ohiopyle Quadrangle (focus of Day 1 stops) and the surrounding Laurel Highlands (focus of Day 2 stops).*

Introduction and Trip Goals

Welcome to the Geology of Ohiopyle State Park and the Laurel Highlands (**Figure 1**). With its high ridges, steep river gorges, caves, and mature rail-trail network, it is no surprise that the region has matured into a popular recreational destination. Our goal over the next two days is to present new geologic and geomorphologic research describing the diverse processes and events that that shape this beautiful part of the Commonwealth.

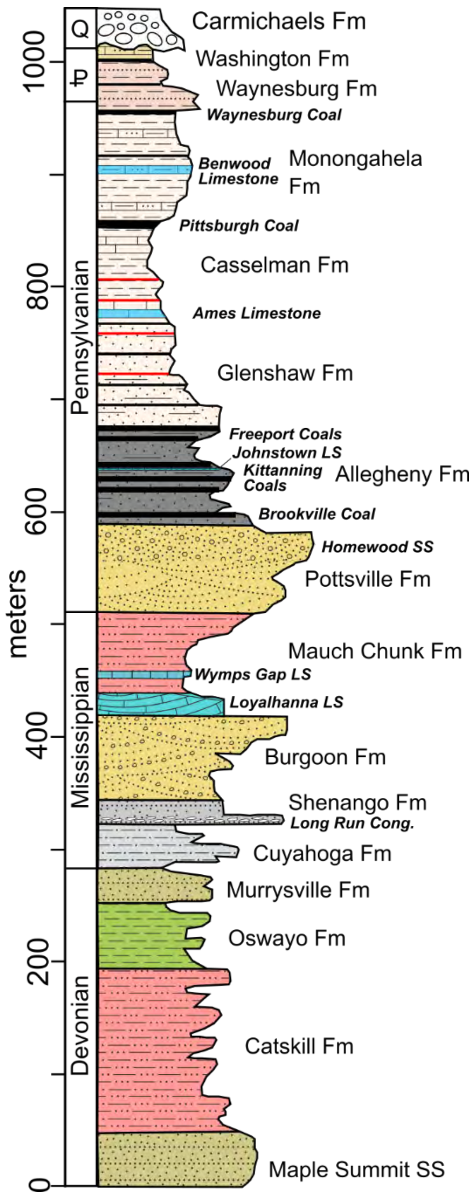


Figure 2. *Stratigraphic column for the Laurel Mountains region.*

Key points covered

1. The stratigraphy, structure, and map distribution of bedrock units (**Figures 2 and 3**; Shaulis, 2020),
2. The resources in the bedrock and their environmental legacy,
3. The Carmichaels Formation, its age, and relation to the formation of the Ohio River (**Figure 4**),
4. The processes and rates of carving transverse drainage across Laurel and Chestnut Ridges (**Figure 5a**),
5. The formation of waterfalls in and adjacent to Ohiopyle State Park and their rate of retreat (**Figure 5b**),
6. The Quaternary paleoecology of a peat bog near the crest of Laurel Hill Anticline in Ohiopyle State Park (**Figure 6**),
7. Joint and bed dip-controlled cave formation (**Figure 8**),
8. Paleoecology of a marine facies, and
9. The identification and classification of geoheritage sites that feature a variety of significant geoheritage values (**Figure 9**).

Structural Setting

Ohiopyle State Park and the Laurel Highlands lie in gently deformed part of the Appalachian foreland that straddles the Allegheny Mountains and Pittsburgh Low Plateau sections of the Appalachian Plateau physiographic province (**Figure 3**). This part of the Appalachian foreland lies above the Grenville margin of North America, including the Rome Trough, an Early Cambrian rift with a long history of differential subsidence and reactivation throughout the Paleozoic (Gao et al., 2000). Deposition and deformation of the strata underlying our field conference venue occurred in the mid to late Paleozoic. Unsteady erosion and sculpting of the landscape started at the close of the Paleozoic and continues to the present. Unlike the Ridge and Valley, the structural anticlines of the Laurel Highlands are topographic highs, whereas the structural synclines are topographic lows. Like the Ridge and Valley, resistant rock types underlie topographically high and steep parts of the landscape and play an important role in the formation of waterfalls.

Stratigraphic Column

The stratigraphic column for the field conference includes sedimentary rocks of late Paleozoic and late Cenozoic age (**Figure 2 and inside front cover**). The Paleozoic rocks span the late Devonian through early Permian periods and collectively define a ~ 1 km thick package of sandstone, siltstone, and mudstone locally rich in bituminous coal, with lesser amounts of conglomerate and both marine and fresh-water limestone. The mineralogy of the clastic deposits represent a diverse, eastern (in the current reference frame) provenance and the waxing and waning of a broad alluvial plain into the

Appalachian foreland in response to the Acadian and Alleghenian orogenies, as well as changes in regional climate spurred by the northward translation of North America from arid mid-latitudes to tropical low latitudes (Levine and Slingerland, 1987). In the major river valleys these Paleozoic strata are unconformably overlain by fluvial, lacustrine, debris-flow, and fluvial-deltaic deposits collectively known as the Carmichaels Formation (Campbell, 1902; Hickock and Moyer, 1940) that can approach 30 m in thickness and lie 10-100 m above the modern channels. The Carmichaels Formation is a single lithostratigraphic unit that most likely represents not only multiple facies, but also multiple phases of deposition spanning a large age range across the Pleistocene and perhaps even the late Pliocene. The Carmichaels Formation is traditionally thought to be genetically related to one or more phases of the early to mid-Pleistocene glacial Lake Monongahela (White, 1896; Jacobson et al., 1988); however, Carmichaels Formation deposits are found at elevations both above and upstream of the commonly agreed upon extent of the lake(s) (Campbell, 1902).

Geologic and Geomorphic Background

The foundation of the landscape that we will traverse for the next two days (**Figure 3**) lies on the sedimentary rocks of the Appalachian foreland, deposited and deformed during the Paleozoic construction of the Appalachian Mountains. The Appalachians and its foreland represent mountain building throughout most of the Paleozoic on the former eastern convergent margin of North America. Sediment supply from the uplifting and eroding Appalachians generally exceeded foreland subsidence during the late Devonian Acadian and Pennsylvanian-Permian Alleghenian orogenies, resulting in mostly clastic, terrestrial deposits to spread across southwestern Pennsylvania in a broad, westward-coalescing (in the modern reference frame) coastal plain. Periods of high eustasy and/or reduced sediment supply resulted in marine incursions and both clastic and carbonate deposition across the Ohiopyle area (**Figure 2**). Drift of the Appalachian foreland to more equatorial positions coupled with glacio-eustasy in the Pennsylvanian lead to the expansion of vast peat wetlands, the precursor to the numerous bituminous coal seams that historically drove economic development of the region. Shortening propagated westward into the western PA foreland as the Alleghenian orogeny progressed, resulting in the broad folds of the Negro Mountain, Laurel Hill, and Chestnut Ridge anticlines and their intervening synclines. Subtle changes in Pennsylvanian and Permian strata thickness across these structures indicates syn-depositional growth of these folds (**Figure 6b**). At the time of their formation, these folds were still deeply buried in the Appalachian orogenic wedge, presumably covered by a thick molassic sequence that is only partially preserved by the Permian sediments in the center of the Appalachian basin further to the south and west. Apatite fission track (AFT) thermochronology and coal vitrinite reflectance suggest ~3-4 km of burial ~250 Ma (Blackmer et al., 1994).

Mountain building continued in the Permian followed by a long period of erosion by west-flowing (in the present reference frame) rivers that reduced Appalachian topography and distributed the detritus further west across North America. At the close of the Allegheny orogeny ~250 Ma, there would have been a highland over all the Appalachian hinterland and the eastern part of the foreland. That highland was crossed by a drainage divide separating rivers that flowed west (with respect to the current coordinate reference frame) into the North American interior from rivers that flowed east into what is now northern Africa. The Allegheny orogeny had built a mountain range similar in width, height, and relief to the modern Andes (Slingerland and Furlong, 1989). Assuming rates of denudation ≤ 1 mm/yr for a range of this scale (Ahnert, 1970), ~15 to 30 km of rock was removed in ~40 Myr,

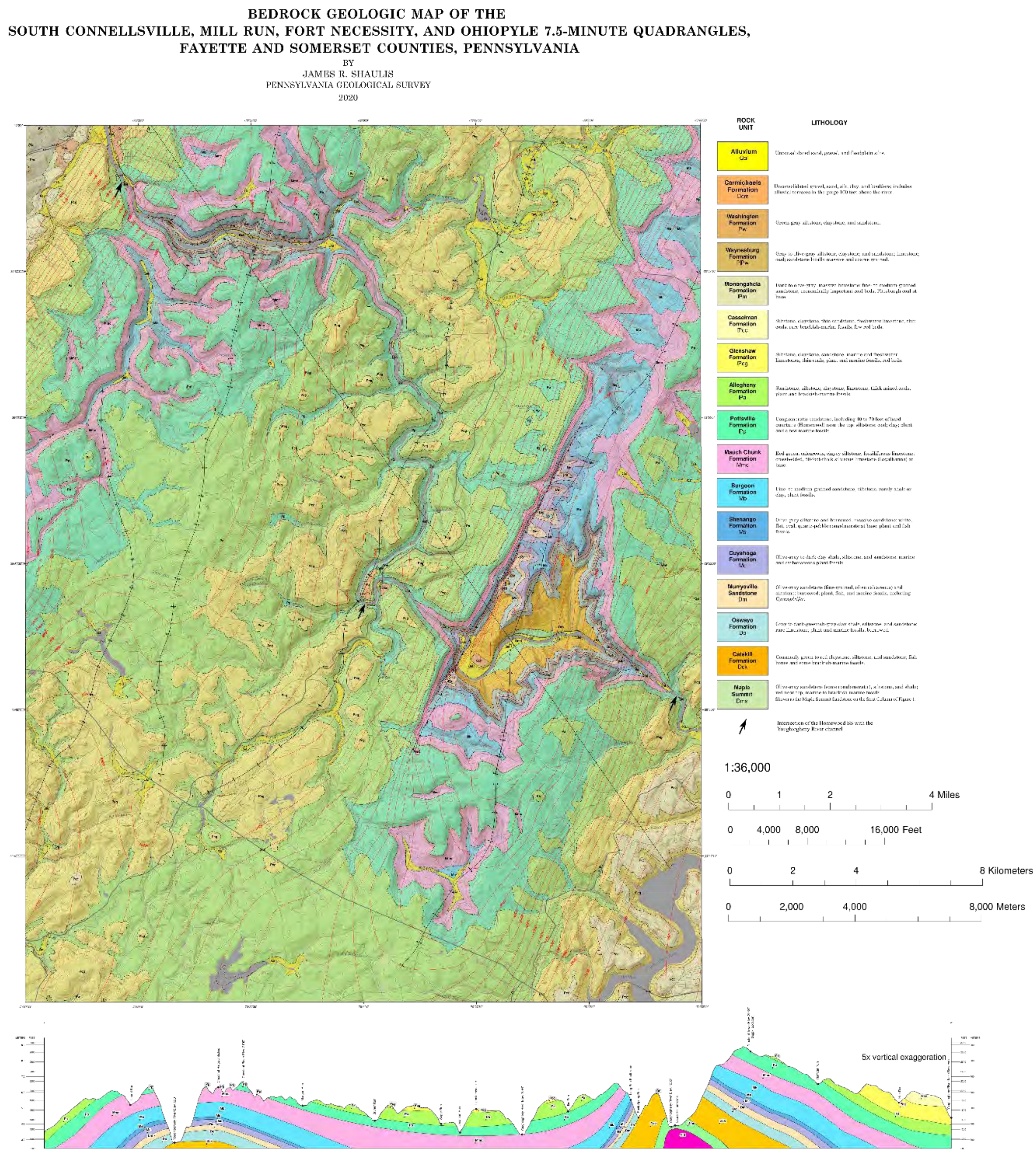


***Figure 3.** Geologic map and cross section of the Ohiopyle 7.5 quadrangle (modified from Shaulis, 2020).*

reducing relief and lowering the topography. Further west across the Laurel Highlands, unroofing likely proceeded at rates between 10 – 20 m/Myr (Blackmer et al., 1994), but even at that pace, 1-2 km of section was removed in the subsequent 100 million years resulting in AFT cooling ages of ~150 Ma (Late Jurassic) for rocks now exposed at the surface.

Regional crustal extension at ~230 Ma began dismembering what remained of the Appalachians forming a wide rift zone like the modern Basin and Range across the former highland (Withjack et al., 2012). Rifting ceased and continental breakup began 201 Ma accompanied by the outpouring of the central Atlantic magmatic province (CAMP) flood basalts. The magmatism included a broad arching of the suture between Africa and North America which uplifted, deeply eroded, and then thermally subsided the remnants of the rift basins. As the continents separated during the break-up phase ~190 Ma, the proto-Atlantic formed as did, presumably, a short, steep Atlantic slope drainage. In this way, a new continental divide and seaward facing escarpment was established with the new Atlantic slope streams to the east and the remnants of the Appalachian and syn-rift rivers to the west. By ~180 Ma, the situation looked somewhat like the Red Sea rift today. By ~120 Ma, the margin had cooled and fully subsided, and coupled with high eustasy, was transgressed by the Coastal Plain (Lower Aptian Potomac Group). By this time, the escarpment had long been retreating westward across the Piedmont, to the Blue Ridge, and into the Ridge and Valley. Continued retreat of the escarpment is marked today by the Allegheny escarpment which forms the eastern continental divide between the Susquehanna and Potomac catchments in the east, from the Ohio and its tributary catchments in the west. The escarpment continues to march westward into the Laurel Highlands, growing the size of the Atlantic Slope streams at the expense of the Ohio drainage.

Erosion and denudation rates for the post-orogenic Appalachians, including the Laurel Highlands, are now well documented from numerous thermochronologic (exhumation), basin analysis, river incision, alluvial and bedrock TCN, soil, suspended sediment, and dissolution mass balance studies (see Pazzaglia et al., 2015 and references therein; Portenga et al., 2013; Portenga et al., 2019). These data cover a wide range of time and space scales and indicate that most of the post-orogenic Appalachian landscape has been and continues to lower between ~10 and 30 m/Myr. In general, TCN-determined rates of exposed bedrock erosion tend to be lower than catchment-wide erosion (Portenga et al., 2013) and Pleistocene hillslope erosion rates scale linearly with mean slope (Portenga and Bierman, 2011; Linari et al., 2017; Reusser et al., 2017).

Glacial Lake Monongahela

Lake Monongahela (Leverett, 1936; Marine, 1997) is the name given to the impoundment that flooded the valleys of the Monongahela and Youghiogheny rivers when a pre-Illinoian ice margin dammed the pre-glacial north-flowing former Pittsburgh River system (**Figure 4**; Harper, 1997; 2002). This lake filled to a level of ~336 m (1,100 ft) before over-topping a sill in the vicinity of New Martinsville, WV, and integrating with the lower paleo-Ohio river to form the modern Ohio River, resulting in the Monongahela River and all of its tributaries including the Youghiogheny River now draining to the Mississippi River. The new base level defined by the elevation of the incised sill at 186 m (610 ft) generated a base level fall that continues to propagate upstream through the rivers that drain the Laurel Highlands. There may have been two or more generations of Glacial Lake Monongahela.

Closely associated with the formation of Lake Monongahela is the deposition of the Carmichaels Formation (Campbell, 1902; Marine 1997; Marine & Donahue 2000; Kite & Harper, 2011). The Carmichaels Formation consists of a stratified mix of clay, silt, and gravelly sand, weathered to reddish-orange to tan colors from material originally dark gray, white and tan in color (**Figure 4d**). Most diagnostically, the Carmichaels Formation contains polymict, rounded, fluvial gravel, cobbles, and occasional bounders (Campbell 1902; Kite and Harper, 2011). The rounded clasts are generally sourced from local resistant sandstone units such as the Homewood Sandstone or Long Run Conglomerate, with the occasional igneous or quartzite clast sourcing from the Appalachian headwaters (Harper, 2002). At the type locality of the Carmichaels Formation, the most abundant concentration and largest of these rounded boulders are found near the bedrock strath (Campbell, 1902). The Carmichaels Formation is often located within broad, flat, abandoned meander bends on the northward flowing tributaries of the Ohio River (**Figure 4c**). These abandoned meanders represent the paleo-valleys of a formerly high sinuosity, low gradient river.

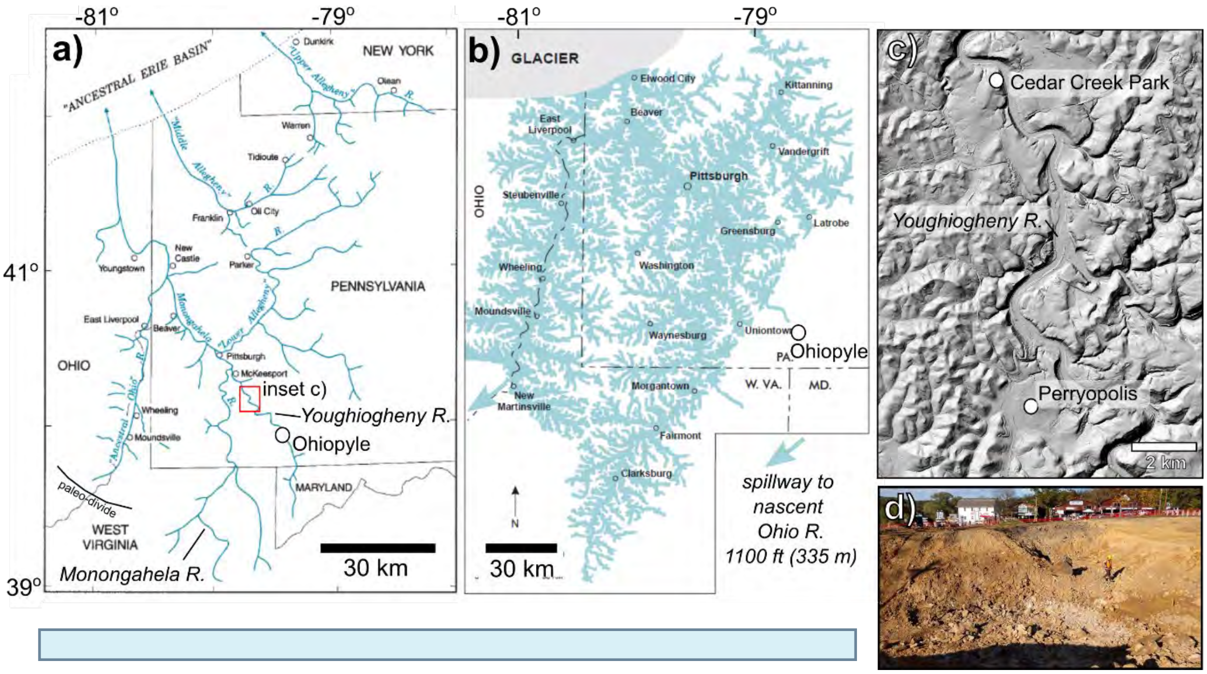


__Figure 4. (a)__ Pre-glacial (Pliocene ?) drainage for western Pennsylvania. Note the paleo drainage divide for the Ohio River near New Martinsville, West Virginia (modified from Harper, 1997). __(b)__ Extent of Glacial Lake Monongahela based on a spillway elevation of 335 m and no glacial isostatic adjustment (modified from Harper, 2002). __(c)__ Shaded relief map of the Youghiogheny River downstream of the Chestnut Ridge Anticline, between Perryopolis and Cedar Creek Park showing numerous abandoned meanders underlain by Carmichaels Formation above the modern channel. __(d)__ Exposures of the Carmichaels Formation at Ohiopyle (October 2019) upstream of the highest extent of Glacial Lake Monongahela, Ethan Kurak for scale.

Efforts to date Lake Monongahela have long been associated with the study of the Carmichaels Formation where three distinct low gradient terrace levels along the Monongahela and Allegheny Rivers in the vicinity of Pittsburgh have been identified (White, 1896; Jacobson et al., 1988; Morgan, 1994; Marine, 1997). The highest level of terrace called the Upper Carmichaels Formation (Jacobson et al., 1988), is thought to be the maximum extent of Lake Monongahela, consisting of deposits ~320-335 m (1050-1100 ft) that are > 780 ka based on their reversed paleomagnetism. The next highest terrace level is at 305 m (~1000 ft), and together with the highest terrace level are thought to represent two pre-Illinoian ponding events. The third terrace level at 280-296 m (920-970 ft) is referred to as the Lower Carmichaels Formation by Jacobson et al. (1998). This terrace is placed as Illinoian in age by Leverett (1934), who traced the terrace level to Illinoian outwash in the Allegheny River Valley near Pittsburgh. Two lower terrace levels that more closely match the grade of the modern river are also found at elevations of 253 m (830 ft) and 267 m (875 ft) and are thought to represent Wisconsinan (White, 1896; Marine, 1997) glaciation and are not comprised of Carmichaels Formation sediments. New studies (Kurak, 2021; Kurak et al., this field book) use cosmogenic ^{10}Be burial and isochron dates to demonstrate middle Pleistocene ages for Carmichaels terraces upstream of Glacial Lake Monongahela, and an early Pleistocene age of ~1.8 Ma for the age of the lake, or at least its highest (oldest) phase. All studies before Kurak (2021) have not accounted for glacial isostatic adjustment (GIA) effects into account in considering how it may affect the elevation of terraces, the spillway at New Martinsville, or the maximum elevation of Glacial Lake Monongahela.

Waterfalls, tors, and the carving of river gorges

The Laurel Highlands are a landscape with many transient features, some of which are rapidly changing like steep river gorges (**Figure 5**) and others that are slowly eroding like the tors at Turtlehead Rock and Bog (**Figure 6a**). One of the familiar natural attractions in the Laurel Highlands are waterfalls and steep, tumbling streams inset into narrow gorges (**Figure 5a**). The waterfalls at Ohiopyle including Ohiopyle Falls (**Figure 5b**), Cucumber Falls, the slick rock at Meadow Run, and the whitewater rapids encircling the Ferncliff Peninsula are all fine examples of these features. A waterfall is a knickpoint, a particularly steep example of one, but a knickpoint all the same. A string of waterfalls or rapids in a river channel define a knickzone that are commonly expressed as convexities in the channel longitudinal profile (**Figure 7**). The rivers that drain the Laurel Highlands alternate between steep, narrow bedrock-floored channel reaches rich with knickpoints, and more gentle alluvial reaches with wide floodplains.

Figure 5. *Examples of* ***(a)*** *a steep, incised reach of the Youghiogheny River from the High Bridge, downstream of the Ferncliff Peninsula as it enters the gorge incised through Chestnut Ridge, and* ***(b)*** *the Ohiopyle Falls knickpoint, the total drop of both falls is ~6 m.*

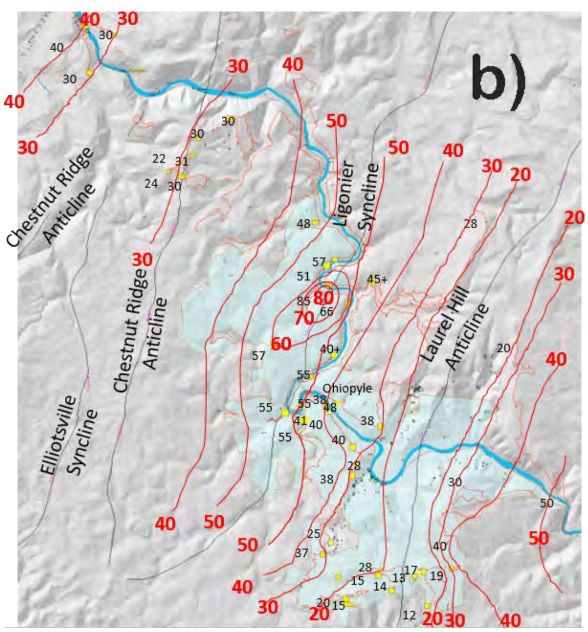


Figure 6a). *Exposures of the Homewood Sandstone and Turtlehead Rock (above) at Turtlehead Rock Bog, Ohiopyle State Park. Jim Shaulis and Mike Simoneau for scale.*

b). *Isopach map (left) of thickness (in feet) of the Homewood Ss member of the Pottsville Formation in the Youghiogheny River Gorge region (Shaulis,2020).*

Knickpoints can either be upstream-propagating transient features originating from impulsive, downstream base level fall, or stable channel steps fixed by adjacent channel reaches of contrasting erodibility. When propagating transients combine with contrasting channel erodibility, knickpoint height and steepness are enhanced (**Figure 7**). For example, the Youghiogheny River encounters the resistant, low-erodibility Homewood Sandstone in three separate locations as it traverses Laurel Hill anticline, Ligonier syncline, and Chestnut Ridge anticline (**Figure 3**). At only one of those locations, starting at Ohiopyle and continuing through the gorge around and downstream of Ferncliff, does the Homewood Sandstone form distinct waterfalls on the river and its tributaries. The other locations are gentle riffles in otherwise mostly alluvial channel reaches.

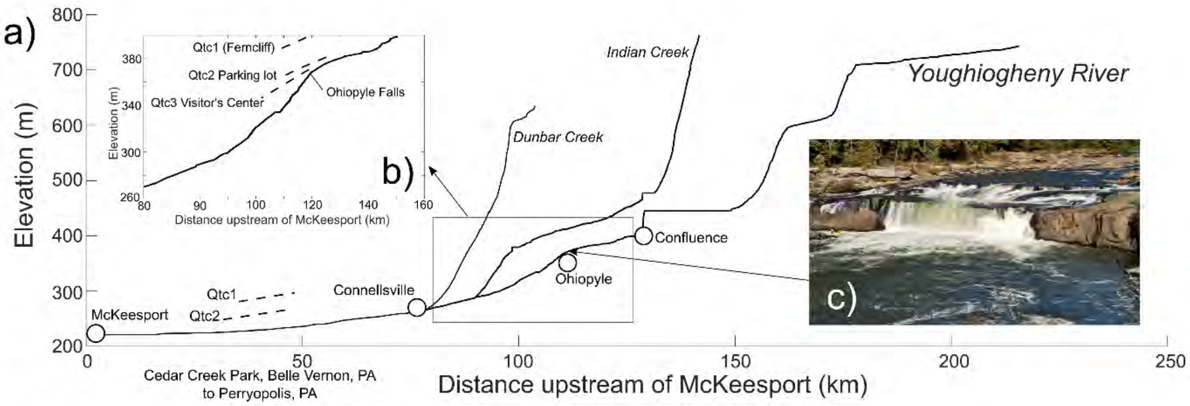


Figure 7(a) *Longitudinal profile of the Youghiogheny River showing the large knickzone at and downstream of Ohiopyle, PA. The large vertical step at Confluence is a dam. Elevations of known Carmichaels Formation (Wagner et al., 1975) straths between Belle Vernon and Perryopolis are shown by the dashed lines (Qtc = Quaternary terrace Carmichaels).* ***(b)*** *inset of the long profile and the elevations of three known straths at Ohiopyle State Park.* ***(c)*** *Photo of Ohiopyle Falls, where the knickzone steepens across the Homewood Sandstone.*

The timing and rate of gorge cutting in the Laurel Highlands can be constrained by the elevation and age of river terraces preserved on their flanks. Several stops on **Day 1** are devoted to observing these terraces and the data collected to date them.

Cave development

Laurel Caverns is formed in a calcite-cemented sandstone, through a process known as phantomization. In this process, groundwater dissolves the carbonate cement. After dissolution of the carbonate cement, insoluble grains remain as phantom bedrock. Water flow is directed along joint planes whose lines are clearly visible in the ceiling of the large rooms. The increased permeability and significant dip of the bedrock in this area of the Chestnut Ridge anticline has resulted in greater groundwater flow that has removed the insoluble grains in some areas. (**Figure 8**).

Figure 8. *In one of the larger rooms of Laurel Caverns, note the joint opening in the center of the ceiling.*

Fossils

Located on the northern side of U.S. Route 40 “The National Pike” the now long-abandoned cut in the hillside known regionally as the J.V. Thompson Quarry, now a restricted access PennDOT facility, offers an exceptional exposure of the Wymps Gap Limestone member of the Mauch Chunk Formation. The Wymps Gap Limestone exposed here, and in other southwestern Pennsylvania locations, is one of the most fossiliferous units in the state and contains abundant invertebrate fossils that include brachiopods, bryozoans, corals, crinoids, blastoids, cephalopods and trilobites.

Geoheritage Sites

Geoheritage sites represent unique, exemplary, or illustrative geologic features of Pennsylvania, and together highlight the geologic diversity of the state. During this year's conference one of our goals is to visit several sites that feature a variety of significant geoheritage values such as educational/scientific, scenic, historic, ecologic, and recreational (**Figure 9**).

A geoheritage site is defined as one that is valued:

1. for its importance to the science of geology to further understand Earth's evolution,
2. as a place to teach earth science,
3. its relationships to local and regional ecology.

Pennsylvania's geoheritage sites are significant examples of paleontological, mineralogical, structural, stratigraphic, and geomorphological features, and the processes that have formed them through geologic time.

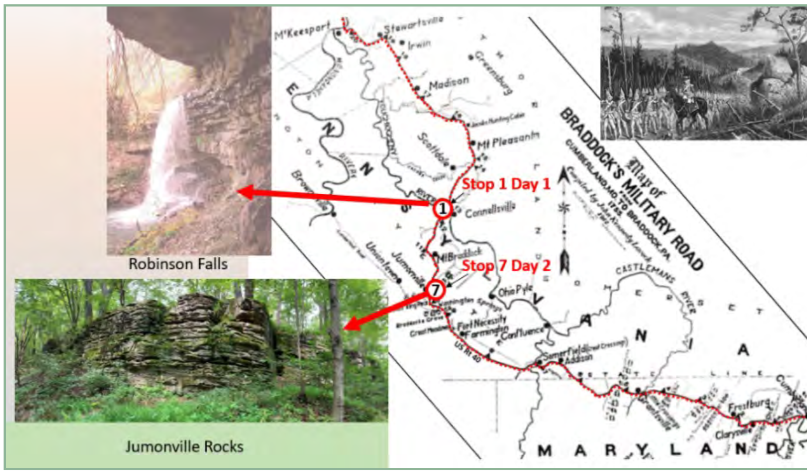


Figure 9. *Although, Jumonville Rocks and Robinson Falls both contain a variety of different geoheritage values, they do have one value – historical – in common.*

In 1755, while on route to take back Fort Duquesne, General Braddock used them both as camp sites for his army.

The Pennsylvania Natural Heritage Program maintains an environmental review database that includes 289 geoheritage sites scattered across the commonwealth. By law, a project that requires an environmental review must search the Pennsylvania Natural Diversity Index (PNDI) database for potential conflicts as part of the permitting process. Geoheritage features are "species of special concern" but are not protected as biotic rare, endangered, or threatened species. If a potential conflict for a geoheritage feature is found, our bureau is alerted of potential impact. The contractor may request guidance on how to best proceed to minimize the impact of their project. The experience has been that many companies do reach out for advice.

Note: *some of these sites also have attributes that make them ecologically significant, primarily as habitat for rare and endangered species of flora and fauna. Some aspects of the ecology have noteworthy geological connections. While the occurrence of the endangered species makes the site significant, the geological attributes need to be maintained and are important to be preserved. The primary management of these sites is performed by ecologists with assistance from the Bureau of Geological Survey. Also, sites whose primary significance is historical or recreational are also managed by organizations that have those interests with assistance from the Bureau of Geological Survey.*

Geoheritage References

Pennsylvania Geological Survey, 2021, Geoheritage Feature Classification, internal document.

Reese, S., 2019, Geoheritage sites – Blazing the trail of geology with the Pennsylvania Natural Heritage Program, in: OFR19-1, Geologic Mapping Forum 2019 Abstracts, Minnesota Geological Survey, 100 p., https://conservancy.umn.edu/handle/11299/202386

Shaulis, James R. and Reese, Stuart O., 2006, Conserving Pennsylvania's geology through the Pennsylvania Natural Heritage Program, Philadelphia Annual Meeting (22–25 October 2006), Geological Society of America *Abstracts with Programs.* Vol. 38, No. 7, p. 516. https://gsa.confex.com/gsa/2006AM/webprogram/meeting2006-10-24.html

Geoheritage Feature Classification

Following is the newly developed geoheritage classification system (PGS, 2021). Sites are classified into six broad categories:

I. Hydrodynamic
- *Rapids; springs; lakes; swamps, bogs; sinking streams, groundwater; ice mines, oil seeps*

II. Geomorphic

a. Depositional
- *Glacial: kames, kame terraces, moraines, eskers, kettles, valley trains, outwash plains, and fans*
- *Periglacial: boulder fields, talus slopes*
- *Fluvial: alluvial fans, alluvial islands*
- *Lacustrine: spits, sand dunes, lacustrine plains, deltas, and kame deltas*
- *Eolian: sand dunes*

b. Erosional
- *Landscape: scenic views (overlooks, vistas, lookouts) of the physiography or topography of landscapes; intracontinental water divides*
- *Fluvial and glaciofluvial: meanders; oxbow lakes; gorges; water gaps; wind gaps; cliffs; terraces; bedrock island; potholes; waterfalls, plunge pools, ravine*
- *Periglacial: pinnacles, tors, spires; rock cities and other erosion-resistant outcrops; pingo scars; other small features*
- *Glacial: striations, grooves, drumlins, fluted topography*
- *Other: Mass movement; solution carbonate-rock weathering features such as caves, sinkholes, others; nonsolution weathering features such as differential erosion, tectonic caves, talus caves, sea caves*

III. Compositional
- *Lithology; type sections; mineralogy; paleontology; sedimentary structures*

IV. Tectonic
- *Folds; faults; joints; foliations*

V. Earth History
- *Proterozoic; Paleozoic; Mesozoic; Cenozoic; Quaternary*

VI. Cultural and Historical
- *Cultural; history; historical extraction*

Geoheritage sites that we will be visiting on this conference:

- Ohiopyle Gorge – *Geomorphic, Erosional, Fluvial and glaciofluvial, Gorge.*
- Robinson Falls - *Cultural and Historical; history* (Primary); *Geomorphic; Erosional, Fluvial and glaciofluvial, waterfalls (Secondary).*
- Ohiopyle Falls - *Geomorphic; Erosional, Fluvial and glaciofluvial, waterfalls.*
- Meadow Run Slides – *Geomorphic, Erosional, Fluvial and glaciofluvial, Ravine.*
- Baughman Rock - *Geomorphic, Erosional, Landscape, Scenic view (overlook, vista, lookout) of the physiography or topography of the landscape.*
- Turtlehead Rock Bog – *Hydrodynamic, Swamp, bog* (Primary); *Geomorphic, Erosional, Periglacial, Rock city and other erosion-resistant outcrops* (Secondary); *Geomorphic, Erosional, Periglacial, Pinnacle, tor, or spire (Tertiary).*
- Jumonville Rocks – *Geomorphic, Erosional, Periglacial, Rock city and other erosion-resistant outcrops.*
- Laurel Caverns – *Geomorphic, Erosional, Other, Solutional carbonate-rock weathering features, Cave.*
- Cucumber Falls – *Geomorphic; Erosional, Fluvial and glaciofluvial, waterfalls.*
- Victoria Bend – *Geomorphic, Erosional, Fluvial and glaciofluvial, Meander*. Victoria Bend is within Ohiopyle State Park and can be seen from Baughman Rock.

ROBINSON FALLS

FORMATION, HISTORY & THE BENWOOD LIMESTONE

JIM SHAULIS – PENNSYLVANIA GEOLOGICAL SURVEY
FRANK PAZZAGLIA – LEHIGH UNIVERSITY

Introduction

Robinson Falls is located on Opossum Run in the Benwood Limestone Member of the Monongahela Formation (**Figure 1**). The goals of our visit to this site are to observe the stratigraphy and sedimentology of the Benwood Limestone Member, discuss the formation and retreat rate of the falls in the context of Glacial Lake Monongahela and the Carmichaels Formation, and summarize the remarkable history of the 18th century documentation of the falls by Thomas Hutchins.

Within the past year Robinson Falls and a surrounding buffer has been purchased by Mr. John Joseph, who grew up on an adjacent farm and has been committed to the preservation of this unique feature. He has now turned over management of the land to the township so it can be utilized as municipal park to be appreciated and enjoyed by the public. He has dedicated this park to his father and set up a trust fund to see that it continues to be maintained for future generations. Discussions now are ongoing about developing a connecting path to the GAP so that it can be made more easily accessible to trail users. This is an important geo-heritage site that has a chance to be enjoyed and appreciated thanks to the generosity of Mr. Joseph, to whom is owed a special thanks. Thanks also to Laura Means who just recently gifted the old Pennsylvania R.R. Opossum Run branch right-of-way, formerly the Catawba Indian War Path, and Braddock Trail which runs along the northwestern edge of the falls to Dunbar Township.

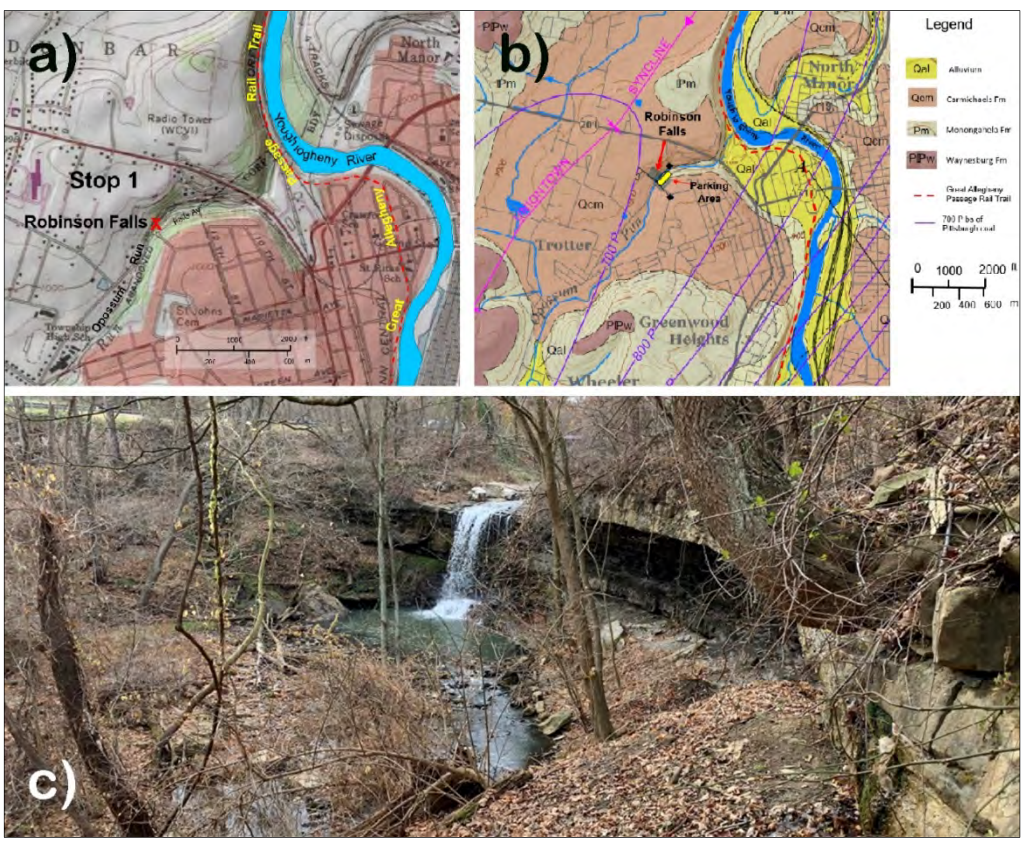


Figure 1. *Location **(a)** and geology **(b)** of Stop 1. Photo **(c)** of Robinson falls tumbling over the Benwood Limestone.*

Robinson Falls

Robinson Falls is an upstream migrating knickpoint on Opossum Run resulting from incision of the Youghiogheny River in response to the base level fall that accompanied the formation of the Ohio River by overflow of Glacial Lake Monongahela. Opossum Creek traverses a broad valley upstream of the falls at an elevation of ~940' (287 m) that is mantled with Carmichaels Formation, exposed and visible in the grassed farm hillslope directly west from the parking area. This broad valley is a remnant of the lower relief landscape of the Youghiogheny River valley downstream of Connellsville that existed prior to formation of the Ohio River. The Benwood Limestone provides a rib of resistant strata that focuses most of the base level fall at Robinson Falls.

Benwood Limestone

The Benwood Limestone lies in the Monongahela Formation (**Figures 1 and 2**) and is the thickest non-marine limestone outcropping in southwestern Pennsylvania. The limestone is part of and helps define the edge of the Dunkard Basin (**Figure 2b**), which is the structural center of the Appalachian foreland lying west of the Allegheny Mountain section of the Appalachian Plateau Province.

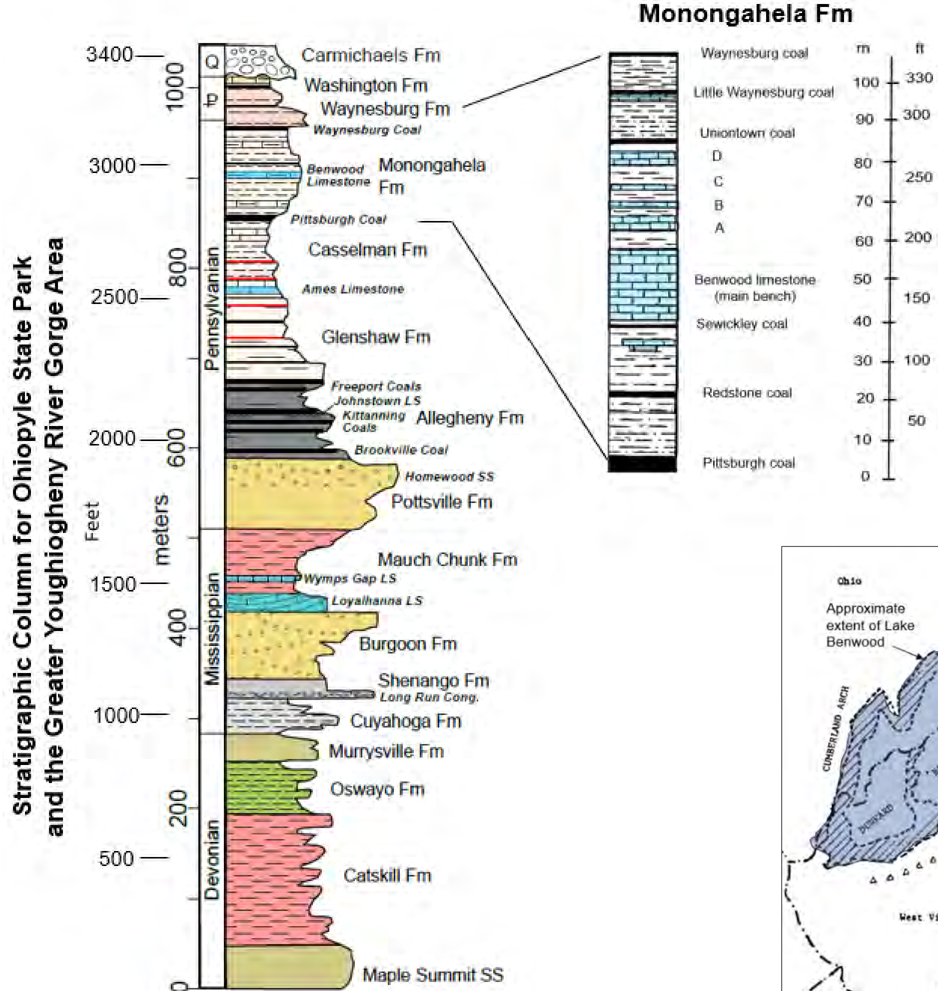


Figure 2a *above, shows the regional stratigraphic position of the Benwood limestone member of the Monongahela Fm in SW PA.*
Modified from Marrs, 1981 (upper right) and Pazzaglia, 2021 (left)

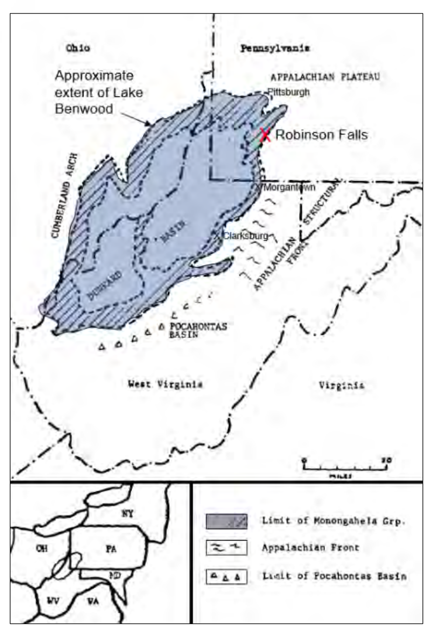


Figure 2b *right, shows the approximate limit of Lake Benwood (Marrs, 1981)*

Using a detailed description of a nearby core boring logged by Vic Skema it was possible to accurately correlate the Robinson Falls section to determine its stratigraphic location within the Benwood limestone complex as shown in **Figure 3**.

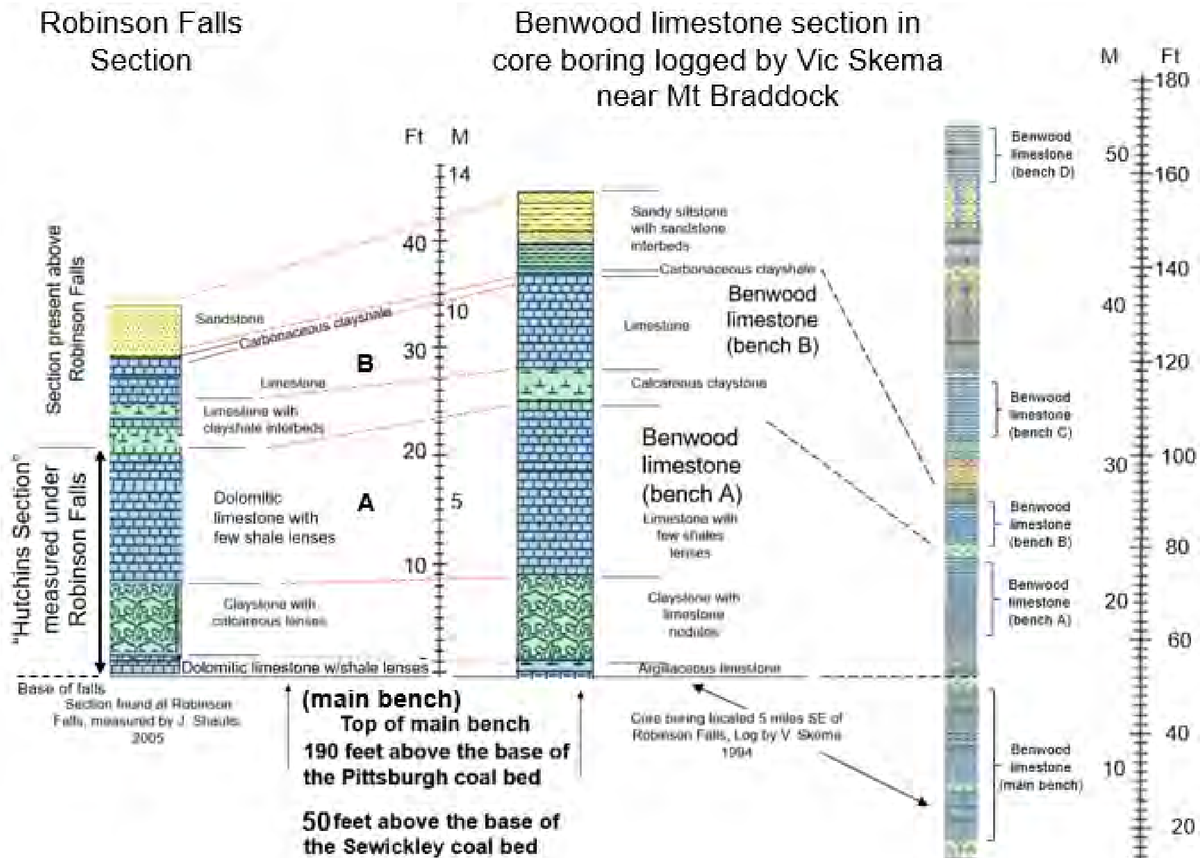


Figure 3 *shows the generalized section outcropping in the immediate area of Robinson Falls. Also shown is the stratigraphic correlation of the Benwood section exposed at Robinson Falls to the same interval penetrated by a nearby core boring. An additional 7ft (2m) of the main bench of the Benwood limestone is exposed downstream below the falls, not shown in the diagram.*

The Benwood Limestone was deposited in an upper delta plain lacustrine environment punctuated by frequent periods of clastic sedimentation (Marrs, 1981). The lakes were populated by burrowing organisms including ostracods and clams (**Figures 4 a, b, c, d**). Dry episodes resulted in evaporitic conditions causing the lake to shallow, which aerially exposed mudflats, favoring the formation of mud cracks and the precipitation of dolomite (Bathurst, 1975). Termination of the Benwood Limestone occurred when clastic material overwhelmed the subsidence in the upper delta plain. Micrite (Folk,1962) forms the matrix for the Benwood Limestone that contains clasts of biofragments, crystalline spar, and occasional intraclasts. The most common matrix supported grains are bio-fragments consisting of ostracods assigned to the superfamily Cyprididacea, genus Carbonita (Moore, 1961), that lived in freshwater environments and produced large broods of offspring. There were also soft-sediment burrowers. In most cases the grains and primary bedding structures are bioturbated with vertical burrows that narrow downward, possibly the result of ostracods, roots, and clams (Klappa,1980). Thin sections and x-ray diffraction analyses were done for several units at the falls and found to have a higher percentage of dolomite present in the more resistant beds. **Figure 5** (a, b) provides a detailed description of the section exposed at the falls along with thin section and x-ray diffraction sample locations.

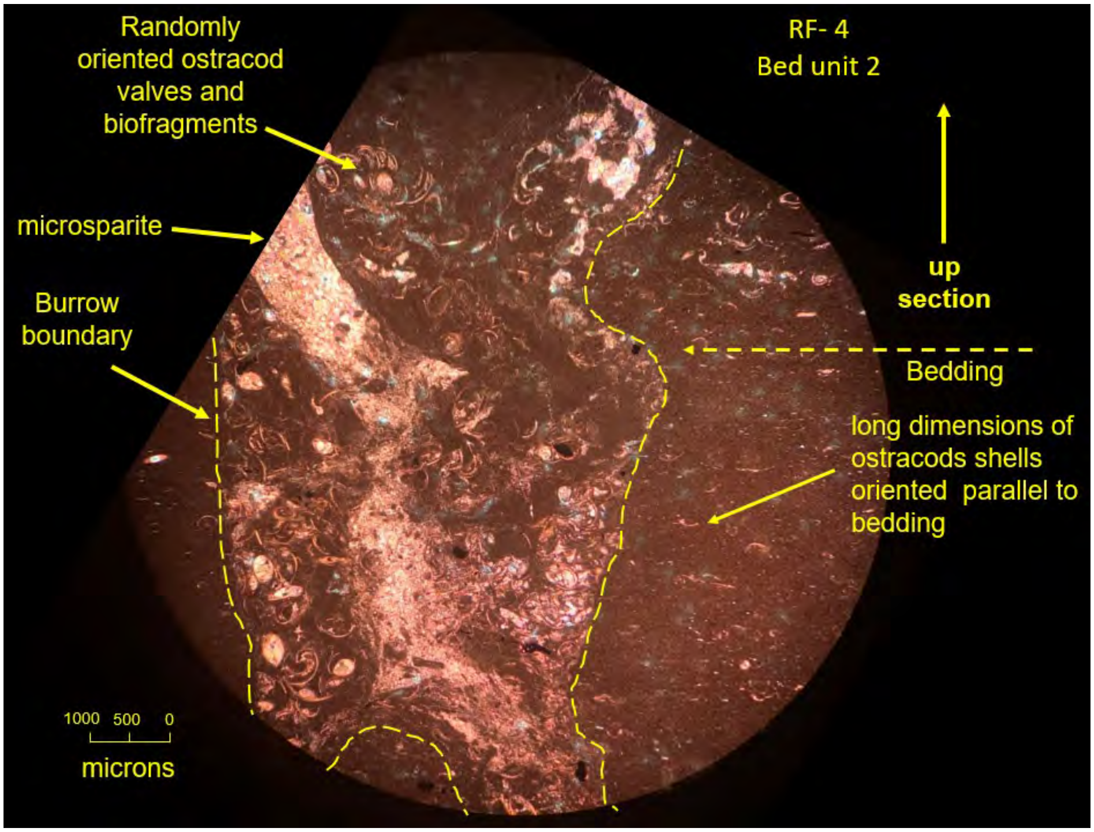


Figure 4 (a) *Photo of micritic limestone bed near base of Robinson Falls section (bed unit 2) showing the orientation of ostracod valves and the narrowing downward of vertical burrowing. Taken through the lens of petrographic Lecia microscope at 25 X magnification. [Refer to Figure 5a for detailed description of bed units in the section].*

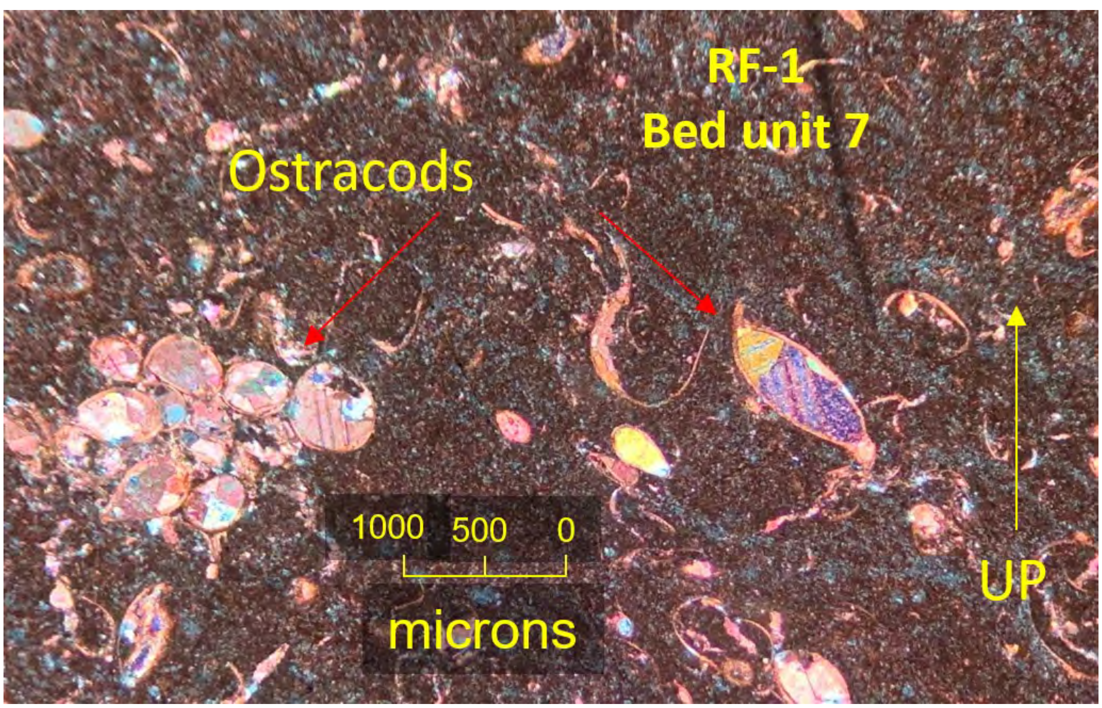


Figure 4 (b) *Photo showing euhedral calcite crystallization within articulated ostracods from top overhanging ledge (bed unit 7) of dolomitic limestone at Robinson Falls. The ostracods range in size from very coarse grained to medium-grained size sand. Taken through the lens of petrographic Lecia microscope at 25 X magnification. [Refer to Figure 5a for detailed description of bed units in the section].*

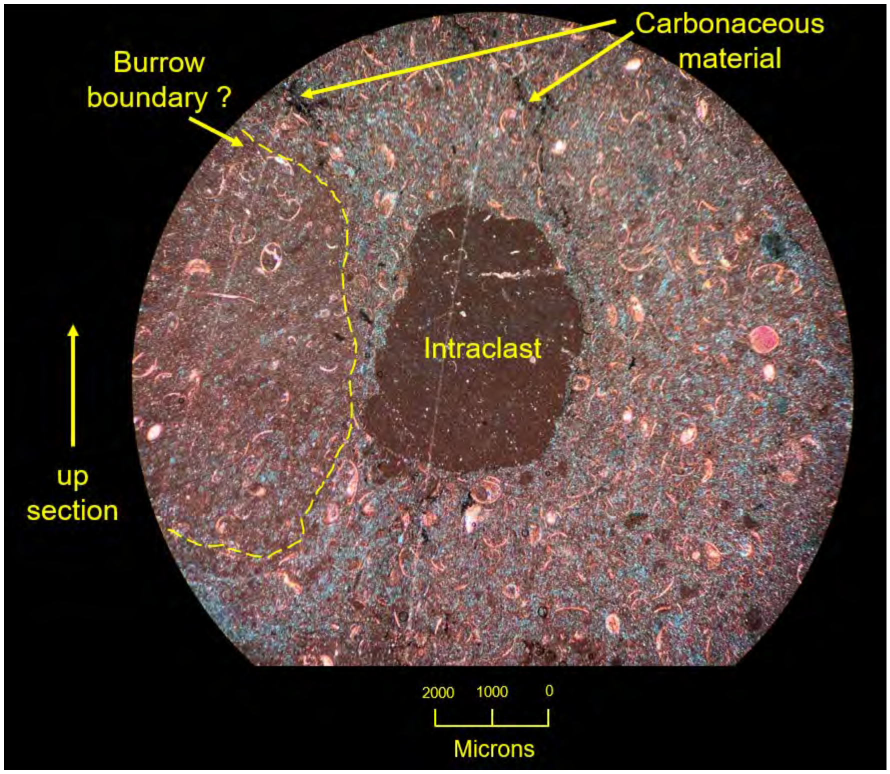


Figure 4 (c) *A larger intraclast and scattered smaller clasts floating in a micritic matrix in a burrowed portion of the top overhanging ledge (bed unit 7) of Robinson Falls. Photo taken through the lens of petrographic Lecia microscope at 25 X magnification.*

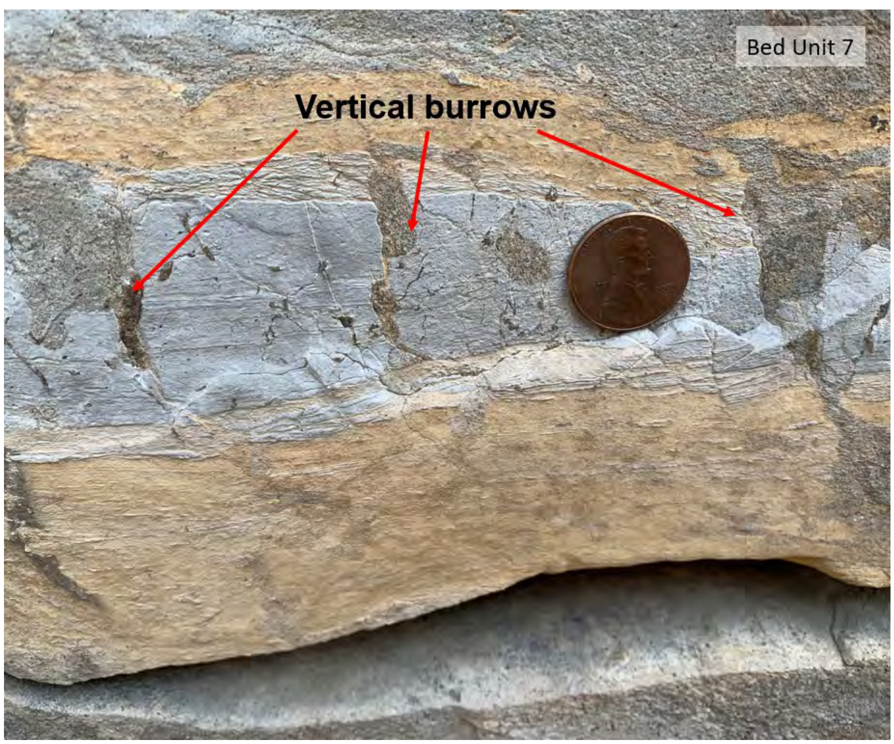


Figure 4 (d) *is a photo of the top ledge (bed unit 7) showing vertical burrowing through layers dolomitic limestone that has been dolomitized during a shallow drying out period of the lake. [Refer to Figure 5a on following page for detailed description of bed units in the section].*

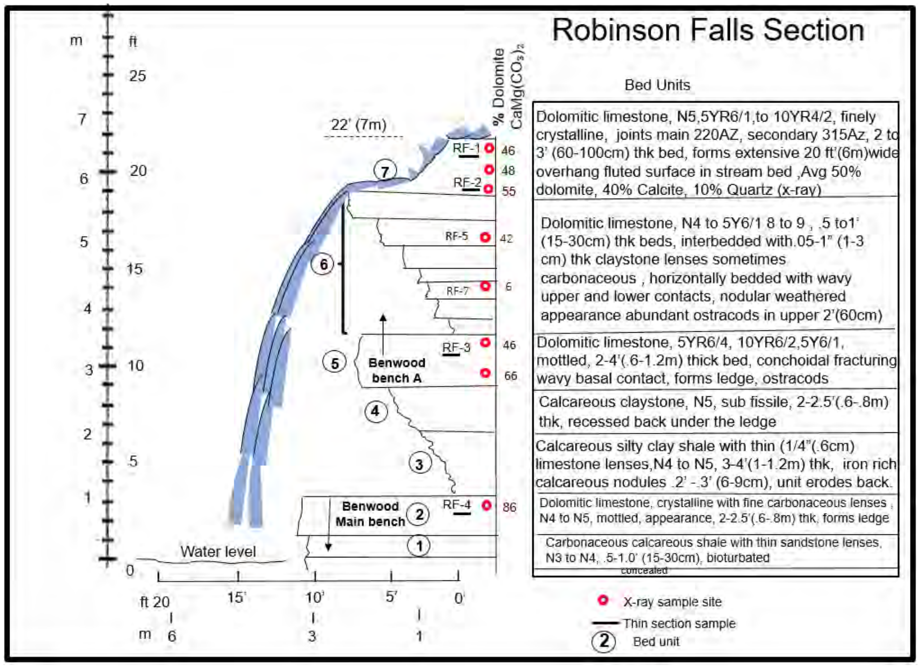


Figure 5a. *Detailed stratigraphy of the Benwood Limestone at the face of Robinson Falls.*

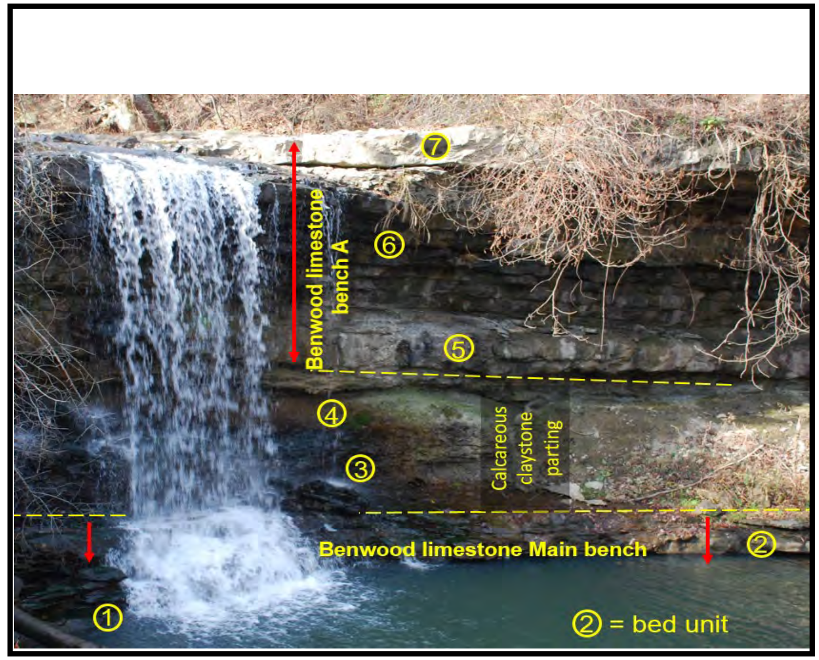


Figure 5b *showing location of bed units at Robinson Falls, as described in Fig 5a. (2016 photo)*

History of Eighteenth Century Documentation of the Falls

Eighteenth century documentation of the falls by Thomas Hutchins may be the first recorded geologic sketch and report for what was to become the State of Pennsylvania (Lesley, 1876). In 1786, Thomas Hutchins presented to The American Philosophical Society in Philadelphia a report he entitled “Description of a remarkable Rock and Cascade, near the western side of the Youghiogheny River, a quarter of a mile from Crawford’s Ferry, about twelve miles from Union-Town, in Fayette County, in the state of Pennsylvania” (T.A.P.S. Volume II, O.S. p. 50). However, when Lesley (1876) reported on it 100 years later, he reported Hutchins’ description as “A Cascade near the Ohiopyle Falls of the Youghiogheny, twelve miles from Uniontown, Fayette County, Pennsylvania. Why did he change the title? Hutchins description as read to the American Philosophical Society on January 28, 1786 was as follows:

> “This cascade is occasioned by a rock of semicircular form, the chord of which, from one extreme end of the arch to the other, is nearly one hundred yards; the arch or circular part is extensive, and upwards of twenty feet in height, exhibiting a grand and romantic appearance. This very curious production is composed of stone of variegated colours, and a species of marble beautifully chequered with veins running in different directions, presenting on a close inspection a faint resemblance of a variety of mathematical figures of different angles and magnitudes. The operations of nature in this structure seems to be exceedingly uniform and majestic; the layers or rows of stone of which it is composed are of various lengths and thicknesses, more resembling the effects of art than nature. A flat thin stone from eight to ten inches thick, about twenty feet wide, forms the upper part of this amphitheater, over which the stream precipitates. The whole front of this rock is made up from top to bottom, as well as from one extremity of the arch to the other, of a regular succession, principally, of limestone, strata over strata, and each stratum or row, projecting in an horizontal direction a little further out than its base, until it terminates into one entire flat, thin, extensive piece, as already mentioned; and which jets out at right angles or in a parallel line with the bottom, over which it impends fifteen or twenty feet, and without columns or even a single pillar for its support. This circumstance, together with the grand circular walk between the front of the rock and the sheet of water falling from the summit, exhibits so noble and singular an appearance, that a spectator cannot behold it without admiration and delight.”

One possible reason for Lesley’s not including some of the references that Hutchins made to the location of his falls and adding some of his own was that J.J. Stevenson who served under Lesley, was just completing work on a Progress Report in the Fayette and Westmoreland Districts (Rpt KKK, 1877) that included information on Cucumber Falls, which had a similar physical profile to the falls that was described by Hutchins and was also near the western side of the Youghiogheny River (**Figure 6**).

Lesley's reference to it being near Ohiopyle Falls would seem to indicate that it was Cucumber Falls that he had in mind.

However, as mentioned previously, the T.A.P.S. record also reads, "a quarter of a mile from Crawford's Ferry, about twelve miles from Union-Town."

Ohiopyle is 12 miles in a straight line distance from Uniontown but there is no historical records of any ferry ever operating near Ohiopyle or any Crawfords residing there. In addition to that, the other thing that must have given Lesley pause about this conclusion that Hutchins made his description at Cucumber Falls was the rock type. Hutchins referred to the rock under the falls as being a "species of marble" and it being "a regular succession principally of limestone".

Stevenson (1877) description of Cucumber Falls includes 25 feet of sandstone conglomerate and carbonaceous shale and a 2-foot coal. Did he think that perhaps Thomas Hutchins, who had been appointed by George Washington as our nation's first "United States Geographer," was not astute enough to distinguish between a limestone and a coarse-grained conglomeratic sandstone that makes up most of Cucumber Falls, or recognize a coal seam? Furthermore, would not such an inaccuracy in our state's first formal recorded geologic description have merited at least a mention by him if he did come to this conclusion?

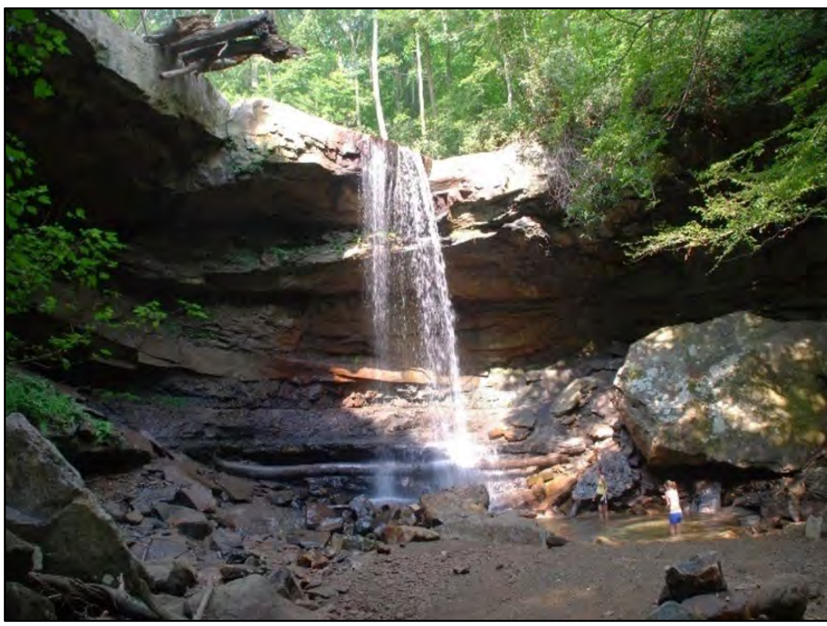


Figure 6 *is of Cucumber Falls taken on 7/29/2011.*

Like the falls Hutchins described, Cucumber Falls has thin pronounced overhanging ledge at the top undercut in an amphitheater like appearance.

Unlike Hutchins falls there is no limestone.

Cucumber Falls is formed on the Homewood sandstone member of the Pottsville Formation and underlying the upper Mercer coal which is exposed near the base.

In 2005 when trying to determine if Lesley was correct it was found that a Colonel John Crawford owned a large tract of land during the mid to late 1700s that was located on the western side of the Youghiogheny River on the western edge of what is today Connellsville, but there was no historical mention of a ferry ever operating anywhere in the area and the likelihood of finding a falls there seemed slim.

In the fall of 2005, after all other leads where exhausted and some thought was being given to the installation of a new historical commemorative plaque acknowledging Hutchins' description of Cucumber Falls, Eric Martin, owner of Wilderness Voyagers, an outfitting business, who does historically-focused trips for people rafting down the Youghiogheny River, was asked, "Have you ever heard of another falls like Cucumber Falls anywhere?"

He answered, "Sure, it has a twin over near Connellsville on Opossum Run."

Interestingly, since Lesley's reporting of the cascades it was never mentioned again in any geological reports or at any society meetings until it was reported on again at a GSA meeting 2011 (Shaulis, 2011). It was apparently not well known, and the reason may be that it's located down in a heavily vegetated, steep-sided hollow that is not easily viewable from any vantage point above. Other accounts of geological phenomena such as landslides, caves, fossil and mineral occurrences, have been presented to scientific organizations and recorded prior to January 28th, 1786, but the description of Robinson Falls *may be the earliest formal reporting of a geological section in Pennsylvania,* describing the lithology at the macroscopic level, in terms of color, texture, composition, and bed thicknesses.

Thomas Hutchins was born in Monmouth County, New Jersey in 1730. He was left an orphan while still very young and before he was sixteen he went to the "Western Country." In 1756, he was commissioned as ensign in the Second Battalion of the Second Pennsylvania Regiment and a few years later in the Forbes expedition that resulted in driving the French out of Fort Duquesne, which the British then rebuilt and renamed as Fort Pitt. By 1762 he was assigned to the 60th Regiment of Foot of the British Army under Henry Bouquet where he quickly rose to the rank of captain. Hutchins played a large role in helping to rebuild and maintain this first permanent English garrison stationed in the Ohio Valley while demonstrating his skills as mathematician, woodsman, surveyor, and tribal negotiator (Quattrocchi, 1944). He was variously assigned duties of mapping supply routes and recording strategic natural and cultural features surrounding Fort Pitt (**Figure 7**).

Figure 7 *is one of Hutchins earlier sketches from the late 1760s. From David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries , material may not be used for commercial purposes.*

After the close of the French and Indian war in 1763, the British found themselves in possession of former French outposts and forts along the Ohio and Mississippi Rivers from the Gulf of Mexico to the Great Lakes. Because of Hutchins' surveying skills and his familiarity with the Native Americans, he was often asked to join in both reconnaissance and military operations to these remote locations. On his journeys he took detailed measurements and made observations about the topography and culture. He produced numerous detailed maps and sketches. The one he's most known for "A Topographical Description of Virginia, Pennsylvania, Maryland, and North Carolina", was published in London on November 1, 1778 (Hicks, 1904). While in London attempting to get his map published, he was accused of treason, imprisoned, loaded with irons and placed in a windowless dungeon cell with felons for more than seven weeks. Hutchins insisted his correspondence with people in America represented only business dealings and nothing of military or strategic importance. When it was determined he couldn't incriminate any higher officers, they released him. Afterward Hutchins resigned from the British military. Having been denied his commission, he left for France, where he joined the American forces with the help of Benjamin Franklin. Upon arriving back in America, he was appointed geographer to the army acting to the south. After the war he was made Geographer of the United States of America (Quattrocchi, 1944).

In the spring of 1784, Hutchins and Reverend John Ewing, provost of the University of Pennsylvania, were commissioned to help complete the surveying of the Mason Dixon boundary line between Pennsylvania and Virginia. The surveying had stopped in 1767, 23 miles short of its goal (Denny, 2009) because of conflict with Native Americans (Rosenberg, 2020; refer to **Figure 8**). In 1784, the plan for the completion of the Mason-Dixon Line was for Hutchins and Ewing to travel to Uniontown to meet the Virginia commissioners; however, they received an express for them to adjust their route and meet for lunch at the widow Crawford's cabin, located in the outskirts of Connellsville. The journal pages from Monday, June 28, 1784 of Hutchins and Ewing indicate that it was after they had lunch that they set off for Uniontown with the Virginia Commissioners. In just a short distance, about ½ mile from the cabin, they came across a beautiful cascade at Harrison's Run, today know as Opossum Run (Quattrocchi, 1944). It was at this time that both Hutchins and Ewing recorded descriptions of the falls in their journals. Description made by John Ewing June 28, 1784:

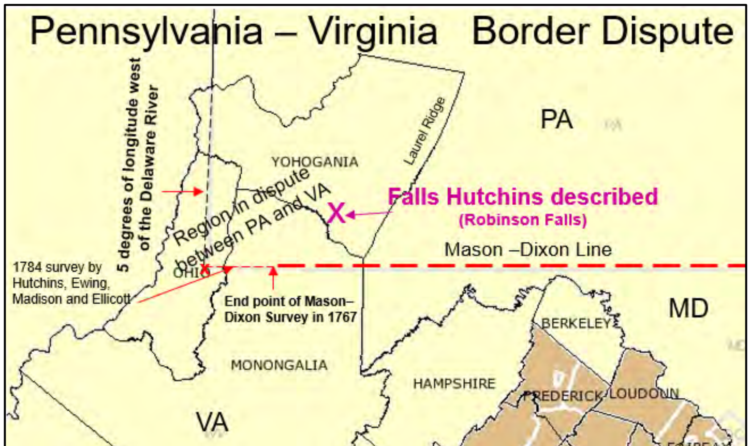


Figure 8 *shows the survey lines of Mason and Dixon, Hutchins, Ewing, Madison, and Ellicott, and the disputed territory west of Laurel Ridge (modified from Atlas of Historic County Boundaries, Newman Library, Virginia Tech Univ). The falls Hutchins described was located in "Yohogania" County that was at the time under the jurisdiction of both Pennsylvania and Virginia courts (ACM,1904).*

At half mile from Mrs. Crawford's there is a most beautiful cascade in Harrison's Run where the water falls perpendicularly over a broad Limestone Rock about 20 feet. This Rock in Front is hollowed into a regular semicircle about 150 yards in circumference and is about 8 to 10 inches thick. It projects about 10 or 12 feet over 15 or 20 strata of Stones of different Thicknesses regularly disposed, whose Front is also hollowed in a regular curved wall under the projecting thin Rock, as if it had been formed of hewn stones, whose Ranges are of different Thicknesses and laid by the Hand of a Mason; the stones in each of these Ranges are nearly of the same thickness from one end of ye arch to ye other but the upper Plate over which ye water falls is one continued stone, under which there is a fine semicircular Walk, between ye falling water and the Front of the different strata of Stones of about 10 or 12 feet broad; and the Pavement of the walk is another continued broad Stone similar to it which lies on the Top and formed into a similar Semicircle and projecting to the same Distance.

This thin Rock is also supported by other similar strata of Stones for 5 or 6 feet deep to ye Bottom of ye Run where ye water falls.

By the assistance of a little Labour in removing some loose stones that lye on the Pavement, and also some of ye stones of ye strata under the second broad Rock, there may be formed a most ample and grand Amphitheatre with gallery above gallery unsupported by pillars.

No journal records of the Virginia commissioners have yet been located.

In 1786, Thomas Hutchins delivered his description to the members of the American Philosophical Society in Philadelphia (Quattrocchi, 1944). During that time, he also developed the Public Land Survey System (section and range) (Bedini, 1998) and put together a proposal for exploring the northwest territories (Norris, 2002).

Unfortunately, while still serving at post of Geographer he died in 1789 before he could arrange for the expedition to the northwest. None other than Lewis and Clark filled the void.

Since Hutchins and Ewing visited the falls ~237 years have passed and from their descriptions one can recognize almost everything they were able to see in 1784 (**Figures 9 a – h**)

(Hutchins) "semicircular form 100 yards across and 20 feet high"

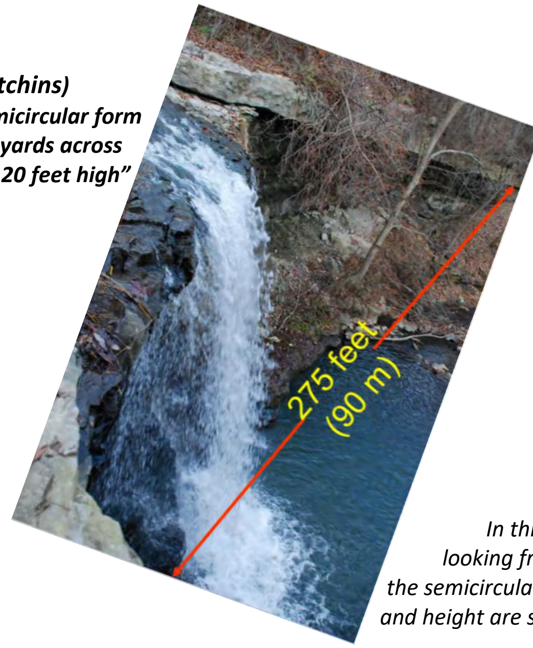


Figure 9 a
In this 2008 photo looking from SE to NW the semicircular appearance and height are still the same.

(Hutchins) "composed of stone of variegated colors"

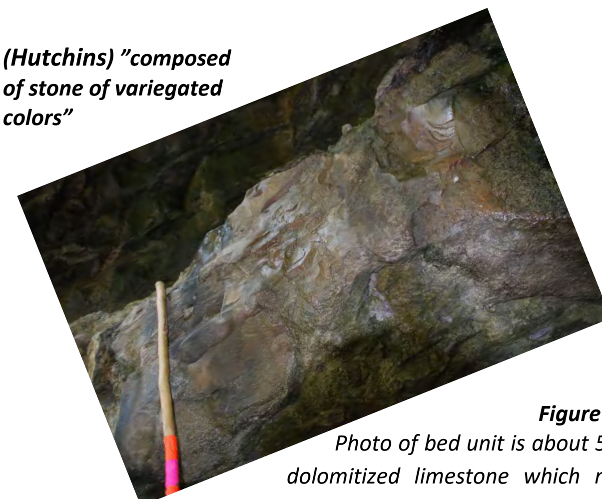


Figure 9 b
Photo of bed unit is about 50% dolomitized limestone which may also be contributing to the mottled appearance.

(Hutchins) "resemblance to mathematical figures"

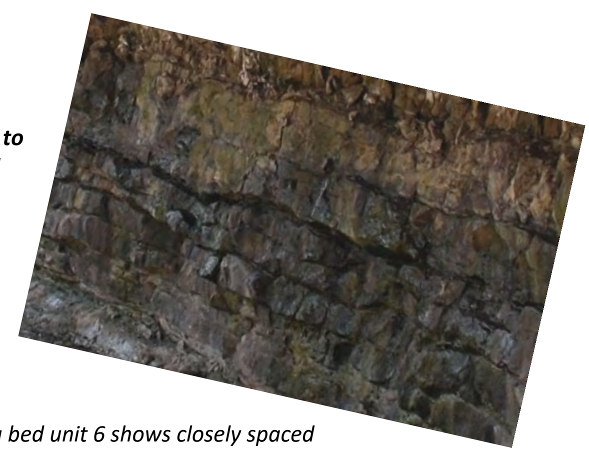


Figure 9 c
Photo showing bed unit 6 shows closely spaced jointing in these uniform horizontal beds which in places resemble plus, minus, and equal signs.

(Hutchins) "rows of stones resembling more the effects of art than nature."

(Ewing) "formed of hewn stones laid by the Hand of a Mason"

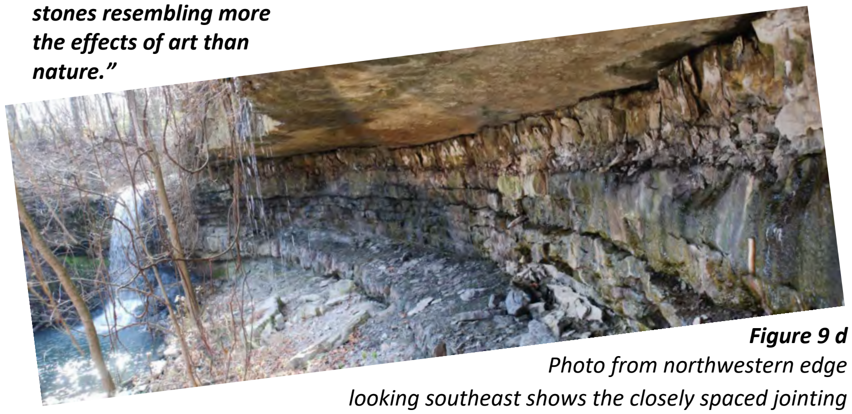


Figure 9 d

Photo from northwestern edge looking southeast shows the closely spaced jointing of uniform repeating layers resembles building blocks that have been arranged in gently curved profile gives one the feel of stone masonry. Beds average about. 8' (25cm) thick and have thin clay shale partings separating them. (see Fig 5a, bed units 5 & 6)

(Hutchins) " limestone, strata over strata each row, projecting in a horizontal direction a little further out than its base until it terminates, into one entire flat, thin. extensive piece."

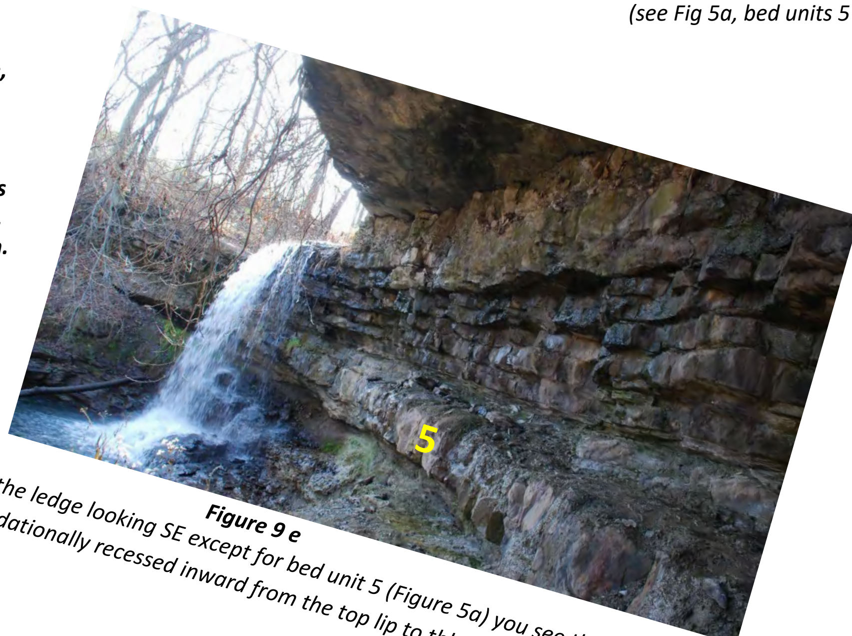


Figure 9 e

Standing under the ledge looking SE except for bed unit 5 (Figure 5a) you see that the beds are gradationally recessed inward from the top lip to thbase of the falls

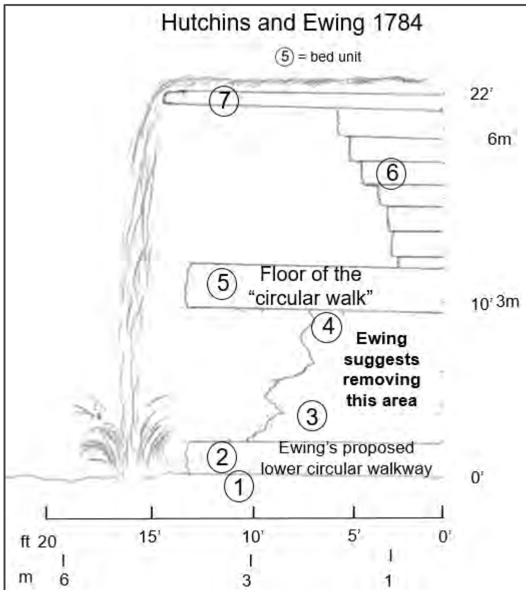
Figure 9 f

Standing under ledge on the NW end of this walkway looking to the SE is best place to view it. The circular walkway probably gave this falls a unique appearance in comparison to most other falls in the region. The description made by John Ewing indicates the circular walkway (Figure 5a, bed unit 5) was much broader then at 10 to 12' (3-3.5m) to what we see today which is 4-5' (1.2-1.5m) on the northern edge, which tapers down to less than a foot (30cm) behind the falls.

(Ewing) "fine semicircular Walk, between ye falling water and the Front of the different strata of Stones of about 10 or 12 feet broad"

(Hutchins) "grand circular walk between the front of the rock and the sheet of water falling from the summit."

Ewing (1784) also had an idea about enhancing this wonder of nature. He proposed that with a little effort another lower gallery with a semicircular walkway (under Bed unit 5, **Figure 9 g,h**) could be created since another pavement is present at water level (bed unit 2) that also extended out to about the same distance as the other two ledges (bed units 5 & 7), which would be 10 to 12 feet (3-4m). Today bed unit 2 extends out close to that original distance farther than any unit above it at the falls (See **Figure 5a**).



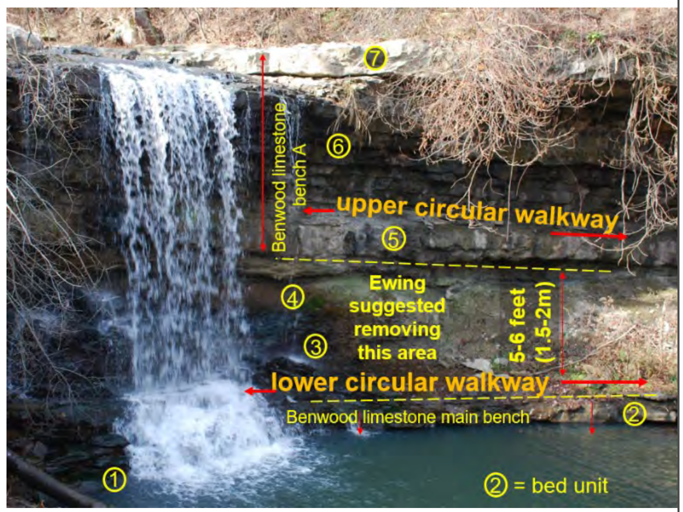


__Figure 9g (left)__ is a sketch of what the falls might have looked like in 1784 with location of the bed units. __Figure 9h (right)__ is a photo from 2008 showing the location of the beds and walkways.

> ***(Hutchins) "A flat thin stone from eight to ten inches thick, about twenty feet wide over which the stream precipitates" and he also says, "which jets out without columns or even a single pillar for its support."***
>
> ***Paraphrasing (Ewing) "This Rock in Front is about 8 to 10 inches thick projects about 10 or 12 feet over 15 or 20 strata of Stones"***

The only thing that is dramatically different from when Hutchins and Ewing made their description is the absence of the top ledge near the falls. We take this to mean that noticeable erosion has taken place.

A portion of this impressive overhanging of the resistant top ledge is still preserved along the northern side of the falls (See photo **Figure 9i** and **Figure 5a**, bed unit 7). Interestingly the well-developed, closely-spaced jointing present in the underlying strata does not appear to be as well developed in this layer as in the ones immediately below it, which perhaps explains to some extent its more resistive nature. It is worth noting that a section of the Pennsylvania Railroad Opossum Branch, which mostly hauled coal and

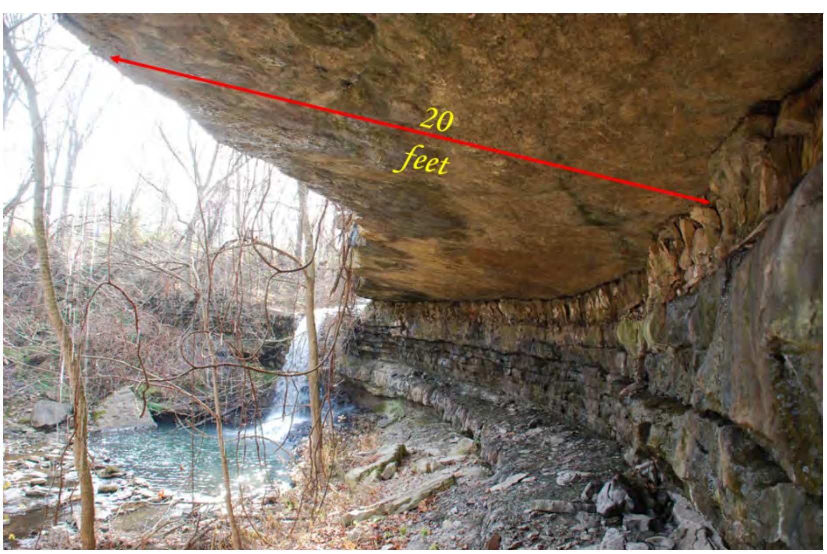


Figure 9i

coke from 1884 to around 1950, followed the Catawba Indian warpath that runs directly on top of this ledge that supports Robinson Falls at the extreme northern edge. Apparently over a half a century of vibrations from the heavy-laden coal trains had little effect in breaking up this ledge.

Looking at a photo taken 113 years ago (Lacock, 1908; **Figure 10 a**) significant changes primarily to the top ledge of the falls are evident (**Figures 10 b and c**). The ledge that was described by Hutchins in 1784 as 20 feet wide supporting the top of the falls had been cut back to a few feet by 1908. John Ewing's report (1784) indicated the ledge was 10 to 12 feet (3-4m), rather than 20 feet (6m) wide. Using Ewing's more conservative estimate, since 1784 the top ledge has retreated back approximately 20 feet (6m) and the lip of the falls ~10 to 12 feet (3 m) resulting in an average retreat rate of ~2.5 and ~1.25 cm/yr for the ledge and lip of the falls, respectively. For comparison, the long-term rate of retreat for the architecturally-similar Cucumber Falls, located in Ohiopyle State Park, is estimated to range from ~0.2 – 0.4 cm/yr (Kurak and Pazzaglia, this guidebook). Given that the Cucumber Falls catchment is only half the size of Opossum Run, the more rapid retreat of Robinson Falls is consistent with a discharge-dependent stream power model for knickpoint retreat where the dominant erosion mechanism is plucking/quarrying. The top ledge appears to be breaking off in small joint-controlled blocks (**Figure 10 b**).

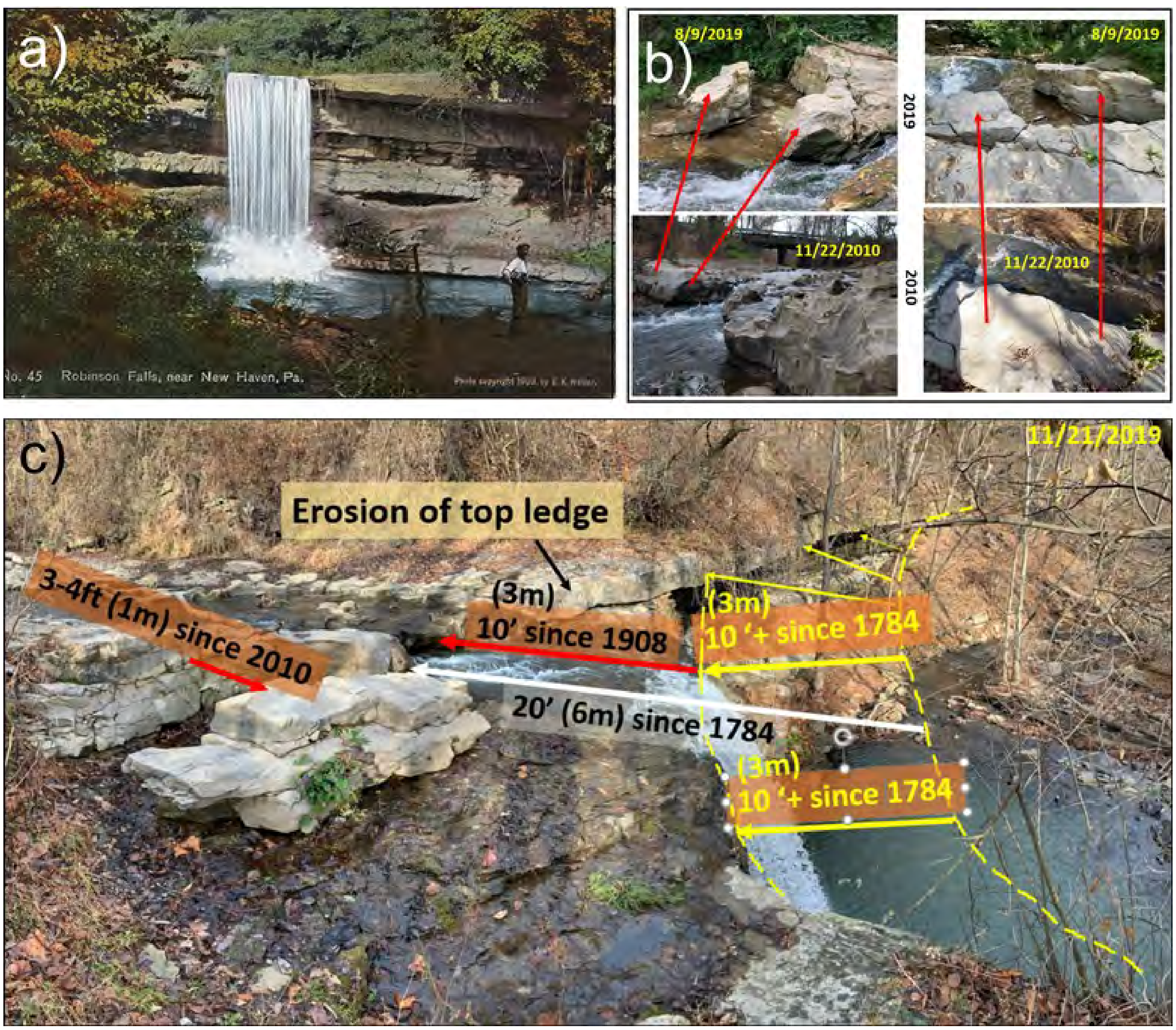


Figure 10. *Evidence for retreat of Robinson Falls over the past 237 years* ***(a)*** *compared to a photo taken in 1908 (Lacock, 1908),* ***(b)*** *evident in plucking over a 10-year period, and* ***(c)*** *summarized from the descriptions of Ewing and Hutchins.*

Fluting also plays a role in wearing down through the rock bed in the channel area above the falls. Just upstream of the falls, in the dolomitic limestone that used to form the overhanging lip, different stages of fluting can be seen (**Figure 11**).

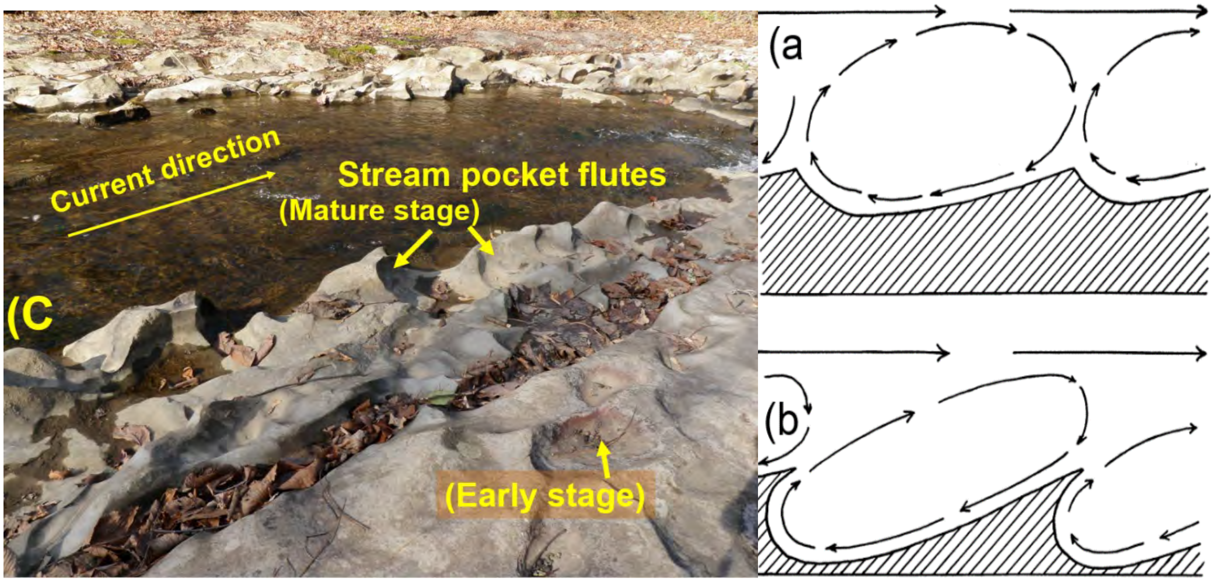


Figure 11. *The upper diagram **(a)** shows the vortices in a current moving to the right and the incipient development of pocket flutes. In an advanced stage of development, shown in the lower diagram **(b)**, the upstream margin of the flute is overlapped of rock (Maxson and Campbell, 1935). The photo on the left **(c)** shows the advanced or mature fluting, which gives the impression of the rocks to be imbricated in appearance due to the sharp undercutting on the upstream edges of the flutes.*

During the winter months water is coming out along many beds below the falls following joint openings and thin shale partings to the surface before it freezes. This leads to break up of the rock especially at the top ledge of the falls. See photo, **Figure 12**.

Figure 12 *shows where the water emerges and freezes at the surface during the winter months.*

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GREAT ALLEGHENY PASSAGE RAIL TRAIL

WESTERN FLANK OF CHESTNUT RIDGE - PLEISTOCENE AND PENNSYLVANIAN

JIM SHAULIS – PENNSYLVANIA GEOLOGICAL SURVEY
JOAN HAWK – NORTHERN ALLEGHENIES GEOLOGIC SOCIETY
FRANK PAZZAGLIA – LEHIGH UNIVERSITY

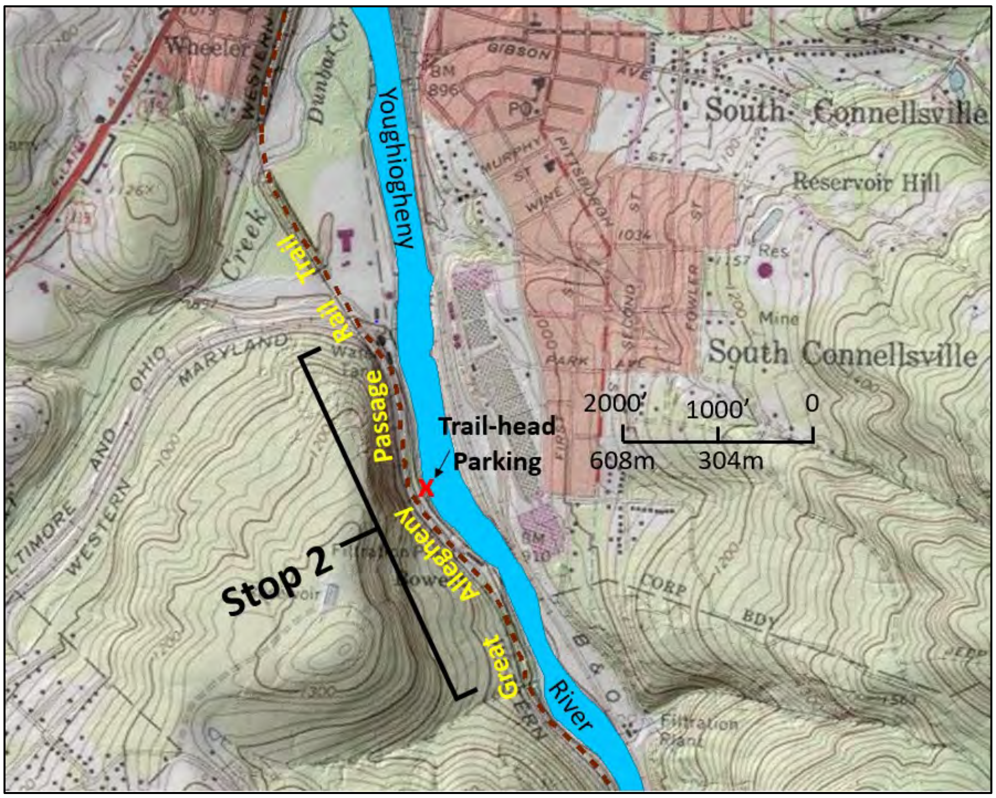


Figure 1. Location of Stop 2 along the Great Allegheny Passage Rail Trail near Connellsville

Introduction

At this locality (**Figure 1**) you are standing near the extreme western edge of the Allegheny Mountain section of the Appalachian Plateau Physiographic Province with the Pittsburgh Low Plateau (Berg,1989). The exposures at this stop are located along the Great Allegheny Passage Rail Trail (GAP). It is the longest multipurpose rail trail in the eastern United Sates and extends 150 miles (241km) from Pittsburgh to Cumberland, Maryland where it joins the C&O Canal Tow Path that continues on to Washington D.C. This route was the Connellsville extension of the Western Maryland Railroad and made a railbed connection between Cumberland and Connellsville (Metzger, 2003). An exposure of Pennsylvanian strata extending from the Connoquenessing sandstone to the Brush Creek coal and marine zone is visible along a section of the rail that begins at a small waterfall on the Connoquenessing sandstone and extends 4,000 feet (1219m) west on the trail to Bowest bridge where it connects with the Sheepskin trail (former Southwest Pennsylvania Railroad) and heads south to Uniontown. In addition to the bedrock, noteworthy exposures of the Carmichaels Formation can be seen above the bedrock in the sides of the old railroad cuts and on abandoned terraces of the Youghiogheny River terraces deposits above them. **Figure 2** is of a geologic section compiled from outcrops exposed along the GAP and **Figure 3** shows the most recent geologic map of this area.

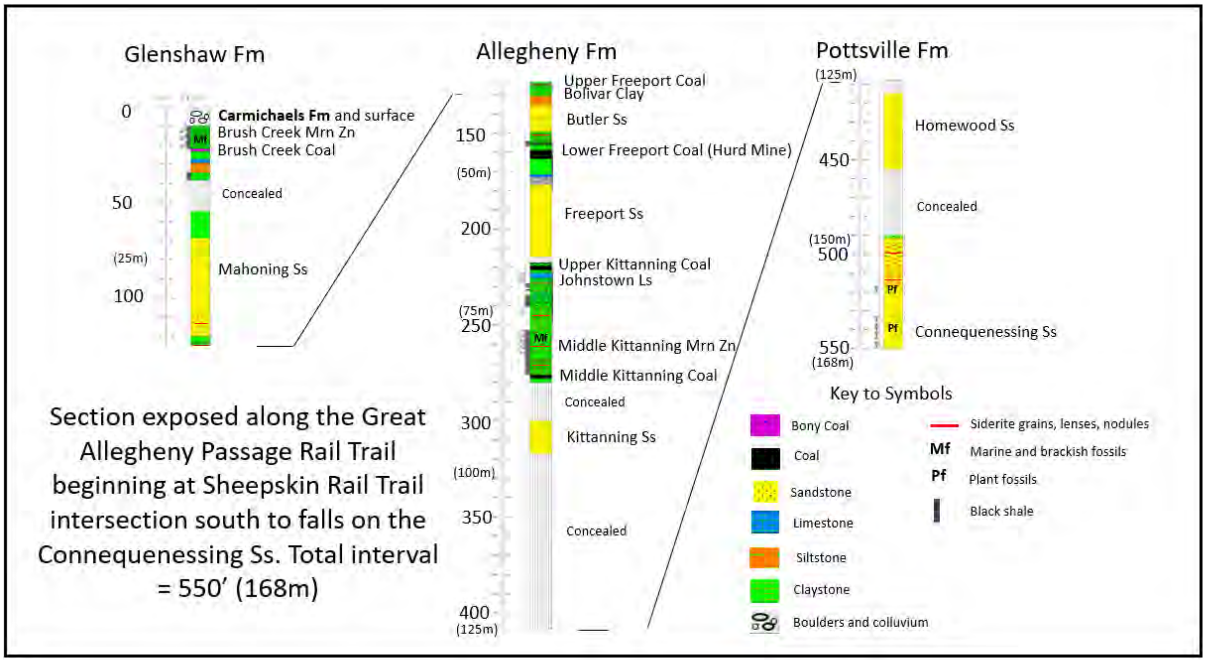


Figure 2. Measured section along the GAP Rail Trail beginning at the Sheepskin Trail connection, 4000′ (1219m) to the southeast. Some bed thicknesses and descriptions were supplemented by W. Moyer (1940) field notes for coal seams and beds immediately surrounding them.

It has been now about forty-five years since the last train used this path. Since that time the vegetation has been allowed to reestablish itself. The Youghiogheny River cut through Laurel Ridge and Chestnut Ridge to create the Youghiogheny River gorge which has the overall greatest relief [2050 feet, (624m)] of any gorge in Pennsylvania (Reese, 2008). The elevation of the river here at the extreme western end of the gorge is 880 feet (268m), the lowest point in the gorge. The highest topographic point in the gorge is on Laurel Ridge at 2934 feet (894m). Between here and the eastern end of the gorge at Confluence, 28 miles (45 km) upstream, the river level at 1340 feet (408m) shows a 460′ (140m) increase in elevation. In contrast by the time the water in the Youghiogheny River in Connellsville reaches the Gulf of Mexico it will have traveled over a 1000 miles (1609 km) and only dropped less than twice as far as it dropped from Confluence to here. The pronounced downcutting and periglacial weathering that took place during the Pleistocene has resulted in steep slopes in many areas that the railroad had to cut into to maintain a navigable grade. The original slope cut into by the railroad when it was first constructed in 1911 has accumulated talus in many areas and has covered strata that was present during the 1930's. This is evident from observations made by Hickok and Moyer (1940), who made detailed descriptions of coal

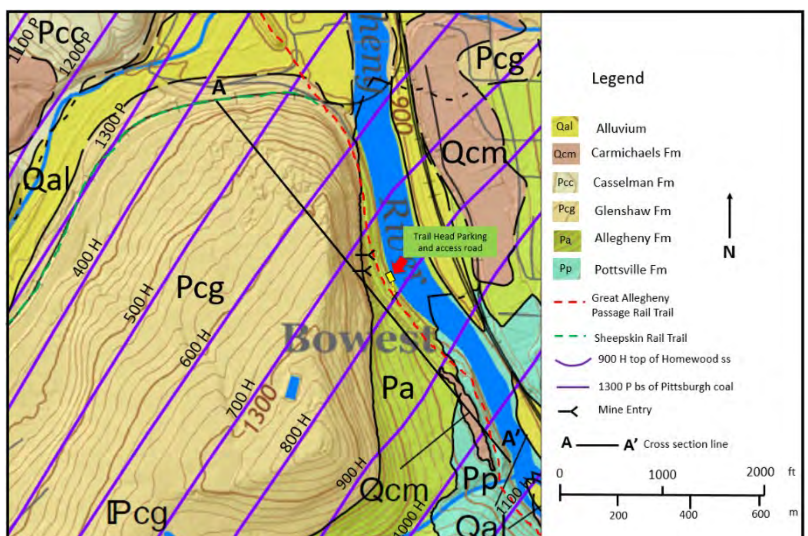


Figure 3. shows the bedrock geology and the Carmichaels Fm along a section of the Great Allegheny Passage Rail Trail that is described in Stop 2. (Shaulis,2020)

beds that are no longer visible today. This combined with the natural succession of vegetation that took place after this track was abandoned has resulted in what we see today, which are small windows of exposures. Fortunately, there are enough key beds still exposed to make accurate stratigraphic identification in most cases. Sandstone ledges still standout as they did in the early days of the railroad but the shale, clay, limestone and coal beds are now in many places covered by talus or vegetation or both. **Figure 4** is a cross section through the western end of Chestnut Ridge where this area is exposed at trail level. The beds here are dipping to the northwest between 6 to 8 degrees, or 12-14 feet (4m) for every 100 feet (30m). Conveniently the portion of the trail near the trailhead entrance that contains the stratigraphic section from the Lower Freeport coal to the Middle Kittanning coal is orientated perpendicular to the dip so the true dip can be seen. The beds exposed along the trail to the east or west of this part of the section are at about 20 degrees from normal to strike and appear to be dipping less steeply. In addition to the bedrock, noteworthy exposures of the Carmichaels Formation in the context of an abandoned meander of the Youghiogheny River can be seen above the bedrock in the sides and on top of the old railroad cuts ~100’ (30 m) above the current river level at an elevation of ~980’ (298 m).

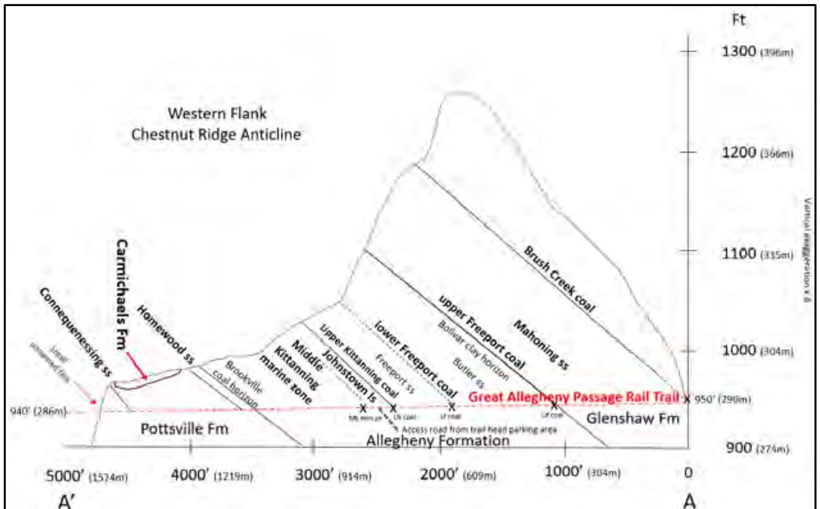


Figure 4. *Cross section A-A’ on Fig 3 showing the section exposed along the Great Allegheny Rail Trail, located on the western flank of the Chestnut Ridge Anticline.*

Carmichaels Formation

The extreme eastern end of this exposure begins at a small waterfall formed by the undercutting of a ledge of Connoquenessing Sandstone of the Pottsville Formation, named for Connoquenessing Creek, Lawrence Co (White, 1878). The bedrock here is beveled by fluvial erosion into a strath that has the planimetric shape of a tight southwest-oriented arc. Cobbles, gravel, and uncommon boulders of the Carmichaels Formation are preserved as terrace deposits atop the strath (**Figure 5**). This terrace is the first patch of Carmichaels Formation upstream of the Pittsburgh Lowlands section, as the Youghiogheny River exits the gorge carved through Chestnut Ridge. These terraces preserved through the Chestnut Ridge Gorge provide a record of Youghiogheny incision between the lower reaches of the river where the base level and Carmichaels Formation deposition is demonstrably linked to Glacial Lake Monongahela and Ohiopyle, where terrace deposition and river incision has responded to other base level and climate conditions (Kurak

Figure 5. *Photo of a terrace deposit mainly lying above the Homewood sandstone member of the Pottsville Formation. The boulder populated center of the old channel deposit is exposed here.*

et al., this guidebook; STOP 3). Among the cobbles and gravels at this site are clasts of the Mississippian Long Run Conglomerate, easily distinguished by its flatted, elongate white quartz clasts. The Long Run Conglomerate is exposed upstream of this locality only in the cores of the Chestnut Ridge and Laurel Hill anticlines and as such, is an excellent indicator for Youghiogheny, rather than local tributary provenance for the terrace alluvium (**Figure 6**). This strath of this terrace projects downstream to the strath at ~940’ (287 m) that forms the lip of Robinson Falls at STOP 1. If this Carmichaels Formation terrace represents alluvial aggradation related to Glacial Lake Monongahela and the drowning of an old meander bend of the Youghiogheny River, the age of the terrace here would be ~1.8 Ma, and the long term rate of incision would be ~17 m/Ma.

Figure 6. *Photo of one of the boulders of Long Run Conglomerate showing the elongate quartz pebbles diagnostic of Youghiogheny axial channel Carmichaels Formation provenance.*

Upper Pottsville Formation through lower Glenshaw Formation

Pottsville Formation

The extreme eastern end of this exposure begins at a small waterfall formed by the undercutting of a ledge of Connoquenessing sandstone, named for Connoquenessing Creek, Lawrence Co (White, 1878). Starting at the base of the falls, the 60-foot-thick (18m) section is as follows: a few feet of olive gray to gray, silty claystone is overlain by a 15 to 20 foot (5-6m) thick, cross bedded, well cemented, light gray, medium to very coarse grained, sub-angular to sub-rounded grained, moderately well sorted sandstone (**Figure 7**), containing well preserved *Sigillaria* (**Figures 8, 9**) and *Calamites* (**Figures 10, 11**) that can be seen in the overhanging ledge adjacent to the falls. Above this sandstone is 40 ft (12m) of interbedded sandstone and siltstones in an overall fining upward sequence. *Sigillaria* appears to have preferred mineral soils of river floodplains, allowing it to survive the drying of the great coal swamps that led to the extinction of many tree-sized lycopsids during the middle of the Pennsylvanian (Arens, 2021).

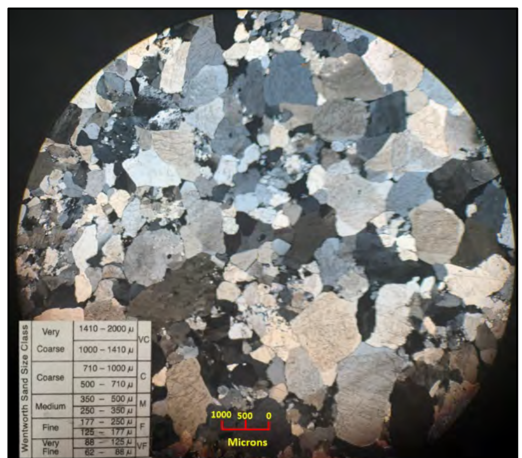


Figure 7 *is a photo of a thin section from near the base of the Connoquenessing sandstone. It consists of medium to coarse grains that are sub rounded to rounded grains, that are mostly of vein quartz, sometimes vacuolized, cemented secondarily with quartz overgrowths. There are a few lithic fragments and some traces of iron. Porosity is less than 5% and ranges from a quartzarenite to a quartzite (Folk, 1974).*

Sigillaria is a genus of extinct, spore-bearing, arborescent plants which flourished during the Late Carboniferous period but dwindled to extinction in the early Permian period. *Sigillaria* appears to have preferred mineral soils of river floodplains, in contrast to its relative, *Lepidodendron*, which grew in peat-forming swamps (Arens,2021). This preference for better-drained soils may have allowed *Sigillaria* to survive the drying of the great coal swamps that led to the extinction of many tree-sized lycopsids during the middle of the Pennsylvanian (318 to 299 million years ago). It was a tree sized lycopodiophyte (vascular plant) reaching a height up to 100 feet (30m), that lacked wood but had thick bark. Support came from a layer of closely packed leaf bases just below the surface of the trunk, while the center was filled with pith. The long, thin grass like leaves were attached directly to the stem and grew in a spiral along the trunk. The old leaf bases expanded as the trunk grew in width and left a polygonal leaf scar pattern arranged in vertical rows on the trunk which look like round marks left by a seal, giving it its name *Sigillaria*. *Sigillaria's* trunk was topped with a plume of long, grass-like leaves, so that the plant looked somewhat like a tall, forked bottle brush. It had Stigmaria, y-shaped roots and the plant bore spores (not seeds) in cone-like structures attached to the stem (**Figure 9**). *Sigillaria*, like many ancient lycopods, had a relatively short life cycle – growing rapidly and reaching maturity in a few years. *Sigillaria* is found in rocks from the middle Devonian to the late Carboniferous; it spans the ages of all the rocks in the Youghiogheny River gorge. It is commonly found preserved in many outcropping ledges or on large boulders. It likely grew along the edges of the distributary channels and was dislodged or uprooted during periods of flooding and then got transported and deposited along with the coarser grained sediments.

Figure 8. *Photo of the underside of the overhanging ledge that supports the falls showing well preserved impressions of Sigillaria branches and trunks.*

Figure 9. Left: *illustration of mature Sigillaria trees with the y-shaped top, ending with two thick bunches of leaves.* ***Right:*** *impression of Sigillaria bark that preserved scars of fallen leaves which look like round marks left by a seal. Sigillum is Latin for "seal" from which Sigillaria derives its name.*

Calamites is another genus of tree-sized, spore-bearing plants that lived during the Carboniferous. It had a distinctive segmented, bamboo-like appearance with vertical ribbing and a well-defined node-internode architecture similar to modern horsetails. Its branches and needle like leaves emerged in

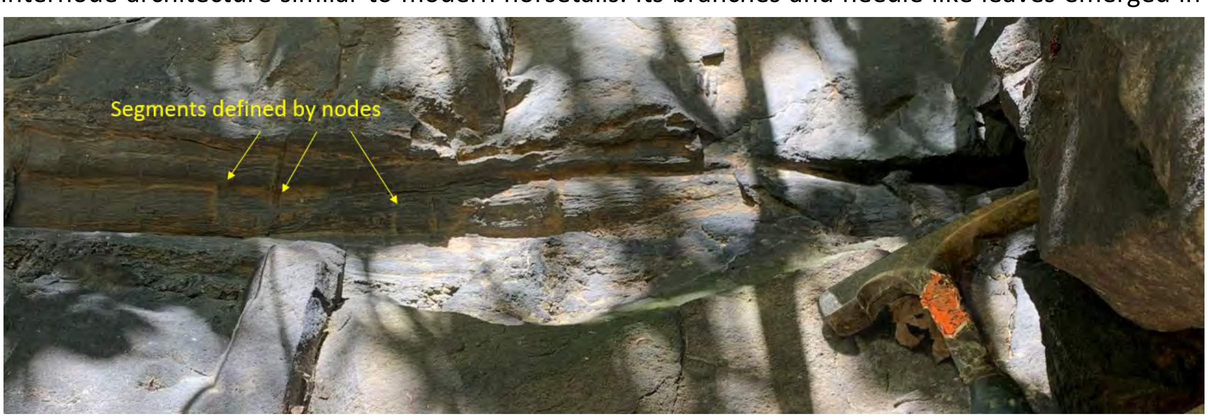


Figure 10. *Underside of the overhanging ledge. A well-preserved impression of Calamites trunk or large branch showing the distinctive segmented nodes where leaves originated.*

whorls from these nodes. Its upright stems were woody and connected by an underground runner; however, the central part of the stem was hollow. Fossils of *Calamites* are commonly preserved as casts of this hollow central portion. *Calamites* grew to about 66 feet (20m) tall and, like *Sigillaria,* grew mostly along the sandy banks of rivers, having the ability to sprout vigorously from underground rhizomes when the upper portions of the plant were damaged (Arens,2021).

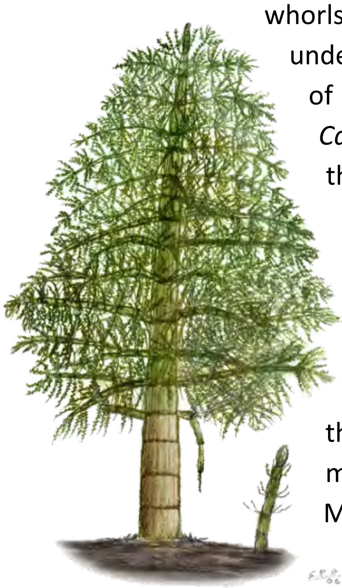


Figure 11. *Artist's drawing of Calamites, showing the segmented nodes on both the trunk and the branches.*

Overlying the top of the Upper Connoquenessing sandstone is a 1-foot (0.3m) thick root worked claystone that maybe equivalent to the lower Mercer underclay followed by a 35-foot (11m) interval that is mostly concealed. This concealed interval is overlain by a 40 foot (12m) thick medium- to coarse-grained sandstone (**Figure 12**) in the stratigraphic position of the Homewood sandstone member. The Homewood sandstone here is medium to light gray, thick to massively bedded but not conglomeratic like it commonly is in most areas of the region. Crossbedding is mainly planar but some trough crossbedded intervals are present near the middle of the exposure. Crossbedding dips to the northwest.

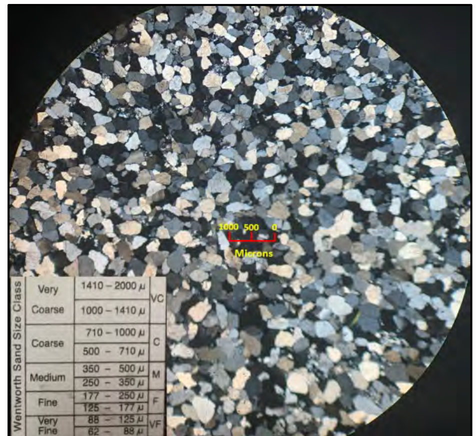


Figure 12. *Photo of a thin section from near the base of the Homewood sandstone showing the medium grained to coarse quartz rich composition. It is well sorted to with sub angular to sub rounded grains. It contains mostly monocrystalline quartz and a few lithic fragments, some muscovite, cemented secondarily with quartz overgrowths. It is a quartzarenite (Folk,1974) with less than 5 % porosity.*

An example of a peat raft occurs in the middle of this interval (**Figure 13**). During flood events distributaries beached their levees and flowed into adjacent swamps present on the coastal plain, ripping up and carrying off portions of the growing peat mats. These chunks of peat mat later became weighed down with sediment to be deposited downstream with the sediment load and incorporated into the rock layers. It has been recently speculated (Krulwich, 2016) that it may not have required a large amount of peat to form coal; it might have taken 600 times less the amount of plant material than it does today. Perhaps a large log might have been enough to form several inches of coal, since the bacteria necessary to break down cellulose fiber had not yet evolved during the Pennsylvanian.

Figure 13 Left *side: A lens of highly carbonaceous to boney claystone with boney coal lenses that extend 10 feet (3m) laterally is present between sandstone layers in the Homewood sandstone representing a possible ripped up portion of a peat mat.* ***Right*** *side: Shows the bulged-up area in the center where the peat was squeezed up into the overlying sediment.*

The depositional setting for the Homewood sandstone where it is coarser grained and conglomeratic was most likely upper delta plain in a braided stream setting with higher energy currents (Donaldson, 1972). These sandstones also are often seen associated with fine grained sediments containing brackish marine invertebrates overlying coal seams, indicating interdistributary bays and swamps; an association with a lower coastal plain environment as well (**Figure 14**).

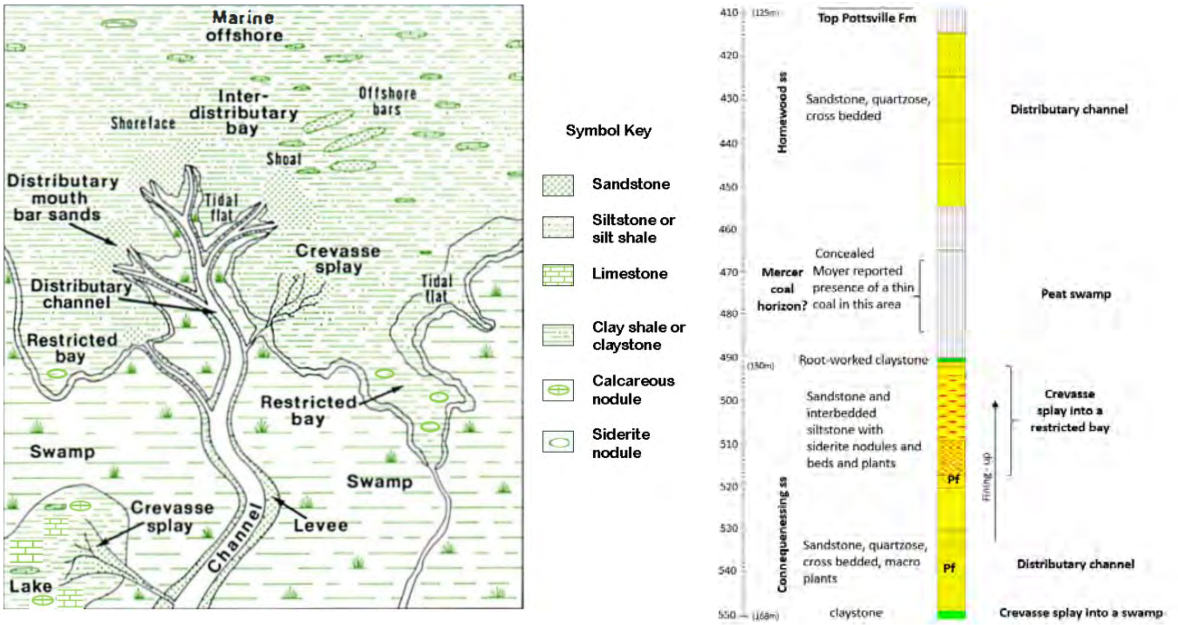


***Figure 14. Left** side: Generalized diagram showing depositional environments common to a Pennsylvanian delta (modified from Flores and Arndt, 1979). **Right** side: Pottsville Formation section exposed along the GAP and interpreted environments of deposition.*

Allegheny Formation

The contact between the Pottsville and Allegheny formation is concealed as is the basal 100 feet (30m) of the formation along the rail trail until you reach the outcrop of the Kittanning sandstone (See **Figures 2 & 4**). The Kittanning sandstone is present here as a 15 to 20 foot (5-6m) thick bedded, light gray (N8) to (5YR8/1), fine grained, micaceous sandstone with some thin carbonaceous streaks. The bedding is mostly tabular cross stratified, consisting of planar beds with angular basal contacts but some appear to be tangential. Beds range from 0.2 (6cm) to 1 ft (30cm) in thickness. The cross bed set tops have an apparent dip of 8 to 10 degrees to the northwest, azimuth 308. Beginning approximately 20 feet (6m) above the Kittanning sandstone, a continuous section extends from the middle Kittanning coal to the upper Freeport coal at the top of the formation. A 23.5 inch thick (60 cm) coal seam was reported by Moyer (1940) at the very base of this interval. This coal lies at the Middle Kittanning horizon. Even though the underclay can be found beneath the talus, excavation by hand has only been able to uncover chunks of loose coal. Above this coal horizon is a more than 30 foot (9m) thick sequence of carbonaceous shale with siderite nodules, lenses and bands that also contains brackish marine fossils (**Figure 15**).

A 15-foot (6m) sequence occurs above this interval that contains calcareous claystone, with calcareous and dolomitic nodules, capped by a 2.5 foot of dolomitic limestone bed, which is the Johnstown limestone. X-ray diffraction analysis shows it to be 56% dolomite, 39% calcite, and 5% quartz. A few feet above the Johnstown limestone lies the upper Kittanning coal seam 2.3 ft (70cm) thick with a 1.15 foot (35cm) parting separating 5 inches (1.5cm) coal and boney coal at the top. In the immediate area, there is little evidence of mining on this seam (**Figures 16 and 17**).

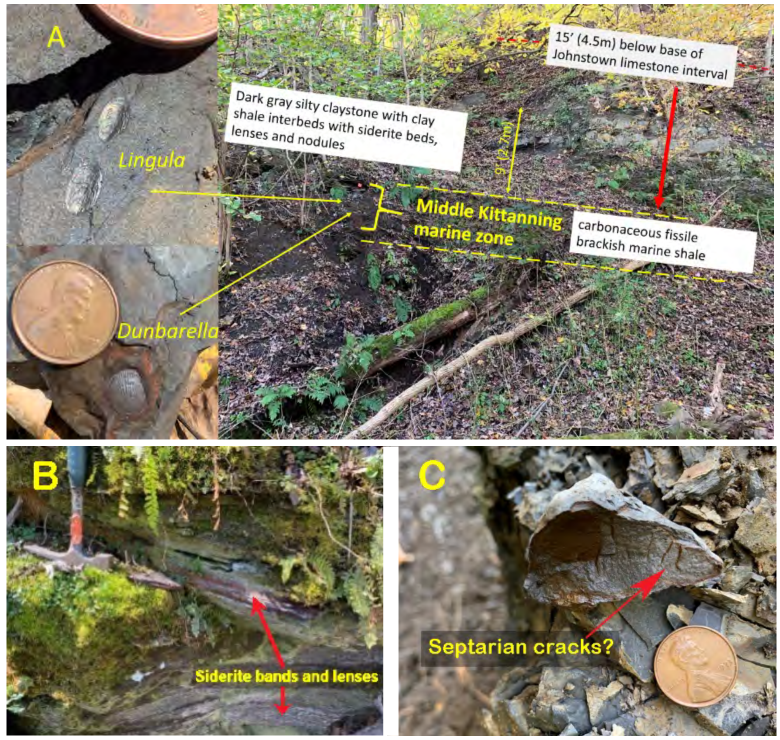
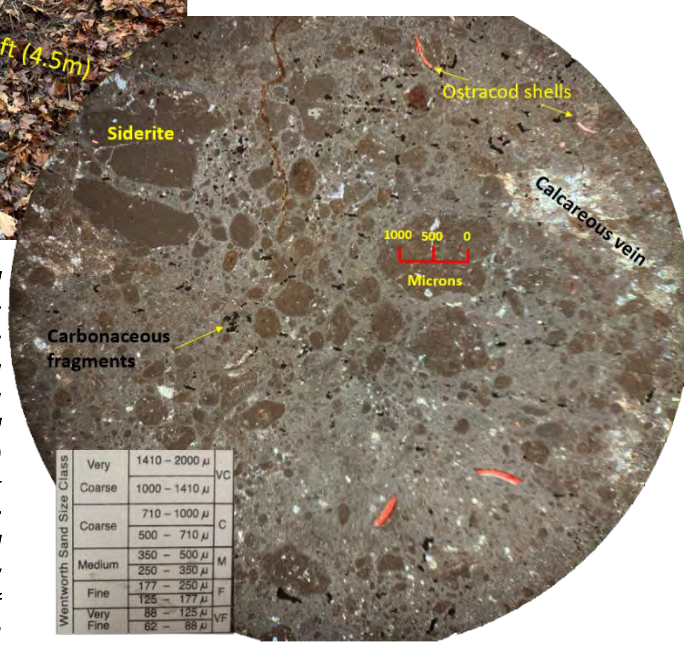


Figure 15 (A): *About in the middle of this 30 foot (9m) sequence is a thin zone of brackish marine fauna representing a restricted bay environment (Donaldson,1972).* ***(B):*** *Siderite bands and lenses are common in this interval. X-ray diffraction analysis of this layer 85% siderite, 11% quartz and 3% Muscovite. This might have been considered a minable source of iron ore in the late 1700's to early 1800's.* ***(C):*** *Irregular shaped nodules appear to have been formed early in the diagenetic process before the main stage of compaction with lamination in the host sediment being deflected around them. Some nodules appear to have either root traces from plants growing in shallow water or septarian cracks possibly formed from contraction through dewatering soon after their formation (Tucker, 1982). X-ray diffraction analysis showed these to contain 60% quartz, 10% Kaolinite, 12%, Muscovite, 3% Siderite, and 15% dolomite. The dolomite could indicate a drying out of a lake or pond to increase the salinity that favored dolomite precipitation and expansion cracks*

Figure 16. *Photo above of the Upper Kittanning coal and Johnstown limestone section exposed along the GAP near the access road to the trail head parking area (Figure 2). The Johnstown limestone interval at this location consists of a claystone with dolomitic and calcareous nodules, overlain by a dolomitic limestone bed at the top. This stratigraphic interval most likely represents a lake or intertidal pond (Davis, 1983) environment that received fine gained sediments until it became more isolated from sediment influx, which led to the formation of more carbonates. Dolomite can be produced penecontemporaneously from the original carbonates by increasing the salinity such as would occur in the drying out of a lake and then flooding it again (Bathurst, 1975) or by flooding a hypersaline lagoon with hurricane rains (Folk,1974).*

Figure 17. *Photo below from a thin section of the Johnstown limestone horizon, a nodular dolomitic limestone bed using Folks classification. Intra-clasts up to pebble size in a micritic matrix could represent burrowing. Calcareous veins and along with carbonaceous fragments and possibly Ostracod shells are also present which support the idea that this was deposited originally as a limestone in a freshwater lake and later dolomitized.*



This interval in conjunction with the one just below it, containing the brackish marine zone above the middle Kittanning coal, is a key stratigraphic interval of beds in the Allegheny formation. It is the only place where a brackish marine unit is overlain by a freshwater limestone or penecontemporaneous dolomitic limestone. In southwestern Pennsylvania, the lowest freshwater limestone or limestone of any origin is the Johnstown limestone, but without the brackish marine zone below, it could be easily mistaken for a limestone under the stratigraphically higher lower or upper Freeport coals. The same holds true for the brackish marine zone above the middle Kittanning coal since brackish zones can occur over the lower Kittanning, Clarion and Brookville coals, stratigraphically lower down in the Allegheny formation. In northwestern and west-central Pennsylvania, the Vanport limestone is present above the Clarion coal but it is a marine limestone and would not be confused with the Johnstown limestone. Depositionally, this sequence could be generalized (**Figure 18**), beginning at the base with a coastal swamp (middle Kittanning coal), transgressed by a restricted bay (middle Kittanning brackish marine zone). The bay eventually became cut off to form a lake, that initially filled with fine grained sediments from crevasse splays or small feeder streams. Then with time became more sediment-starved and eventually dried up to form a dolomitic limestone (Johnstown). Later sediment influx filled the lake to a level to which the water depth would support plants and created another swamp (upper Kittanning coal). This swamp received periods of sediment influx before being totally overwhelmed with crevasse splay sediments (Freeport sandstone).

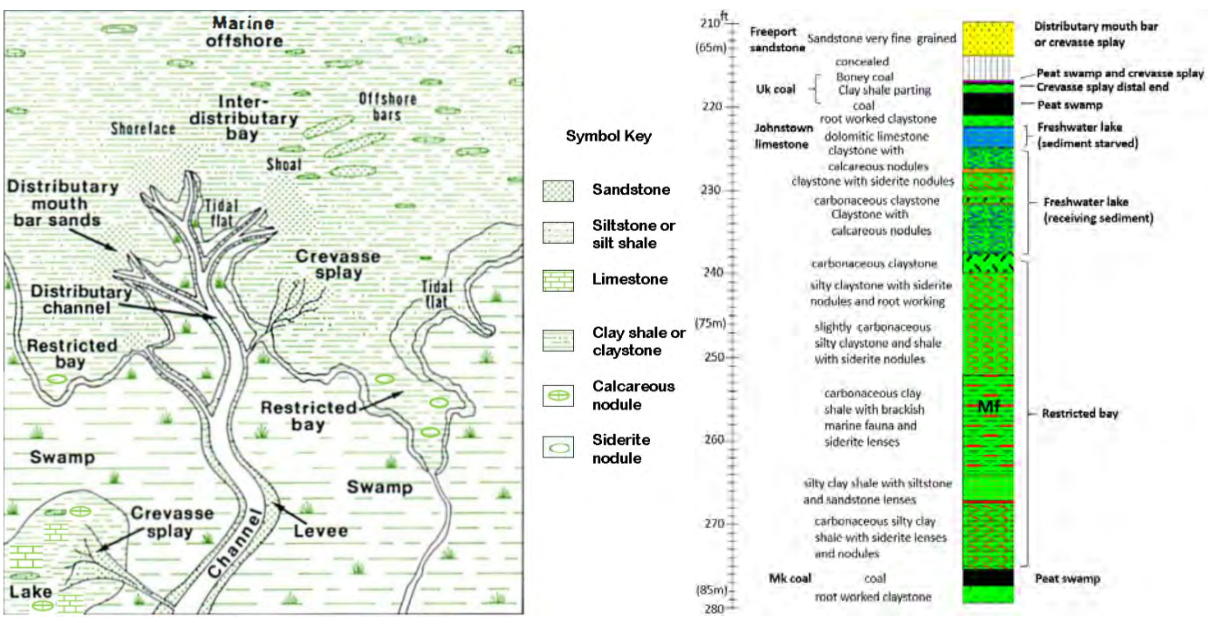


Figure 18. Left side: *Generalized diagram showing depositional environments common to a Pennsylvanian delta (modified from Flores and Arndt,1979).* ***Right side:*** *Approximate middle third of the Allegheny Formation section exposed along the GAP and interpreted environments of deposition.*

A flint clay lies above the Freeport sandstone and is overlain by a limestone bed and root worked underclay (Moyer,1940) and is in turn overlain by the lower Freeport coal. The lower Freeport coal was mined along the GAP trail by the commercial American Manganese Manufacturing Company (AMMC) and a small local operation known as the Hurd Mine (**Figure 19**).

The Hurd mine which borders the GAP was in operation during the 1920's and from available mine maps, appears to be connected to the AMMC Furnace No. 1 mine. When the mines were abandoned in the 1920's the entries were likely not sealed and water could flow freely from the AMMC workings

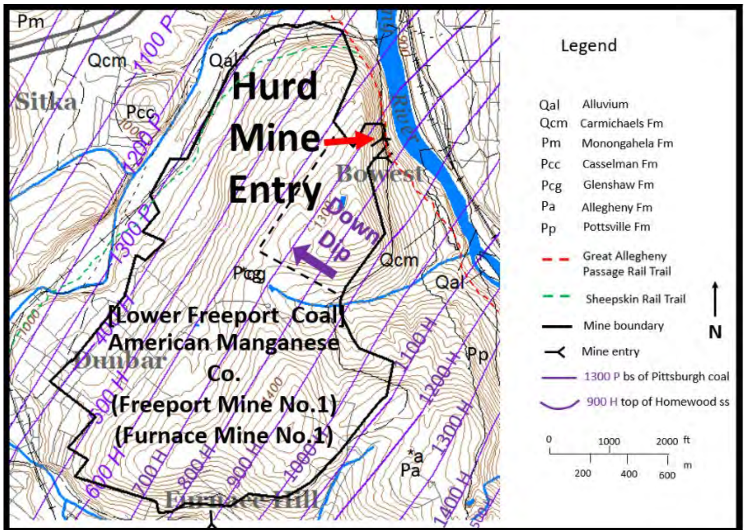


***Figure 19** shows the location of both the Hurd mine and the AMMC's Freeport (Furnace) No. 1 mine. Structure contours projected on the top of the Homewood sandstone show a possible 100-acre recharge area over the workings, with a several hundred feet of head that contributes water to the Hurd mine near the GAP trail.*

into the small Hurd mine, where it discharged through one of the Hurd mine drift openings. The discharge did not seem to be much of an issue while the Western Maryland railroad line was active; they protected the tracks by directing flow with ditches. When the track was abandoned in the 1970's and then converted into a rail trail in 1981, the discharge became a problem as the trail ditches became clogged and the water flowed over and eroded the trail. In 1991, about 10 years after the rail trail was established through this area, the Department of Environmental Protection, Bureau of Abandoned Mining Reclamation (BAMR) was asked to remediate the discharge (Hawk, 2021). DEP excavated the Hurd entry with a backhoe, installed five pipes into the entry to re-route the water under the trail and to then to the Youghiogheny River, then backfilled with stone (Joe Stepusin, PADEP, 2/13/20). The discharge, remediation effort and results are illustrated in **Figures 20** and **21**.

***Figure 20.** Photos from the pipe installation and water drainage project undertaken by BAMR in 1991 along the Great Allegheny Passage rail trail. Upper left: original Hurd mine opening. Top right: mine water flowing over and washing out the rail trail. Lower left: process of covering over outlet pipes in main entry. Lower right: installation of drainpipes under the rail trail.*

The main bench of the lower Freeport is overlain by thin shale and a thin rider coal followed by a carbonaceous clay shale with siderite nodules. This is overlain by a 25 foot (8m) fining-upward sequence beginning with a fine-grained sandstone (Butler), siltstone, claystone (Upper Freeport, Stevenson, 1878) which lies under the upper Freeport coal horizon at the top of the Allegheny formation. The upper Freeport coal at this location is represented by a boney claystone containing thin lenses of coal contained in a 1.5 foot (48cm) interval. The Mahoning sandstone, at the base of the overlying Glenshaw formation above the upper Freeport coal, has eroded down onto it and has completely removed it in some locations (**Figure 22**).

***Figure 21** is a photo of the same section of trail today where the lower Freeport coal seam intercepts the GAP trail.*

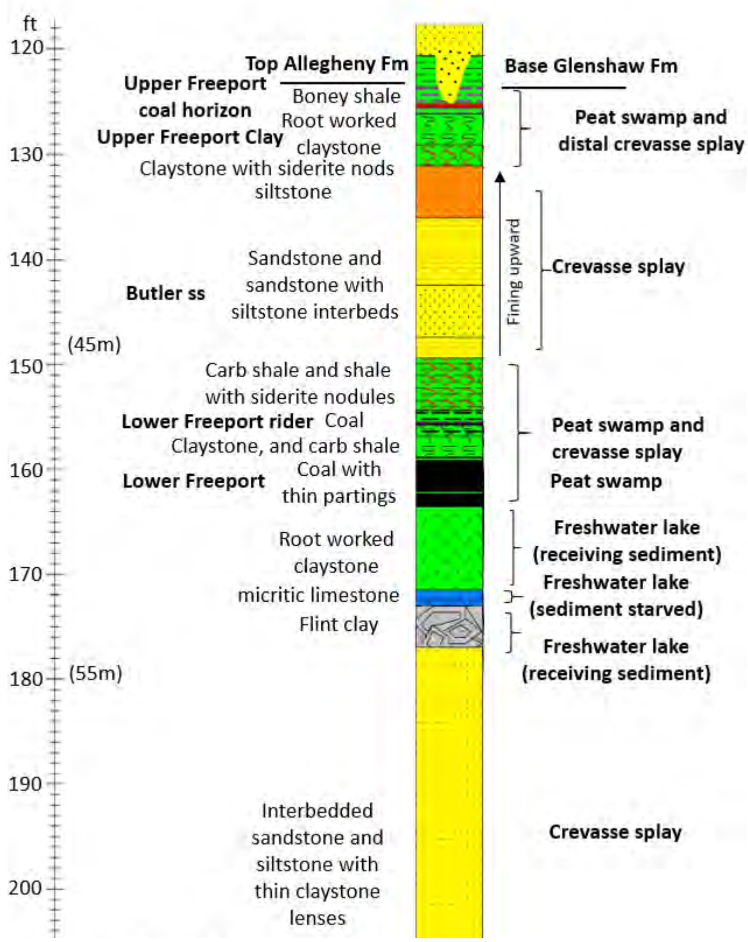


***Figure 22** shows approximately the top 1/3 section of the Allegheny Formation exposed along the GAP rail located just to the east the trailhead parking lot access road and the interpreted depositional settings.*

The depositional history of the of the lower and upper Freeport interval consists of two fining-upward sequences, beginning with the Freeport sandstone, a distributary channel and crevasse splay deposit, which slowly became isolated from sediment input to form a lake, represented by flint clay and micritic limestone. The lake developed into a swamp that developed a thick peat (lower Freeport). Coal formation was interrupted by a small crevasse splay deposit, becoming isolated again to form a rider coal (lower Freeport rider). The rider coal is overrun again by another, larger fining-upward crevasse splay, but is never fully isolated to form a peat swamp (upper Freeport) that still received frequent inputs of fine grained clastics (**Figure 22**).

Glenshaw Formation

The lower boundary of the Glenshaw Formation lies at the top of the upper Freeport coal bed. This boundary coincides with Rogers' (1858) base of the "Lower Barren Measures" that extended to the base of the Pittsburgh coal bed, so named because of a paucity of minable coal beds or other beds of economic value. This interval was renamed Conemaugh series by F. Platt (1875) for exposures along the Conemaugh River valley in the Allegheny Plateau of western Pennsylvania. Following Roger's terminology this part of the section was mapped by J.J. Stevenson in 1878 in his Geology of Fayette and Westmoreland district Part l and ll, as part of the Lower Barren measures. In the 1903 Connellsville-Brownsville Folio this same outcropping was remapped as the Conemaugh Formation by M.R. Campbell, and Hickok and Moyer, in the 1940 report, Geology and Mineral Resources Report of Fayette County, recognized it as the Conemaugh Group. The Conemaugh Group was then subdivided by Flint (1965), while working in southern Somerset County into the Glenshaw, characterized it by a series of laterally persistent marine limestones often associated with underlying thin coals, and the overlying Casselman Formation that lacked distinctly marine limestones. In 1980, on the state geologic map of Pennsylvania, this area was relabeled the Glenshaw formation. It has remained unchanged since then (Shaulis and McElroy,1988; Shaulis, 2020). The Mahoning sandstone lies at the base of the Glenshaw formation in this area. The Mahoning sandstone either rests on top of the upper Freeport coal (**Figure 23**) or erodes part way down through it in the area exposed along the rail trail.

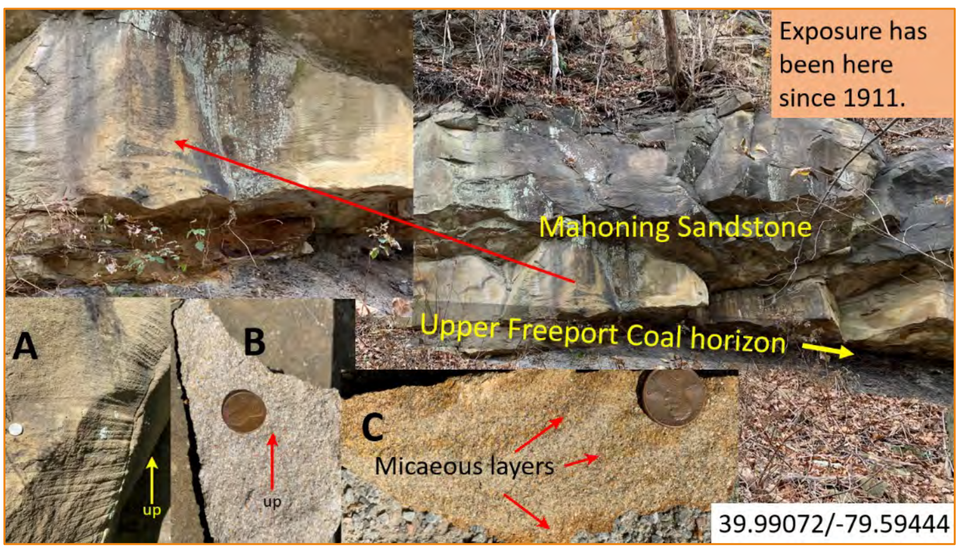


Figure 23. *Differential weathering on lower 8 feet (2.5m) of the Mahoning sandstone photo insert **(A)** and top photos; Photo insert **(B)** is normal to bedding and shows grains surrounded by secondarily coated iron stained grains; Photo insert **(C)** shows micaceous layers alternating on a surface that cuts across the bedding planes a slight angle perhaps ½ inch (1cm) thick.*

At this location the Mahoning sandstone consists of 50-foot (15m) overall fining-upward sequence of sandstone. It is more medium-grained and thicker bedded in the lower half with some fine-grained to siltier and thinner beds in the middle to upper half. The bottom 3 feet (1m) erodes, in places, down into the underlying upper Freeport coal horizon and contains ripped-up pieces of coal and carbonaceous fragments, channel lag deposits, consisting of sideritized shale clasts, and has a hummocky, undulatory, erosional base. This is overlain by 8 feet (2.5m) of medium-to fine-grained, micaceous sandstone with kaolinite surrounding some of the grains (**Figures 24** & **25**). On a few of the flatter, vertical surfaces that were exposed during the construction of the Western Maryland Railroad bed in 1911 (Metzger, 2003) are layers that contain a concentration of mica flakes or kaolinite grains that have weathered differentially to reveal fine cross bedding within the larger more horizontal beds. X-ray analysis of multiple samples in this interval shows these strata to be made up of Quartz, from 66-91%, Kaolinite, from 9-21% and Muscovite from 0-13% but averaging 7%.

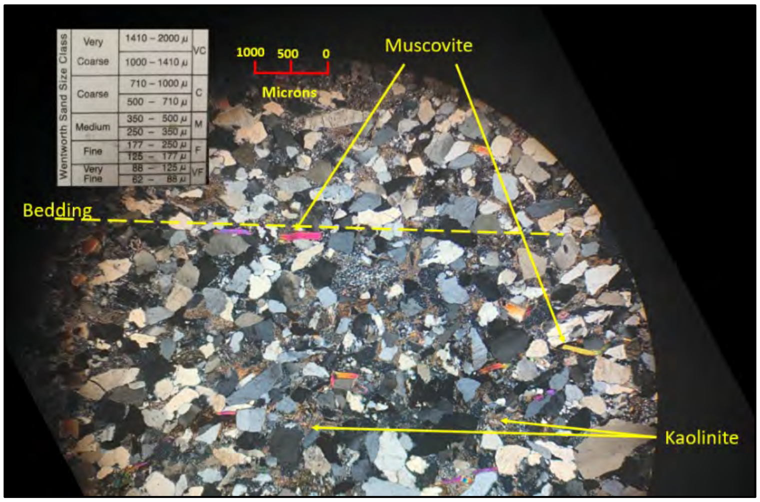


Figure 24. *Photo of a thin section from near the base of the Mahoning sandstone showing the kaolinite cement (brown) surrounding quartz grains which are primarily medium in size but range from fine to coarse, moderately well sorted. Elongated quartz gains and mica flakes are aligned parallel to bedding. Vein quartz and a few polycrystalline recrystallized metamorphic quartz grains. Some siltstone clasts. Sublitharenite probably with about 5 percent porosity (Folk,1974)*

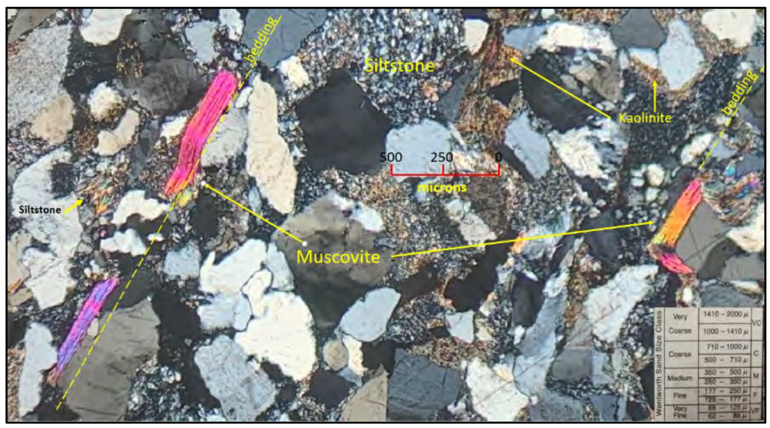


Figure 25. *Enlarged photo of thin section. Right center shows elongated crystals of mica displaying the ductile deformation of detrital muscovite grains ductile around rigid quartz grains during compaction. The more ductile fragments like siltstone have been pushed into the pore spaces and also surround the more rigid quartz grains along with the kaolinite.*

About 60 feet (18m) above the top of the Mahoning sandstone, exposed high up on the steep slope above the rail trail just a few 100 feet (30m) south of the intersection of the Sheepskin Trail, the Brush Creek coal and overlying carbonaceous clay shales of the Brush Creek Marine Zone can be seen, especially in leaf off conditions. Several large trees have uprooted and removed the soil cover to expose this part of the section (**Figure 26**).

Figure 26. *Photo, left, from 3/12/2020, is shortly after a large tree uprooted and exposed a section containing the Brush Creek coal and marine zone.*

The Brush Creek limestone was named by I.C. White in 1878 for outcrop along Brush Creek in Cranberry Township in Butler County. Stevenson (1878) referred to it as the Philson coal. With some effort, you can climb up there and get a good look at a little over a 1 foot (30cm) thick boney coal seam overlain by a highly carbonaceous shale that contains marine invertebrates (**Figure 27**).

No concentration of marine invertebrates form a coquina limestone bed over the coal, as is normally the case in some areas. The outcrop is very weathered and it is difficult to collect good fossil specimens from this site.

Under the coal is a 4 foot (1m) root worked claystone and under that a 2 foot (60cm) argillaceous freshwater limestone underlain by 4 foot (1m) of claystone and siltstone with possible calcareous inclusions.

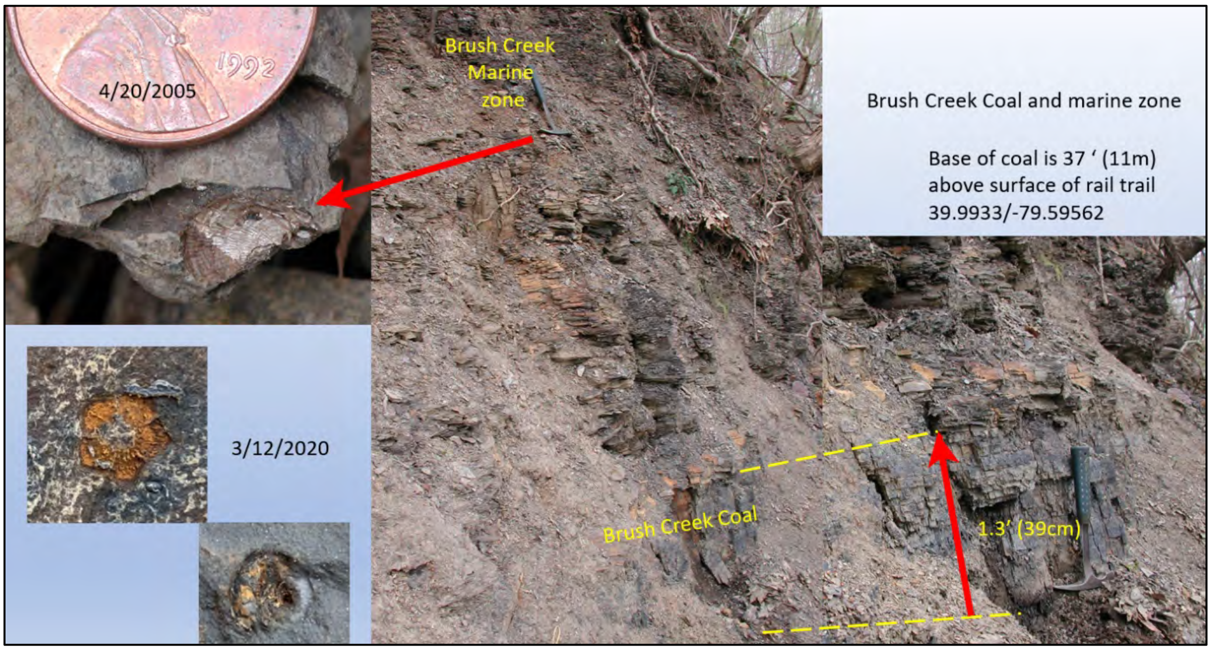


Figure 27. *Photo shows close up of the Brush Creek Coal and several marine fauna found in the shales just above the coal.*

Upward from the base of the Glenshaw Formation at this location **Figure 28** shows the environmental depositional sequence, which is: filling in of a peat swamp (Upper Freeport coal) by a distributary channel or large crevasse splay of fining upward deposits (Mahoning ss); the channel/splay abandons the area which then subsides into a lake (clay and siltstone stone with calcareous veins); then a sediment starved lake forms (limestone); crevasse sediments fill lake (rooted claystone); a coastal peat swamp forms, with intermittent crevasse splay deposits (Brush Creek coal with shale partings); followed by the transgression of interdistributary bay deposits (Brush Creek marine zone dark shale with marine fossils). The depositional setting was a subsiding lower delta plain with lakes that filled in with sediment to become swamps that eventually subsided, or water levels rose and transgressed to cover over the coastal landscape with nearshore marine to interdistributary bay sediments (Ferm and Horne, 1979).

In leaf on conditions it will be difficult to see the interval above the Mahoning sandstone.

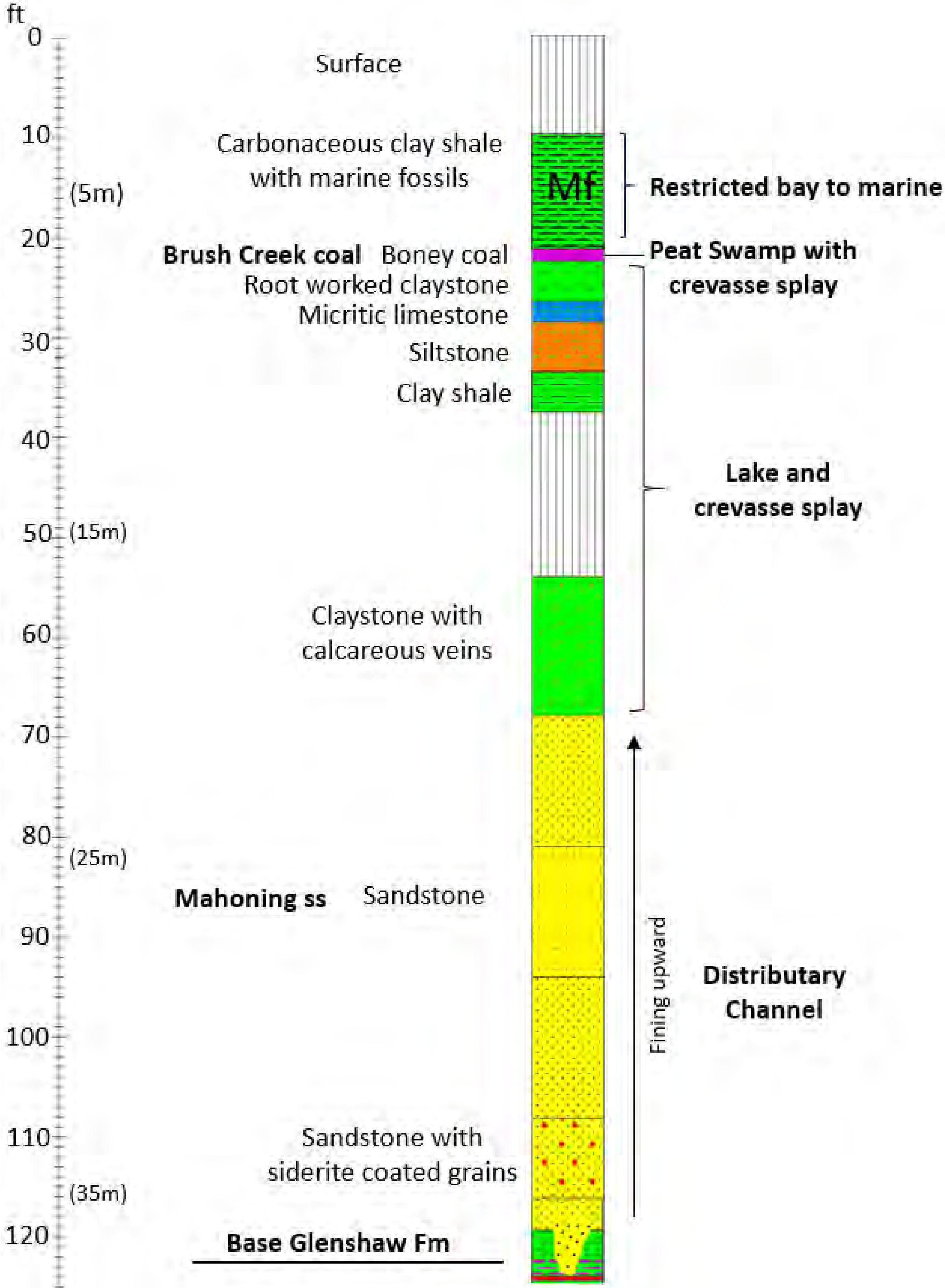


Figure 28. *Left side diagram shows approximately the lower 1/3 of the Glenshaw Formation exposed along the GAP trail that extends from the Sheepskin Trail connection south 1000' (304m) with interpreted depositional settings (right).*

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THE AMERICAN MANGANESE MANUFACTURING COMPANY

AND REMEDIATING THE ABANDONED HURD MINE DISCHARGE

JOAN HAWK. P.G. – NORTHERN ALLEGHENIES GEOLOGIC SOCIETY

Abstract

The American Iron and Manganese Manufacturing Company (AMMC) made only a fleeting appearance on the stage of the Connellsville area coke region history. The region already had much of its coal mining and coke making years behind it when, in 1914, AMMC purchased the holdings of the Dunbar Furnace Company in Fayette County and manganese and iron ore from the Minnesota companies, Cayuna-Mille Lacs Iron Company and Cayuna-Duluth Iron Company. These acquisitions provided AMMC with the raw materials needed to make ferromanganese, a critical component in making steel. AMMC was the first company in America to manufacture ferromanganese for the open market. AMMC was soon mining coal, producing ferromanganese, and making coke; but just nine years later it was all over. The properties were sold; the mines were idled, the furnaces and ovens that had produced coke and ferromanganese were torn down and sold for scrap.

A few small-scale mining operations coexisted with the large-scale operations; one of these was the Hurd mine. The Hurd mine was a small mine that operated adjacent to AMMCs Furnace No. 1 mine, and mined coal about the same time that AMMC was winding down its operations. Its legacy is an alkaline discharge that continued to flood and erode the Great Allegheny Passage trail until 1991, at which time it was redirected under the trail, and ultimately to the Youghiogheny River. It is possible that the little Hurd Mine intercepted the workings of its much larger neighbor, creating a larger volume than would be expected from the Hurd mine alone.

The Beginning

A demand for manganese alloys was created with the use of the Bessemer and open-hearth process of making steel in the 1870s (Hewitt, 1917). In the first quarter of the last century 14 pounds of ferromanganese, which contains 77 to 80 percent manganese, was added to every ton of steel produced in open hearth furnaces, whereas poorer quality spiegeleisen was used in the Bessemer process (Hewitt, 1917). The ferromanganese was made in the typical iron blast furnaces (Hewitt, 1917) that were found in the Connellsville area.

The following appeared in the Connellsville Weekly Courier on April 23, 1914:

> ***PLAN MANGANESE MANUFACTURE FOR THE OPEN MARKET***
>
> ***Dunbar Furnace is part of the Deal to Open American Trade***
>
> ***FOREIGNERS NOW IN CONTROL***
>
> *In Pittsburg[h] the plans of the company are arousing keen interest. If it is formed, and proceeds with its plans , it will be the first company to manufacture manganese for the open market in America. The Carnegie Steel Company has been a producer of manganese from imported ores for the Steel corporation furnaces and mills for some years but has never done much with the open market, frequently having to purchase ferro-manganese from abroad to supplement its own supply. In extremely dull times it has sold manganese in small lots. All other manganese is from English and German producers and until the new Underwood tariff law took effect importations of manganese were made with a stiff duty on it. It is now free of duty.*

On December 31, 1913 the newly formed American Manganese Manufacturing Company (AMMC) had filed papers as a Pennsylvania Domestic Business Corporation (PENNLine, 2021). On July 1, 1914, AMMC purchased the holdings of the Dunbar Furnace Company, which included 7,000 acres of land, all the properties and capital stock of the Dunbar Furnace Company, the Dunbar Coal & Coke Company, 160 shares of the New Haven & Dunbar railroad, 25 shares of the Dunbar Electric Company, 10 shares of the Dunbar Water Company and the interest of the furnace in the company (Connellsville Weekly Courier, July 9, 1914). The transfer also included the acquisition of manganese ore in Minnesota held by the Cayuna-Mille Lacs Iron Company and an iron ore deposit held under the name of Cayuna-Duluth Iron Company (Connellsville Weekly Courier, April 23, 1914). The acquisition of the ore deposits was to enable AMMC to produce ferromanganese in America for American blast furnaces and steel work, and was the first company to manufacture manganese for the open market in America (Connellsville Weekly Courier, Apr 23, 1914). Dunbar Furnace Company "includes not only two stacks, but a silica sand plant, a by-product coke plant and a terminal railroad, electric powerhouse and much modern equipment. It is said that the furnace property is well located for a manganese producing center" (Connellsville Weekly Courier, Apr 23, 1914). With the acquisition of the Minnesota manganese and iron ores, ferromanganese production would soon follow in Pennsylvania. The purchase also included the coal mines of the Dunbar Coal & Coke Company; notably the Furnace No. 1 mine (Former Freeport No. 1 mine), which abuts the Great Allegheny Passage trail.

A quote from *Dunbar: The Furnace Town* (1983, Dunbar Centennial Committee)

> *For years, Dunbar's iron industry must have been an amazement to Pittsburgh industrialists. Here, iron was made with coke on a continuous basis since 1854. Pittsburgh did not have a successful iron furnace until 1859; for they had no local iron and they encountered problems with their large capacity furnace, which Dunbar had seemingly solved.*

Dunbar Furnace Company

Dunbar Furnace, originally Union Furnace, was built on Dunbar Creek, a tributary to the Youghiogheny River, in 1791 by prominent Fayette County resident, Isaac Meason. A second, larger furnace was built in 1793 by Meason, Dillon & Co., further downstream of the original furnace and named Union Furnace 2 (Hughes, 1931). In 1844 it was enlarged and renamed Dunbar Furnace (Hughes, 1931). A hot-blast and blowing engine was added circa 1852 (Heald et al., 1990). The furnace went through several owners until 1860 when it was bought by the Youghiogheny Iron and Coal Company (Heald et al., 1990). In 1871 it was reorganized as the Dunbar Iron Company, and later renamed the Dunbar Furnace Company (Hughes, 1931). In 1875 Dunbar Furnace Company installed a laboratory for the analysis of iron ore; both Lake Superior and native carbonate ores were used (Heald et al., 1990).

In 1895 the Dunbar Furnace Company installed Semet-Solvay by-product coke ovens, which was an unusual move since their by-products were used in the manufacture of steel. Typically, by-product ovens were constructed near their end-users – steel plants, e.g., Pittsburgh; however, at Dunbar, they instead were located close to the coal source (Heald, 1990) and shipped the coke to steel-producing centers (Heald et al., 1990)

The conversion of coal to coke results in the production of gases, including ammonia, that could be refined into oils, dyes, fertilizers, explosives, tars, and pitch, which could be sold. The older beehive coke ovens simply emitted these gases into the atmosphere; however, by-product coke ovens captured the gas and used it to heat the ovens (NPS, 1992). By-product ovens converted a little more than 73% of the coal to coke, while beehives produced about 69% (Diciccio, 1992, in, NPS, 1992). In addition, by-products reduced coking time from the typical 24 to 48 hours for beehives to 12 to 24 hours for by-products ovens (NPS, 1992).

Although by-product ovens were more efficient and economical in the production of coke, and produced a commodity that could be sold, the operators in this region were reticent to invest capital in by-product coke ovens. This was primarily because they cost more to build than beehives. A beehive oven cost $300, whereas a by-product oven cost from $1,600 to $2,200 (Enman 1962, 308, in NPS, 1992). At the turn of the [last] century, Pennsylvania's beehive ovens still made more than 65% of United States coke and most of these operations were in the Connellsville region (Henderson et al. 1990, 213).

The American Manganese Manufacturing Company

When AMMC purchased the furnace holdings it gained access to raw materials for the production of iron including coal, iron ore, limestone, sand, clay, bluestone and timber (Heald et al., 1990). AMMC began production of manganese alloys, ferromanganese, spiegeleisen, high manganese iron, and various grades of pig iron. The 80-percent ferromanganese manufactured at Dunbar was, reportedly, the highest quality produced in the United States (Heald et al, 1990). Ferromanganese is best suited for steel production in open-hearth steel furnaces, whereas spiegeleisen, with a much lower manganese content of 12 to 33 percent, was best suited in the older Bessemer steel-making process. The source of AMMC's manganese was the Lake Superior ores that were included with their purchase of Dunbar Furnace Company holdings.

The coal for making coke in the AMMC's by-product coke ovens was obtained from their Furnace mines, across the Youghiogheny from Connellsville, near Dunbar, and was washed in AMMC's nearby coal-washing plant (Hickok and Moyer, 1940) to remove impurities prior to making coke. The Furnace No. 1 mine abuts the Great Allegheny Passage (GAP) trail. Originally identified as being in the Upper Freeport coal on mine maps prepared by the Works Progress Administration (WPA) in the 1930s and in Pennsylvania Geological Survey County Report 26 (Hickok and Moyer, 1940), the Furnace No. 1 mine likely lies in the Lower Freeport Coal. This is supported by mine maps that shows a heading of the small Hurd Mine, which has been correlated to lie in the Lower Freeport Coal 1 (Shaulis, personal communication, 2020), intercepting a down dip section of Furnace Mine No.1. The Hurd Mine opened in the early 1920s; however, little is known about the operator and whether this mine supplied coal to the local coke ovens at that time or at all. The Pittsburgh coal from the nearby Connellsville field was the best quality for producing metallurgical coke in old-style bee-hive ovens; however, the Upper and Lower Freeport coals, if washed or blended, were suitable for use in AMMC's product ovens at Dunbar (Davis, 1928).

During the time of coke production in the Dunbar-Connellsville area, coal for use in beehive ovens coal had to meet the following requirements (Davis, 1928):

- Volatile matter - ~ 32 %
- Oxygen - between 4 and 10 %
- Sulfur - not over 1.25 %
- Phosphorous under 0.02 %
- Ash - not over 7%

For use in by-product ovens coal, the requirements were: (Davis, 1928):

- Volatile matter - ~ 18% (with mixing)
- Sulfur - not over 1.5 %
- Phosphorous under 0.02 %
- Ash – 4 to 7%

AMMC had a good run, but it would soon come to an end. In the Spring of 1922, approximately two weeks after the United Mine Workers strike, AMMC ran out of raw materials. They reopened in May of 1923; however, they never quite recovered (Heald, 1990). AMMC failed on November 28, 1922 and the property was sold April 28, 1924 to the Dunbar Corporation (Heald et al., 1990). Within months of the sale, the works were dismantled and sold for scrap (Heald, 1990; Hickock and Moyer, 1940) and you would be hard pressed to find any trace of the once magnificent operation.

Post AMMC

The Hurd Mine

About the time that AMMC shuttered its operations, Washington Hurd (also spelled as "Herd") opened a small mine on the Lower Freeport coal located within what is shown in the location of the unmined block of coal at the northeast limit of the Furnace No.1 mine on **Figure 1**. **Figure. 2** shows the layout of Hurd mine workings (Pennsylvania Mine Map Atlas). Although the southern property line is cut off, the property shape closely matches the small unmined block shown in **Figure 1**. Dates on the Hurd workings indicate that coal was mined from circa 1921 to circa 1922.

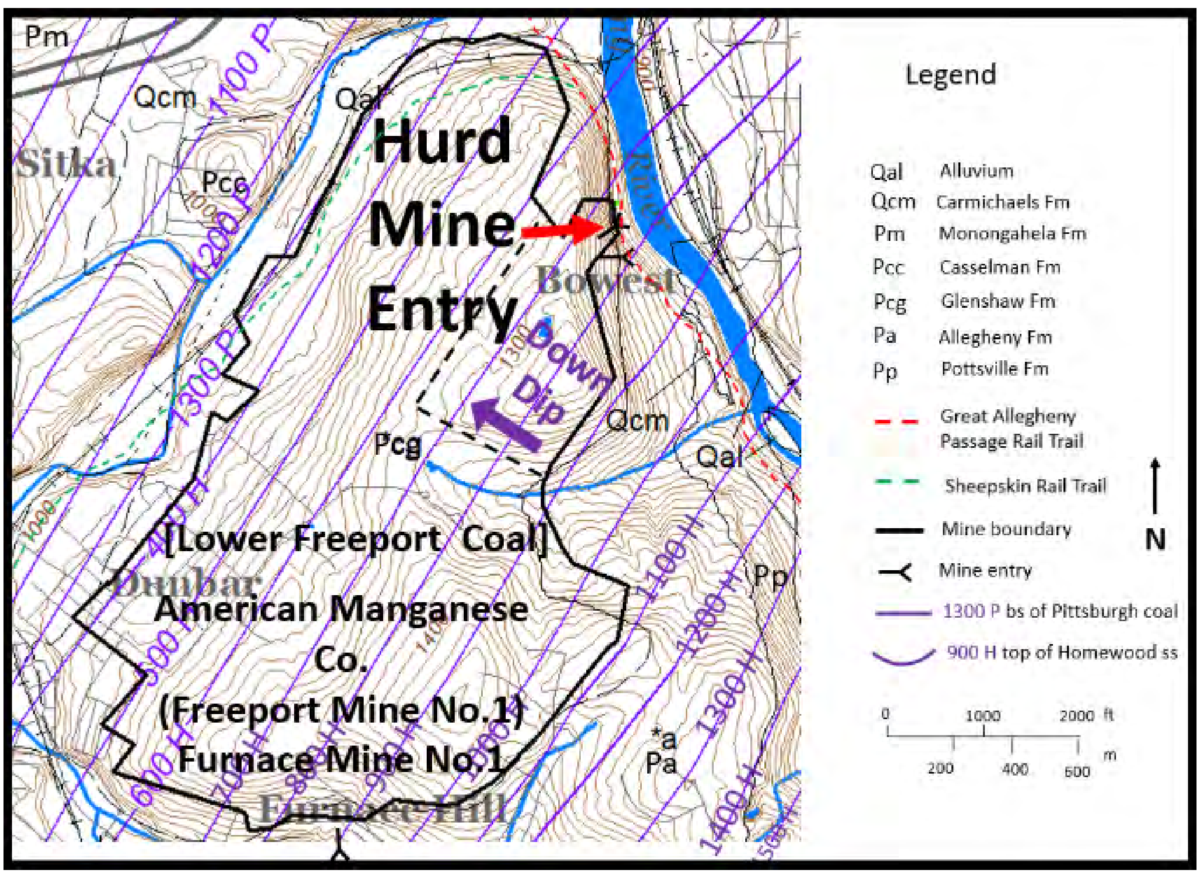

***Figure 1** shows the location of the Hurd Mine with respect to the American Manganese Co. Furnace (Freeport) No. 1 Mine.*

There is a discharge associated with the Hurd mine, which borders the GAP Trail. Discharge measurements and water quality analyses were obtained by Mike Timcik of the Department of Environmental Protection, Bureau of Abandoned Mine Reclamation. Measured flows were:

October 2020: 39 gallons per minute (gpm) or 56,160 gallons per day (gpd).
April 2021: 200 gpm or 288,000 gpd.

What is interesting, is that there is only a faint outline of the Furnace No. 1 mine workings visible on the Hurd map (**Figure 2**). Also interesting, is that a drift entry on the Hurd mine crosses eastward into the area of the Furnace No. 1 workings and towards the GAP Trail. A heading from this drift entry appears to intercept a heading of the Furnace No. 1 workings, with an annotation of "water." In addition, there are two other drift openings further south.

Figure 2. *Hurd Mine workings. Circle shows where a heading in the Hurd Mine intercepts a heading in the Furnace No. 1 mine. Black arrow indicates approximate north. Source: Pennsylvania Mine Map Atlas IUPAG_00530..*

Regardless of whether the Hurd Mine actually cut into the workings of the Furnace No. 1 Mine, the Furnace No. 1 mine covers an area of approximately 660 acres, a much larger area than the Hurd mine, which has an approximate area of 9 acres. In addition, unlike the Hurd mine, whose support pillars were left intact, large sections of the Furnace mine were pillared, likely leading to collapse of the roof, and creation of new fractures and bedding plane separations, which would facilitate ground water flow from the Furnace mine into the Hurd mine.

When both the Furnace No. 1 and the Hurd mines were abandoned, approximately 100 years ago, the up-dip entries on the Furnace mine and the entries on the Hurd mine were likely not sealed. As water entered the Furnace mine workings, it encountered the steeply-dipping clay floor beneath the Lower Freeport coal, and flowed via gravity toward the Hurd workings. When the Western Maryland Railroad made the cut to lay the track in 1911, the Hurd mine had not yet been opened. We do not know if the mine was discharging during active mining; however, it probably was based on the annotations on the mine map. After decades of water infiltration and accumulation, significant head would have built up and it would have been only a matter of time before a large discharge would have developed.

Figure 3. Photos from the pipe installation and water drainage project undertaken by BAMR in 1991 along the Great Allegheny Passage rail trail. Upper left: original Hurd mine opening. Top right: mine water flowing over and washing out the rail trail. Lower left: process of covering over outlet pipes in main entry. Lower right: installation of drainpipes under the rail trail.

The discharge did not seem to be much of an issue while the Western Maryland railroad line was active, they protected the tracks by directing flow with ditches. When the track was abandoned in the 1970s and later, converted into a rail trail in 1981, the discharge became a problem as the trail ditches became clogged and the water flowed over and eroded the trail. In 1991, about 10 years after the rail trail was established through this area, the Pennsylvania Department of Environmental Protection (DEP), Bureau of Abandoned Mining Reclamation (BAMR) was asked to remediate the discharge (**Figure 3**). DEP excavated the Hurd entry with a backhoe, installed five pipes into the entry to re-route the water under the trail and to then to the Youghiogheny River, then backfilled with stone (Joe Stepusin, PADEP, 2/13/20).

Water quality samples were collected by Mike Timcik, PADEP and analyzed at the PADEP-Bureau of Laboratories Harrisburg. Analyses indicates field pH values of 6. 6 and 6.1, elevated iron and sulfate; however, alkalinity exceeds acidity (**Table 1**).

Michael Timcik, PADEP BAMR (personal communication, November 17, 2020) provided a concise description of what happens in a deep-mine:

> *The water in the anoxic deep mine environment contains dissolved ferrous iron (Fe^{+2}). If the water is net acidic with low pH, it will need to be treated with alkaline material (caustic soda, hydrated lime, limestone) to raise the pH to facilitate the conversion of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}). Increasing the dissolved oxygen in the water by aeration would facilitate the transition to Fe^{+3} which then precipitates out.*
>
> *The Hurd discharge is net alkaline and within the proper pH range to facilitate precipitation without the addition of alkaline material and additional aeration. Once the water comes out of the anoxic deep mine environment, the dissolved ferrous iron (Fe^{+2}) immediately begins to oxidize to ferric iron (Fe^{+3}) and precipitates.*
>
> *The extent to which this process happens is proportional to the amount of dissolved oxygen present in the water. A rule of thumb is that 1.0 mg/L of oxygen is required to oxidize 6.99 mg/L of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}). The Hurd discharge contains ~6-7 ppm of dissolved iron, therefore, it would not require much additional dissolved oxygen for precipitation of iron to occur.*
>
> *If, in the future, iron reduction of the discharge is desired, a small holding pond could be installed to let the ferric iron (Fe^{+3}) settle out. The ferrous to ferric conversion would create some additional acidity, but the naturally high alkalinity levels present would compensate for that.*

HURD MINE WATER QUALITY DATA SUMMARY

Sample Date	Source	Flow (gpm)	pH (field)	pH (lab)	Specific Conduct. (umhos/ cm)	Temp. (field) (deg. C)	Net Acidity (lab "Hot") (mg/l)	Total Alkalinity (mg/l)	Total Fe (mg/l)	Total Al (mg/l)	Total Mn (mg/l)	Total Sulfate (mg/l)	Susp. Solids (mg/l)	Acid Loading (lbs/day)	Iron Loading (lbs/day)	Mn Loading (lbs/day)
Mine Portal Discharge at hillside above trail.																
10/29/2020	2148-001	39.0	6.6	6.4	1073	12.5	-86	111.00	6.62	<0.3	0.91	513.80	<5	-40.32	3.11	0.43
04/20/2021	2148-001	200.0	6.1	6.7	1023	12.8	-87.2	114.20	8.05	<0.3	0.87	446.60	<5	-209.63	19.35	2.10
Statistics																
	Count	2.0		2				2	2	0	2	2		2	2	2
	Max	200.0		6.7				114.20	8.05	0.00	0.91	513.80		-40.32	19.35	2.10
	Min	39.0		6.4				111.00	6.62	0.00	0.87	446.60		-209.63	3.11	0.43
	Average	119.5		6.6				112.60	7.34		0.89	480.20		-124.97	11.23	1.26
	75th Percentile	159.8		6.6				113.40	7.69		0.90			-82.64	15.29	1.68
	90th Percentile	183.9		6.7				113.88	7.91		0.91			-57.25	17.73	1.93

GPD

10/29/2020 **56,160**

10/04/20/21 **288,000**

Source: PADEP-Bureau of Laboratories Harrisburg

Abbreviations:

gpm = gallons per minute
gpd = gallons per day
mg/l = milligrams per liter
deg.C = degree Celsius
lbs/day = pounds per day
Fe = iron
Al = aluminum
Mn = manganese

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INCISION OF THE YOUGHIOGHENY RIVER THROUGH THE LAUREL HIGHLANDS DETERMINED BY A NEW RIVER TERRACE STRATIGRAPHIC AGE MODEL, OHIOPYLE STATE PARK, SOUTHWESTERN PENNSYLVANIA

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Abstract

New surficial mapping and dating of alluvial deposits along the Youghiogheny River in southwestern Pennsylvania has generated a new terrace stratigraphic model linking well-known deposits of the Carmichaels Formation with terraces further upstream through Ohiopyle State Park. Flights of four to six terraces are found in three distinct zones with gradients that are subparallel to the channel, including a steep convex reach of the river. Numeric ages obtained from 25 terrestrial cosmogenic nuclide (TCN) samples and one optically stimulated luminescence (OSL) sample constrains the timing of terrace genesis on the Youghiogheny River, over the past 1.2 Ma, with terrace deposition coinciding with glacial climates. TCN burial and isochron ages of ~610 ka and ~300-350 ka are used to construct long-term incision rates ranging from ~20 m/Myrs upstream of Ohiopyle where the channel gradient and subparallel terrace profiles are gentle to ~50 m/Myrs downstream of Ohiopyle where the river profile is steeper in a broad convex knickzone. There were at least two base level falls totaling ~81 m conflated in the knickzone between Ohiopyle and Connellsville, the top of which includes Ohiopyle Falls and is retreating at a rate of ~1 cm/yr. Of the total base level fall, ~45 m is likely attributed to the draining of Glacial Lake Monongahela and formation of the Ohio River now dated at ~1.8 Ma by TCN burial ages on type-Carmichaels lacustrine facies exposed along the river in the Pittsburgh low plateau. The other ~36 m is attributed to non-uniform uplift of the Laurel Highlands, with a hinge more or less at Connellsville, which may be ongoing.

Introduction

Fluvial terraces have long been used to reconstruct the incision histories of rivers that are known to be driven by unsteady changes in climate and base level (Pazzaglia, 2013). Rivers draining the Laurel Highlands in southwestern Pennsylvania are inherited from a syn-Appalachian drainage that has been impacted by several, major post-orogenic changes in base level ranging from the formation of the Atlantic passive margin to the integration of the Ohio River (Granger et al., 2001). Evidence for these base level changes are encoded in several steep channel reaches called knickzones that also locally coincide with steep-walled gorges incised through structural and topographic highs. The Youghiogheny River, a major tributary of the larger Monongahela catchment, rises at the continental divide near the Allegheny escarpment and flows northwest nearly orthogonal to the Laurel Highlands before joining the trunk Monongahela River in the Pittsburgh low plateau (Figure 1). Like all rivers draining this part of the Appalachians, the Youghiogheny River is flanked by fluvial terraces that, in their downstream reaches, have an unclear relationship with the former Glacial Lake Monongahela and associated deposits of the Carmichaels Formation (Campbell, 1902; Harper, 1997, 2002; **Figures 1c, 2**).

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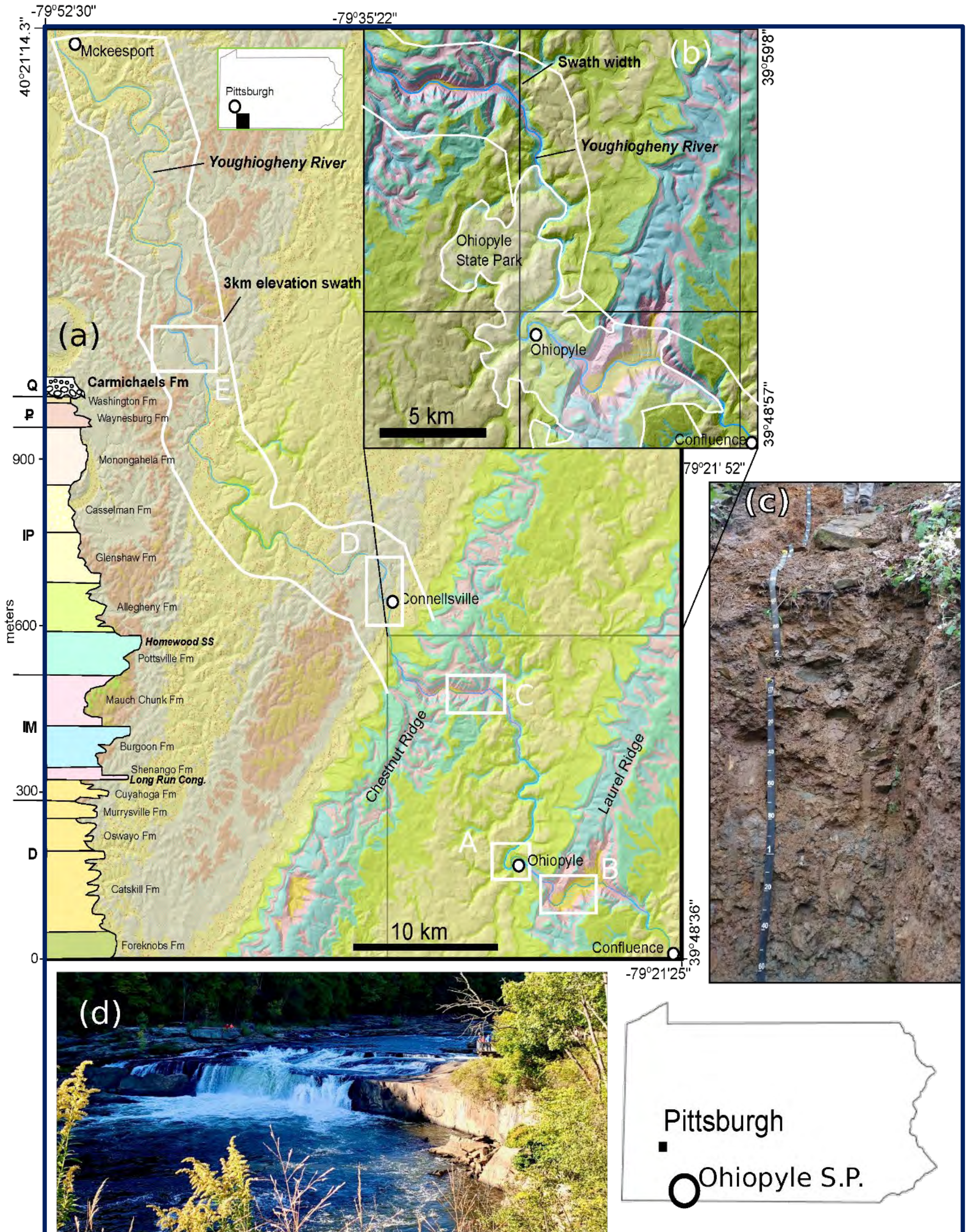

Figure 1: ***(a)*** *Geologic Map showing underlying stratigraphy for the mapped section of the field area between Confluence, PA and McKeesport, PA. White boxes represent locations shown in Figures 4 and 5: A=Ohiopyle, B=Victoria Bend, C=Camp Carmel, D=Connellsville, and E= Cedar Creek Park.* ***(b)*** *Inset map showing the geology of the area surrounding Ohiopyle State Park and the Youghiogheny River Gorge in more detail.* ***(c)*** *Example of the Carmichaels Formation as exposed along the Youghiogheny River, see Figure 6 for details. Lower tape for scale is 2 m long.* ***(d)*** *View of Ohiopyle Falls as seen from the Ohiopyle State Park visitor center in Ohiopyle, PA.*

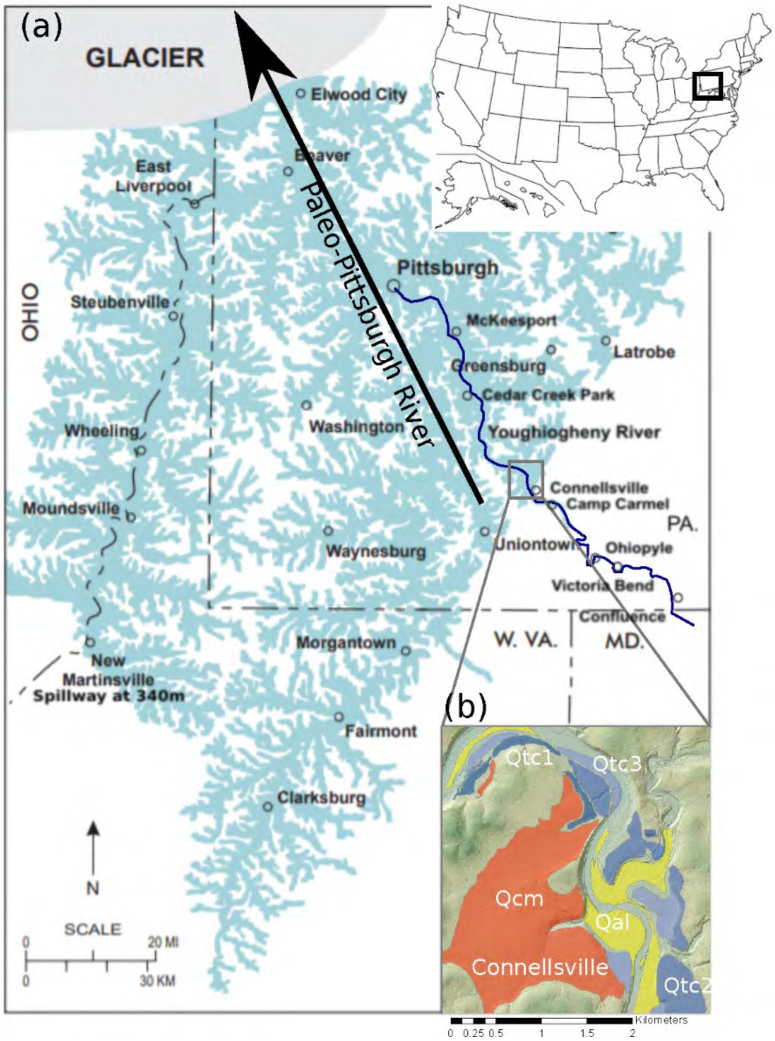

Figure 2: ***(a)*** *Reconstruction of Glacial Lake Monongahela showing extent of the lake and location (modified from Harper, 2002). Blue line indicates the course of the Youghiogheny River, showing geographic locations mentioned in the text.* ***(b)*** *Example of broad abandoned meander with terraces at Connellsville, PA. Terrace nomenclature discussed further in* ***Table 2.***

Since 2017, a combination of new exposures of Youghiogheny River terrace deposits in Ohiopyle State Park, material support from the PA Geologic Survey and the USGS EDMAP program, and logistical support from Ohiopyle State Park has resulted in an age model of the terraces, based primarily on terrestrial cosmogenic nuclide (TCN) dates, assembled through several undergraduate and graduate projects at Lehigh University. Detailed 1:24,000-scale mapping of terraces from Connellsville through Confluence, PA has resulted in several possible terrace correlations that reconstruct the incision of the Youghiogheny River over the past million years (Kurak, 2021). The terrace map reveals a coherent suite of terraces at the reach scale, but a proposed correlation across the Laurel Highlands downstream to Pittsburgh requires two or more regional base level falls, only one of which is demonstrably related to the draining of Glacial Lake Monongahela and formation of the Ohio River. The terrace map also adds an important data layer to a new generation of bedrock maps in and around Ohiopyle State Park (Shaulis, 2020). Ohiopyle is the most visited park in the PA State Park system with several large waterfalls and other evidence of active river incision that the terrace map and age model help place into a broader landscape evolution context.

The goal of this paper is to use the terrace map and a stratigraphic age model anchored at Ohiopyle, PA to propose tectonic, climatic, and river integration processes responsible for base level change and river incision across the Laurel Highlands. It also presents new evidence for the age of Glacial Lake Monongahela and critically evaluates ideas regarding the formation of tight bedrock meanders in the Ohiopyle area.

Location and geologic setting

The Youghiogheny River study reach and Ohiopyle State Park are primarily located in Fayette County, Pennsylvania southeast of Pittsburgh (**Figure 1**). The region mapped for the EDMAP project is an irregular strip ~ 1-2 km wide and 30 km long following the Youghiogheny River from Confluence, PA to Connellsville, PA (**Figures 1a**, **b**) spanning parts of the South Connellsville, Ohiopyle, Mill Run, Fort Necessity, and Confluence 7.5 minute quadrangles. Terraces in regions outside of the park are compiled from existing sources (Wagner et al., 1975; Marine, 1997; Marine and Donohue, 2000). The Youghiogheny River is a major tributary of the Monongahela River, falling 600 m over 216 km, and draining 4,440 km^2 of the Allegheny Plateau portion of the Appalachian foreland north and west to the Ohio River. The long profile has a broad knickzone (convexity) that stretches from Connellsville to Ohiopyle, coincident with the river's path through the Chestnut Ridge anticline (**Figures 1d**, **3**). The knickzone is decorated by several rapids and waterfalls, the highest and most spectacular being the ~6 m high Ohiopyle Falls (**Figure 1d**). The Youghiogheny River and its tributaries are deeply incised into the rolling uplands of the Allegheny Plateau generating a local, valley-side relief of ~200 m.

This part of the Appalachian foreland is underlain by gently folded middle and late Paleozoic siliciclastics, carbonates, and coal (**Figure 1a**, inset column). The oldest rocks are exposed in the partially breached cores of the Chestnut Ridge and Laurel Hill anticlines where the river traverses the Devonian and Mississippian Maple Summit, Catskill, Oswayo, Shenango, Burgoon, and Mauch Chunk formations. Some of these units, in particular the Shenango Formation, contain distinctive facies including the flat-pebble Long Run Conglomerate that can be used to distinguish clasts that have been fluvially-transported great distances in the terraces of the Youghiogheny River from locally-sourced material. In contrast to these older rocks, the broad intervening syncline centered on Ohiopyle State Park exposes the Pennsylvanian Pottsville Formation and overlying coal-bearing Allegheny Group. Within the Pottsville Formation is the thickly-bedded, cross-stratified, pebbly orthoquartzite Homewood Sandstone, a particularly resistant unit that forms the crests of many waterfalls including Ohiopyle Falls (**Figure 2d**).

The rocks currently exposed on the Allegheny Plateau were formerly covered by 2.5-4 km of late Paleozoic strata (Zhang and Davis, 1993), a thin wedge of which is still preserved further west in the foreland. Apatite fission track thermochronology and coal rank indicates that the rocks at the surface cooled below ~120^{o}C in the early Mesozoic, suggesting long-term rates of erosion of ~10-30 m/Ma (Blackmer et al., 1994). Pleistocene glaciation has played a large role in rearranging the recent drainage of the Allegheny Plateau and in lowering base level through the formation of the Ohio River as an ice-marginal stream. The cumulative result of Pleistocene drainage rearrangement in the Allegheny Plateau has been a wave of recent incision by rivers presumably including the Youghiogheny at rates as high as ~40 m/My, and local, short-term rates that approach ~100 m/My (Ward et al., 2005) resulting in the steep walled gorges, numerous knickpoints, and waterfalls on tributary channels.

Fluvial terrace, lacustrine, debris-flow, and fluvial-deltaic deposits collectively known as the Carmichaels Formation (Campbell, 1902; Hickock and Moyer, 1940), some of which lie 10-100 m above the modern channel, are preserved along the Youghiogheny River (**Figure 1c**). The Carmichaels Formation is a complex lithostratigraphic unit that most likely represents not only multiple facies, but also multiple phases of deposition spanning a large age range across the Pleistocene. The Carmichaels Formation is traditionally thought to be genetically related to one or more phases of the early to mid-Pleistocene glacial Lake Monongahela (White, 1896; Jacobson et al., 1988; **Figure 2**); however, Carmichaels Formation deposits are found at elevations both above and upstream of the commonly agreed upon extent of the lake(s) leading to alternative explanations for their genesis (Campbell, 1902).

Glacial Lake Monongahela and Carmichaels Formation

Glacial Lake Monongahela (Leverett, 1936; Marine, 1997) is the name given to the body of water that flooded the valleys of the Monongahela and Youghiogheny rivers when a pre-Illinoian ice margin dammed the pre-glacial north-flowing river systems of the Allegheny Plateau. This lake filled to a level of ~336 m (1,100 ft) before finding an outlet to the paleo-Ohio River in the vicinity of New Martinsville, WV, creating a propagating knickpoint as the river adjusted to a new elevation of 186 m (610 ft). As Lake Monongahela drained, it incorporated systems including the ancestral Allegheny and Monongahela rivers into the new Ohio River system (Harper, 1997). In addition to its initial formation, subsequent ice sheet advances are hypothesized to have re-blocked outlets, causing one or more additional phases of Glacial Lake Monongahela.

Closely associated with the formation of Glacial Lake Monongahela is deposition of the Carmichaels Formation (Campbell, 1902; Marine 1997; Marine and Donahue 2000; Kite and Harper, 2011). The Carmichaels Formation consists of a stratified mix of clay, silt, and gravelly sand, weathered to reddish-orange to tan colors with polymict, rounded, fluvial gravel, cobbles, and occasional boulders (Campbell 1902; Kite and Harper, 2011). The Carmichaels Formation (Fm) is commonly located within broad, flat, abandoned meander bends on the northward flowing tributaries of the Ohio River (**Figure 2b**). These abandoned meanders represent the paleo-valleys of a formerly high sinuosity, low gradient river. The Carmichaels Fm likely represents multiple facies, as well as multiple phases of deposition spanning the Pleistocene, representing one or more phases of Lake Monongahela, and the accompanying glacial-interglacial climate changes. Past studies (White, 1896; Jacobson et al., 1988; Morgan, 1994; Marine, 1997) have recognized several distinct low gradient terrace levels associated with the Carmichaels Fm on the Monongahela and Allegheny Rivers in the vicinity of Pittsburgh. The highest level terrace (Jacobson et al., 1988) is thought to be the maximum extent of Lake Monongahela, consisting of deposits currently at ~320-335 m (1050-1100 ft), while lower terrace levels down to 280-296 m (920-970 ft) are thought to result from subsequent ponding events. Two lowest terrace levels at 253 m (830 ft) and 267 m (875 ft) more closely match the grade of the modern river, and are thought to represent Wisconsinan glaciation (White, 1896; Marine, 1997).

The Carmichaels Fm has been dated using paleomagnetism (Jacobson et al., 1988; Marine, 1997), with samples from the highest terrace level being paleomagnetically reversed, indicating that they are > 788 Ka. In contrast, deposits of the Carmichaels Fm lower in the landscape are normal polarity, indicating that these terrace levels were formed < 788 Ka. Marine (1997) conducted further mapping and paleomagnetism studies on the Carmichaels Formation in the Allegheny River valley sampling terraces at multiple levels. All of those samples except one are normal polarity, with the one reversed polarity sample interpreted as pre-lake terrace material. In contrast to Jacobson et al., (1988), Marine (1997) concludes that all Carmichaels Fm terraces represent the result of one Lake Monongahela event which deposited the Carmichaels Fm across a range of elevations, burying older, mostly fluvial terrace deposits of the ancestral Monongahela River system. Marine's (1997) interpretation suggests that the mapped terraces are more indicative of the paleo-base level, and slow, pre-early Pleistocene incision of the ancestral Monongahela River system, rather than the ponding event associated with Glacial Lake Monongahela.

Methods

Data for terraces and the longitudinal profile of the Youghiogheny River include mapping and fieldwork, collection of samples for terrestrial cosmogenic nuclide (TCN; https://www.uvm.edu/cosmolab/methods.html) and luminescence dating (Rittenour, 2018), and river long profile analysis from a digital elevation model (Whipple and Tucker, 1999). TCN field samples, including bulk sand and rounded cobbles, were chosen based on access, terrace distribution, and opportunity to obtain best estimates for erosion rates and age of significant landforms. Samples collected for exposure ages included corrections for topographic shielding. Samples collected for burial or isochron analysis were sampled from the deepest possible location in order to provide for maximum, post-burial shielding. All TCN samples were processed and 10Be and 26Al extracted at the University of Vermont Cosmogenic Lab Facility. Luminescence dating was completed at the Utah State Luminescence Laboratory. Minimum exposure ages and steady-state erosion rates were calculated using the Cronus online calculator (https://hess.ess.washington.edu/; Balco et al., 2008). Burial and isochron ages were calculated following methods outlined in Hidy et al (2010) and Erlanger et al. (2018), respectively. All results, data sheets, uncertainties and modeling of TCN and luminescence data are reported in Kurak (2021). Mapping was done by foot, boat and bike on a 1:10,000 scale using a 1-m LiDAR topographic base between Confluence, PA and Connellsville, PA. Mapping between McKeesport, Pa and Connellsville, PA was done on a 1:24,000 scale based primarily on historical literature, 1 m LiDAR digital elevation models (DEM), and field visits. Terrace treads and straths were identified in the field and have been further verified using the DEM. Terrace thickness has been determined through field measurements, and the use of topographic metrics such as changes in slopes in areas where fluvial deposits were found.

The resulting terrace map notes the location and elevation of the erosional base of the terraces, called a strath, and the constructional tops, called a tread. The gradient of adjacent straths reconstructs a paleo-reach of the river's former longitudinal profile. These paleo-longitudinal profiles can be compared in gradient and separation from the modern channel profile to determine the location, rate, and steadiness of river incision. A river long profile is a simple plot of channel distance with respect to channel elevation (**Figure 3**, solid blue line). It has been long known that the concave-up shape of most river long profiles reflects a power law relationship between reach-length gradient (S, m/m) of a stream channel and drainage area (A, m^2), a proxy for channel discharge (Hack, 1957). The long profile plot has properties of concavity (θ), defined by the negative slope of the $logS$-$logA$ regression, and steepness (k_s), defined by the intercept where A is 1 m^2,

$$S = k_s A^{-\theta} \quad (1).$$

To model the incision of a river channel into bedrock (E, m/yr) it is now accepted to use a stream power-based rule (Howard, 1994),

$$E=KA^mS^n \quad (2),$$

where K is a rock erodibility term, essentially a velocity with units of $m^{0.1}\,yr^{-1}$ when stream concavity is the reference concavity (θ_{ref}) of 0.45, and where the exponents m and n describe power-law dependencies for A and S respectively. Combining equations (1) and (2) under uniform, steady-state base level fall (uplift, U) and erosion (E) conditions when the elevation of the channel does not change over time ($dz/dt = 0$), and solving for S gives:

$$dz/dt = U - E = 0 \quad (3a),$$

and

$$U = KA^mS^n \quad (3b),$$

and

$$S = (U/K)^{1/n}A^{-m/n} \quad (3c).$$

Comparing equation (1) to (3c) it is immediately evident that θ and m/n are equivalent and

$$k_s = (U/K)^{1/n} \quad (4).$$

Because θ and k_s co-vary, it has become common practice to apply the reference concavity for all of the streams in the watershed, resulting in a normalized k_s value (k_{sn}). For the case where the channel erosion is a detachment limited quarrying and plucking process, which is a good first-order assumption for sediment-starved Appalachian streams, the exponent dependency on slope (n) is ~1 (Whipple, 2004). With the simplifying assumption that n=1 and using θ_{ref}= 0.45, the units on channel steepness (k_{sn}) are $m^{-0.9}$ and equation (4) becomes

$$k_{sn} = (E/K) \quad (5).$$

Combining equations (1) and (5) and substituting dz/dx for S, an expression for the response time (τ, yrs) of the system (Whipple and Tucker, 1999) emerges:

$$(dz/dx) = ((dz/dt)/K)A^{-m} \quad (6a)$$

$$K(dz/dx) = (dz/dt)A^{-m} \quad (6b),$$

$$dt = dx / K A^m \quad (6c),$$

$$\tau=\int_{x_0}^{x}\frac{dx}{K(x')A(x')^m} \qquad \text{(6d),}$$

where x_0 is the starting distance at the mouth of the stream. Equation (6d) describes the amount of time (τ) it takes for a transient erosional step (a knickpoint) to move up the long profile as a kinematic wave (Howard, 1994; Whipple and Tucker, 1999).

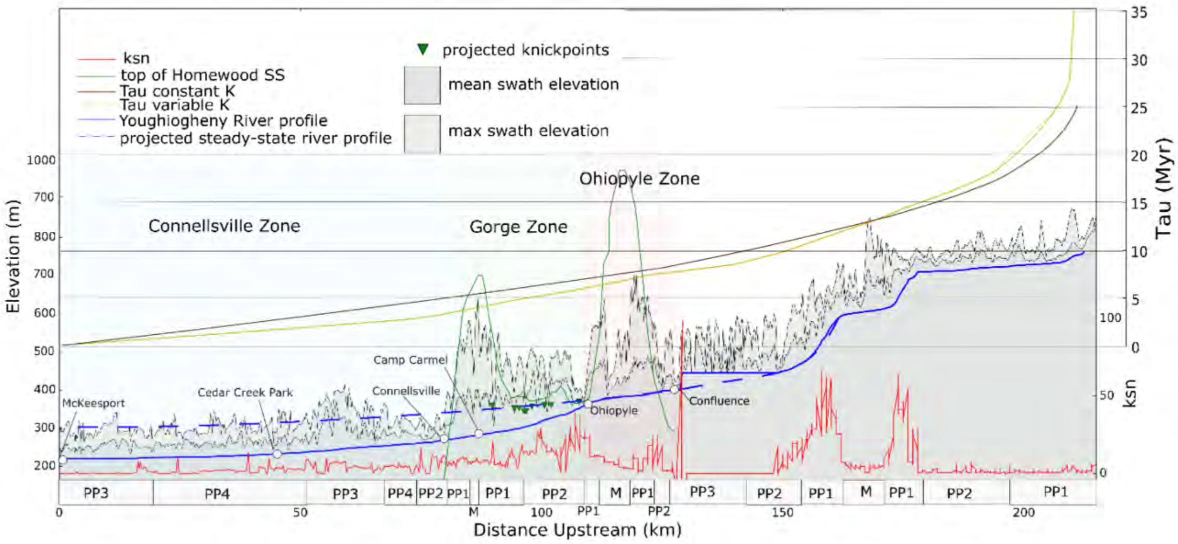

Figure 3: Youghiogheny River long profile, steepness, and response time. The blue line represents the Youghiogheny River base elevation obtained from 1-m LiDAR DEM data from its headwaters down to its confluence with the Monongahela at McKeesport, Pa. The dashed blue line represents a projected steady-state river level projected downstream from the knickzone at Ohiopyle (eq. 1). Green triangles depict projected elevations of knickzones along tributaries of the Youghiogheny R., also representing the paleo-elevation of the tributary confluence with the Youghiogheny channel. The gray and lighter gray shading in the background represent the mean and max elevations of a 3 km swath based around the course of the river ***(Figure 1).*** *The values of ksn are represented in the graph in red below the long profile calculated using eq. 1. The peak in ksn at Confluence is an artifact of the dam. Geology traversed by the Youghiogheny River is shown in boxes along the bottom with symbols representing the group or formation. PP4 = the Pennsylvanian shales, limestones and coals of the Monongahela Formation. PP3 = Pennsylvanian sandstones, shales, and red beds of the Conemaugh Group. PP2 = the relatively more resistant shales sandstones and limestones of the Pennsylvanian Allegheny Group. PP1 = the resistant Pennsylvanian Pottsville Formation, including the hard Homewood Sandstone that forms the lip of many waterfalls in the region, the top of which is represent in the cross section as a green line. M represents the various formations of the Mississippian, including the Mauch Chunk Formation, the Burgoon Sandstone, and the Shenango Formation with the resistant basal Long Run Conglomerate. Also included within this section is brief outcroppings of Devonian units such as the Catskill Formation that are too thin to depict on the long profile. River response time, or tau (τ), in millions of years is depicted in brown and yellow for constant K and variable K dependent on geology respectively* ***(Table 1).***

Results

Long Profile

The Youghiogheny River downstream of Confluence consists of a distinct and unique shape, with two shallow gradient zones separated by a broad convexity between Connellsville and Ohiopyle (**Figure 3**). The river is underlain throughout by sedimentary rocks from the middle to late Paleozoic, with the oldest Devonian and Mississippian rocks exposed in the partially breached cores of the

Chestnut Ridge and Laurel Hill anticlines (Wagner et al., 1975; Shaulis et al., 2021; Figure 1). Channel reach steepness is greatest at the obvious knickzones, including the broad convexity between Connellsville and Ohiopyle as well as where the channel is flowing over the Pottsville Formation including the Homewood Sandstone (**Figure 3**, red line, unit PP1). The response time of the Youghiogheny trunk channel can be modeled assuming a uniform rock erodibility (K) derived from a catchment average channel steepness (k_{sn}) or from a reach-length rock-erodibility ($K(x)$) determined locally from the reach-length channel steepness, in both cases using a catchment-wide average erosion of 30±10 m/Myr for equation (5) (**Table 1**). Inserting those values of K into equation (6d) results in two similar plots of response time (τ) with respect to channel distance (**Figure 3**; yellow and brown lines). The variable K model (**Figure 3**, yellow line) indicates that a base level fall that initiated at the confluence of the Youghiogheny River with the Monongahela River, perhaps in response to integration of the Ohio River following the drainage of Glacial Lake Monongahela, would reach Connellsville after ~3.5 Myr, Ohiopyle after ~6 Myr, and take ~35 Myr in total to reach the catchment's headwaters. If the Ohio River drainage integration base level fall impacted the entire Monongahela and lower Youghiogheny River all the way to the lower part of the Chestnut Ridge gorge more or less instantaneously, a possibility supported by the terrace deposits at Camp Carmel discussed below, that knickpoint would essentially arrive at Ohiopyle in ~2 Myrs. These response time models further indicate that the current mean retreat rate for the top of the knickzone, including Ohiopyle Falls, is ~ 10 km/Myr or 1 cm/yr. Real retreat rates probably have varied with changes in Pleistocene climate, that impact both A and K in equation 6d.

Table 1. Values for k_{sn} and K on the Youghiogheny River*

**based on the whole catchment (constant K scenario), as well as underlying rock type (variable K scenario) Unit nomenclature is the same as that of Figure 3.*

Rock Unit	k_{sn} ($m^{-0.76}$)*	K ($m^{0.24}$ yr^{-1})**	K stdE ($m^{0.24}yr^{-1}$)***
Catchment	8±0.2	3.75E-06	1.25E-06
PP4	4.84±0.07	6.20E-06	2.18E-06
PP3	4.86±0.04	6.17E-06	2.06E-06
PP2	9.2±0.05	3.26E-06	1.09E-06
PP1	11.92±0.08	2.52E-06	8.39E-07
M	10.89±0.19	2.75E-06	5.06E-06
D	0.02±0.05	1.50E-03	7.52E-03

*m/n (θ) = 0.38 **E= 30±10 m/Myr ***stdE= standard error for K

Terrace Stratigraphy

Alluvial and lacustrine deposits of the Carmichaels Formation (**Table 2**) form the basis for Youghiogheny River terrace maps, geochronology, age models, and long profile evolution models. These alluvial deposits range from those just above the modern floodplain of the river to up to 60 m above the modern channel in abandoned meander bends (White, 1896; Campbell 1902; Marine 1997) (**Figure 2c**). Terrace stratigraphic models are separated into three "zones" based on their topographic signature and spatial distribution along the Youghiogheny River long profile. These three zones (**Figure 3**) are named the Connellsville Zone consisting of the reach between McKeesport, PA and Connellsville, PA; the Gorge Zone, which is the reach between Connellsville and Ohiopyle that includes the gorge carved through the Chestnut Ridge anticline; and the Ohiopyle Zone, which is the reach between Ohiopyle and Confluence that includes the gorge carved through the Laurel Hill anticline.

Ohiopyle Zone The upstream portion of the Youghiogheny River, called the Ohiopyle Zone, consists of the stretch between Ohiopyle and Confluence containing six terrace levels (Qto1-6, **Figure 4a**,**b**; **Figure 5a**,**b**) plus a modern floodplain (Qal). In the vicinity of Ohiopyle, these terraces are exposed as broad, relatively flat benches within the town and along the Ferncliff Peninsula, along a wide meander called Victoria Bend farther upstream (**Figure 4b**) and at Confluence. Between Victoria Bend and Confluence, these terraces are commonly underlain by steep, hanging, alluvial fans with tributary catchment provenance. Terraces in the Ohiopyle zone tend to follow the shallow gradient of the upper Youghiogheny River. These terraces vary in thickness between 2-10 m, and often have 1-4 m of colluvium capping the treads. Straths are only locally exposed, but around Ohiopyle are constrained by drill cores and a few outcrops or estimated through breaks in hillslopes and the presence of rounded cobbles, often increasing in size and quantity near the base of a deposit.

The highest terrace level (Qto1) found at Ohiopyle and the crest of Ferncliff is characterized by a colluviated slope with large, rounded boulders of clasts such as the Homewood Sandstone and the Long Run Conglomerate, both of which have an upstream provenance.

The next highest terrace level (Qto2) is most easily defined by a sharp terrace riser with a base of around 384 m (1260 ft) on the Ferncliff Peninsula. Much of this terrace is covered by colluvium, but exposures showing several meters of weathered sand and gravel along stream cuts are accessible from the Sugarloaf hiking trail connecting the Great Allegheny Passage Trail to Sheridan Street in Ohiopyle as well as on the Ferncliff Trail on the Ferncliff Peninsula.

The third (Qto3) and fourth (Qto4) highest terraces have their straths constrained by drill cores and exposures around Ohiopyle, where the strath elevation may vary by as much as 10 m locally, particularly for Qto4. Most of Ohiopyle is constructed on the treads of these two terraces, resulting in significant human modifications of the original terrace morphology. On Ferncliff and Victoria Bend, these terraces exist with less anthropogenic modification, but as is common with the previous terraces, the treads tend to have a colluvial cover.

The fifth highest terrace (Qto5) is relatively thin at Ohiopyle but appears to thicken once it wraps downstream around Ferncliff (**Figure 4a**). It is expressed there as a distinct flat step, with rounded cobbles well-exposed through the riser. Rounded cobbles are also found within stone walls on the top of the terrace which were evidently constructed using local materials.

The lowest terrace level (Qto6) only exists downstream of and directly at Ohiopyle Falls, and likely represents the elevation of the top of Ohiopyle Falls knickpoint as it retreated around Ferncliff. Lower alluvium deposits representing the modern floodplain also periodically occur downstream of Ohiopyle Falls.

In the Ohiopyle Zone between Victoria Bend and Confluence, the Qto5 terrace level appears to transition into the river's modern floodplain, while Qto4 becomes host to the local segment of the Great Allegheny Passage Rail Trail (**Figure 4b**). Exposures of the Qto2-Qto3 levels become expressed as perched alluvial fans originating from smaller tributary streams that can capture the larger round cobbles found in the main channel, and the occasional apparent terrace benches. The highest terrace (Qto1) is only found in a few places upstream of Ohiopyle.

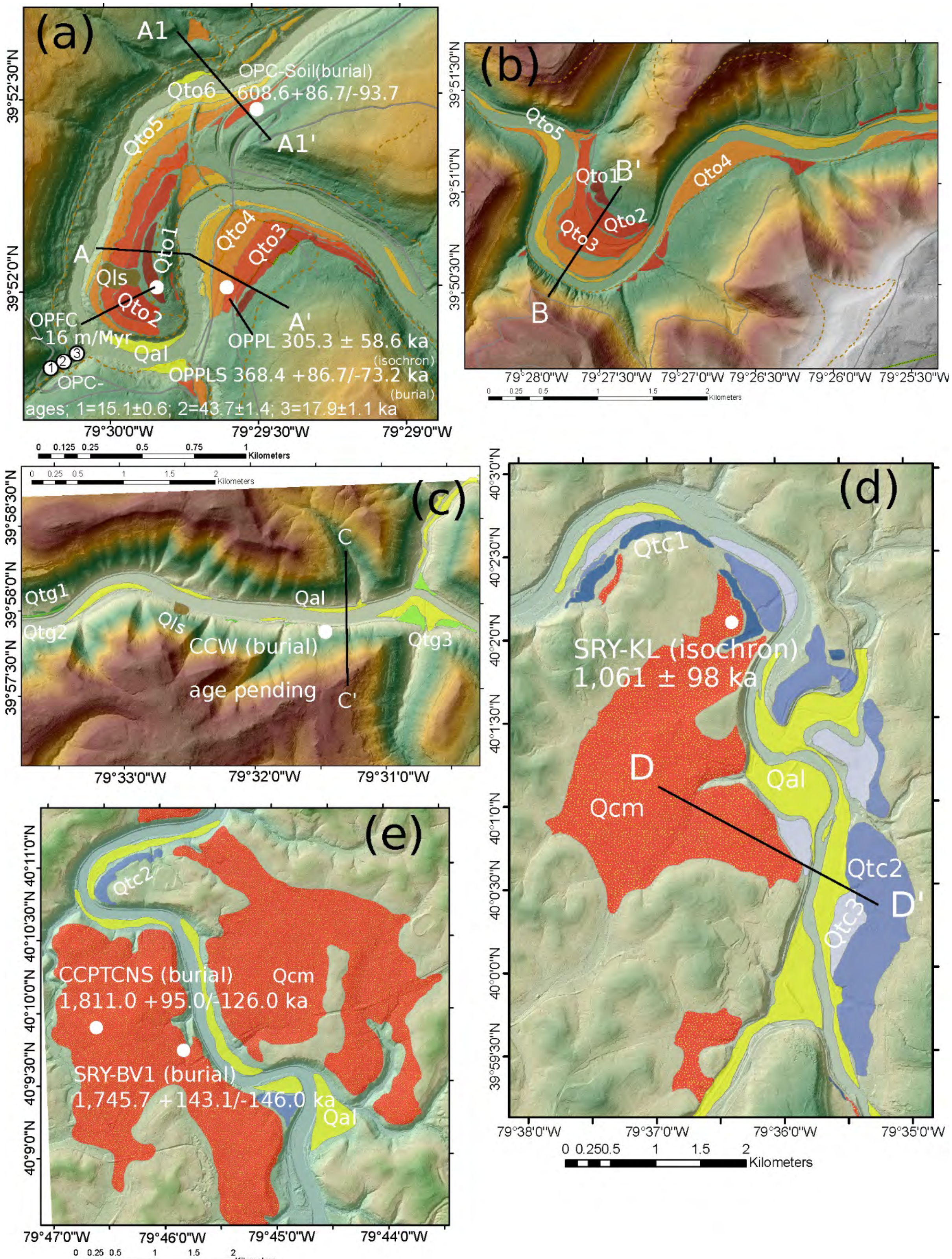

Figure 4. *Terrace distribution at 5 key sites, along with locations of TCN samples and ages (See **Figure 1** for locations). Cross section lines correspond by letter to the terrace stratigraphic models detailed in **Figure 5**, as well as white boxes of **Figure 1.** Terrace nomenclature is presented in **Table 2.** and dated samples are noted and presented in **Table 3.*** ***(a)*** *Terrace distribution at Ohiopyle and the Ferncliff Peninsula in the Ohiopyle Zone* ***(b)*** *Terrace distribution at Victoria Bend in the Ohiopyle Zone.* ***(c)*** *Terrace distribution at Camp Carmel in the Gorge Zone.* ***(d)*** *Terrace distribution at Connellsville in the Connellsville Zone.* ***(e)*** *Terrace distribution at Cedar Creek Park in the Connellsville Zone.*

Soils developed through the terrace treads are broadly consistent with their relative stratigraphic age. Thick orange-red, clay rich soils are developed in the higher terraces (Qto1,2, and 3), reddish-brown and yellow clay loam soils are formed in Qto4, and brown loamy soils are formed in the lowest, youngest terraces (Qto5, 6).

The map pattern of terraces in the Ohiopyle zone indicates that the flight of terraces at Ohiopyle and the flight of terraces on the west slide of the Ferncliff Peninsula have co-evolved as the Youghiogheny channel has shifted west and incised downward. These are classic inner-meander loop terraces. Coupled with the axial stream provenance of Qto1 at the crest of Ferncliff, they indicate that the tight bedrock meander loop forming the Ferncliff Peninsula has always been part of the axial Youghiogheny river channel (c.f. Campbell, 1902), at least in the context of the current regional topography.

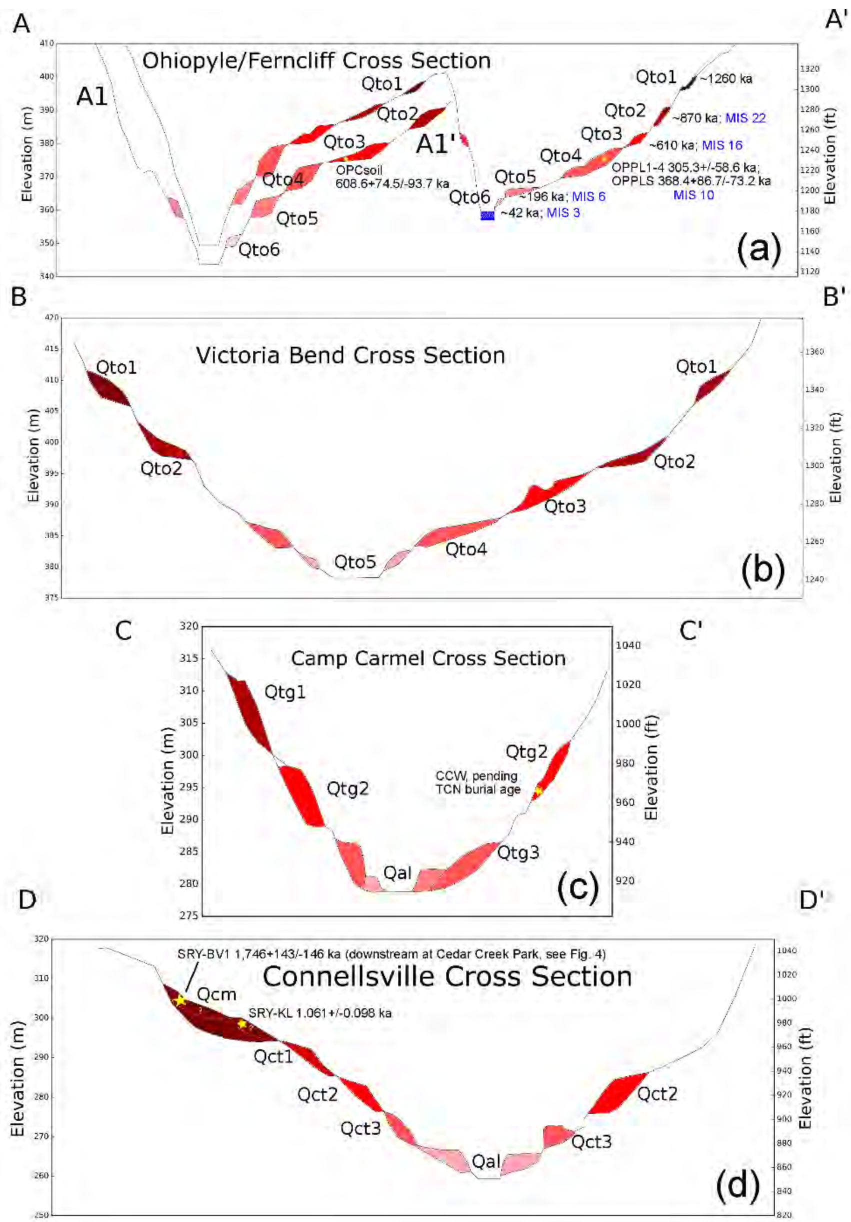

***Figure. 5:** Schematic cross sections of four key sections of the Youghiogheny River, aligned to the cross-section lines of **Figure 4.** Terrace nomenclature and sedimentology is presented in **Table 2.** TCN sample locations and approximate elevations indicated as a star, along with corresponding dates. Terrace colors are a representation of position in the landscape, not of unit correlation through each site.*

Table 2. Terrace stratigraphy, nomenclature, and descriptions for the Youghiogheny River

Unit Name	Description
Qls	Landslide and debris flow deposits consisting of host material of unknown age.
Qal	Alluvial bars and floodplains of the modern Youghiogheny River consisting of rounded to subangular clasts supported by a sandy matrix. Usually thin with treads located <5 m above the modern channel level. Often yellow-brown in color.
	Ohiopyle Zone
Qto6	Terrace with a thin yellow-orange sandy matrix and the occasional cobble. Terrace is located on a bedrock strath with elevations at or below that of Ohiopyle Falls.
Qto5	Terrace consisting of yellow-orange sandy matrix with rounded cobbles, appearing very similar to the modern floodplain, and essentially taking its place upstream of Ohiopyle Falls. Downstream of Ohiopyle Falls it often has a colluvial cover.
Qto4	Thick deposit of sand, silt, and clay containing rounded cobbles of various sizes, with a large concentration near the strath. Color consists of a distinct orangish-red color with occasional yellow layers consisting mostly of sand. At Ohiopyle the deposit is heavily altered, but elsewhere often contains a colluvial cover. Strath elevation constraind by drill logs to ~370 m (1214 ft) at Ohiopyle. Upstream of Ohiopyle often houses the Great Allegheny Passage Rail Trail. Strath often <10 m above the modern river channel.
Qto3	Terrace with a strath constrained by drill cores at 378 m (1240 ft) at Ohiopyle. Consists of a reddish-orange sandy matrix with generally small rounded cobbles. Is preserved as both a fluvial terrace deposits and as an alluvial fan terrace from tributaries of the Youghiogheny River in the stretch between Victoria Bend and Confluence. Some exposures indicate the development of a soil. Often is covered by colluvium of varying thickness. Streth is usually between 11-16 m of the modern river channel.
Qto2	Terrace consisting of fluvial and alluvial fan deposits often preserved along tributaries, identifiable by the presence of rounded cobbles. Uppermost portions of the deposit also appear to be developing a soil. Terrace tread often covered by thick alluvial deposits, but on the Ferncliff Peninsula hosts a distinct terrace riser confirming its presence. often found 18-24 m above the modern river channel.
Qto1	Oldest terrace in the Ohiopyle Zone. Deposits are heavily colluviated, but contain rounded boulders of fluvially transported sandstones such as the Homewood Sandstone and Long Run Conglomerate. Strath elevation poorly constrained but inferred by changes in slope to be ~30 m above modern river channel.
	Gorge Zone
Qtg3	Fill terrace ~8 m above the modern Youghiogheny River channel, above modern alluvial deposits. Consists of sand and rounded to subangular cobbles.
Qtg2	Most common terrace level fround 15-25 m above the modern channel. Often preserved as parts of alluvial fans or broad extensive "benches" within the Gorge Zone. Consists of rounded to subangular cobbles and small boulders within a sand/silt/clay matrix reddish orange to brown in color, with some deposits looking similar to the classic Carmichaels Formation This unit often has a thick colluvial cover which sometimes contains large (>10 m radius) boulders originating from the steep rock walls of above.
Qtg1	Highest and rarest terrace level within the Gorge Zone, generaly 30 m or higher above the modern channel. Often contain large rounded to subangular boulders derived of the Long Run Conglomerate and Homewood Sandstone. Collluvial cover of at least 1 m in many instances.
	Connellsville Zone
Qtc3	Lowest terrace in the Connellsville Zone, with a strath on average 8 m above the modern channel. Relatively thin deposit of sands and gravels with rounded to subangular cobbles. Corresponds to the 1st terrace of Jacobsen et al. (1988) and Marine (1997).
Qtc2	Highest terrace that generally follows the course of the modern Youghiogheny River rather then the old, shallow gradient path indicated by the abandoned meander bends. Strath elevation is consistently ~16 m above the modern channel. Deposits consists of sand and silt with rounded cobbles of sandstone of local origin. Terrace deposits are mostly found on the inside of modern meander bends. Corresponds to the 2nd level terrace of Jacobsen et al. (1988) and Marine (1997).
Qtc1	Lowest terrace strath level preserved that follows the course of a paleo-river channel characterized by the broad abandoned meander bends. Consists of thick fills of sands and clays with large rounded cobbles. Color is generally reddish orangish to brown. Corresponds to the 3rd terrace level of Jacobsen et al. (1988) and Marine 1997). Strath level is generally 30-50 m above the modern channel level, but this decreases upstream due to the steeper grade of the modern river vs the paleo-river. In most areas, is incorporated into Qcm and only found as a representative strath elevation, but is present as a distinct terrace level at Connellsville.
Qcm	Classic Carmichaels Formation of Campbell et al. (1902) consisting of thick deposits reddish to orange clays, silts sands and rounded cobbles. Interpreted as terraces reworked by deposits of Lake Monongahela. Likely represent multiple strath levels of an older, low gradient paleo-river, and sometimes incorporates unit Qtc1. Ranges from 50+ m above the modern channel at McKeesport, PA to 25+ m above the modern channel at Connellsville, PA. Corresponds to the 3rd and 4th terrace level of Jacobsen et al. (1988) and Marine (1997).

Gorge Zone The Gorge Zone of the Youghiogheny River comprises the middle section of the long profile from Connellsville, PA to Ohiopyle, PA. Here the Youghiogheny River narrows and carves a deep gorge through Chestnut Ridge where the long profile is convex. Four terraces are preserved in this reach ranging in elevations from 2 m to 30 m above the modern channel, collectively defining a cluster of terraces sub-parallel to the modern channel. The two lowest (Qal and Qtg3 of **Figures 4c**; **5c**) levels of these terraces are close to the modern floodplain level and are very likely fill-cut terraces of the modern Youghiogheny River.

The next highest terrace (Qtg2) is typically found 15-20 m above the modern river channel and is mostly identified by the presence of a significant number of rounded cobbles above the modern channel. This terrace is expressed as flat benches on the side of the river gorge that can be quite extensive, reaching up to 1.3 km in length along the course of the river, often on inside meander bends or near the mouth of larger tributaries. Deposits vary in thickness, ranging from 5-25 m, commonly with a colluvial cover 1-6 m thick and topped with large stone blocks that have fallen from above. Straths are difficult to find in this stretch due to colluvial cover and steep slopes. They are exposed locally either as a result of stream cuts, horizontal incision by the Youghiogheny River, or because they intersect the Great Allegheny Passage Rail Trail. At one location west of Camp Carmel, the Great Allegheny Passage Trail intersects terrace Qtg2. Temporary excavation there exposed ~2 m of dark sandy gravel and sand Carmichaels Fm lacustrine facies (**Figures 4c**, **5c**, **6**), overlain by ~ 1 m of rounded fluvial gravel encased in a dark orange-brown, weathered matrix, that is unconformably overlain by ~ 2m of reddish-brown and brown colluvium. The lacustrine facies have been sampled for a TCN burial age that is still pending in the summer of 2021.

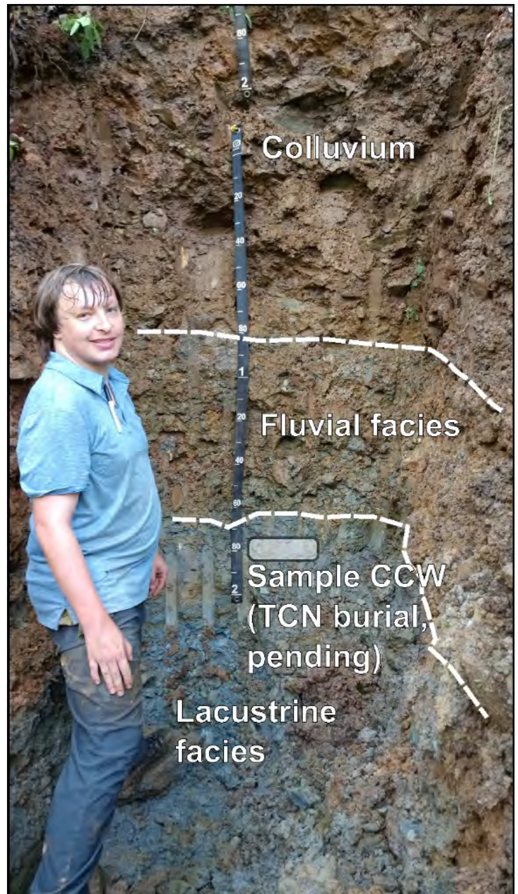

Figure 6. *Photo of the excavated exposure of terrace Qtg2 west of Camp Carmel on the Great Allegheny Passage Trail showing the lower 2+m (tape for scale) and the dark lacustrine facies at the base of the exposure. The terrace strath was not exposed but estimated to be another 2 m below the level of the trail at ~264 m at this location.*

The highest terrace level (Qtg1) is poorly preserved and exposed, but where present, has a strath ~30 m above the modern channel. The tread and risers of the Qtg1 are covered by colluvium and littered with large, rounded boulders mixed in a sand and clay matrix.

Connellsville Zone The Connellsville Zone includes the characteristic Carmichaels Formation of the literature (White, 1896; Campbell, 1902; Jacobsen et al., 1988). Closely related to studies on terraces done by White (1896) on the Monongahela River and Marine, (1997) on the Allegheny River, four terrace levels are identified (Qcm, Qtc1-Qtc3). However, while these earlier studies identified the top three terraces as Carmichaels Fm deposits from Lake Monongahela, only the top two terrace levels (Qcm & Qtc1, **Figures 4d**,**e**; **5d**) were identified as such in this study on the Youghiogheny River. While there are undoubtedly Lake Monongahela deposits higher in the landscape than these mapped terraces, Qcm represents the highest Lake Monongahela deposits that have unambiguously buried older Youghiogheny River terrace straths. Any higher deposits along the main Youghiogheny River lack the topographic signature of a mappable terrace deposits, and very likely represent alcoves or bays within Lake Monongahela where lake deposits could be preserved against buttress unconformities. This inference is supported by the apparent decrease in the presence of cobbles above 304 m (1000 ft) (Campbell, 1902). However, it should be noted that measured elevations for the two highest terraces (White, 1896; Marine, 1997) are generally above the maximum elevation of topography within a 3 km swath (**Figure 3**) indicating a potential preservational bias for lower terraces over the upper terraces.

The Qcm and Qtc1 (**Figure 4d**,**e**) terrace deposits occur in broad flat abandoned meander bends that follow a shallower, more sinuous gradient then the modern channel, and most closely correlate to the third terrace level of White (1896) and Marine (1997). Deposits of Qcm tend to vary in thickness from 8-25 m and consist of clays, silts, and sands ranging in color from reddish-orange to tan. At some locations, the more deeply buried portions of the deposit take on a more brown-grey color. Within the matrix is a scattering of rounded to subangular cobbles derived from local sandstones, which appear to be most abundant close to bedrock straths (Campbell, 1902).

Bedrock straths for these deposits are difficult to locate, but some can be identified through stream cuts or through well or drilling records (White, 1896). The lowest bedrock straths in these abandoned meander bends tend to occur 50-60 m above the modern channel (Campbell, 1902), although this difference decreases to ~25 m around Connellsville on the Youghiogheny River. This strath surface is mostly buried and included as part of the Qcm deposit due to lack of exposure, however in locations where it is visible, it has been labeled as Qtc1. The bedrock straths also show considerable variation in elevation, being higher on inside bends of the loops and lower on the outside.

In contrast to the upper two levels of terraces on the Youghiogheny River, the lower levels of terraces in this reach (Qtc2-4 and Qal) more closely follow the gradient of the modern stream channel. These terraces are found along the straighter, steeper course of the modern long profile, often preserved as small deposits in the inside loops of modern meander bends. While still consisting of clays, sands, and rounded cobbles, these terraces were not recognized as being part of the Carmichaels Formation in this study (c.f. Kite and Harper, 2011).

Geochronology and sample ages

Geochronological analysis from twenty-six samples (**Table 3**) are assembled to calculate incision and erosion rates and construct a terrace age model used for correlation. This project contributed 21 new samples; an additional 5 samples providing exposure ages/erosion rates, come from previous unpublished projects (Li, 2018). These twenty-six samples provided 19 ages and/or erosion rates in the form of 5 burial ages, 13 exposure ages/erosion rates, two isochrons from 7 samples, and one OSL/IRSL age (Kurak, 2021).

10Be concentrations on bedrock faces are used to calculate a minimum exposure age for samples OPC1 – OPC5, SRY-OP6 – SRY-OP8, and OPFC2 – OPFC6, based on no surface erosion, or a steady-state erosion rate and saturated exposure. OPC1-OPC4 represent recent erosion processes such as rock falls in the steep gorges of the Youghiogheny valley, yielding exposure ages ranging from 10.6 ± 0.5 ka to 43.7 ± 1.4 ka, and steady-state erosion rates ranging from 17.0 ± 0.6 m/Myr to 71.7 ± 3.5 m/Myr.

Table 3. Terrestrial cosmogenic nuclide (TCN) data and OSL/IRSL samples with associated numeric ages and erosion rates
from this study and Li et al. (2018)

Sample	Deposit	Lat	Long	Elev (m)	10Be Concentration (a/g)	10Be Uncertianty (a/g)	26Al Concentration (a/g)	26Al Uncertainty (a/g)	Exposure Age (ka)[1]	Steady-State Erosion Rate (m/Myr)[1]	Burial Age (ka)	Isochron Age (ka)[2]
OPC1	Rock	39.8638	-79.5017	360	8.296E+04	3.413E+03	N/A	N/A	15.1 ± 0.6	50.1 ± 2.1	N/A	N/A
OPC2	Rock	39.8642	-79.5017	360	2.238E+05	7.055E+03	N/A	N/A	43.7 ± 1.4	17.0 ± 0.6	N/A	N/A
OPC3	Rock	39.8644	-79.5016	360	6.964E+04	4.108E+03	N/A	N/A	17.9 ± 1.1	45.3 ± 2.7	N/A	N/A
OPC4	Rock	39.8631	-79.5027	360	5.923E+04	2.858E+03	N/A	N/A	10.6 ± 0.5	71.7 ± 3.5	N/A	N/A
OPC5	Rock	39.8227	-79.4331	863	1.655E+06	2.493E+04	N/A	N/A	248.0 ± 4.9	3.05 ± 0.1	N/A	N/A
SRY-OP6	Rock	39.8339	-79.4327	863	1.814E+05	5.008E+03	N/A	N/A	30.5 ± 0.9	24.2 ± 0.7	N/A	N/A
SRY-OP7	Rock	39.8227	-79.4331	863	1.085E+05	3.999E+03	N/A	N/A	12.9 ± 0.5	55.6 ± 2.1	N/A	N/A
SRY-OP8	Rock	39.8227	-79.4331	863	7.698E+04	3.232E+03	N/A	N/A	9.0 ± 0.3	79.5 ± 3.4	N/A	N/A
OPFC2	Rock	39.8638	-79.5017	399	2.990E+05	1.008E+04	N/A	N/A	53.9 ± 1.9	13.5 ± 0.5	N/A	N/A
OPFC3	Rock	39.8642	-79.5017	399	3.177E+05	1.322E+04	N/A	N/A	57.5 ± 1.9	12.7 ± 0.5	N/A	N/A
OPFC4	Rock	39.8644	-79.5016	399	2.450E+05	6.845E+03	N/A	N/A	43.7 ± 1.3	16.8 ± 0.5	N/A	N/A
OPFC5	Rock	39.8631	-79.5027	399	2.228E+05	6.052E+03	N/A	N/A	39.6 ± 1.1	18.5 ± 0.5	N/A	N/A
OPFC6	Rock	39.8227	-79.4331	399	2.928E+05	7.513E+03	N/A	N/A	52.7 ± 1.4	13.8 ± 0.2	N/A	N/A
OPPLS	Sediment	39.8840	-79.4930	378	5.905E+05	1.139E+04	3.335E+06	9.478E+04	84.2	N/A	368.4 +86.7/ -73.2	N/A
OPC-Soil	Sediment	39.8748	-79.4914	372	5.427E+05	1.122E+04	2.810E+06	8.023E+04	82.1	N/A	608.6 +74.5/ -93.7	N/A
SRY-BV1	Sediment	40.1620	-79.7636	277	3.794E+05	8.822E+03	1.380E+06	5.287E+04	156.6	N/A	1,745.7 +143.1/ -146.0	N/A
CCPTCNS	Sediment	40.1631	-79.7756	292	6.427E+05	1.385E+04	2.224E+06	6.656E+04	86.4	N/A	1,811.0 +95.0/ -126.0	N/A
CCW	Sediment	39.9650	-79.5291	302				Pending				
OPPL1	Cobble	39.8840	-79.4930	378	3.319E+05	9.471E+03	1.999E+06	8.537E+04	N/A	N/A	N/A	305.3 ± 58.6
OPPL2	Cobble	39.8840	-79.4930	378	4.219E+05	1.035E+04	2.494E+06	8.589E+04	N/A	N/A	N/A	
OPPL3	Cobble	39.8840	-79.4930	378	3.932E+05	1.397E+04	2.452E+06	8.333E+04	N/A	N/A	N/A	
OPPL4	Cobble	39.8840	-79.4930	378	3.679E+05	1.187E+04	2.125E+06	1.102E+05	N/A	N/A	N/A	
OPPL5	Cobble	39.8840	-79.4930	378	3.554E+05	1.174E+04	2.328E+06	8.690E+04	N/A	N/A	N/A	
SRY-KL3	Cobble	40.0351	-79.6063	300	2.695E+05	7.281E+03	1.133E+06	4.208E+04	N/A	N/A	N/A	1,061 ± 98
SRY-KL4	Cobble	40.0351	-79.6063	300	1.985E+05	5.617E+03	8.521E+05	3.070E+04	N/A	N/A	N/A	

Sample	Deposit	Lat	Long	Elev (m)	Num of Aliquots	Dose Rate (Gy/kyr)	Fading Rate (%/decade)	Equivalent Dose (Gy)	Age (kyr)	Method
SRY-BV2	Sediment	40.1620	-79.7636	280	11(16)	3.19 ± 0.15	3.0 ± 0.6	700 ± 130	>295 ± 60	IRSL

[1]Uses STD exposure age method [2]Uses Stone Isochron method

In contrast OPC5 is located high in the landscape on a visibly highly weathered outcrop indicating that it is more readily interpreted as a long-term steady state erosion rate. It yields an exposure age of 248.0 ± 4.9 ka and a steady state erosion rate of 3.05 ± 0.1 m/Myr. Overall, the oldest ^{10}Be exposure ages come from the most deeply weathered bedrock exposures, which are farthest from the ground surface. In contrast, when solved for steady-state erosion rates, the most weathered surfaces reveal slow erosion, whereas the freshest, steepest surfaces have rapid erosion rates. For example, five fluvial boulders embedded in a colluvial slope at the crest of the Ferncliff Peninsula, samples OPFC2-6 have an average exposure age of ~50 ka and mean steady-state erosion rate of ~16 m/Myr, a value consistent with their stratigraphic position in the landscape and colluvial erosion of the slope (Bierman et al., 1995; Hancock and Kirwan, 2007; Matmon et al., 2003).

Burial ages were taken at a number of sites along the Youghiogheny River terraces from the vicinity of Ohiopyle to broad meander bends downstream near Cedar Creek Park (**Figures 2**, **4**, **5**). Near Ohiopyle, samples OPC-Soil and OPPL provide middle Pleistocene ages of 608.6+74.5/-93.7 ka and 384.4+86.7/-73.2 ka for intermediate to lower terrace levels in the stratigraphic section. SRY-BV1 and CCPTCNS burial ages were taken from deposits at two different levels near Belle Vernon, PA, yielding ages of 1,746+143/-146 ka, and 1,811+95/-126 ka respectively. These two samples yielded overlapping uncertainties indicating that they are the same age despite coming from different elevations. These early Pleistocene ages are consistent with the reversed magnetism of Glacial Lake Monongahela deposits.

The isochron age obtained using samples OPPL1-OPPL5 and burial age sample OPPLS both originate from the same site on the Qto4 terrace level at Ohiopyle (**Table 3**). The OPPL isochron yields an age of 305.3±58.6 ka, an age which is within the uncertainty of the burial age reported above. The second isochron age was generated using samples taken from a site near Connellsville (**Figure 4d**). Unfortunately, half of the intended samples for the isochron consisted of chert rather than fine quartz sand, and thus were unusable for TCN dating. As a result, this isochron only has two data points, making it statistically unsound, but still useful as a crude age estimate. The isochron generated from these two points provides an age of 1.061±0.098 Ma.

One OSL/IRSL sample labeled SRY-BV2 was taken at the same location as the SRY-BV1 site. This sample yields a minimum, saturation age of >295±60 ka.

Terrace Stratigraphic Age Models

Fluvial stratigraphy, numeric ages, and landscape geometry and distribution are used to construct a representative terrace stratigraphic model for the Youghiogheny River between Confluence and McKeesport (**Figures 5** and **7**). The correlation hinges on the terrace stratigraphy synthesis in the four schematic cross sections representing key stretches of the river where terraces are best preserved (**Figure 5**).

In the Ohiopyle Zone, ages for the full flight of terraces can be estimated by extrapolating the ages of the dated Qto3 and Qto4 terraces, resulting in ages of ~1.26 Ma for Qto1, 870 ka for Qto2, ~610 ka constrained by a TCN date for Qto3, ~300 ka to ~350 ka constrained by TCN burial and isochron samples for Qto4, ~196 ka for Qto5, and an age of ~46 ka for Qto6 on Ferncliff. This age model results in incision rates of ~51 m/Myr and 26 m/Myr for the channel reaches within the steepened Gorge Zone and Ohiopyle Zone respectively (**Figures 3**, **7**). The Ohiopyle zone terraces are similar in distribution and gradient to those further upstream stretching across the Victoria Bend and continuing to Confluence (**Figure 4b**). Through this reach, the rate of incision is ~20 m/Myr (**Figures 3**, **7**).

In contrast, correlation downstream through the Gorge Zone and into the Connellsville Zone is more challenging. A proposed connection between Qtc1 at Connellsville and Qtg2 at Camp Carmel (**Figure 4c**; TCN burial age pending) based on elevation and sediment texture can be made, potentially creating a link between these two zones and establishing the upstream extent of Glacial Lake Monongahela. The long term mean incision rate of the river based on the 1.8 Ma age for Glacial Lake Monongahela in the Connellsville Zone would be ~17 m/Myr (30 m/1.8 Myr) which compares well to the ≥15 m/Myr for Qgt2 given that Qtc1 is stratigraphically younger than the ~1.1 Ma Qcm isochron age (SRY-KL). This ambiguity in terrace age and correlation in the Gorge Zone will be improved by the pending age of the Camp Carmel sample. Even though the correlation of the Camp Carmel or Connellsville cross sections to the Ohiopyle or Victoria Bend cross sections is unclear (**Figure 5**), the topographic distribution of terraces in the region seems to indicate that Qtg2 may transition into the Qto5 terrace at Ohiopyle. The fragmentary terrace preservation between Ohiopyle and Connellsville preclude any firm correlation through the Gorge region, but the terraces here seem to have a gradient similar to that of the modern channel.

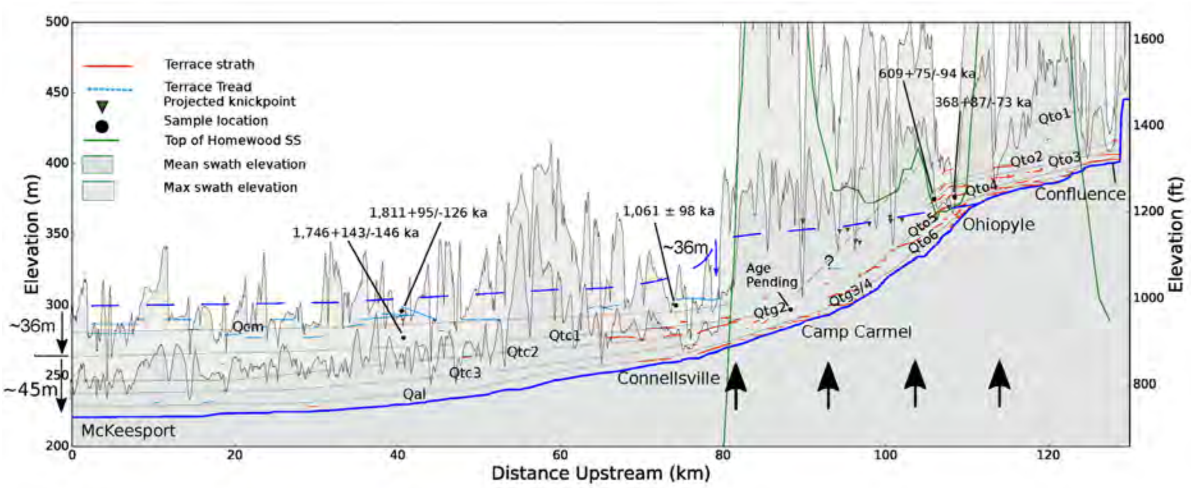

Figure 7. Interpretation of terrace stratigraphy and correlations along the long profile. Thin gray lines represent proposed terrace correlations. Blue dotted line represents a steady-state profile projection downstream, offset by ~36 m to account for the discrepancy in its projected elevation at the Monongahela confluence and the elevation of the Ohiopyle-Confluence steady-state elevation (see Figure 3). Gray dashed line suggests a correlation between the similar-aged Qto1 and Qtc1 that requires steep bending through the convex reach. Other symbols and lines as in Figure 3.

Interpretations

Incision record of base level fall

The incision history of the Youghiogheny River is constrained by the distribution and age of the river terraces and comparison with modern and paleo-river profiles (**Figure 7**). The channel reach from Ohiopyle to Confluence, PA was carved through the Laurel Hill anticline, crossing rocks of variable erodibility (**Figure 3**, **Table 1**). Nevertheless, the variation in stream steepness is modest, and the channel maintains a nearly constant gradient indicating that this reach is near or at grade. Paleo-channel gradients determined by the terraces in this reach are all parallel to the modern channel, indicating that incision has been uniform and steady when averaged over long periods of time.

Downstream projection of the graded reach between Ohiopyle and Confluence using equation (1) indicates that the modern long profile projects far out over the Gorge reach, passing first through the hanging mouths of tributary channels (green triangles in **Figures 3** and **7**) and then through the maximum topographic envelope of the Pittsburgh low plateau, arriving at the Monongahela River confluence at an elevation of ~300 m. In summary, ~81 m of total base level fall is apparent at the confluence of the Monongahela and Youghiogheny Rivers from the downstream channel projection (**Figures 3** and **7**). Based on the elevation of the now dated Carmichaels Fm (~1.8 Ma) and its preferential preservation in abandoned meander loops along the flanks of the incised Youghiogheny valley, ~45 m of the total base level fall, or the mean separation of the Qcm and Qtc1 strath with the Youghiogheny channel, can be attributed to the draining of Glacial Lake Monongahela and integration of the modern Ohio River. The remaining ~36 m of base level fall, nearly all of it lying in the Gorge knickzone, must have an alternative origin. Furthermore, the ages of the terraces at Ohiopyle are all < 1.2 Ma, and must be correlative, at least in time, to terraces far below the projected channel in the Connellsville zone. Time-correlative terraces must therefore increase in gradient considerably as they traverse the Gorge zone carved through the Chestnut Ridge anticline.

Two possibilities emerge from these long profile and paleo-long profile constraints. The first is that the knickzone in the Gorge reach is not transient, but rather a long-lived feature of the Youghiogheny River long profile. This is an unlikely explanation. The rock types in the Gorge reach are exactly the same as those in the Ohiopyle to Connellsville reach, yet the breached Chestnut Ridge anticline is a steep knickzone whereas the breached Laurel Hill anticline is not. The second possibility is that the Gorge reach knickzone is a transient composite of two base level falls, one in the past ~1.8 Ma related to the integration of the Ohio River through the draining of Lake Monongahela, with the other being an older but also perhaps ongoing, non-uniform rock uplift of the Laurel Highlands with respect to the Pittsburgh low plateau, accommodated more or less at Connellsville. Most of the ~36 m of the Gorge reach knickzone would have to be attributed to this uplift-driven base level fall as the more recent drainage integration base level has yet to fully propagate through the Gorge reach based on the inferred slow rates of incision below the lacustrine beds exposed in the Qtg2 terrace at Camp Carmel (**Figures 4c**, **5c**, and **6**).

Assuming that the Gorge reach knickzone is a composite transient of at least two different and ongoing base level falls, then the river incision history and ages of the terraces becomes complicated by overlapping relative uplift processes. For the reach between Ohiopyle and Confluence, the incision is uniform, a given terrace deposit has a similar age throughout, and the given strath would have been abandoned more or less isochronously. In contrast in the Gorge Zone, a given terrace deposit may have a similar age throughout, but the strath would have been abandoned in a time-transgressive manner determined by the retreat velocity of the knickzone. The response time curves (**Figure 3**) indicate that the knickzone around Ferncliff leading up to Ohiopyle Falls is retreating at a mean rate of ~ 1 cm year (10 km/Myrs). At that rate, the knickzone has moved through the hanging mouths of the tributary channels in ~2 Myrs (**Figures 3**, **7**). This time-transgressive migration and abandonment of straths and tributary mouth confluences in the Gorge Zone has the summary effect of taking any terrace timeline upstream of Ohiopyle and steepening it more than the current channel profile, so that it can converge and ultimately project below the early Pleistocene Carmichaels Formation terraces of the Connellsville reach (**Figure 7**). This steepening of the terraces is geomorphic marker evidence of non-uniform uplift.

The terrace correlation and relative uplift problem is further complicated by the fact that we do not know the location of the base level falls and furthermore, it is unlikely that they originated at a single point. So, for convenience and reference in **Figures 3** and **7**, we could choose the confluence with the Monongahela River or Connellsville as the base level fall point. From the confluence with the Monongahela, any base level fall would take ~6 Myr to get to get up to Ohiopyle, or ~3.5 Myrs to travel from Connellsville to Ohiopyle. The draining of Glacial Lake Monongahela and formation of the Ohio River is one of those base level falls that we assert occurred 1.8 Ma. This drainage integration event involved a drop of ~45 m that is represented in a strongly reclined knickzone that stretches from the Monongahela confluence all the way to the core of Chestnut Ridge upstream of Connellsville. The second base level fall involves the uplift of the Laurel Highlands with respect to the Pittsburgh Plateau that may have initiated before the drainage integration event but may also be ongoing, involving ~36 m of differential uplift. In summary, we envision the big knickzone between Connellsville and Ohiopyle to be the juxtaposition of these two base level fall processes.

Possible mechanisms driving the non-uniform uplift processes include dynamic support (Moucha et al., 2008; Rowley et al., 2013; Moodie et al., 2017) perhaps focused through inherited basement heterogeneities such as the early Paleozoic Rome Trough that underlies the Laurel Highlands and is known to have a long and complicate post-rift reactivation history (Gao et al., 2000). Flexural isostatic (Pazzaglia and Gardner, 1994) and glacial isostatic adjustment (GIA; Pico et al., 2019) effects are also possible explanations for the apparent warping of terrace timelines, but these have yet to be fully investigated.

Climatic influences on terrace genesis

Terraces in the Ohiopyle zone offer some insights into the terrace formation mechanism for graded river profile reaches. TCN ages obtained on terraces Qto3 and Qto4 both indicate terrace deposition during known glacial periods (**Figure 5a**, cross-section A-A'). Using the incision rate constrained by these two dated terraces, the projected age of the other terraces in the Ohiopyle flight similarly indicate terrace alluvium being deposited during known glacial stages (Railsback et al. 2015). The unsteadiness of Pleistocene climates through numerous glacial-interglacial cycles likely impacted Youghiogheny discharge, sediment yield from hillslopes, or both leading to unsteady incision punctuated by terrace alluvium deposition (van den Berg, 1996; Vandenberghe, 2003; Wegmann and Pazzaglia, 2009; Gunderson et al., 2014).

Downstream of Ohiopyle, the more rapid incision associated with multiple downstream base level falls and propagation of the transient knickzone seems to have precluded similar genesis and preservation of sub-parallel climatic terraces. Here the terraces have been forming more locally by stochastic processes as meander loops are truncated (Finnegan and Dietrich, 2011). However, the Qtg2 terrace is preserved almost contiguously for over a kilometer distance with a steep gradient subparallel to the modern channel. It is possible that the formation of this terrace was influenced in places by climatically-influenced changes in sediment load.

Conclusions

Detailed mapping and numeric dating of river terraces together with modeling of the longitudinal profile of the Youghiogheny River focused on Ohiopyle State Park allowed reconstruction of the history of base level fall and river entrenchment across this portion of the Laurel Highlands. The river terraces in the study area are a younger, fluvial facies of the Carmichaels Formation, which in its type section in the Pittsburgh low plateau is intimately related to the formation of Glacial Lake

Monongahela, here dated ~1.8 Ma by TCN burial ages. A flight of six fill terraces that bury irregular straths in and around Ohiopyle indicate that the main terraces were created by unsteady incision in step with glacial-interglacial climate changes over the past 1.2 Ma. The map pattern is consistent with the Youghiogheny River forming and being locked into its tight meandering pattern around Ferncliff for the period of time represented by the terraces. TCN burial and isochron ages of ~610 ka and ~300-350 ka are used to construct long-term incision rates ranging from ~20 m/Myrs upstream of Ohiopyle where the channel gradient and subparallel terrace profiles are gentle to ~50 m/Myrs downstream of Ohiopyle where the river profile steepens into a broad convex knickzone. Modeled channel response time indicate that the current rate of retreat for the top of the knickzone, including Ohiopyle Falls, is ~10 km/Myr or ~ 1 cm/yr. Comparison of the river profile to the terrace profile and the response time model further indicates that there have been at least two base level falls conflated in the knickzone between Ohiopyle and Connellsville. A total of ~81 m of base level fall is suggested by projection of the graded channel between Ohiopyle and Confluence downstream to the river's confluence with the Monongahela River. Of that total, ~45 m is likely due to the draining of Glacial Lake Monongahela in the early Pleistocene and formation of the Ohio River. The other ~36 m is attributed to non-uniform uplift of the Laurel Highlands with respect to the Pittsburgh low plateau, with a hinge at Connellsville, which may be ongoing.

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Stop 4

Meadow Run Slides

Geoheritage Site: Meadow Run Slides

Classification: *Geomorphic, Erosional, Fluvial and glaciofluvial, Ravine.*

MEADOW RUN SLIDES

KNICKPOINT INVESTIGATION – UPPER CONNOQUENESSING SANDSTONE DEPOSITION

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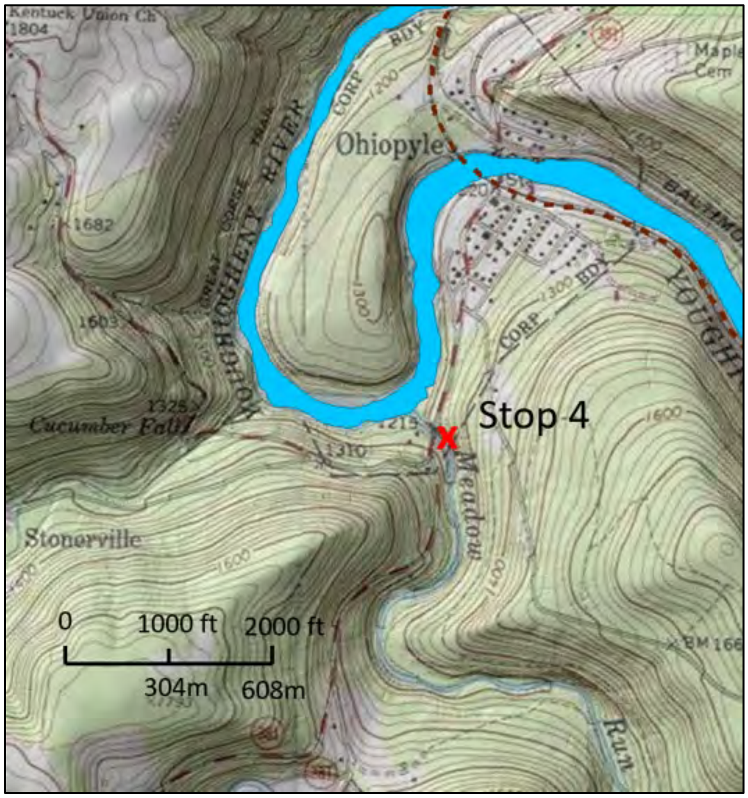


Figure 1. *Location of Stop 4 is in Ohiopyle State Park at the Meadow Run Slides area just south of Ohiopyle along Route 381*

Introduction

On any day of the week during the summer months the parking lot for Meadow Run Slides is often filled (*photo, opposite page*). This is one of the most popular destinations in Ohiopyle State Park and one of the most challenging for the brave few that attempt to navigate the course. The Slides are located (**Figure 1**) on a stretch of Meadow Run where the stream bed changes in character from being a wider, low gradient channel to a dramatically narrow one with a much steeper gradient. You enter the Slides at the top where Meadow Run is still at a low gradient, sit down and scooch yourself forward into the narrow channel area until you begin to be transported by the water and you are on your way. Once you are in the narrow channel, depending on the water level and flow rate, you are pretty much committed , and there is no getting out or turning back until you reach the base of the Slides where the gradient and velocity of the flow dramatically lessens as the water spreads out across a much wider channel area. Water levels often dictate degree of difficulty in successfully completing the slide without receiving any noticeable marks in the form of large bruises, skin scrapes or worse. Some injuries can be severe enough to require a trip to the hospital and perhaps that is one reason there are usually far more spectators than participants.

Topographically, the slide area begins at 1200' (365m) and drops 20' (6m) in elevation over a distance of 250' (75m) on its way to meet up with the Youghiogheny River. This is a much steeper gradient compared to the area above the slides where it is only 20' (6m) in 1000' (304m) or about 100 feet (30m) per mile. The Meadow Run Slide area is what's known as a "knickzone" but not a waterfall. The base level of Meadow Run is controlled by the base level of the Youghiogheny River at the confluence elevation of ~1165' (355 m). The knickzone has formed in response to the regional drop in base level of the Youghiogheny River, and the top of the slides shares a common elevation with the lip of Ohiopyle Falls, Cucumber Falls, Sugar Run Falls, and others in the Park. Importantly, these falls are not restricted to the Homewood Sandstone, although when the knickpoint coincides with this unit, it usually is a waterfall.

Geology and Depositional Setting of the Meadow Run Slides Area

As outlined by Brezinski and Kolar (2011), the paleoclimate of southwestern PA during the Pennsylvanian varied from arid to humid. During the early Pennsylvanian (Moscovian) the setting was low latitude; humid and warm conditions prevailed year round and were the most humid (highest precipitation) of any part of the Pennsylvanian. Therefore, source rocks were subjected to intense chemical weathering. According to Skema (2005) the outcrops south of New Castle PA (Moravia St Interchange) have significant amounts of siderite reflect extensive leaching of iron in the terrestrial setting, consistent with this paleoclimate reconstruction. Shaulis also notes the presence of siderite in the beds surrounding the Mercer coals (refer to stratigraphy section, **Figure 6**, this report).

Sediments available for deposition at this time were 'mature' and consisted mostly of quartz (monocrystalline). The source areas for the sediment were found to the southeast from erosion of uplifted terrains from earlier phases of the Appalachian Orogeny southeast of PA, and therefore transport in southwestern PA was primarily from southeast to northwest.

Materials subjected to uplift, weathering and erosion included the rock of the Paleozoic section. Of these materials, only the most stable materials were likely to survive intensive chemical weathering and therefore primarily quartz sand was transported into the basin. At least in southwestern PA/ Ohiopyle area, the lower (Early) Pennsylvanian sections are dominated by sandstone with few very thin clay and coal units that occasionally have thin brackish sediments overlying them. This strongly implies that the depositional setting was distant from the shoreline for much of the time and gradients were high enough that fluvial transport could not form floodplains to any great extent, and therefore deposition of clays and coals was minimal in this area at that time.

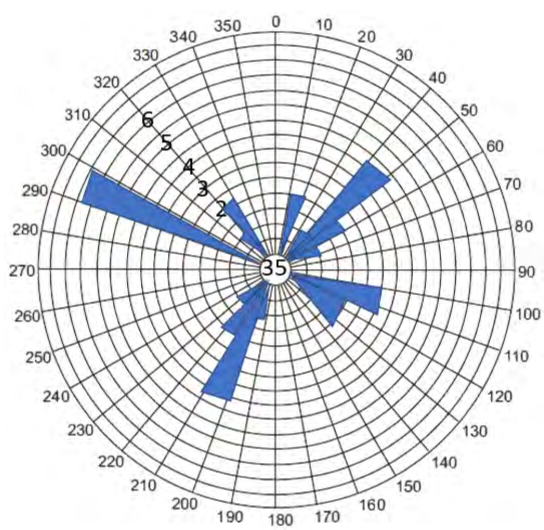


***Figure 2** shows jointing directions in the Meadow Run Slides area.*

Jointing

The majority of Joint directions in the Meadow Run area are either systematic (295 Az) or non-systematic (205-225 Az) (**Figure 2**).

Joint planes in the Meadow Run exposures are not well developed since the main channel direction in the slides area lines up mostly with the non-systematic joint direction (218AZ) but in several

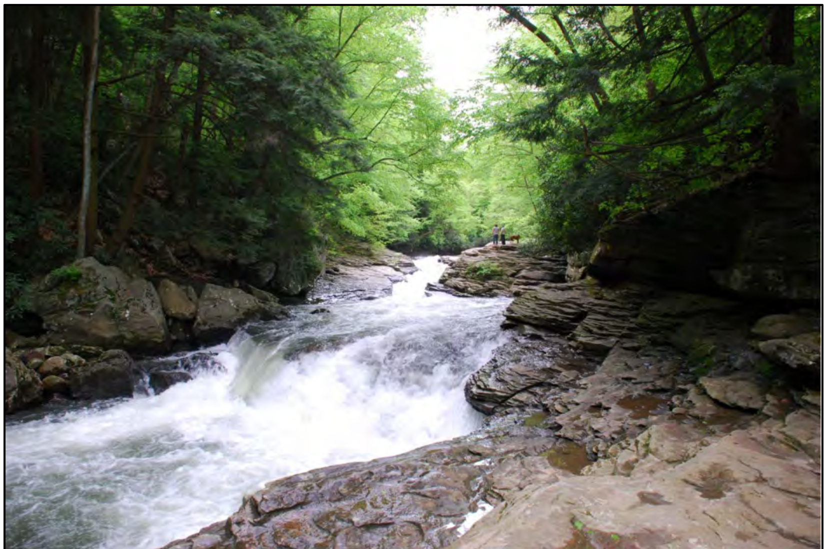


Figure 3. Photo of the Meadow Run slides. Looking upstream there is a noticeable nonsystematic joint set on the right-hand side (west side) of the channel that is influencing its course. Systematic joints cut across nearly normal to the stream channel.

places the systematic joint direction (Nickelsen and Hough, 1967) can be seen cutting across nearly normal to it (**Figure 3**).

The best place to look at the jointing in the Connoquenessing sandstone is at the entrance to Meadow Run.

In low water conditions, they are easy to recognize and have a large influence of the angle of the rapids in the Youghiogheny River (**Figure 4**).

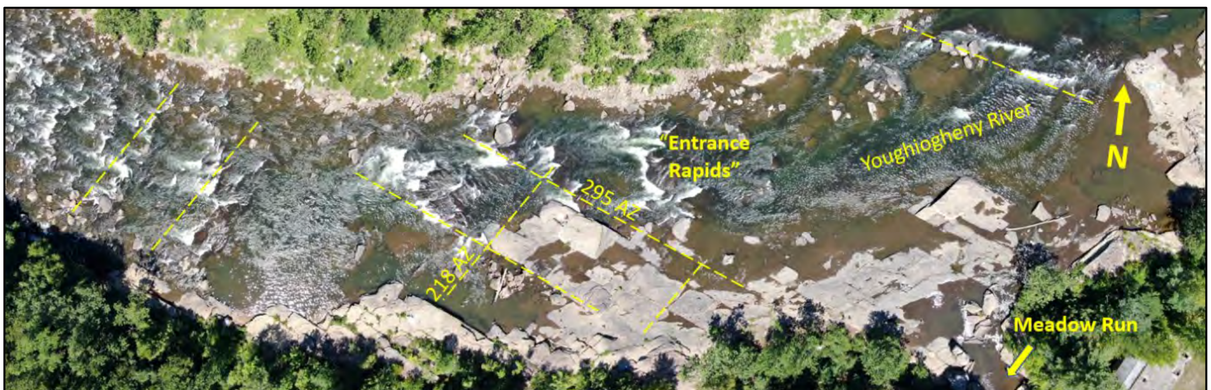


Figure 4 *is a photo showing how the systematic or primary joints (295 Az) impact the upper portion of the "Entrance Rapids" while the lower area of rapids approaching Cucumber Run, seem to be controlled by the nonsystematic or secondary joints (218 AZ). Photo by Craig Ebersole, BOGS, 2019.*

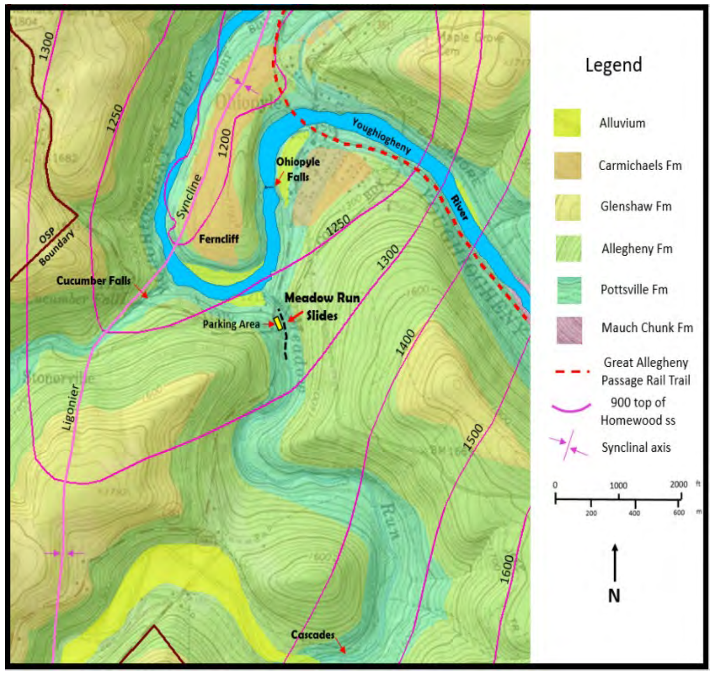
Stratigraphy and interpretation of the outcrop from Ohiopyle Falls and Meadow Run

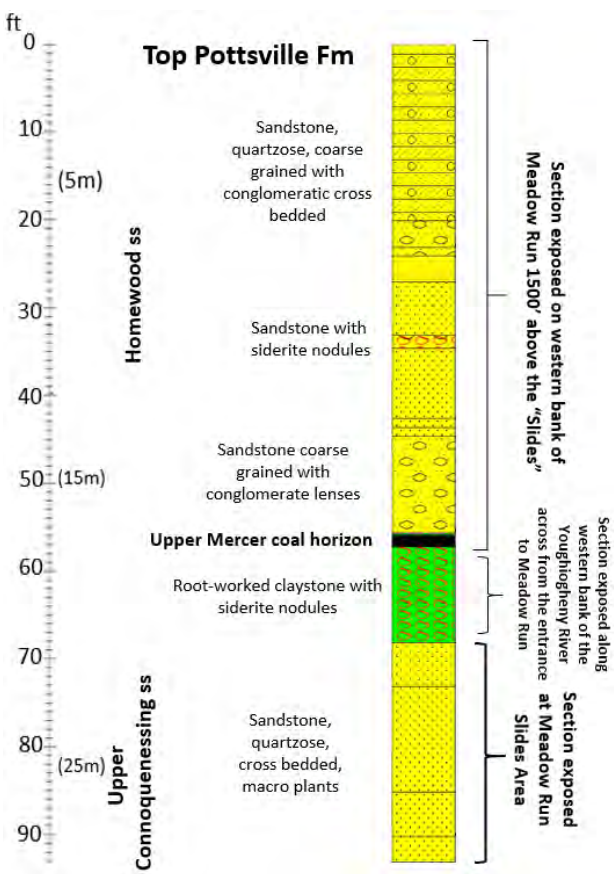
Geographically, the section included in this description extends from the Ohiopyle Falls near the Visitors Center and the 'flats' below the falls, up Meadow Run through the Slides to approximately a trail junction about a mile upstream.

Stratigraphically, the distribution of rock units is as follows. Ohiopyle Falls near the Visitors Center are held up by the Homewood Sandstone. Downstream a short distance from the Falls near the Visitors Center is an undercut bank and alluvial cave with an outcrop of 2-3'(0.6-1m) thick bone shale and underclay interpreted as the Upper Mercer Coal.

At this locality, you are standing just east of the axis of the Ligonier syncline. Rock layers generally dip gently northwest as you travel upstream on Meadow Run, because they occur on the southeast limb of the Ligonier Syncline. See **Figure 5**.

Figure 5 is a geologic map (Shaulis, 2021 publication pending) for the region showing the location of Meadow Run Slides in the Pottsville Formation on the southeastern limb of the Ligonier syncline.





The lower one mile of Meadow Run maintains a gradient at approximately the same as the dip of the strata following roughly along in the upper portion of the Connoquenessing sandstone and has exposed the overlying potion of the Pottsville Formation in its banks. The section exposed in the lower one mile of Meadow Run and the lower portion of Ferncliff along the Youghiogheny up to the main falls is shown summarized on **Figure 6** by Shaulis.

***Figure 6** shows the stratigraphic section exposed along the stream banks of the lower one mile of Meadow Run except for the interval immediately below the Upper Mercer coal is mostly concealed.*

Stratigraphy

The Ohiopyle Falls are held up by basal beds of the Homewood Sandstone (**Figure 7**) that have a combined thickness of approximately 5 m and are relatively massive. Tangential cross bedding is evident in boulders of the Homewood exposed near the junction of the Youghiogheny and Meadow Run. Cross beds are 30-50 cm thick and relatively low angle (15˚) with thin horizons of milky quartz pebbles sometimes present not only in the cross beds, but also as relatively horizontal layers in the Homewood.

Exposed in the riverbank just downstream from the Visitors Center on the Ferncliff side across from Meadow Run about 20 feet (6m) above river level is an outcrop of Upper Mercer coal and shale that has been errored into by the overlying Homewood sandstone member. The Mercer coal interval lies just above the upper Connoquenessing sandstone that is forming the extensive bedrock flats below the falls at the Visitors Center at the mouth of Meadow Run. The unit below the Mercer coal interval is identified as the upper Connoquenessing Sandstone which is regionally subdivided into the upper and lower Connoquenessing sandstone on the basis of a Quakertown coal that is present in this region. **Figure 7** shows all these units which are included in the Pottsville Formation.

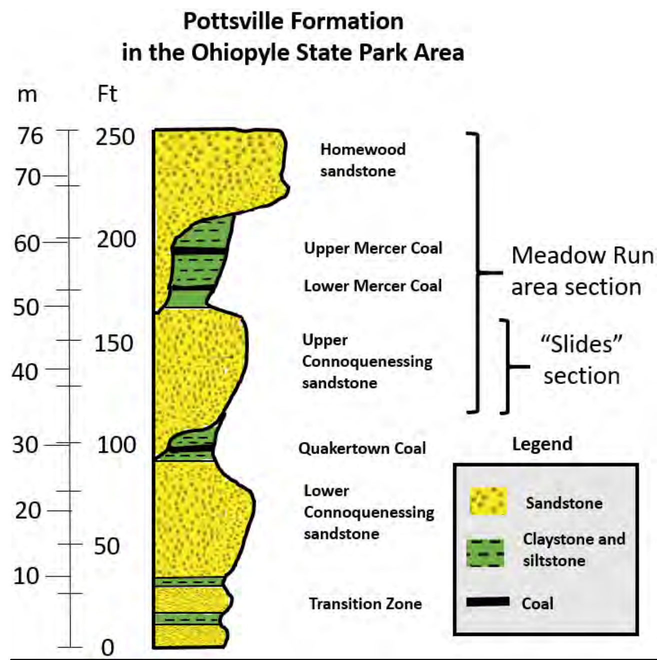


***Figure 7** shows the generalized section of the Pottsville Formation in the Ohiopyle region and the portion exposed in the Meadow Run Slides.*

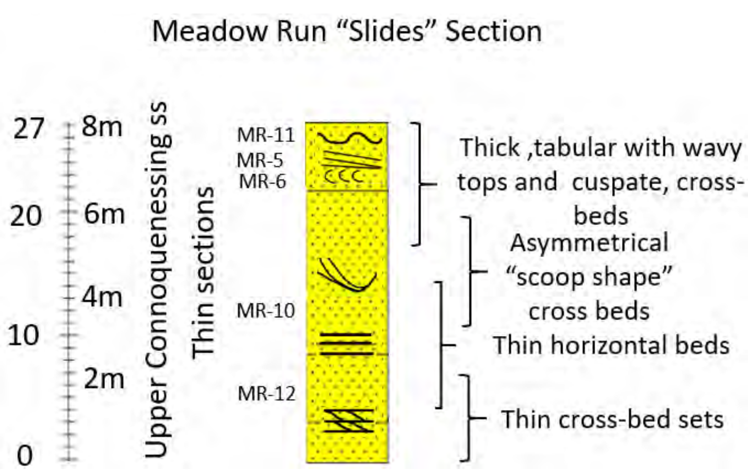


***Figure 8** shows the approximate stratigraphic position of the units and corresponding thin section samples in the Meadow Run Slides exposures.*

Although there are many outcroppings In the Meadow Run "Slides" area, they only expose about 25 to 30 feet (8 – 9m) of section made up of sandstone. The sandstone beds range from very fine to fine-medium grained, micaceous, cross to planar horizontal bedded 1 to 3 inches (2.5-7.5cm) thick. Bed forms transition laterally. There doesn't appear to be any stratigraphic datum within the sequence and no continuous vertical section was available to examine so it was extremely difficult to determine an exact thickness using overlapping sections. The regional dip of the beds was used to make a best estimate. Based on these exposures we have recognized 4 units largely based on sedimentary structures (**Figure 8**).

These units are described from top to bottom. Note; since these units were largely exposed laterally rather than vertically we had to interpret their vertical order. Thin sections were made to better define the lithologies of these units.

1) **Thick bedded tabular crossbeds:** Largely tabular crossbeds 30-100 cm thick, mostly 'foresets' about 10 degrees. Occasionally tops covered with cuspate ripples (15 cm) wide (cut and fill?). Occasional large-scale trough channels about a meter wide and exposed for at least 10 m. Both the cuspate ripples and large scale trough channels are best illustrated on flats downstream from Ohiopyle Falls. **Figure 9** developed in a sublitharenite (**Figure 10**).

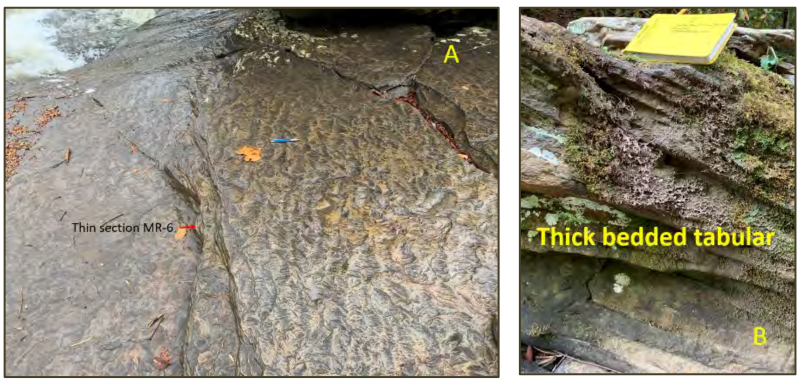


Figure 9 (A) *is of cuspate ripples located on thick tabular beds at the mouth of Meadow Run current direction to the SW*

(B) *is thick tabular beds located above the slides area dipping to the NW*

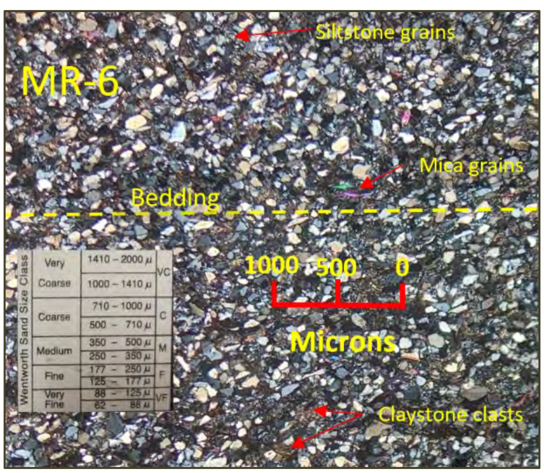
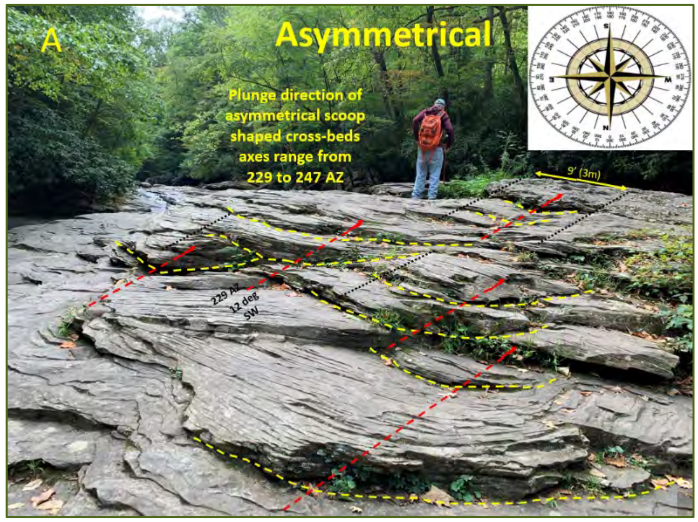


Figure 10, *site MR-6 (refer* ***Figure 9****) Image of a thin section made from the "cuspate ripples" a very fine to fine grained sandstone with compacted detrital matrix made up of clay and silt clasts, mica grains scattered throughout, quartz grains often surrounded by matrix, elongated grains commonly orientated parallel to bedding, vein quartz, monocrystalline, mostly detrital quartz, little authigenic quartz overgrowths ,little quartz cement, sub rounded to sub angular, moderately sorted, silty, borderline sublitharenite to litharenite , close to 25 % lithoclastics , porosity less than 5%, rounded and angular grains are mixed probably from an older sedimentary source, submature to mature (Folk,1974)*

2) **Medium asymmetrical 'scoop shaped' trough cross beds:** Troughs with scoured bases. 20-50 cm wide, 10-20 cm deep. 'Festoon' e.g. vertically stacked and lateral adjacent extending over 10 m. Oriented with transport to SW. NE trough bedding steeper than SW (**Figure 11**).

Figure 11 (A) is the well-developed asymmetrical scoop shaped cross-beds located along the upper reaches of the "Slides" area. Axes of the scours seem to be uniformly plunging in a southwest direction at 10 top 15 degrees. Southeastern sides of the scours are steeper dipping to the northwest while the northwestern sides are less inclined and dipping to the southwest more aligned with the axes.



(B) shows a close up of an asymmetrical scooped shaped cross-bed located in the upper portion of the "Slides" area. Beds appear to be of uniform thickness near the axis and thin toward the sides.

3) **Very thin bedded horizontal beds:** Horizontal beds 2-5 cm thick, laterally extensive (+10 m). Some intervals wavy bedded (L 10 cm, H 5 mm), also laterally extensive. Outcrops often have a 'ribbed' appearance (**Figure 12**) and were formed in a borderline litharenite (**Figure 13**).

Figure 12. Photo of a section just below the lower end of the "Slides" of a very fine to fine grain sandstone very exhibiting thin planar horizontal bedding.

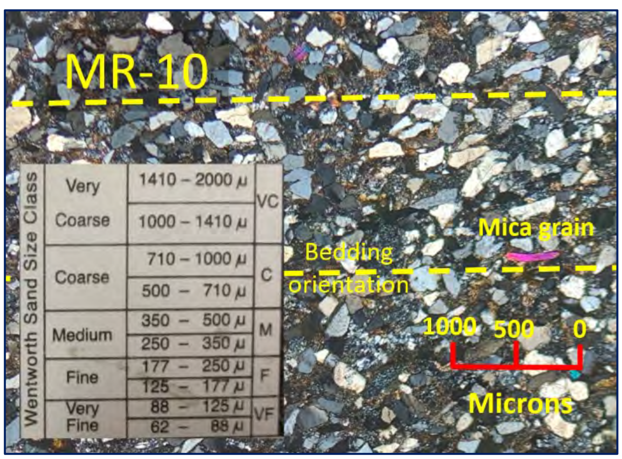


Figure 13 (MR-10) *Thin section image of a silty fine to very fine grained sandstone with compacted detrital matrix made up of clay and silt clasts, mica grains scattered throughout, grains often surrounded by matrix, sub-rounded to sub-angular, well-sorted, elongated grains commonly orientated parallel to bedding, vein quartz, monocrystalline, little authigenic quartz overgrowths, borderline litharenite to sublitharenite, just over 25% lithoclastics, porosity less than 5%, submature to mature. (Folk,1974)*

4) **Thin trough cross bedded sets:** Trough crossbeds 5-25 cm thick. Numerous sets interbedded/interfingered in section, but separated from adjacent sets by horizontal beds. Bases eroded into beds below. Orientation somewhat uncertain since exposures were largely '2d' and are compositionally a sublitharenite. See **Figures 14** and **15**.

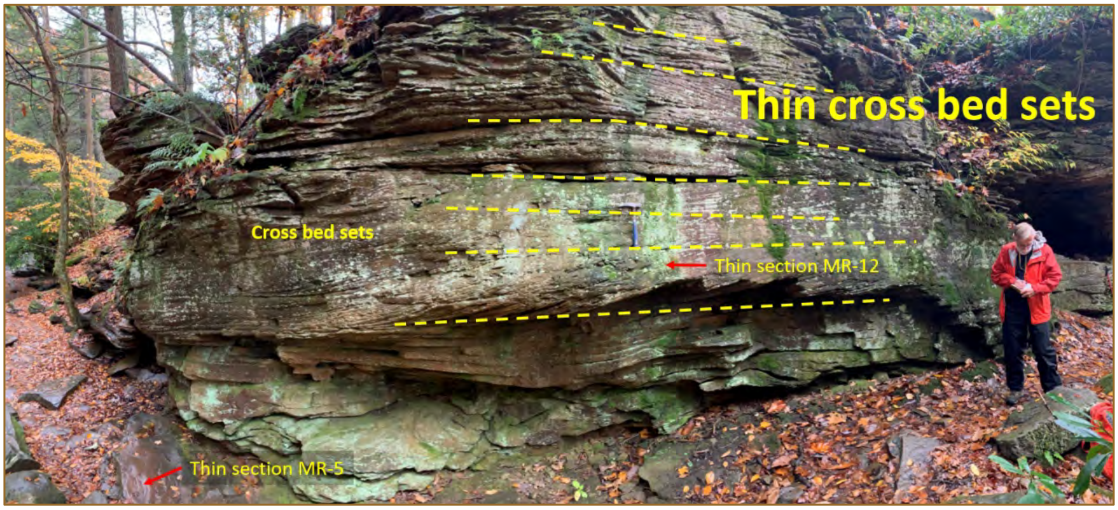


Figure 14, above, is a photo of section about 300 feet (90m) downstream from the base of the "Slides" containing numerous uniform (.8 feet (24cm) thick) cross-bed sets.

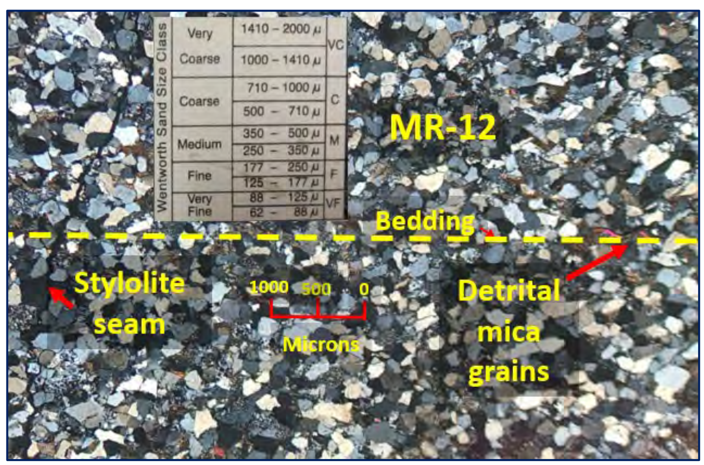


Figure 15 site (MR-12) *(location follow arrow Figure 14). Thin section image (right) of a silty, fine to medium grained sandstone with compacted detrital matrix made up of silt clasts with subordinate clay clasts, few mica grains scattered throughout exhibiting ductile deformation, quartz grains in places can be surrounded by matrix, but often are grouped together, sub-rounded to sub-angular, well to moderately sorted, elongated grains commonly orientated parallel to bedding, stylolite seam composed of organic matter, vein quartz, monocrystalline, authigenic quartz overgrowths not uncommon, 15 to 20% lithoclastics, sublitharenite approaching a litharenite, porosity less than 5%, mature (Folk, 1974)*

Rock layers generally dip gently northwest as you travel upstream on Meadow Run, because they occur on the southeast limb of the Ligonier Syncline (Figure 5). The dip of the limb and the gradient of the valley of Meadow Run are fairly similar allowing a limited exposure of the Connoquenessing Sandstone to be examined along Meadow Run. The Homewood Sandstone exposed along the eastern edge of the Meadow Run is easily reached from SR381. Outcrops of the Homewood accessible near SR 381 Bridge contain a well preserved 20'(6m) *Lepidodendron* log exposed near the top of the outcrop. Blocks of Homewood that have mass wasted into Meadow Run valley can also be examined upstream.

Beginning at the junction of Meadow Run and the Youghiogheny River, east of the SR 381 Bridge, exposures of Connoquenessing Ss. occur along and above Meadow Run. This section of the Connoquenessing Ss. (**thin trough cross bedded sets**) comprises medium-grained sandstone with minimal pebble content (Figure 15). Structures of this sandstone unit are a combination of sets/co-sets of low angle tangential cross bedding typically 10 cm thick (range 5-25 cm) and planar beds about a couple of cm thick extending laterally for several meters. Some the cross beds 'interfinger' with each other and some are underlain by eroded bases. Most of the faces exposing this unit are fairly 2 dimensional which made determining the orientation of the crossbedding challenging (**Figure 14**).

The **very thin bedded horizontal beds** are especially well exposed in the section between the trail to the Slides and the SR 381 Bridge. Their planar nature is enhanced by weathering along planes that gives the outcrop a 'ribbed' appearance. This could be a consequence of graded bedding, but this was difficult to verify given how mossy the outcrops are. In addition a number of these planar layers have a cross sectional 'wavy' (sigmoidal) appearance with wavelengths of 10 cm and wave heights of 5 to 10 mm. Since this outcrop was 2 dimensional no associated bedding planes were noted that would allow identifying these as ripples with characteristic forms (**Figure 12**).

Just upstream of the trail to the Slides parking lot, outcrops of the **medium asymmetrical scoop shaped trough cross beds** occur. This unit is characterized by distinct 'scoop shaped' tangential cross bedding about 10-20 cm thick. The width of the scoops varies between 20 and 40 cm. The infillings of the scoops indicate sediment transport towards the SW. Many examples of these bedforms are located in this outcrop and perhaps can be described as 'festoon' i.e. they repeat in a vertical sequence of several meters and also occur adjacent to each other for 10's of meters (mostly limited by the size of the exposure. (See **Figure 11**)

Although outcrop is somewhat limited upstream from the Slides, the structures just above the **asymmetrical scoop shaped trough cross beds** again are low angle planar tabular cross beds with some low angle tangential cross beds. We infer these are another occurrence of the **thick bedded tabular cross beds** (**Figure 9**). Just below the major bend in Meadow Run (1000'- 304m upstream from the slides), an undercut lip is formed from eroding a 'coaly' shale at the base (**Figure 16**). This shale interval is inferred to be equivalent to the Mercer Coal and represents the stratigraphic lower boundary of the Homewood Sandstone as seen below the Ohiopyle Falls.

Figure 16. *Photo of Meadow Run 1000 feet (304m) upstream from the slides where it makes a bend to the southwest before it heads around to the east. The Homewood sandstone member and the Upper Mercer coal are outcropping in the cut bank on the western side.*

The upstream Homewood outcrops are composed of coarser grained sandstone with some intervals and layers of milky quartz pebbles (**Figure 17**). Beds appear significantly thicker (25-50 cm) and with tangential cross beds which are typically also about 25-50 cm thick. A significant number of plant fossils also are associated with these beds, which are mostly 'stem' fragments 20-30 cm long and appear oriented in some horizons at 260˚. This outcrop of Homewood Sandstone continues around a sharp bend and rapids in Meadow Run and some distance beyond, before it begins to raise up to the southeast away from the base level of the stream. (See **Figure 5**)

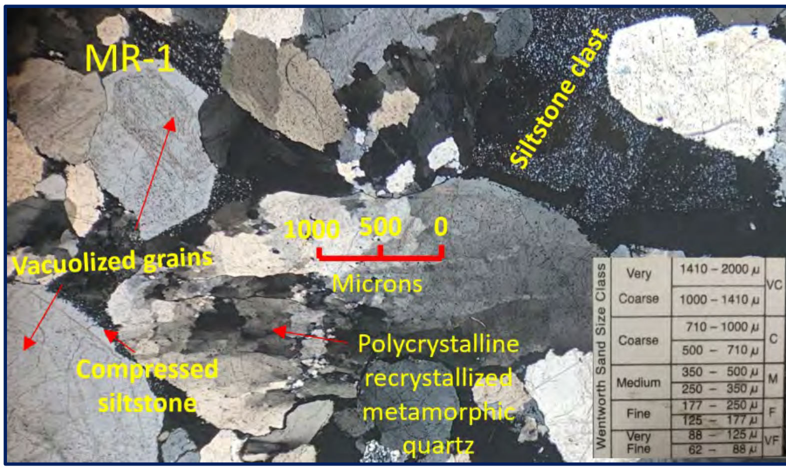


__Figure 17.__ Image of a thin section from near the base of the Homewood sandstone showing the coarse to very coarse grained quartz and quartz pebble composition. It is well to moderately sorted with sub angular to sub rounded grains. It contains mostly monocrystalline quartz but does have some polycrystalline metamorphic quartz and a few lithic fragments, mostly siltstone grains that are compressed between quartz grains, cemented secondarily with quartz overgrowths, euhedral shaped grains indicating quartz cement, and some iron. Grains are sometimes striated that are possible vacuoles in vein quartz or from compression. It can be classified as a mature quartzarenite. (Folk,1974) and appears to have a porosity less than 5%.

Crossbedding and current indicators

Forty (40) crossbedding orientations (**Figure 18**) were made in the Upper Connoquenessing Ss in the Meadow Run Slides area, but the majority were confined to the thick tabular and scoop shaped beds and were oriented to the SW or NW . All the trough axes for the scoop shaped bed were to the SW. Some scoop shaped beds and thin cross set beds had dips to the SE and only a scoop shaped like unit about 1000'(300m) upstream had the majority of the dips to the NE. Log orientations all were to the SW.

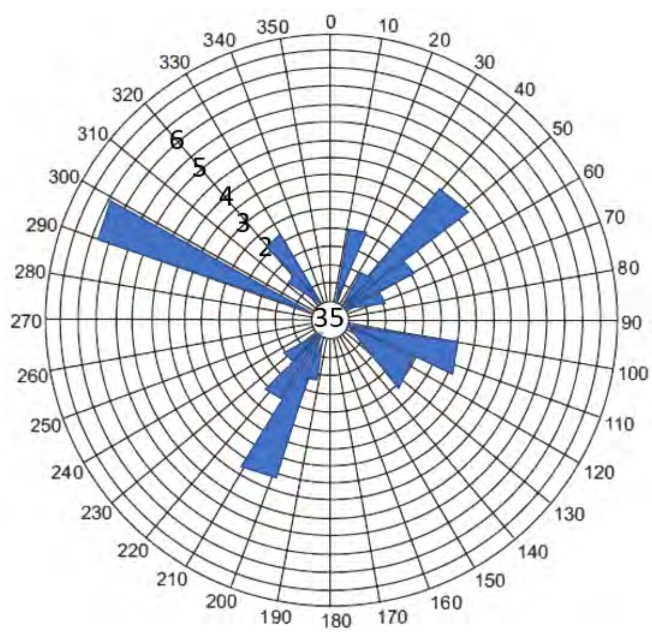


__Figure 18__ shows cross bed orientations in the Upper Connoquenessing Ss in the Meadow Run Slides area that may indicate a more northeasterly source direction

Interpretation and Speculations

It is confidently inferred that all of these units are non-marine given the lack of any recognizable marine fossils throughout and relatively poor sorting of the sandstone. Longstanding, well established interpretations of the Pennsylvanian paleogeography incorporate eroding mountain highlands and fluvial transport of sediment to lowland areas. The question then is, "was the field area characterized by low gradient meandering rivers with stable banks or braided streams /alluvial plain with abundant sand?"

The general lack of shale with imbedded lenses/channels composed of sandstone and containing clay intraclasts throughout the outcrops might preclude a fluvial meandering river/floodplain as seen in typical "Catskill delta" and Allegheny Fm. outcrops. However, given the limited exposures, perhaps a more extensive regional study might reveal the presence of these elements. The analysis and interpretation of the Battery Point Sandstone (Quebec) offered some parallels and possible insights in interpreting these exposures.

The dominance of planar tabular cross bedding, planar horizontal bedding and some parting lineations particularly in the Connoquenessing Sandstone is noteworthy. Tabular cross bedding is often interpreted as evidence of transverse bars in braided river complexes, but the lateral continuity of these structures and a scarcity of channel forms with large scale cross bedding suggests that flowing channels were rare or obliterated after deposition. If a braided stream model is relevant then the transverse bars must have been sizable and longitudinal bars obscure. Cant (1982 p. 124) notes "braided rivers with more steady discharges and more topographic differentiation develop …straight crested tabular bars at high stage" Reineck and Singh (1980 p 262) note transverse bars are common in distal parts of gravelly streams. These are reasonable parallels to conditions during deposition of the Pottsville.

Likewise the scoop shaped crossbreds could be interpreted as subaqueous dunes migrating downstream in channels. If deposition was laterally widespread and more subaerial, then perhaps slope wash was a significant depositional mechanism that produced sheets of sand that spread over the area which deposited relatively sedimentary structure free materials. This mechanism could dominate in higher parts of the watershed in relatively close proximity to drainage divides. Similar deposits are noted in the Mesozoic rift basin sediments of western MA (Turners Falls area). One might anticipate coarser clastic material (pebbles-cobbles) would be deposited in this setting close to the sources but if they were more distant, sediment would reflect a lack of these coarsest materials. Also, if the source of the sediment was dominated by recycled Paleozoic sediments weathered in 'tropical wet' conditions, probably there was little clast material available and therefore generally sand was deposited.

Heavy rains resulted in flows crossing the surface washed in clastic sands, but because of the high permeability of the terrain they flowed across, there was little chance for runoff to coalesce into higher order streams. A relatively quiet period at the end of depositing the Connoquenessing Ss. resulted in a short interval accompanied by deposition of thin coals and clays. This was followed by a major influx of sediment (sand) resulting in the thick bedded, tangential cross bedded composing the Homewood Sandstone. At least in the Ohiopyle area, deposition was rapid and continuous and resulted in a relatively thick, well cemented sandstone body (Homewood Ss.) from this extensive weathering and rapid transport. The Homewood Ss. is also associated with a significant amount of oriented plant debris washed in from the upper part of the watershed. None of this plant material is easily interpreted as in situ since trunk or vertical growth orientations of plant fossils were not noted.

Perhaps the ‘massiveness’ of the Homewood reflect relatively high, constant temperature/precipitation and a high rate of transport into the basin as a consequence of frequent storms (hurricanes? monsoons?). With little weathering of deposits between storms, the sand transported by repeated storms would have ‘amalgamated’ into a relatively uniform thick sand mass. Because the sand transported was relatively uniform, little evidence of individual storm/seasonal events would be recognized (e.g. reactivation surface are not recognizable). Likewise, since these materials were deposited relatively high up in the watershed, one might assume that sorting would be poor. However, if the sediment supplied was from recycled Paleozoic units, mineralogical and size ‘diversity’ was curtailed and the deposited sediment would have been relatively uniform.

The presence of linguoid ripples directly overlying some of the tabular cross beds suggests that they were deposited in a temporarily subaqueous setting with declining water levels; slope wash was initially deep enough to form the tabular cross beds and as the flow subsided, linguoid ripples formed in shallow water (?pools?) that lingered on the draining surfaces. These upper parts of the watershed were perhaps more similar to alluvial fans formed under humid conditions rather than tropical river systems. Presumably, the depositional setting was unstable enough that Pennsylvanian vegetation could not become well established on these slopes before the next storm occurred. However, by the time the overlying Allegheny Fm. was deposited, more floodplain/lower gradient conditions prevailed and typical coal measures were deposited during that interval.

Meckel (1967) in studying the exposures of the Pottsville in PA east of the Susquehanna River, also seems to reach the conclusion that the Pottsville was deposited by braided streams on an alluvial plain (p.239). Although this conclusion was considered tentative, other supporting evidence such as trends in thickness, and changes in pebble size and concentrations bolstered this conclusion. So although data supporting this conclusion from Ohiopyle are somewhat sparse, it seems like a plausible outcome. Likewise, although the battery Point Fm. (Cant and Walker 1976) seemed to contain more shale and siltstone than the Connoquenessing, there were a number of sedimentary structures in common suggesting braided stream deposition.

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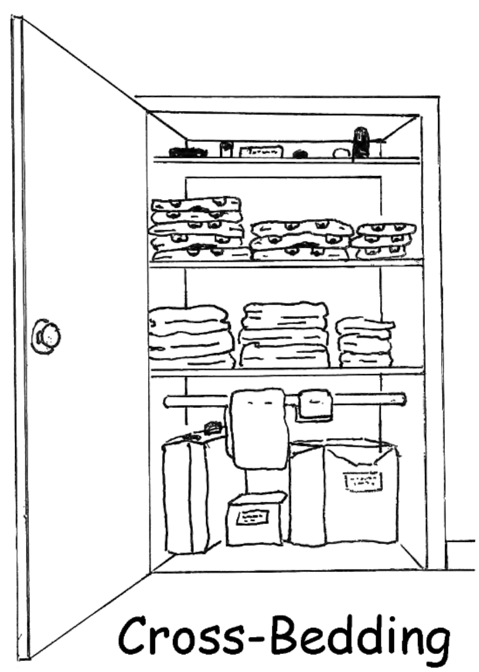

Cross-Bedding

CUCUMBER FALLS

KNICKPOINT OBSERVATION – UPPER POTTSVILLE FORMATION

FRED ZELT – EARTH SCIENCE EXCURSIONS, LLC
EXXONMOBIL (RETIRED)

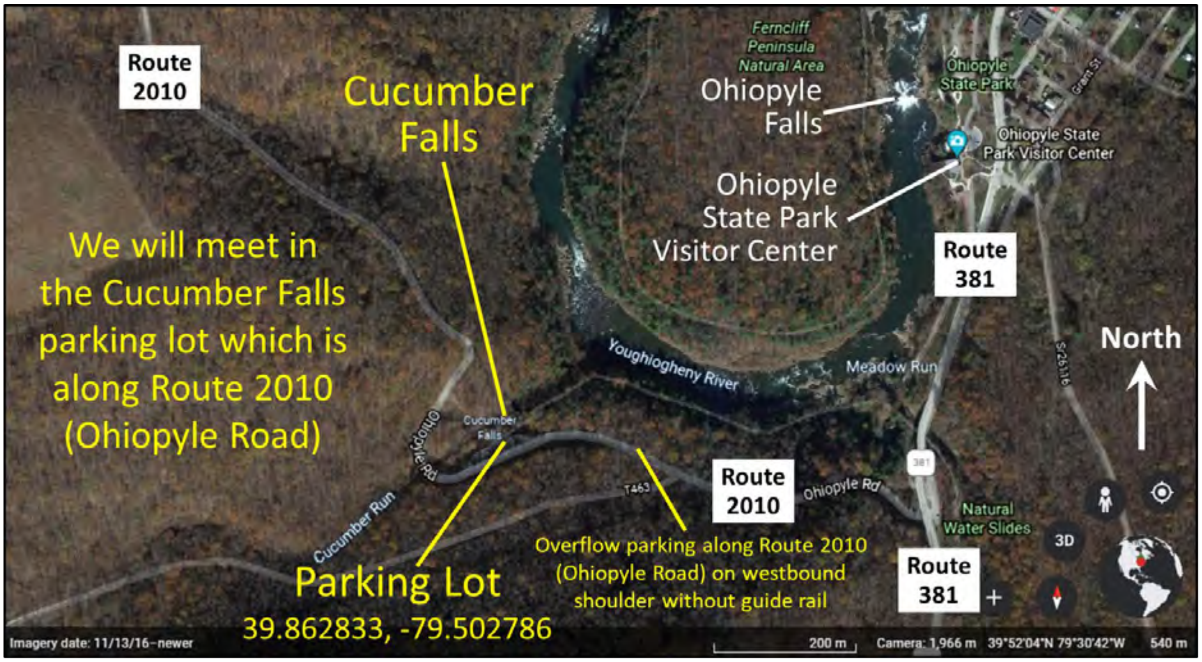

Figure 1. *Satellite map of pre-conference trip meeting area in Cucumber Falls parking lot. We will meet in the parking lot at the junction of the Cucumber Falls and Great Gorge trails (39.862833, -79.502786). Parking in the Cucumber Falls lot is limited, and additional parking is available on the westbound shoulder of Route 2010/Ohiopyle Road, east of the Cucumber Falls parking lot. Parking on the shoulder is not allowed where there is a guide rail.*

Introduction

Lovely and popular Cucumber Falls is a knickpoint held up by Homewood sandstone and underlain by Mercer coals that will be discussed during the main Field Conference, but time will not permit us to visit it then. This pre-conference trip will provide an opportunity to observe the nature of the upper Pottsville Formation at the waterfall and along Cucumber Run between the waterfall and the Youghiogheny River, led by a geologist who is familiar with the trail. Observations made during the trip will provide context for Conference discussions of waterfall knickpoint migration up the Youghiogheny River and Cucumber Run.

Logistics

We will meet in the Cucumber Falls parking lot on Route 2010/Ohiopyle Road (39.862833, -79.502786) for a brief orientation starting at 9:00 am on October 7, 2021 (**Figure 1**). Up to 10 hikers should bring water, sturdy hiking boots and a walking stick; level of difficulty is moderate due to rocks, roots, holes in the path, slippery rocks near the stream, and a moderate climb back to the parking area from our turnaround at the confluence of Cucumber Run and the Youghiogheny River. Please bring a hard hat if you wish to approach the waterfall or closely examine rocks near the waterfall.

There are no restroom facilities at this location, but restrooms are available at the Ohiopyle State Park Visitor Center. The Visitor Center parking areas are more than 100 meters away from the building, so if you stop there on the way to Cucumber Run please allow adequate time.

We will return to the Cucumber Falls parking area no later than 10:30 am. After the conclusion of this trip, you may choose to hike the Great Gorge Trail along the Youghiogheny River downstream of Cucumber Falls, or the Cucumber Falls Trail upstream along the Youghiogheny to the mouth of Meadow Run.

Geologic Setting

Cucumber Falls occurs on Cucumber Run very near the axis of the Ligonier Syncline (**Figure 2**; Shaulis, 2020). The Pennsylvanian Pottsville Formation in western Pennsylvania is traditionally subdivided into units including Homewood and Mercer zones based on dominant lithology and position relative to coal and marine marker units (**Figure 3**). Cucumber Falls is held up by the Homewood sandstone and underlain by the Mercer coals, sandstones and mudstones of the upper Pottsville Formation (Shaulis, 2020).

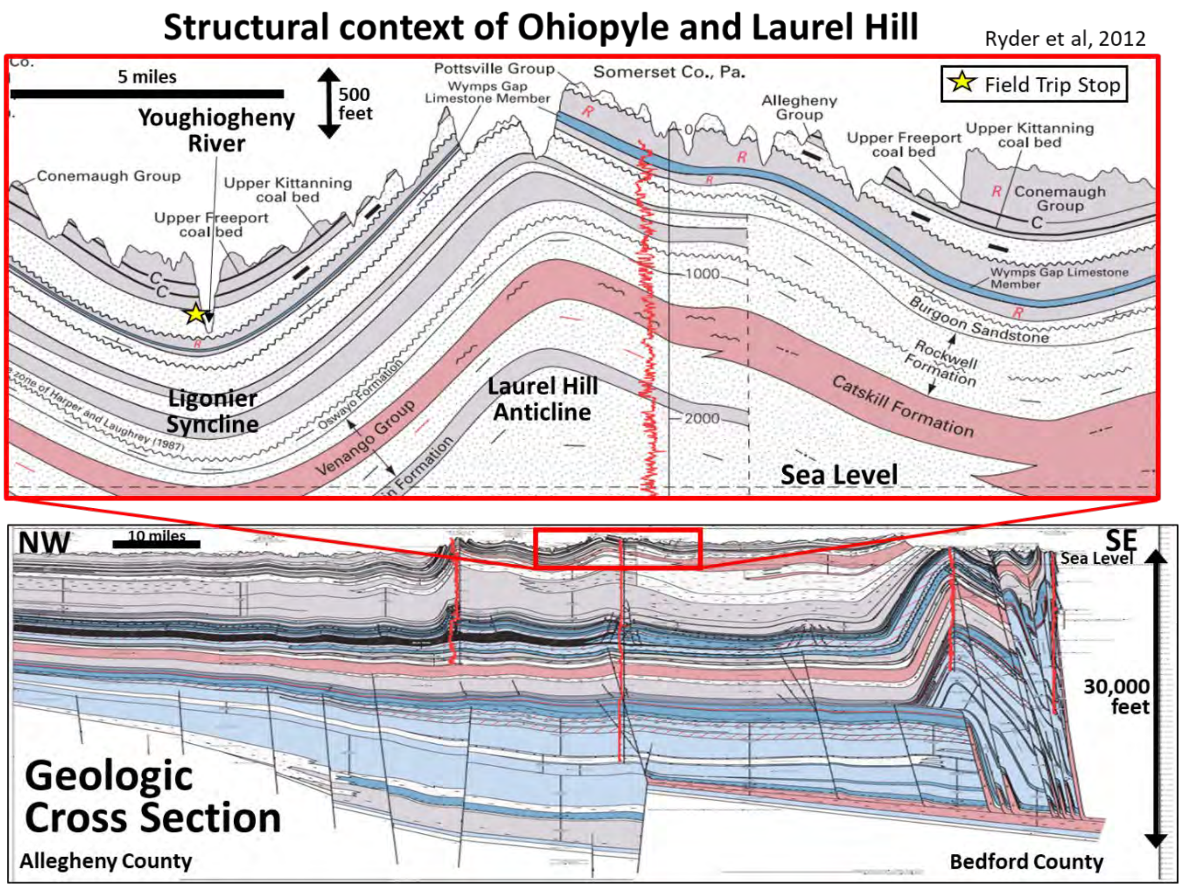

__Figure 2.__ Structural context of strata in southwestern Pennsylvania. The Cucumber Falls outcrop is located near the axis of the Ligonier Syncline. Section is from Ryder et al, 2012.

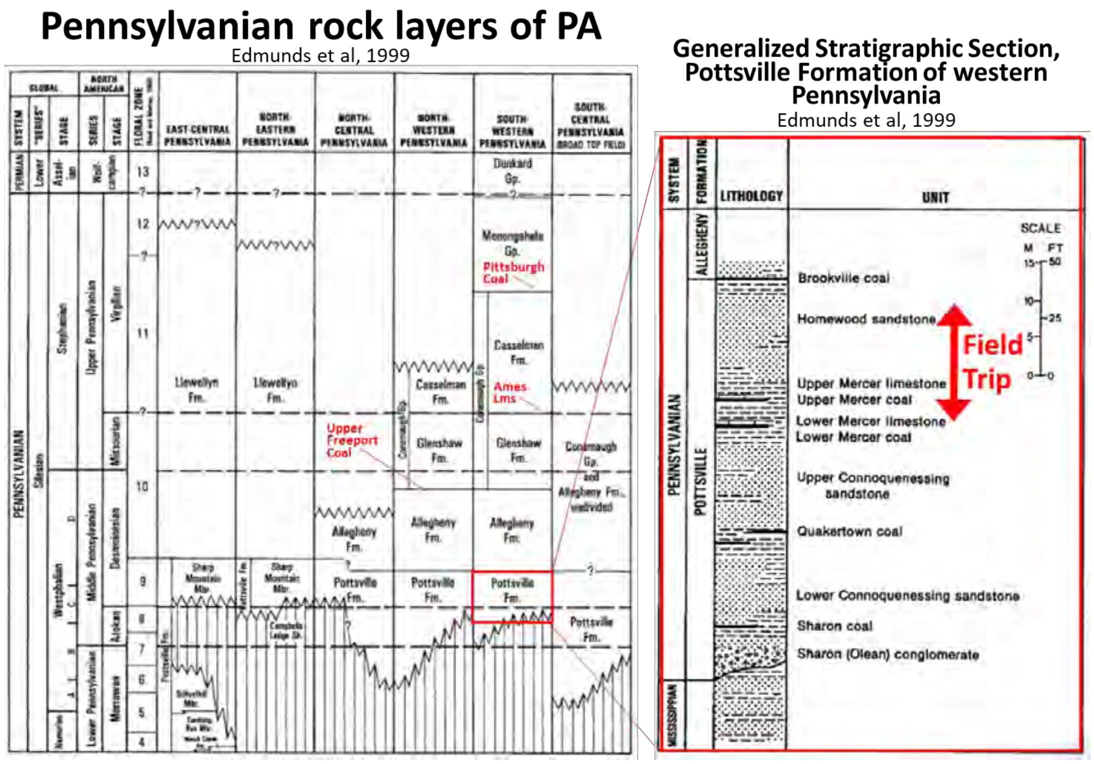

Figure 3. Generalized stratigraphic section of the Pottsville Formation in western Pennsylvania. From Edmunds et al, 1999.

Thoughts on Knickpoint Migration

The Cucumber Run watershed is modest in size (17 square kilometers; Wikipedia, 2021a), smaller than the adjacent Meadow Run watershed (107 square kilometers, Wikipedia 2021b) and two orders of magnitude smaller than the Youghiogheny River watershed upstream of Ohiopyle (2,800 square kilometers). As Pazzaglia et al (2020a) described, Cucumber Falls, Meadow Run Waterslides and Ohiopyle Falls represent knickpoints on these waterways. Cosmogenic radionuclide age dates constrain rates of knickpoint migration along the Youghiogheny River and Cucumber Run (Pazzaglia et al, 2020b). The age dates indicate a slower rate of upstream migration of Cucumber Falls than Ohiopyle Falls. This was shown to be consistent with the much smaller volume of water in the Cucumber Run watershed as well as the observation that the Cucumber Falls knickpoint has migrated a much shorter distance upstream than has Ohiopyle Falls since the knickpoints bifurcated at the mouth of Cucumber Run. Migration of the Ohiopyle Falls knickpoint around the Ferncliff Peninsula was interpreted to have occurred through at least two 100,000-year glacial/interglacial climate cycles.

Ohiopyle Falls, Cucumber Falls, Meadow Run Waterslides and the whitewater of the Youghiogheny River below Ohiopyle are scenic and recreational treasures. Deep understanding of the origins and evolution of these features provides opportunities to convey to the public fundamental concepts of science and climate, including what is known about climate change over the last 200,000 years.

Rate of knickpoint migration on the Youghiogheny River likely varied significantly across the different climate regimes of the last glacial/interglacial cycles. Within glacial/interglacial cycles annual rainfall, number of freeze-thaw cycles and accumulation of snow and ice, (compare **Figures 4 a, b**) along with the volume of water flow during thaws may have been much higher during parts of climate cycles other than the current interglacial climate regime.

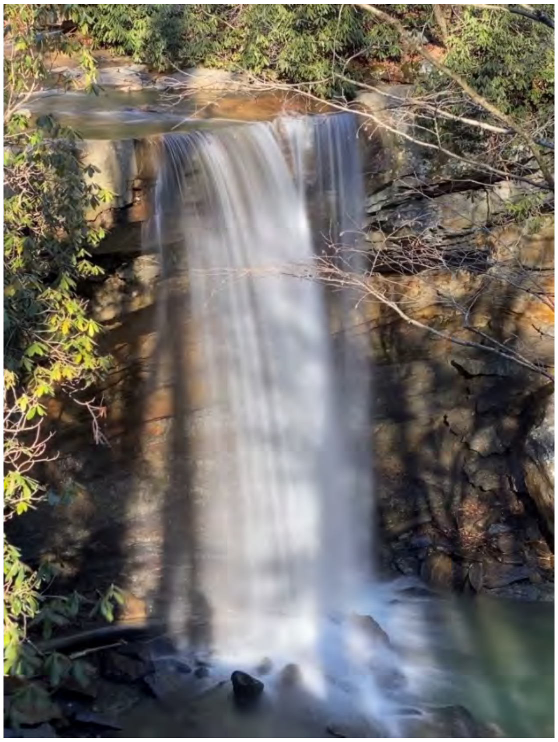

Figure 4a. *Photograph of Cucumber Falls, Ohiopyle State Park PA in direct sunlight. This long exposure photo was taken at 8:56 am on March 13, 2021.*

Figure 4b. *Winter photograph of Cucumber Falls, Ohiopyle State Park PA. This long exposure photo was taken on February 12, 2021.*

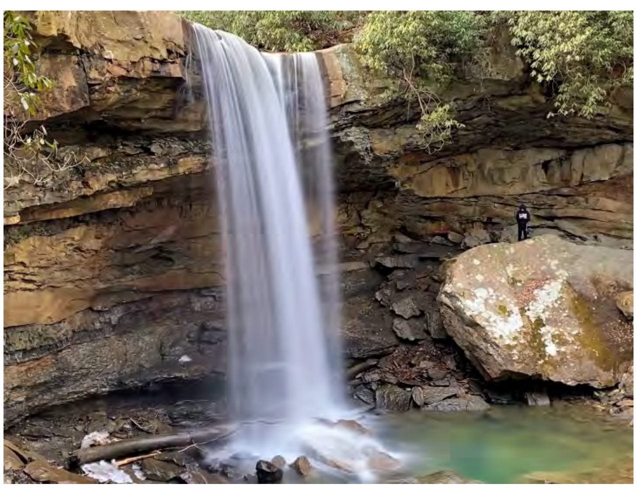

Figure 5. *Photograph of Cucumber Falls in Ohiopyle State Park PA.*

The resistive, amalgamated sandstone at the top of the waterfall is underlain by sandstones with erosional surfaces, coals and mudstones. There is a person on the right for scale. This long exposure photo was taken on March 10, 2021.

Additional evidence of recent rates of knickpoint migration can be found in waterfall photographs from the 1800's and early 1900's. Comparison of old and new photographs of three western Pennsylvania waterfalls shows little if any significant erosion and upstream migration in the last 110 to 140 years (**Figure 5**). The upper edge of Cucumber Falls and large sandstone blocks at the base of the waterfall appear to be the same in a 1909 photograph as in 2021. Photographs of Buttermilk Falls on Clark Run in Beaver County, PA from the late 1800's are similar to today, with the same sandstone blocks at the base of the falls. Carved graffiti on fallen and in-place sandstone blocks behind Buttermilk Falls include the dates 1888 and 1890, consistent with the sandstones having been in place and exposed since then. The large sandstone blocks in front of Ohiopyle Falls appear to have been in place and unchanged since the waterfall was photographed in late 1800's. However, erosion and knickpoint migration rates may have been much higher during other parts of the glacial/interglacial climate cycles in watersheds like Clarks Run that may have received glacial meltwater from nearby glaciers as well as the Youghiogheny, Cucumber and Meadow Run watersheds which drained periglacial upland areas.

Research Opportunities

The unique geometry of the Youghiogheny River, Cucumber Run and Meadow Run may enable discernment of variations in knickpoint migration rate in different parts of glacial-interglacial climate cycles. Additional age dates along the knickpoint migration paths could indicate which parts of the most recent glacial-interglacial climate cycles had high versus low rates of erosion and knickpoint migration. This has implications for climate models of the region.

Further application of cosmogenic age dating to Pleistocene erosional and depositional features of the Allegheny, Monongahela and Ohio River drainage systems is likely to yield insights of regional significance. The work of Frank Pazzaglia and co-workers at Ohiopyle has shown the way and yielded significant results. Similar work on the type Parker Strath at Parker, PA, the large perched river terrace in Pittsburgh's Oakland-East Liberty-Swissvale area and other prominent perched river terraces along the Allegheny, Ohio, Monongahela and Beaver rivers is likely to significantly increase understanding of the landscapes on which many people live in western Pennsylvania and adjacent states. Each year thousands of people visit scenic areas such as Buttermilk Falls Natural Area in Beaver County, PA and Fall Run Park in Shaler Township near Pittsburgh. Improved understanding of knickpoint migration timing, knickpoint migration rate and landscape evolution would deepen public understanding of these popular waterfalls and increase awareness of fundamental concepts of science and climate.

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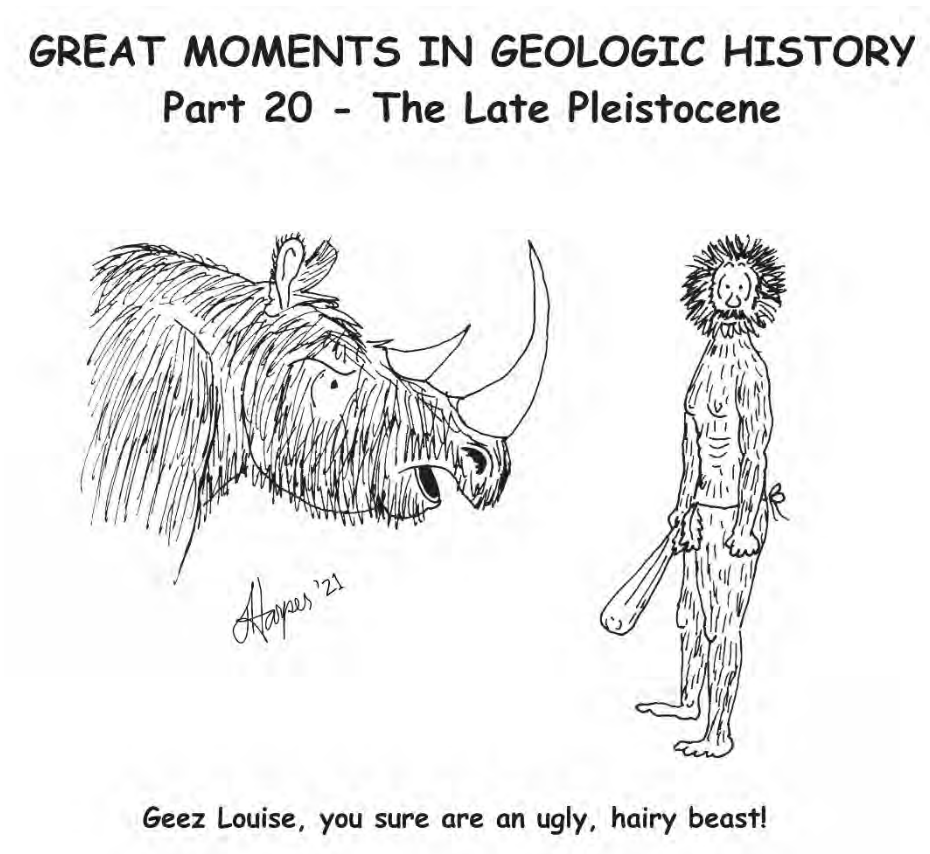

HIKE TO MEADOW RUN CASCADES

EMPHASIS ON DEPOSITIONAL ENVIRONMENTS AND PALEOCURRENTS IN THE HOMEWOOD AND CONNOQUESSING SANDSTONES OHIOPYLE STATE PARK – PRE-CONFERENCE TRIP

FRED ZELT – EARTH SCIENCE EXCURSIONS, LLC
EXXONMOBIL (RETIRED)

Figure 1. *Map of Meadow Run Cascades from the Pennsylvania Department of Conservation and Natural Resources. We will meet in front of the Ohiopyle State Park Visitor Center (1), walk to Flat Rock (2) and Cascades (3). Please note North is toward the upper left and the actual location of the Cascades Waterfall is at the red star rather than where indicated on the map.*

Introduction

This pre-conference field trip supplements conference visits to other, more easily accessible outcrops of the Pottsville Formation in Ohiopyle State Park. We will hike the Meadow Run Trail to an exposure of the Connoquenessing sandstone at Meadow Run Cascades. The Connoquenessing at Cascades is very well exposed during low water in Meadow Run. October is typically the month with the lowest precipitation in this area, so we are hopeful the rocks will be well exposed during our visit. When the water level in Meadow Run is high the rocks are less visible, but the small waterfalls and cascades are quite scenic.

Highlights of the Cascades sandstone outcrop include an unusually fine bedding plane and side exposure of a one-meter tall dune with a linear crest, scour pit in the trough on the lee side of the dune, and the east-directed cross bedding that is typical of this locality. On the way to Cascades we will pass an outcrop of quartz-rich and cross-bedded Homewood sandstone, and see a bedding plane exposure of the Connoquenessing with ripple marks at Flat Rock. Natural fractures consistent with dominant area trends are also well exposed at Cascades and Flat Rock when the water level in Meadow Run is low.

Logistics

We will meet in front of the Ohiopyle State Park Visitor Center for introductions and an orientation at 11:00 am on October 7, 2021 (**Figure 1**). We will meet in front of the Ohiopyle State Park Visitor Center for introductions and an orientation at 11:00 am on October 7, 2021.

Geologic Setting

The Flat Rock and Cascades outcrops occur on Meadow Run, between the Ligonier Syncline and Laurel Hill Anticline (**Figure 2**). The Cascades outcrop is upstream of the Waterslides outcrop of the Pottsville Formation (see previous pre-conference field trip article, this Guidebook). There are multiple outcrops of Pottsville sandstones along Meadow Run. This is because from Waterslides through Flat Rock to Cascades, the rise in elevation of Meadow Run is roughly matched by rise in structural elevation of the Pottsville from the Ligonier Syncline to the flank of the Laurel Hill Anticline.

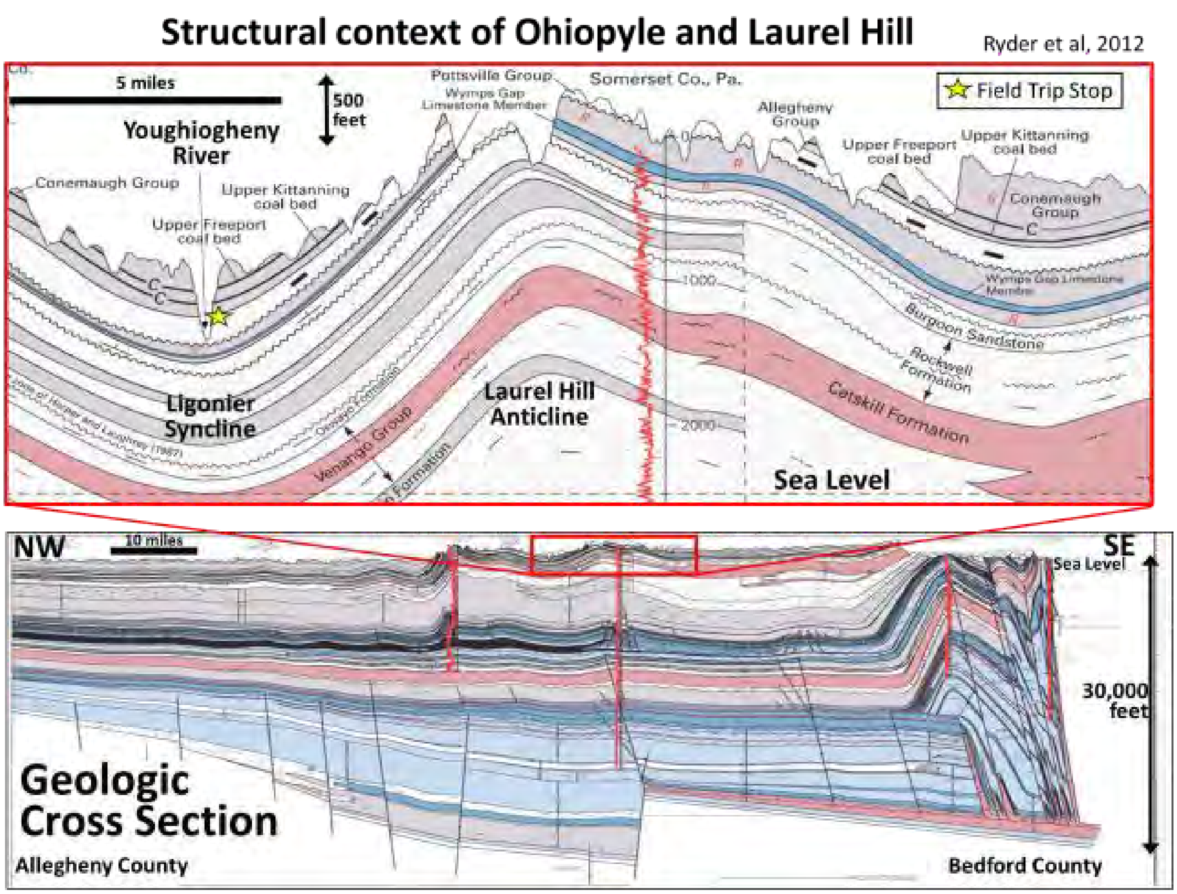

Figure 2. Structural context of strata in southwestern Pennsylvania. The Meadow Run Cascades outcrop is located on the eastern flank of the Ligonier Syncline. Section is from Ryder et al, 2012.

The Pottsville Sandstone in western Pennsylvania is traditionally subdivided into units including the Homewood sandstone and Connoquenessing sandstone based on dominant lithology and position relative to coal and marine marker units (**Figure 3**). However, there is a high degree of lateral variability in lithology with key markers missing in some locations (Renick, 1924; Carswell, 1965; Harper, 2005). For example, the Homewood sandstone at the type locality in scenic Buttermilk Falls Recreation Area near the village of Homewood in Beaver County, Pennsylvania (**Figure 4**) is likely to be at the stratigraphic level of the Connoquenessing sandstone elsewhere (Skema, 2005).

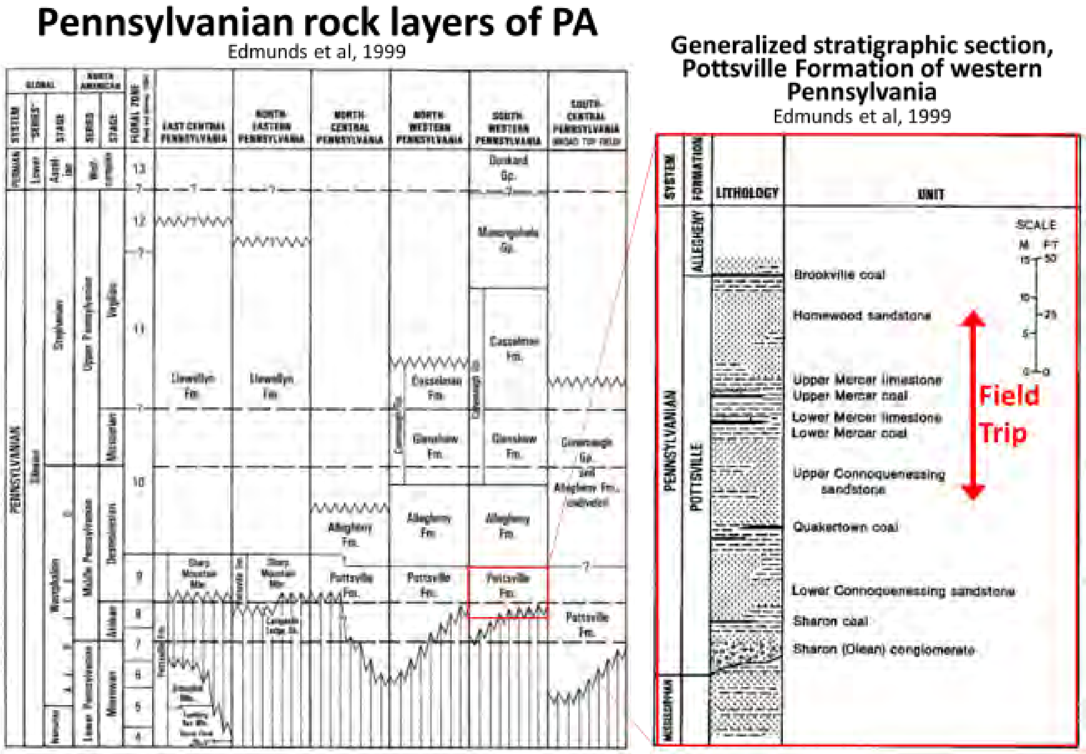

Figure 3. *Generalized stratigraphic section of the Pottsville Formation in western Pennsylvania. From Edmunds et al, 1999.*

The Pottsville Formation in Ohiopyle is in a major wedge of sediment supplied by mountains on the eastern edge of North America that were uplifted by Alleghanian orogeny (**Figure 5**). Understanding of sediment dispersal patterns within the Appalachian Basin during Pottsville time has evolved based on combination of sediment provenance and paleocurrent studies. For example, study of detrital zircons placed Ohiopyle on the northeastern fringe of the Pennington-Lee depositional system with sediments dispersed from highland areas in Virginia and North Carolina (Thomas et al, 2004). More recent reconstructions feature southwesterly-directed transverse drainage within the basin to the west of Ohiopyle and recognize that penecontemporaneous structural features may have controlled local drainage patterns (Thomas et al, 2020). Pottsville paleocurrent directions in western Pennsylvania are in important part of the sediment dispersal story.

Figure 4. *Photograph of Buttermilk Falls and Pottsville Formation sandstone near Homewood in Beaver County, PA. The waterfall is near the axis of a channel with an amalgamated sandstone fill. The sandstone bedding plane at the top of the waterfall has abundant quartz granules. The sandstone unit at Homewood is unusually thick (155 feet, Skema,2005).*

Cross bedding, channels and lack of marine fossils in the well-exposed sandstones of the Homewood and Connoquenessing at Ohiopyle State Park and Clarks Run are consistent with fluvial and upper delta environments, with indications of tidal influence in places. Easterly-oriented dominant paleocurrent directions are indicated by cross bedding in the upper Connoquenessing at

Cascades and the Connoquenessing-equivalent sandstone at Buttermilk Falls near Homewood, Beaver County. Comparison of cross bedding styles and paleocurrent orientations in well-exposed Connoquenessing sandstones at Cascades, Waterslides on Meadow Run and the upper part of Entrance Rapids on the Youghiogheny River indicates a high degree of variability within a relatively small area.

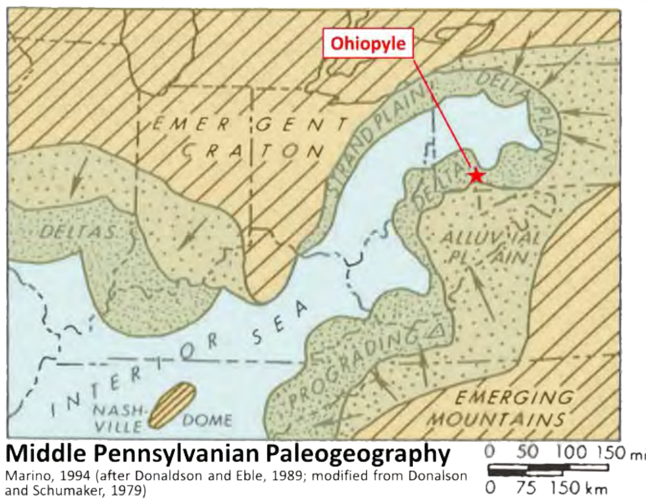

Figure 5. *Paleogeographic map of Middle Pennsylvania strata in the central Appalachian Basin. Although this map represents a time slightly younger than the Pottsville Formation when marine incursions were more extensive, it suggests the possibility that Ohiopyle could have been on the eastern edge of a deltaic depocenter in Pottsville time. Modified from Marino, 1994; after Donaldson and Eble, 1989 and modified from Donaldson and Schumaker, 1979.*

Homewood sandstone

While hiking Meadow Run Trail, we will have the opportunity to examine an outcrop of Homewood sandstone that is several meters thick. Like well-exposed outcrops and blocks of Homewood at Baughman Rock and elsewhere in Ohiopyle, the Homewood is quartz-rich with abundant white quartz granules and, in places, pebbles. Planar cross-bedding is visible. The most easily observed cross bedding at Baughman Rock and along the Meadow Run Trail indicate deposition by easterly-directed paleocurrents.

The Homewood sandstone thins on the Laurel Hill and Chestnut Ridge anticlines and thickens in the Ligonier Syncline and toward the Uniontown and Youghiogheny synclines suggesting penecontemporaneous structural control on deposition or preservation of the sandstone (Shaulis, 2020). East-directed cross beds that have been observed combined with the opportunity to test the hypothesis that deposition or preservation of the Homewood sandstone at Ohiopyle was structurally controlled suggest that a more through sedimentological study in and near the park could yield interesting results.

Meadow Run Flat Rock

Flat Rock is a prominent bedding plane sandstone exposure in the channel of Meadow Run, near the Meadow Run Trail (**Figure 6**). A cliff with Homewood sandstone and coals of the Mercer zone overlie the Flat Rock sandstone bedding plane outcrop, indicating that the Flat Rock bedding plan exposure is in

Figure 6. *Photograph of Flat Rock on Meadow Run, Ohiopyle State Park, PA. This bedding plane exposure of upper Connoquenessing sandstone includes ripple marks and natural fractures. A sandstone bed with cross lamination oriented to the southeast is in the foreground on the right. This photo was taken during field work by Pennsylvania Master Naturalists with low water in Meadow Run on September 26, 2020.*

the upper Connoquenessing (Jim Shaulis, personal communication, 2020). Ripple marks are prominent on the bedding plane at Flat Rock. Cross lamination in one sandstone bed exposed on the southeastern side of the outcrop is oriented to the southeast.

Unlike Pottsville bedding plane outcrops at Baughman Rock, Cascades and Entrance Rapids which exhibit both orientations of natural fractures that are common in the area, fractures at Flat Rock represent only NNW-SSE oriented cross-fold fractures (**Figure 7**). Fold-parallel fractures were not observed at Flat Rock during visits with groups of Pennsylvania Master Naturalists when the stream was low, and the bedding plane was well exposed in September 2020. The Youghiogheny River in Ohiopyle State Park is well known to follow both dominant fracture orientations (Reese, 2006), and Meadow Run also follows them.

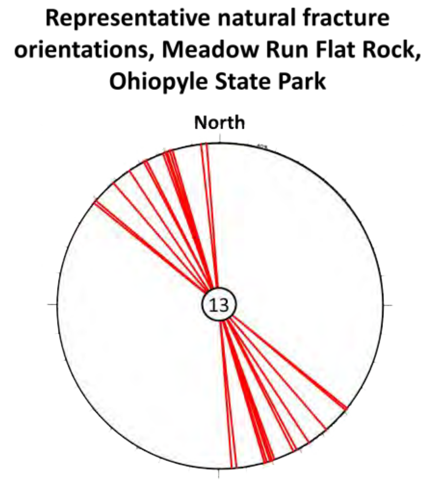

Figure 7. *Orientations of natural fractures in upper Connoquenessing sandstone, Meadow Run Flat Rock, Ohiopyle State Park.*

Meadow Run Cascades

Careful mapping has indicated that the 14 meters of sandstone exposed in the bed of Meadow Run at Cascades is in the upper Connoquenessing interval (Jim Shaulis, personal communication, 2020). Water levels in Meadow Run are highly variable. In late winter or early springtime when snow in the watershed melts, most of the outcrop can be cover and scoured by the stream. October is the month with the lowest precipitation in Ohiopyle (U.S. Climate Data, 2021), and the pre-conference trip on October 7 should be a good time to observe the Cascades outcrop. A section was measured at Cascades on October 22, 2020 (**Figure 8**), when water levels were especially low due to lower-than-usual rainfall in prior months.

Cross bedding is abundant and dominated by planar to low-angle cross lamination. Ripple marks are much less common than decimeter-scale cross bedding. Bedding plans are commonly wavy due to erosion and preservation of the tops of bedforms. Trough cross-bedding and planar tops of beds are also present. Representative directions for each bed were measured, and they indicate a strong easterly orientation (**Figure 9**). Cross beds indicating paleocurrents to the west were rare. Unlike at Waterslide and Entrance Rapids, good examples of sigmoidal cross

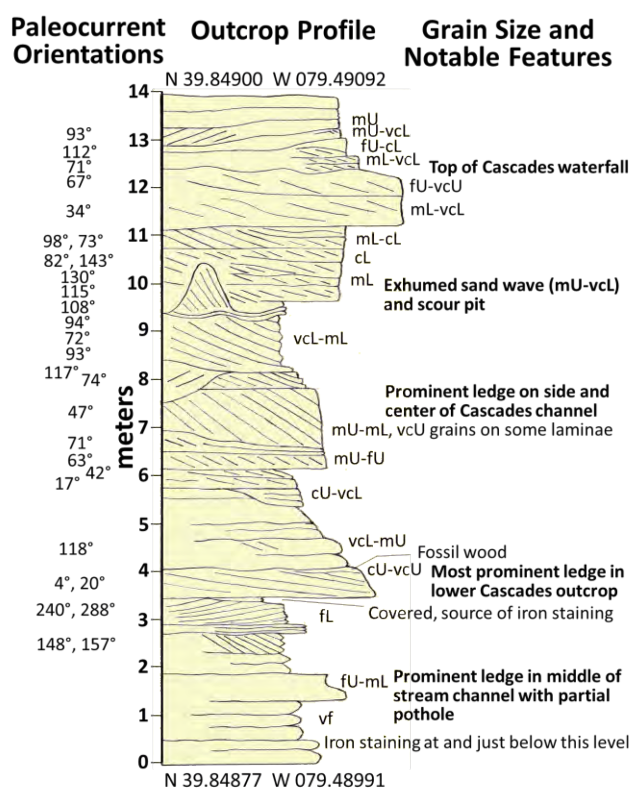

Figure 8. *Measured section of upper Connoquenessing sandstone, Meadow Run Cascades, Ohiopyle State Park.*

bedding were not observed. Natural fractures exposed on the bedding plane above the upper waterfall represent cross-fold and fold-parallel orientations (**Figure 10**).

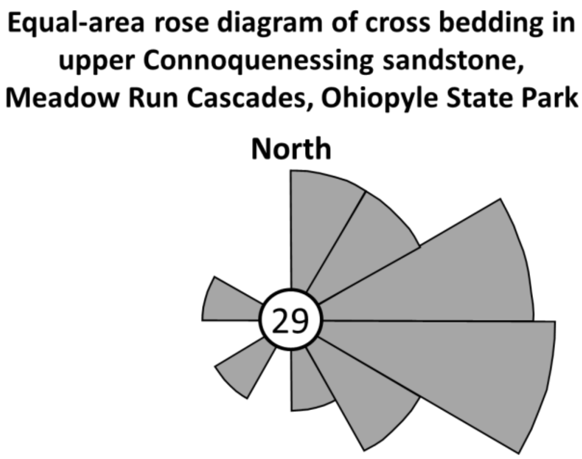

Figure 9. *Paleocurrent measurements in upper Connoquenessing sandstone, Meadow Run Cascades, Ohiopyle State Park.*

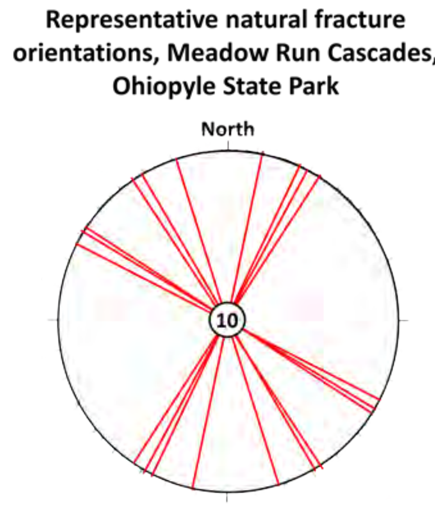

Figure 10. *Orientations of natural fractures in upper Connoquenessing sandstone, Meadow Run Cascades, Ohiopyle State Park.*

One of the most interesting sedimentological features of the Cascades outcrop is an excellent exposure of a sand wave and scour pit (**Figures 11, 12**). The exhumed sand wave occurs on the west side of the outcrop, 3 meters below the top of the prominent, cross-bedded ledge that forms the small waterfall in the upper Cascades. The crest of the sand wave is exposed for several meters, is linear and indicates that the height of the dune decreased from one meter where it is exposed in cross section to significantly less where the outcrop ends at the edge of the Meadow Run scour zone. A large scour pit occurs on the lee side of the exhumed fossil dune. Conformable sandstone laminations are preserved on top of the scour pit, providing evidence that it is a Pennsylvanian feature not an artifact of recent erosion by Meadow Run. Lamination exposed in the cross-section of the dune indicates a paleocurrent orientation of 115°, consistent with the dominant direction in this outcrop.

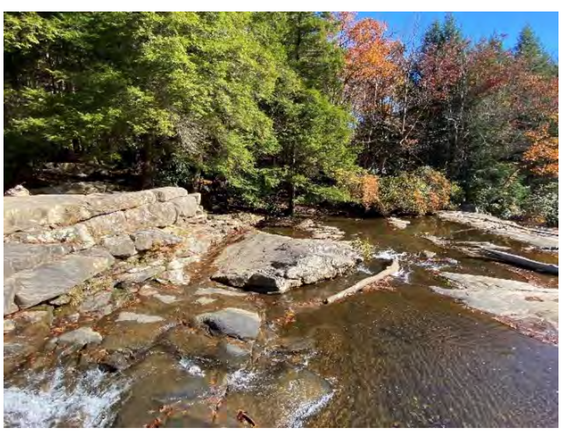

Figure 11. *Photograph of sand dune in upper Connoquenessing sandstone at Meadow Run Cascades, Ohiopyle State Park. The exhumed dune is in the center of the photo, and it is one meter high. Planar cross bedding of sandstones in the prominent ledge that forms the upper waterfall is visible on the left. Photo taken during low water in Meadow Run 10/22/2020.*

Figure 12. *Photograph of exhumed sand dune and scour pit in upper Connoquenessing sandstone at Meadow Run Cascades, Ohiopyle State Park. Planar lamination within the dune is oriented to the southeast (to the right). The scour pit is in the top center of the photograph. Hammer for scale near crest of dune Photo taken 10/22/2020.*

The Cascades includes lower and upper waterfalls created by prominent ledges (**Figures 13, 14**). A fossil pothole occurs near the base of the section (Figure 15). In summary, when exposed during periods of during low water in Meadow Run the Cascades outcrop provides an excellent opportunity for sedimentological analysis of the upper Connoquenessing sandstone. Comparison with outcrops at Meadow Run Waterslide and Youghiogheny Entrance Rapids, which will be examined during the Field Conference, indicates that bedding styles within this unit vary significantly within a few kilometers.

Figure 13. *Photograph of Meadow Run Upper Cascade, Ohiopyle State Park. The exhumed dune is on the right, in front of the prominent, waterfall-forming ledge. Natural fractures were observed and measured on the bedding plane on top of the ledge. Photo taken 10/22/2020.*

Figure 14. *Photograph of Meadow Run Lower Cascade, Ohiopyle State Park. The top of the prominent, waterfall-forming ledge in the center of the photograph is at 4 meters in the measured section (Figure 8). Photo taken 10/22/2020.*

Research Opportunities

Rigorous analysis of depositional environments, paleocurrent orientations and potential structural control on deposition or preservation of the Homewood sandstone in Ohiopyle is likely to add to understanding of this prominent rock layer, which is viewed by most of the million annual visitors to Ohiopyle State Park. Paleocurrent analysis of the Homewood sandstone on public land in the park would be a well-defined project for a geology student.

Similarly, easterly-oriented paleocurrents in the Connoquenessing interval at Cascades and near Homewood, Beaver County PA suggest that rigorous analysis of this unit in western Pennsylvania may yield interesting results.

Figure 15. *Photograph of fossil pothole in sandstone at Meadow Run Cascades, Ohiopyle State Park. The pothole is left of center in the photo. The top of the ledge with the pothole is at 1.9 meters in the measured section (figure 8). The walking stick is 1.5 meters long. Photo taken 10/22/2020.*

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BAUGHMAN ROCK OVERLOOK

JIM SHAULIS – PENNSYLVANIA GEOLOGICAL SURVEY
FRANK J PAZZAGLIA – LEHIGH UNIVERSITY

Introduction

The goal of the Baughman Rock stop (**Figure 1**) is to provide a scenic overview of the park as an appropriate backdrop for discussing the geologic and landscape evolution of the Laurel Highlands. Baughman Rock lies at an elevation of 618 m (2028') and is a Geoheritage Site classified as: Geomorphic, Erosional, Landscape, Scenic view (overlook, vista, lookout) of the physiography or topography of the landscape (PGS, 2021). The Baughman Rock lookout lies on the Homewood Sandstone of the Pottsville Formation that here has a strike of 295 and dips 12 degrees to the NW.

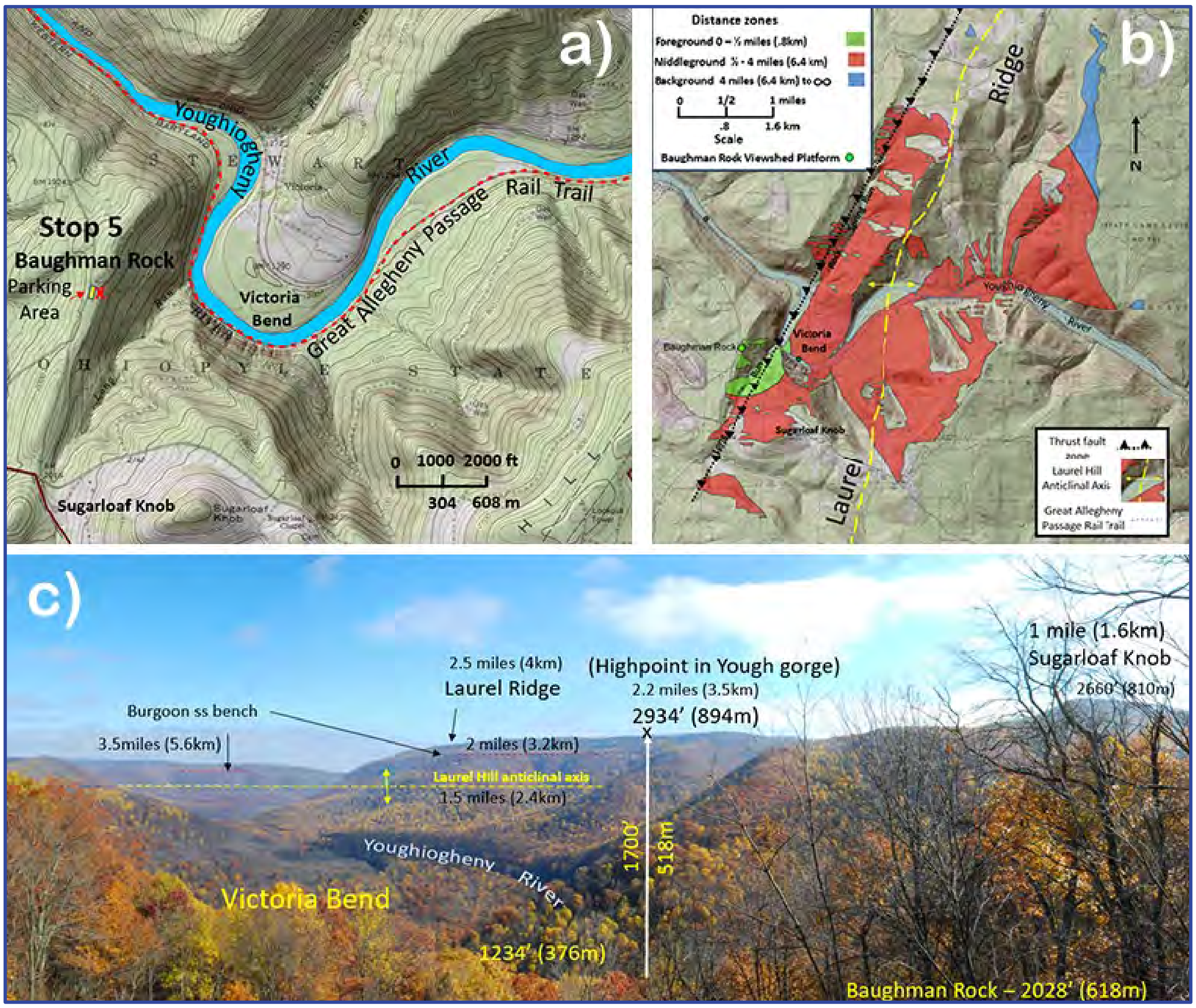

Figure 1(a) *Location of the Baughman Rock overlook**,** **(b)** the viewshed from the overlook consisting almost exclusively of "middle ground" considered to be the idea distance to view scenery (USDA,1995), and **(c)** annotated photo(10/29/2008) showing the 518 m of relief of the Youghiogheny River gorge carved through the core of the Laurel Hill Anticline.*

The Baughman Rock overlook is one of the best places for a visitor to the park to view the spectacular scenery found in the Youghiogheny River gorge. From Baughman Rocks there is an uninterrupted, approximately 150-degree, fan shaped, view, ranging from northeast to nearly due south and is an excellent representation of the Appalachian Mountain Section of the Appalachian Plateau physiographic province of Pennsylvania (**Figure 1b**). Here one can see a landscape that contains several distinct landforms; the Youghiogheny River Gorge, Victoria Bend, and the Laurel

Ridge that have been developed from sequences of rock with variable degrees of resistance to weathering (**Figure 1**). The Youghiogheny River Gorge is one of the deepest in the state of Pennsylvania in terms of greatest overall relief (Reese 2008). Baughman Rock at 2934 feet (894 m) on the crest of Laurel Hill to 1234 feet (376 m) at Youghiogheny River level spans a total of 1700' (518 m) of peak cross- sectional maximum relief which ranks 2nd in the Commonwealth (Reese 2008; **Figure 1c**).

Topography and Structure

In the Allegheny Mountain Section of the Appalachian Plateau Province, topography closely reflects the underlying geologic structure due the presence of dip slopes. Dip slopes form whenever resistance sandstone layers are inclined at usually less than 20 degrees and extend over wide area. Weathering of bedrock down to these resistant layers forms topographic slopes that closely reflect the attitude of inclination or "dip" of the underlying geologic structure. The anticlinal structural end points of the fold are traceable south west 19.5 miles, into West Virginia (Hennen, 1914), and to the northeast approximately 15 miles, into Clearfield county, PA (Faill,2011). The Laurel Ridge, visible in the middle and background zones of the view from Baughman Rock, as a definable topographic feature extends about 70 miles (113 km) from Nicktown in Cambria County northeastward, and southwestward to the town of Flat Rock in Fayette County. The highest ridge tops are underlain by resistant sandstones of the Pennsylvanian age Pottsville formation and the secondary or lower ridges and benches are underlain by sandstones of Mississippian age Mauch Chunk formation, Burgoon formation. Holding up the ridge crests and upper slopes is the youngest rock in the view shed, the Pennsylvanian age (300 my), Pottsville sandstone. It is a very hard, quartz rich rock, that is very resistant to either chemical or physical weathering and in fact is the hardest rock encountered at the surface in southwestern Pennsylvania.

Victoria Bend, a conspicuous large meander formed by the Youghiogheny River and visible from the overlook, has a large alluvial deposit including Carmichaels Fm on the inside portion of the meander loop and is another good example of topography adjusted to rock type and structure. The two sides of the meander reflect the secondary joint direction which is parallel to the trend of the axial folds (Nickelsen, 1967; **Figure 2a**). The outer edge of the middle portion of the meander is the cut bank, perpendicular to the axis of the major axial fold or in line with the primary joint direction present in the rocks of this region. The gorge walls are the steepest in the area along the cut bank side of the river.

A possible explanation for the development of the meander at this location may be due to the presence of the Long Run thrust fault zone (**Figure 2**). The northwestern limb of the Victoria Bend meander is aligned with the strike of this fault zone which contain steeply inclined, northwesterly dipping (from 25 degrees to vertical), rock strata that have been fractured along slip planes, making them much easier to erode in a northeast/southwest direction. This fault is identified as a back thrust because in several locations offsets can be seen where the rocks have been displaced along fault planes inclined along strike with upward movement on the hanging wall to the southeast or opposite to the tectonic transport direction. It is expressed topographically as an 8 mile (12.9 km) long linear set of drainage features on the western limb of Laurel Hill anticline that are oriented in a southwest / northeast direction, parallel to the anticlinal axis. The drainages and segments of drainages from southwest to northeast are: Long Run, the north-western side of Victoria Bend in the Youghiogheny River, Rock Spring Run and the upper half of Bear Run and possibly an upper branch of Fulton Run. Portions of the first three are visible from Baughman Rock. The beds exposed at Baughman Rock are inclined more steeply (10 to 12 degrees) than most areas along the western flank of the Laurel Hill anticline as a result of the Long Run thrust fault (Shaulis,2020). Just to the east, the anticlinal axial area in this portion of Laurel Hill parallels what has been identified as the eastern edge of the Rome Trough (Root, 1978) and is also the site of facies changes in the Tully Limestone related to growth faults (Harper and Piotrowski, 1979).

Structurally, the Laurel Hill anticlinal axis runs parallel to the trend of the mountain which forms the eastern most limit of the view on the south side of the Youghiogheny River gorge. The eastern limb of the anticline can be seen rising in the furthest views on the north side of the gorge, with its rock layers dipping to the southeast at about 5 to 6 degrees. As a structural landform, the Laurel Hill anticline can also be further described as a large amplitude open fold, characterized by having its inner limbs spreading out from the axial center at 70 to 120 degrees (**Figure 2**).

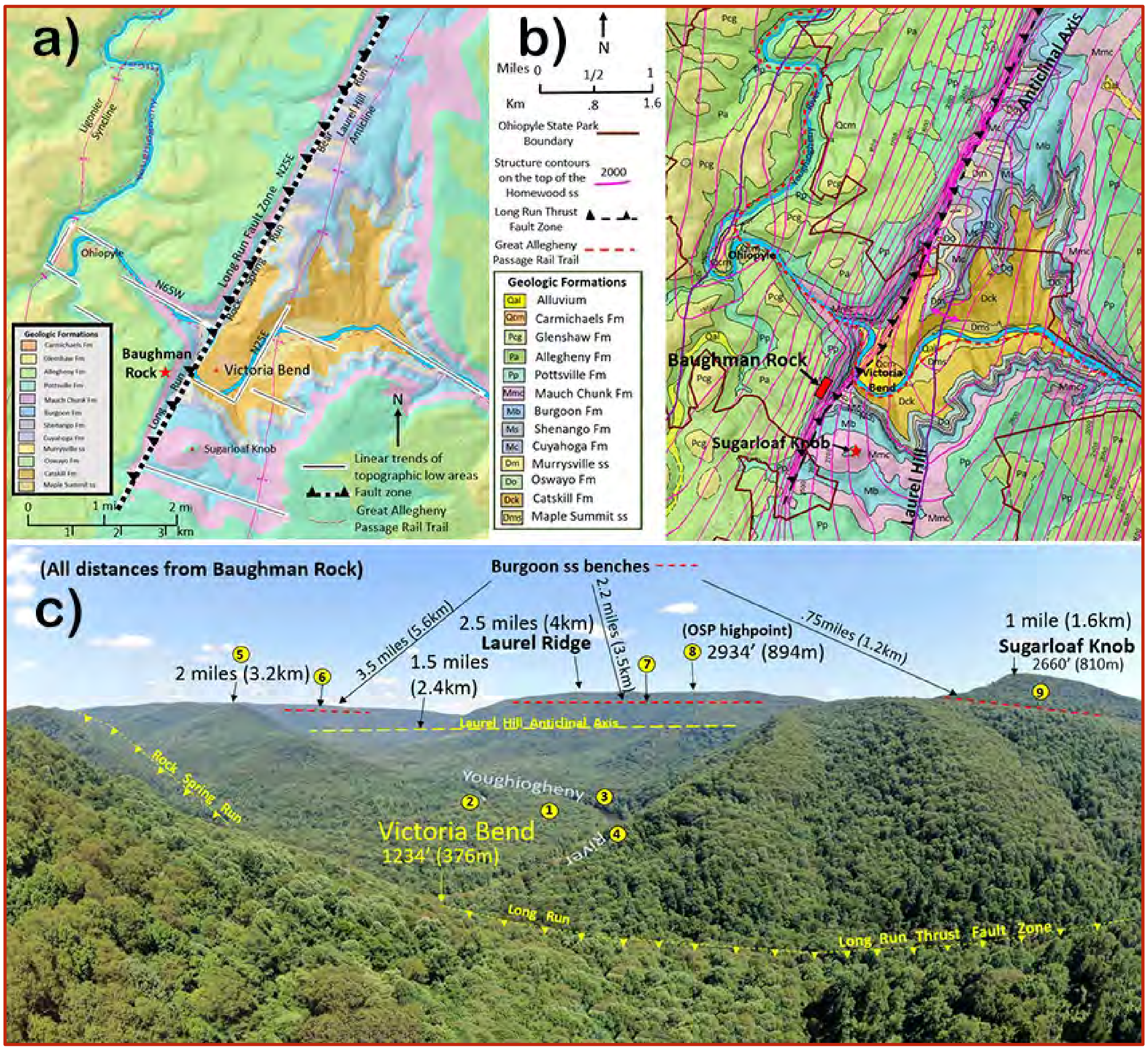

__Figure 2.__ __(a)__ Geologic map of the Victoria Bend region at the core of the Laurel Hill Anticline showing likely fault and joint control for the size and location of the meander. (b) Geologic map showing structure contours on the top of the Homewood Sandstone, and the role of rock type in shaping the topography (Shaulis,2020 pub pending). (c) View from Baughman Rock with major geologic, topographic, and cultural features.

Landmarks and Cultural Features

The view from Baughman Rock overlook takes in many geologic, topographic and cultural features which are numbered on **Figure 2**. They are listed as follows:

1. Victoria Bend meander.
2. CSX Railroad. It was constructed in 1871 as the Baltimore and Ohio railroad and was the preferred side of the valley for a rail bed.
3. The southern side of the gorge contains the Great Allegheny Passage rail trail which now occupies the former Western Maryland Railroad bed that was completed in 1911 and then abandoned in 1975 (Metzger, 2003). Portions of long unit trains can be seen and heard on the CSX tracks today while only visitors can be seen or heard on the path of the GAP trail depending on atmospheric conditions and vegetative cover.
4. On the Youghiogheny River water trail rafters/boaters can be seen and heard when favorable weather and leaf cover conditions exist.
5. Possible location of Native American burial sites. Numerous large stone oblong cairns with collapsed centers are located here that the locals believe have Native American origins. A unique, 270-degree view of the gorge in available here in leaf off conditions.
6. Cleared areas for planting of game feed crops on Game Lands No. 111 can be seen on the eastern slope of Laurel Hill Ridge on the north side of the gorge.
7. Mostly on the south side of the gorge, block plantings of evergreens, primarily hemlock and spruce, associated with camps and old homesteads can be seen on top of the ridge.
8. Location of the foundation of a forest fire lookout tower near the high point in the park on crest of Laurel Ridge. Several large hemlocks remain and can still be seen from Baughman Rock to visibly mark the spot.
9. On the western flank of the Laurel Hill anticline, in the extreme southeastern portion of the view Sugarloaf Knob is visible. It's high elevation that allows it to be seen from many regional vantage points and its isolated location, and distinct" bread loaf" shape, have made it a landmark and a natural curiosity. It is a popular destination for visitors to Ohiopyle State Park.

Fluvial sculpting of the Laurel Highlands

Where the Youghiogheny River has cut through the center of the Laurel Hill anticline the Devonian age Catskill and Maple Summit formations are exposed (**Figure 2a, b**). These rocks are 360 million years of age and are the oldest rocks that outcrop in southwestern Pennsylvania. The youngest rocks in the view, are the Pennsylvanian age (300 my) Pottsville sandstone, make up the view shed platform, the Laurel Hill Ridge crest, and the top surface or the eastern flank of Laurel Ridge visible in the furthest background (**Figure 2c**).

Fluvial sculpting of the Laurel Highlands by the Youghiogheny and other rivers including the Monongahela, Cheat, and Conemaugh and their predecessors has proceeded at unsteady rates since the close of the Allegheny orogeny. Thermochronology from coal vitrinite reflectance (Zhang and Davis, 1993) and apatite fission track (Blackmer et al., 1994) indicate 3-4 km of burial of the coals and intervening clastic sedimentary rocks now exposed at the surface. Despite the impressive amount of relief at this locality, the Youghiogheny River is not particularly steep through the gorge carved in the Laurel Hill Anticline. For example, the size of the meander at Victoria Bend is approximately 1219 m x 1219 m and the overall shape of the meander form can be seen extending around the gorge in this region to about the 2500-foot (762 m) level, a vertical distance of 386 m. To achieve this amount of down cutting one could argue that the Youghiogheny River would of have had to remained locked into this fixed meander form for an extended period time. The long-term rate of incision of the river through this reach, determined by dated and correlated river terraces (Kurak et al., this guidebook) is ~30-40 m/Ma so at that rate, the Victoria Bend meander has been deepening the gorge at this location for ~10-12 million years, or since the middle Miocene.

Preliminary results from a linear inversion model of fluvial topography for the Youghiogheny catchment that accounts for variable rock erodibility (Gallen, 2018), assuming a single point of base level change at Connellsville provides some insight into the long-term rock uplift and incision history of the Laurel Highlands with respect to the Pittsburgh Lowlands (**Figure 3**). This model suggests that uplift (incision) rates were slow during the middle Tertiary at rates ~10 m/Ma. Through the late Miocene rock uplift rate increase to as much as 80 m/Ma. A second pulse of rapid uplift in the early Pleistocene may be related to impulsive base level fall associated with the draining of Glacial Lake Monongahela and formation of the Ohio River base level.

We would interpret this model to say that Laurel Highland gorge incision commenced in the late Miocene and locally, like the Laurel Hill Anticline reach, is now fully adjusted to rock type. Given that hillslopes in the Laurel Highlands are eroding at slower rates in the range of 3 – 16 m/Ma (Kurak, 2021; Kurak et al., this guidebook), it is not surprising that river incision rates at several tens of meters per million years through hard rocks will result in the high relief landscape typical of the Laurel Highlands.

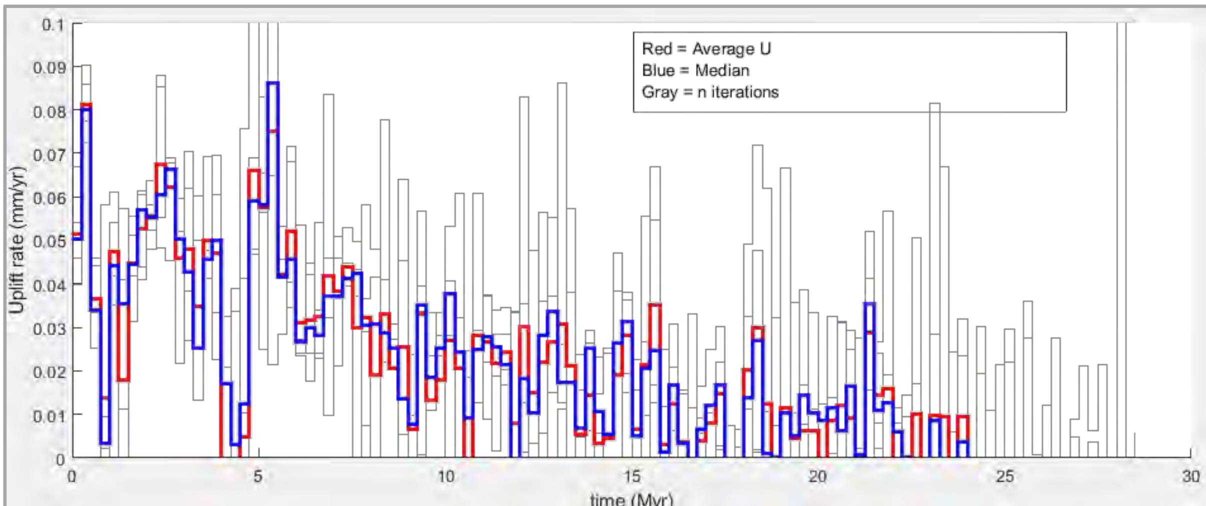

Figure 3. *Preliminary results of a linear inversion of fluvial topography model that accounts for variable rock erodibility for the Youghiogheny catchment upstream of Connellsville showing how the rate of rock uplift has varied over the past 30 million years for this part of the Laurel Highlands.*

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TURTLEHEAD ROCK BOG

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Introduction

Turtlehead Rock Bog is a highly unique depositional basin containing a richly detailed record of ecological and depositional history spanning much of the Holocene (Mason, 2017). The basin is small (~110^{2}m) and confined by a "rock city" of large boulders. This rock city is structurally located on the eastern flank of the Laurel Hill anticline about 2 miles (3.2 km) from the axis, within beds from the Homewood sandstone member of the Pottsville Formation that are inclined at 4 degrees to the southeast (**Figures 1 and 2**). Basins like Turtlehead Rock Bog are exceptionally rare in unglaciated landscapes, and its small size and overhanging forest vegetation (**Figure 2**) make it an ideal setting for paleoenvironmental reconstruction using both terrestrial plant macrofossils and pollen (Jackson & Booth, 2007). Forest hollows of similar size have a long history in paleoecology because of their unique ability to provide stand-scale reconstructions of vegetation and fire history, and therefore information on past vegetation at the local spatial scales most often relevant to ecological management (Calcote, 1995). Because of its tremendous value, the bog is currently a Geoheritage Site that can only be visited with pre-approval by the Ohiopyle State Park management (contact park office: Ph# 724-329-8591). An age-depth model obtained from the bog coupled with ^{10}Be TCN exposure ages in the rock city help constrain the geomorphic development and evolution of this unique feature.

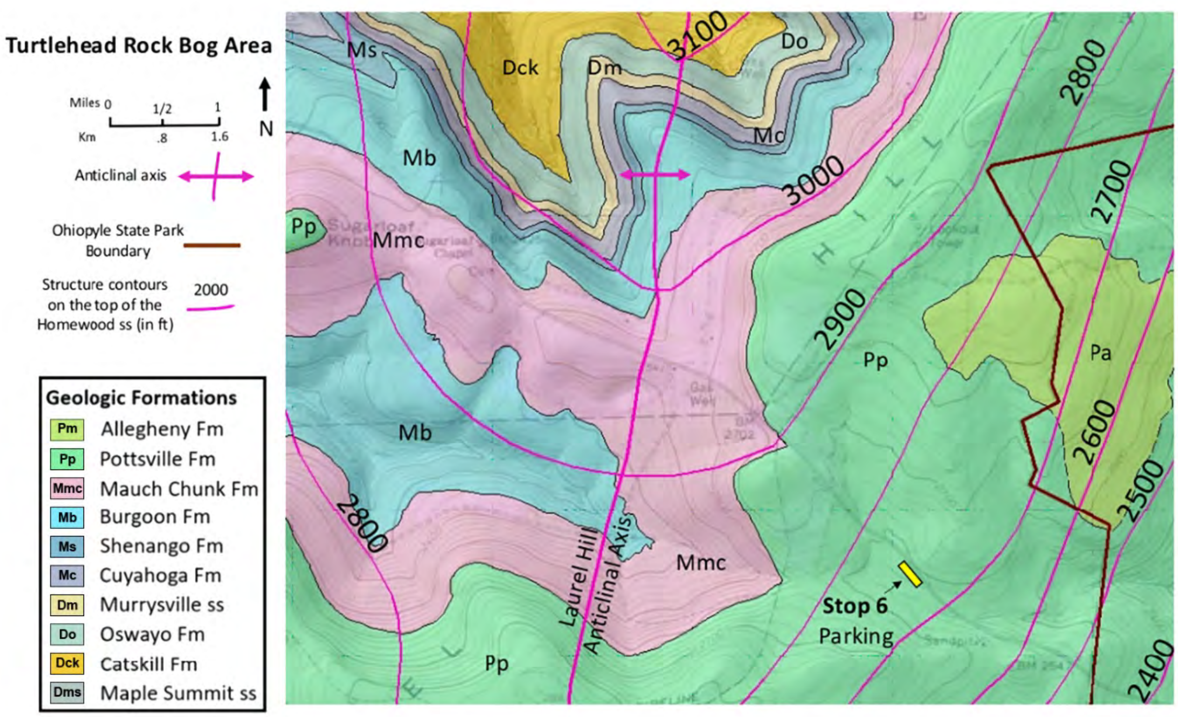

Figure 1. Topographic and geologic setting of Turtlehead Bog.

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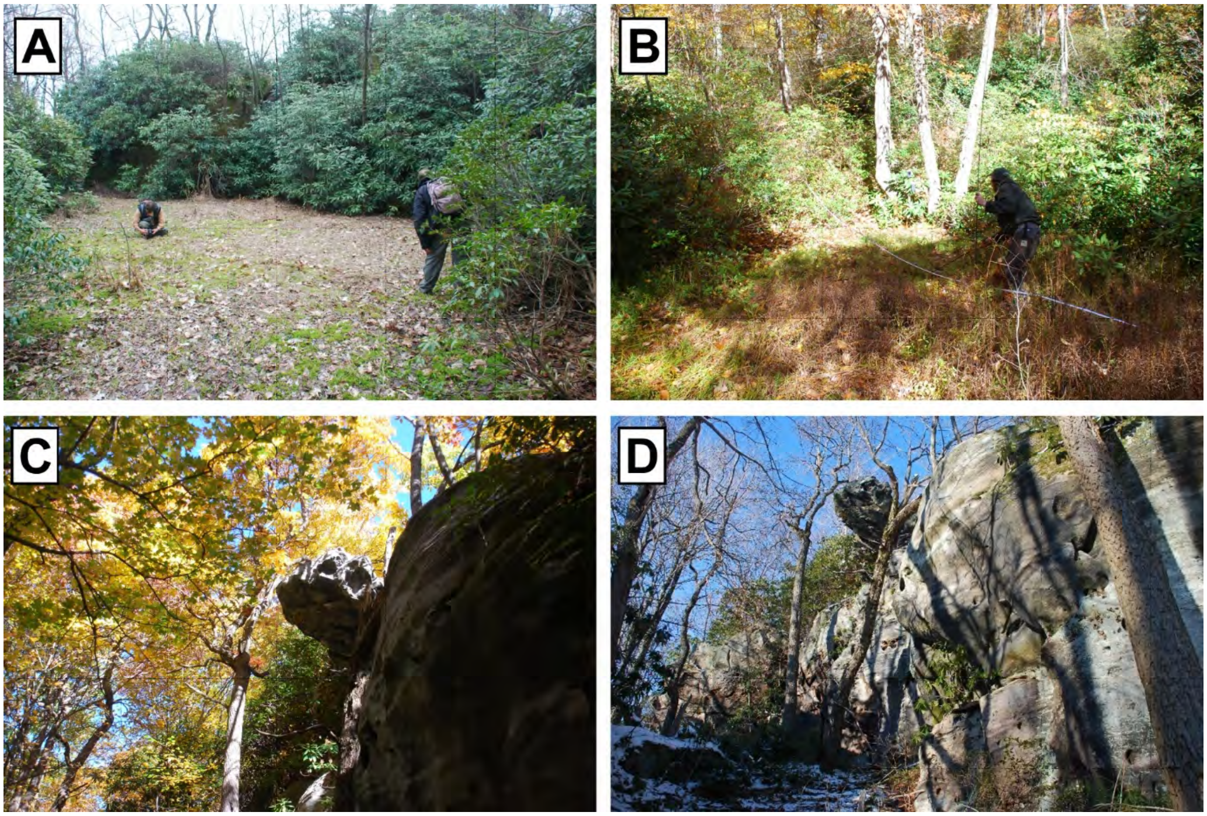


Figure 2. *Site images showing (A and B) from Turtlehead Bog, (C) Turtlehead Rock, note the opferkessel weathering, and (D) part of the rock city surrounding the bog.*

Geological and hydrological setting

The stratigraphic section exposed in the rock city is approximately 14.6 m (48 ft) along the southwestern edge, but not in a continuous vertical face (**Figure 3**). On weathered surfaces it appears to be massively bedded with some intervals displaying trough and planar cross bedding. Bedding sets range from 15 cm (0.5 ft) to 1.2-1.5m (4-5 ft). Compositionally, it ranges from medium to very coarse-grained quartz pebble conglomerate, with the quartz pebbles often selectively sorted onto the base of graded beds, although pebbles appear to be randomly distributed in places. The quartz pebbles are 2-5mm in diameter and are sub-rounded to sub-angular. Cross beds are trough to tabular and have an apparent northwestern dip, supporting the interpretation of a southeastern highland source area formed in a braided river system (Meckel, 1967).

Samples were taken for thin section analysis at several locations within the rock city (**Figure 3-b,c**). Quartz grains in all samples were sub-rounded to sub-angular and had noticeable dust rims with quartz overgrowths indicating that they were transported (Milliken,2000) (**Figure 3c**). Grains were well to moderately well sorted and ranged in size from medium to very coarse, with quartz pebbles up to 4 mm in diameter. Vacuoles in grains and stylolites were common indicating grains underwent compression. Porosity was often 10% or more, likely due to the removal of either quartz or siltstone grains (**Figure 3c**).

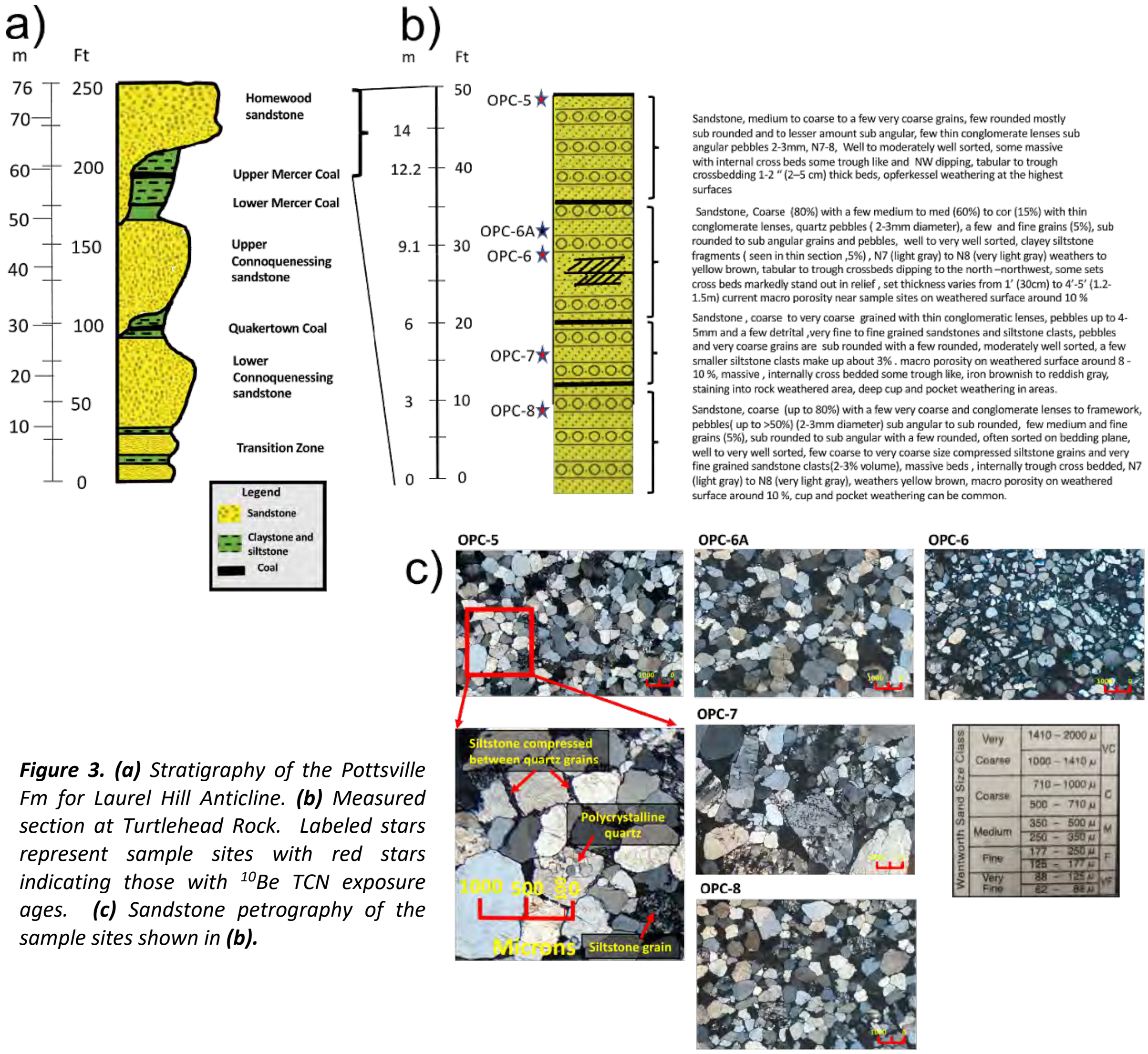


***Figure 3. (a)** Stratigraphy of the Pottsville Fm for Laurel Hill Anticline. **(b)** Measured section at Turtlehead Rock. Labeled stars represent sample sites with red stars indicating those with ^{10}Be TCN exposure ages. **(c)** Sandstone petrography of the sample sites shown in **(b)**.*

The area covered by the rock city is about 90 m (300 ft) x 90 m (300 ft) or 0.75 hectares (2 acres; **Figure 4**). Boulders have vertical faces that have been separated along joints that follow closely the two regional systematic and non-systematic joint directions, with only one being non-vertical (**Figure 4a,b**). Boulder dimensions and orientation were difficult to accurately measure using ground observations or drone photography due to the heavy vegetation cover, therefore lidar imagery was used to make estimates (**Figure 4c**). The blocks commonly are rectangular in shape, elongated in a northwest-southeast direction parallel to the systematic joint direction, and 9 m (30 ft) to 15 m (50 ft) in length and 1.5 m (5 ft) to 9 m (30 ft) in width. The southeastern side of the rock city is the best suited to observe the joint faces.

Turtlehead Rock Bog is likely artesian-fed through joint openings in the Homewood sandstone bedrock lying up dip, and therefore it is not a true, precipitation-fed bog. The recharge area is estimated to be 4 hectares (10 acres) with an approximate 15 meters (50 ft) of hydraulic head. It is most likely part of a perched aquifer system with the impermeable base being an underclay or shale associated with the Upper Mercer Coal seam (Figure 3a). The bog volume filled to spillway level is approximately 220 m^3 (8,000 ft^3). Cutting across the middle of the rock city exposure, at the northwestern edge of the bog, is a well-developed sub-vertical joint dipping normal to the non-systematic (Nickelsen, 1967) strike direction at 55 degrees. In places a 1.25 cm (0.5 in) thick siderite layer coats this joint surface. No evidence of block rotation or offset is visible. Multiple, closely spaced vertical systematic joints intersect in this area of the sub-vertical joint (**Figure 4d,e**). The abundance of joint openings in this area could be providing a conduit for groundwater into the bog; however, no springs are present at the surface.

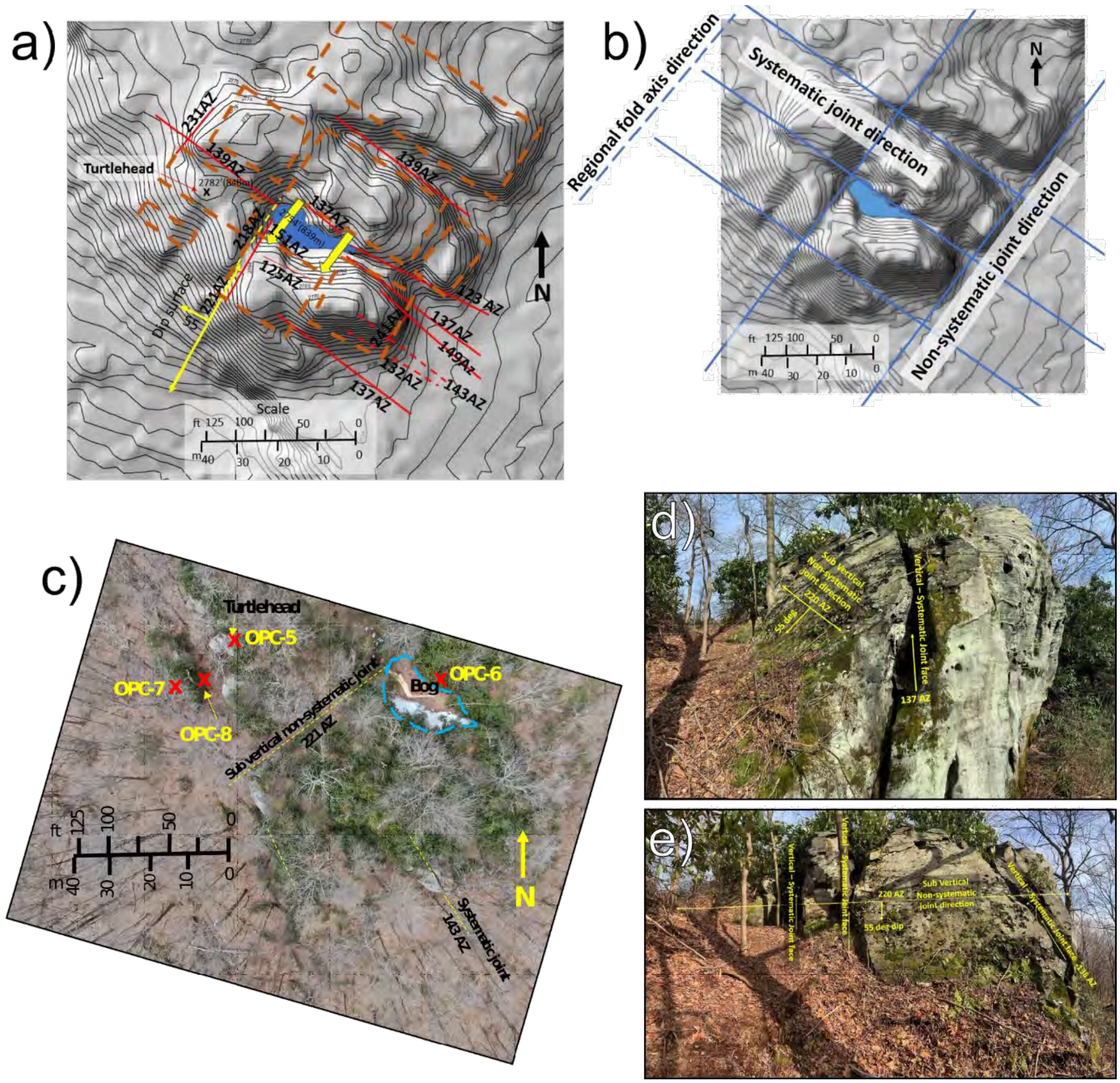


Figure 4. ***(a)*** *Measured joint orientation derived from a lidar 1-m DEM base, major Homewood Sandstone blocks outlined in orange dashes.* ***(b)*** *Joint orientations in the context of the Laurel Hill Anticline fold axis.* ***(c)*** *Aerial joint photo with joint orientations and sample locations superimposed.* ***(d*** *and* ***e)*** *Field photos of the bedrock blocks with join orientations superimposed.*

Ecological setting

An oak-black birch forest surrounds Turtlehead Rock Bog today, and the weathered Homewood sandstone boulders adjacent to the basin are occupied by great laurel (*Rhododendron maximum*), mountain laurel (*Kalmia latifolia*), and a diverse tree community of sassafras (*Sassafras albidum*), black birch (*Betula lenta*), red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), and several oak species (e.g. *Quercus prinus*, *Q. rubra*, *Q. macrocarpus*) (**Figure 2a,b**). The bog itself is occupied by a floating peat mat that is dominated by three-way sedge (*Dulichium arundinaceum*), other wetland sedge species (*Carex* spp., *Scirpus* spp.), cinnamon fern (*Osmunda cinnamomea*), and scattered patches of *Sphagnum* moss. Some areas of the peat mat are firmer than others, and near the spillway where the basin is deepest the peat mat is particularly thin.

Depositional and vegetation history

Sediment cores were collected from the bog in 2015 using a modified piston-corer with a serrated edge designed for peat coring, as well as a smaller Russian peat corer (**Figure 5a**). Plant macrofossils, pollen, and charcoal were examined and quantified to reconstruct depositional and developmental history, as well as the composition and fire history of the surrounding forest (Mason, 2017). Two overlapping cores were collected from Turtlehead Rock Bog at sites where the peat mat was thickest (core location 1) and where the basin was deepest (core location 2) (**Figure 5b**).

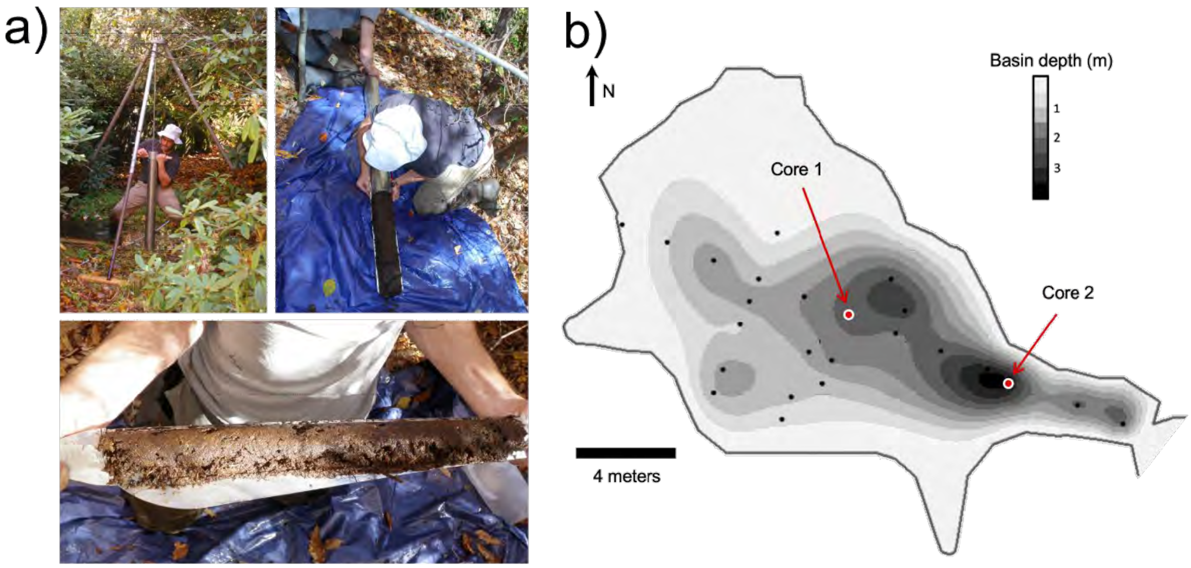


Figure 5. ***(a)*** *Photos of the coring and contents of cores at Turtlehead Bog.* ***(b)*** *Generalized map of Turtlehead Bog showing the core locations and basin depth.*

Sediment characteristics and an age-depth model developed from 16 radiocarbon dates and the position of ragweed (*Ambrosia*) pollen increase associated with European land clearance, indicate that two fundamentally different depositional environments have occupied the site for at least the past 9000 years, and these sedimentary environments were separated by a >1000-year long depositional hiatus (**Figure 6**). Below, we summarize this

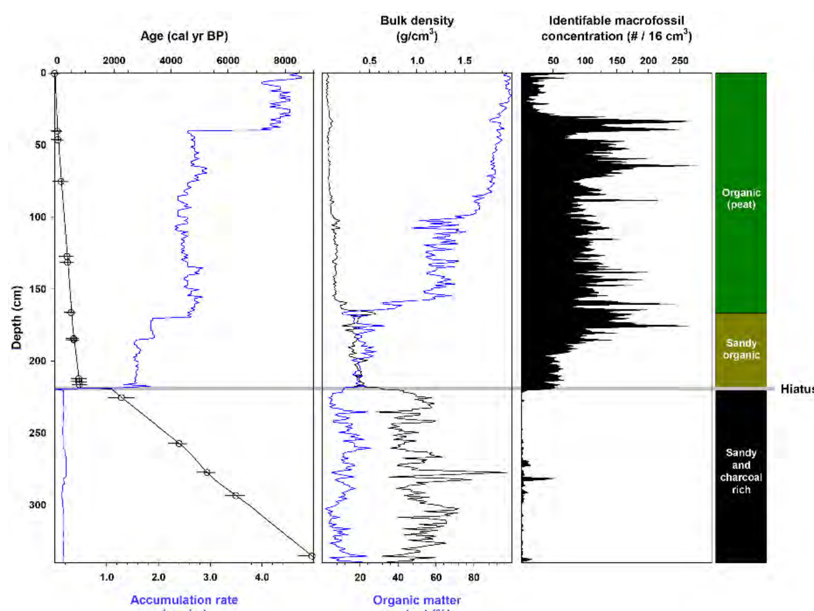


Figure 6. *Age-depth model, bulk density, and loss on ignition (organic matter) data from a core 1 and 2 composite section.*

history of deposition along with changes in the characteristics of the wetland and forest vegetation occupying the site. Additional details can be found in Mason (2017).

Fern-dominated wetland (>9000 to ~2000 cal yr BP)

Radiocarbon dating of the lowermost sediments indicates that deposition in the bog likely began prior to 9000 years ago. Our probe-rod depths were about 50 cm deeper than we could get with our corer, and the basal sediments in our core were radiocarbon dated to 8660-9200 cal yr BP (2 sigma range). Assuming a constant accumulation rate, a projected age for the lowest sediments is about 12,000 cal yr BP.

The lowermost meter of the recovered core was sandy and charcoal-rich, with low organic matter content and high bulk density. Sediments in this meter of the core likely accumulated slowly (0.17 mm/yr) from about 9000 to 2000 cal yr BP. Poor preservation of plant macrofossils during this interval limits our ability to reconstruct the wetland plant community in much detail (**Figure 7**). However, pollen and spore preservation suggest a wetland environment occupied by a diversity of ferns (*Osmunda, Polypodium*, and likely *Thelypteris* or a similar genus) and some depths contained achenes (seeds) of woolgrass (*Scirpus cyperinus*). Forest surrounding the bog was dominated by hemlock (*Tsuga canadensis*) and birch (*Betula*) from about 9000 to 7000 cal yr BP, and (*Quercus*) and at times chestnut (*Castanea*) were major components of the forest between about 7000 and 2000 cal yr BP (**Figure 8**). Fires were most frequent when the forest was dominated by oak and chestnut. The boulders surrounding the bog were occupied by shrubs like *Rhododendron* since at least shortly after bog formation (**Figure 8**).

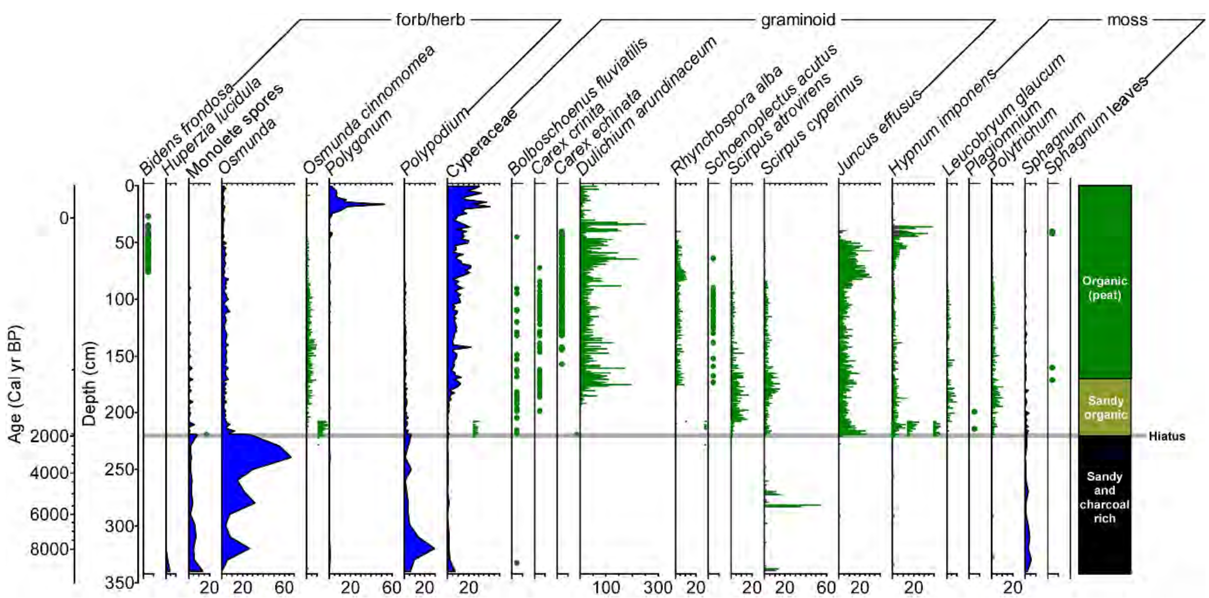


Figure 7. Turtlehead bog wetland pollen and macrofossil data.

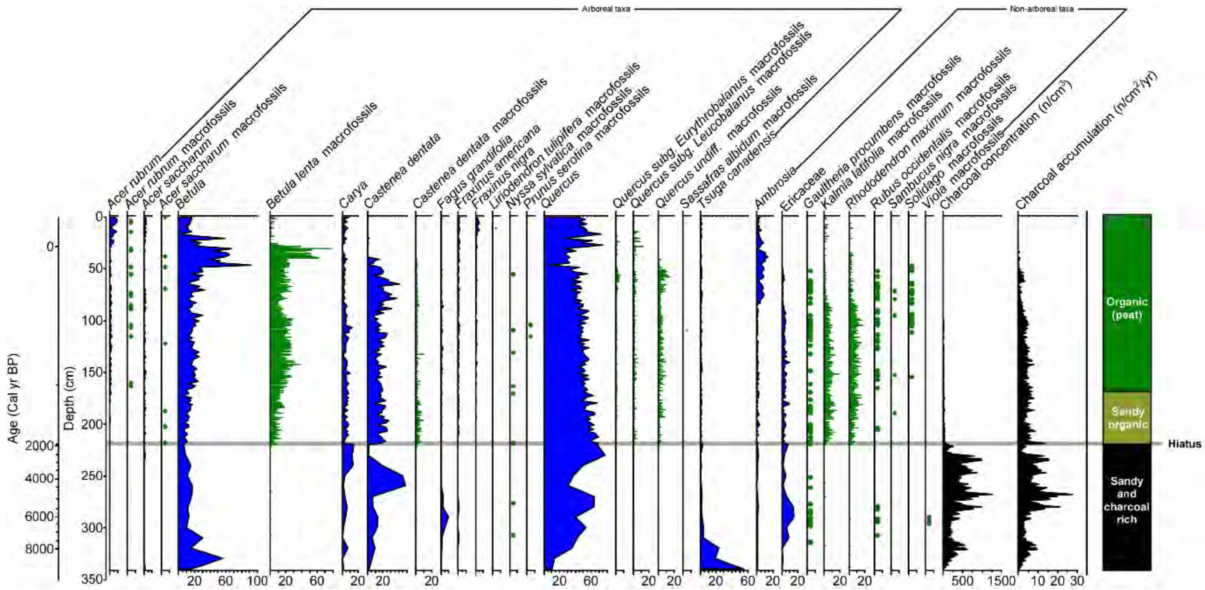


Figure 8. *Turtlehead bog terrestrial pollen, macrofossils, and charcoal.*

Depositional hiatus (~2000 to 900 cal yr BP)

Sediment stratigraphy, soil bulk density, organic matter content, and total macrofossil concentration exhibited large shifts at about 220 cm in the core and radiocarbon dates from a few centimeters above and below this horizon indicate a dramatic change in age between these depths (**Figure 6**). Based on the abrupt changes in bulk density, the sudden preservation of macrofossils, arboreal pollen changes, a low in organic matter content, and the large amount of time represented between the dated horizons (~1200 years), it is very likely that there was a depositional hiatus.

The depositional hiatus or extremely low sediment accumulation rate lasted over 1000 years, from about 2000 to 900 cal yr BP, and could have been caused by increased decomposition of organic matter due to hydrological changes and potentially erosion at the sediment surface. However, various lines of evidence suggest that periods of extended drought during this time internal may have inhibited organic matter preservation and accumulation. Oak (*Quercus*) and hickory (*Carya*) pollen reached their highest values just prior to the hiatus (**Figure 8**), when organic matter drops to near its lowest levels (~5%) (**Figure 6**). Increases in these tree genera would be consistent with a shift toward more arid conditions. Other regional records also provide some support for drought episodes during this time interval, including Sr:Ca ratios measured from speleothems in West Virginia about 95 km southwest of Turtlehead Rock Bog. These records suggest two multi-centennial arid periods beginning at 2000 and 1200 cal yr BP, and the magnitude of change in Sr:Ca ratios at 2000 cal yr BP was one of largest departures in the 7000 year-long record (Springer et al., 2008). At Cranesville Bog (~30 km south) a peatland established about 1200 cal yr BP as the forest community shifted abruptly from abundant beech (*Fagus*) to one that was oak and pine-dominated, consistent with drought conditions (Booth et al. 2016). Furthermore, reconstructed bog water-table depths in eastern lower Michigan revealed large multi-decadal-scale drought events at two major intervals in the late Holocene: from 1900 to 1600 cal yr BP and again between 1000 and 700 cal yr BP (Booth et al., 2012). The later episode of drought and high moisture variability is well-documented at sites spanning from the western United States to at least portions of the east (e.g. Hubeny et al., 2011). Drought, or multiple episodes of drought, potentially led to aerobic conditions in the upper sediments of Turtlehead Rock Bog that were not conducive to organic matter preservation.

Modern wetland and floating peat-mat establishment

At about 900 cal yr BP the basin began rapidly accumulating organic-rich sediments, although sand weathered from the adjacent sandstone boulders remained an important inorganic component until about 550 yr BP (**Figure 6**). The mean sediment accumulation rate for the first 150 years after the hiatus was about an order of magnitude greater (1.6 mm/yr) than the mean of the sediments below the hiatus, bulk density decreased by more than half, and organic matter content nearly doubled. These more organic-rich sediments were likely deposited while the site was occupied by a diverse sedge-dominated marsh. Well preserved macrofossils indicate that cinnamon fern (*Osmunda cinnomomea*), river bulrush (*Bolboschoenus fluviatilis*), common bulrush (*Scirpus atrovirens*), woolgrass (*Scirpus cyperinus*), common rush (*Juncus effusus*), and a diversity of moss species (e.g., *Hypnum imponens, Leucobryum glaucum, Polytrichum*) occupied the wetland (**Figure 7**). Forests dominated by multiple oak species, black birch, and chestnut were established by this time along with a diverse of shrubs on the adjacent boulders (**Figure 8**). Fire was an important component of the ecosystem prior to the last 100 years.

The modern floating peat mat likely became established about 550 cal yr BP. Sediment accumulation rate increased (2.6 mm/yr), bulk density dropped to half its previous mean, and organic matter content tripled. Many of the same wetland plant species that occurred in the marsh environment continued to occupy the basin; however, quite a few new species also established at this time including three-way sedge (*Dulichium arundinaceum*), white beak-sedge (*Rhynchospora alba*), hard-stem bulrush (*Schoenoplectus acutus*), fringed sedge (*Carex crinita*), and star sedge (*Carex echinata*) (**Figure 7**).

The influence of humans on the forest landscape is obvious in the upper portions of the sediment core, particularly the ecological signatures of clear-cutting, pathogen introduction, and changes to the fire regime. The earliest evidence of human disturbance around Turtlehead Rock Bog is the increase of ragweed pollen in the late 18th Century when the area was settled by immigrants from surrounding states, but human influence on the record was generally subtle at this time. During the 19th Century, however, several forb taxa like devil's beggartick (*Bidens frondosa*) and knotweed (*Polygonum*) were introduced or expanded within the wetland, and logging of the upland altered forest composition. Birch and oak pollen reached their extreme high and low values, respectively, around 1900 when regional fire suppression efforts began (Stout et al., 2000). Within a few decades the local population of American chestnut was eliminated by the blight, and the resulting canopy gaps were likely temporarily filled by black birch, a known gap-colonizing species. In the absence of American chestnut, oak has recovered to pre-settlement levels over the last several decades, even in the absence of fire (**Figure 8**).

Geomorphic Origin of Turtlehead Rock and Turtlehead Rock Bog

Long-term weathering of Homewood sandstone and the evolution of the broader Ohiopyle landscape led to the local presence of conditions suitable for bog formation and the preservation of the remarkable paleoecological record of Turtlehead Rock Bog; however, the dynamics and mechanisms of the bog's origin are unclear. The bog is situated in depression aligned with the systematic joint orientation, with an outlet dammed by the non-systematic orientation (**Figure 4a,b**). The systematic joint directly north of the bog is not dammed, so presumably it is some combination of variable chemical weathering of the Homewood Sandstone guided by the joints, and physical movement of the joint-encircled blocks that lead to the formation of the closed depression.

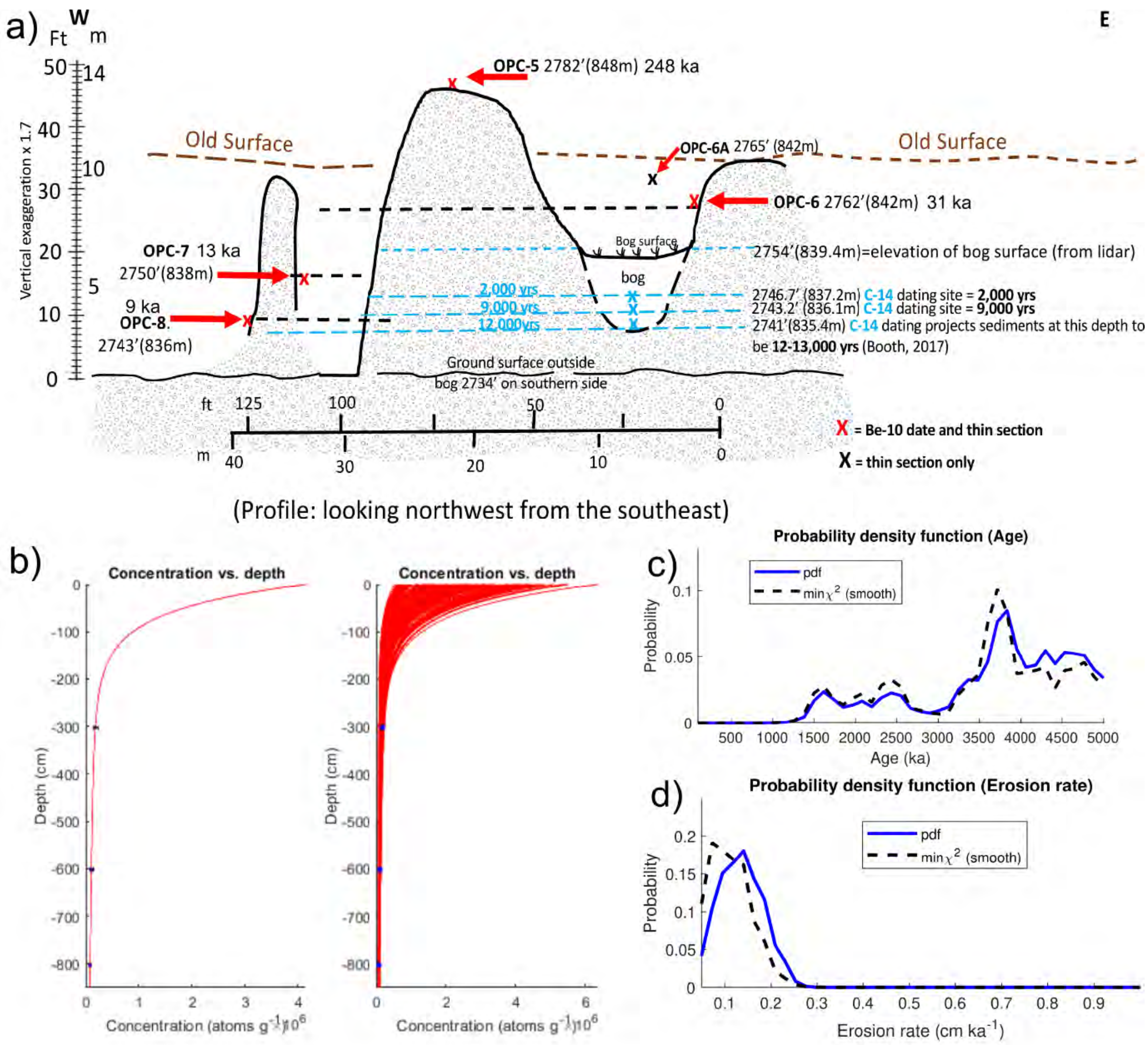
If the bog is ~12,000 years old how much earlier did the boulders that surround it become weathered deeply enough to form the depression? Cosmogneic ^{10}Be exposure ages place some limits on the maximum exposure ages or steady-state erosion rates for surfaces in the rock city, including the turtlehead (**Table 1**). Assuming no erosion, the highest point of the Homewood sandstone ledge (at the "turtlehead") indicates that it has been exposed for ~250 ka (Li and Pazzaglia, 2018). Three samples on the vertical rock faces 7, 10, and 12 m below the turtlehead have minimum exposure ages of 30.5, 13, and 9 ka (**Table 1**). Conversely, if the TCN data are interpreted in terms of continuous exposure and a steady-state erosion rate, the turtlehead is eroding at 3.2 m/Ma, and the three samples below are eroding at 25, 58, and 83 m/Ma, respectively (**Table 1**). The younger exposure ages are consistent with the faster erosion rates. In fact, the slow steady-state erosion rate of the turtlehead is consistent with the pitted, deeply-weathered appearance of this part of the outcrop. In contrast, the fast erosion rates of the samples below the turtlehead are consistent with the sub-vertical, fresher faces of the joint surfaces.

The cosmogenic data can be modeled assuming that the turtlehead has long been exposed to weathering and its ^{10}Be cosmogenic concentration represents a steady-state condition between the production of ^{10}Be, decay of ^{10}Be, and surface erosion (**Figure 9**). However, the ^{10}Be concentrations of the samples below the turtlehead almost certainly represent ^{10}Be production on the joint surfaces of the Homewood Sandstone blocks as the rock was being weathered. Stated another way, it is possible that the rock city is composed of corestones of a former bedrock weathering profile that was mostly encased in saprolite, with just the turtlehead sticking out above the former ground surface (Linton, 1955). The lowest sample (OP8) has the smallest concentration of ^{10}Be because it would have been the most shielded sample, many meters below the former ground surface. We treat samples OP6, OP7, and OP8 as representing ^{10}Be production at the bedrock-saprolite interface when the rock city corestones were still below the land surface. However, the model is under-constrained by several factors, including knowing where the original land surface was located. As an example, placing the original land surface at 844 m, would have the turtlehead and ~ 4m of rock full exposed, whereas the rock beneath was encased in the saprolite of a weathering profile. Again assuming a steady-state soil thickness, the modeling indicates a middle Pliocene (~3.7 Ma) land surface that had a rate of soil production and landscape lowering of ~1.4 m/Myr. Doubling that rate of erosion to the current 3.2 m/Ma resulted in the stripping of the soil/saprolite and exposing the irregular bedrock surface to its current level by the late Pleistocene, including a depression that could later be occupied by the bog.

Although speculative and under-determined, the modeling of the ^{10}Be concentrations as part of a related former weathering profile has some merit in terms of the overall rates of landscape evolution, hillslope erosion (**Table 1, samples OPFC 2 through 6**), and soil formation in the Laurel Highlands. Former sand quarries in the Homewood Sandstone, some located close to the Turtlehead bog, indicate that the Homewood Sandstone is locally chemically disintegrated into saprolite. It is possible that a pre-Pleistocene climate favored chemical weathering and the landscape was lowered primarily by these processes at very slow rates of ~1-2 m/Ma. A change to Pleistocene climates and glacial-interglacial cycles favored more physical weathering and local stripping of the saprolite to eventually expose corestones with their weathered joint faces. The mobilized saprolite provided the sediment to incising rivers to build the Carmichaels Formation and related terraces. By the late Pleistocene and many glacial cycles later, most of the saprolite had been stripped, exposing the jointed Homewood Sandstone to periglacial processes (Palmer and Neilson, 1962). In this way, a combination of chemical weathering to generate a depression in the corestones that was later enhanced by periglacial movement to form a closed basin is a possible explanation for the bog that is consistent with the basal age.

Table 1. Cosmogenic ^{10}Be exposure age and steady state erosion rate data. (Kurak, 2021).

Sample Name	Lat	Long	Elev (m)	Shielding	concentration (atoms/g)	concentration uncertainty (atoms/g)	Minimum exposure age (ka)	Steady-state erosion rate (m/Ma)
OPC1	39.8638	-79.50174	360	0.98	8.30E+04	3.41E+03	15.1±0.6	50.1±2.1
OPC2	39.86418	-79.50174	360	0.95	2.24E+05	7.06E+03	43.7±1.4	17.0±0.6
OPC3	39.86436	-79.50163	360	0.69	6.96E+04	4.11E+03	17.9±1.1	45.3±2.7
OPC4	39.86307	-79.50271	360	0.99	5.92E+04	2.86E+03	10.6±0.5	71.7±3.5
OPC5	39.82274	-79.4331	863	1	1.66E+06	2.49E+04	248±4.9	3.05±0.1
SRY-OP6	39.83386	-79.4327	863	0.71	1.81E+05	5.01E+03	30.5±0.9	24.2±0.7
SRY-OP7	39.82274	-79.4331	863	0.53	1.09E+05	4.00E+03	12.9±0.5	55.6±2.1
SRY-OP8	39.82274	-79.4331	863	0.65	7.70E+04	3.23E+03	9±0.3	79.5±3.4
OPFC2	39.8638	-79.50174	399	1	2.990E+05	1.008E+04	53.9±1.9	13.5±0.5
OPFC3	39.86418	-79.50174	399	1	3.177E+05	1.322E+04	57.5±1.9	12.7±0.5
OPFC4	39.86436	-79.50163	399	1	2.450E+05	6.845E+03	43.7±1.3	16.8±0.5
OPFC5	39.86307	-79.50271	399	1	2.228E+05	6.052E+03	39.6±1.1	18.5±0.5
OPFC6	39.82274	-79.4331	399	1	2.928E+05	7.513E+03	52.7±1.4	13.8±0.2



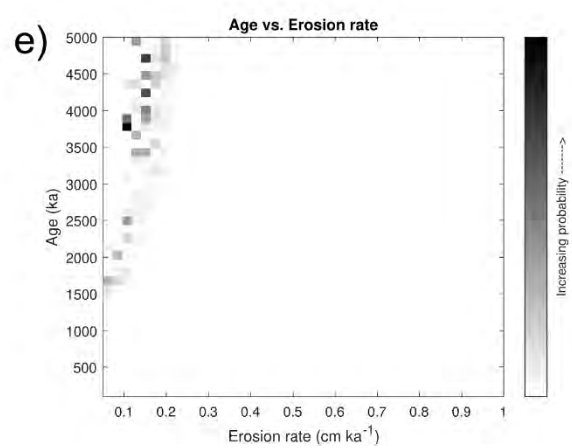


Figure 9. ***(a)*** *Schematic illustrating the exhumed corestone model for the genesis of the Turtlehead Rock bog and rock city, showing the sample locations and hypothesized former land surface.* ***(b)*** *Best-fit exponential* ^{10}*Be production curve based on samples OPC-6, 7, and 8 (left) and 10,000 Monte Carlo simulations (right).* ***(c)*** *Probability density function of model age and* ***(d)*** *model erosion rate.* ***(e)*** *Age vs erosion plot showing range and possibility of age and rate of soil formation/erosion when soil and saprolite was in place.*

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THE FOSSIL COLLECTOR:

A GEOLOGIST'S JOURNEY

DAVID WHITE'S FIELD TRIP TO OHIOPYLE, SUMMER 1900

Roberta L. Sirmons [1], Clifford H. Dodge [2], Geoffrey Henderson [1], and William A. DiMichele[1]

Introduction

At the turn of the 20th century, the United States was changing rapidly: from rural to urban, from agrarian to industrial, from isolated to connected. The telegraph, steam engine, trains, and iron and steel were transforming the country. The Industrial Revolution created demand for coal, especially to feed the growing steel mills. Railroads linked the country together from east to west, and penetrated the isolated mountains and hollows where the coal was found. Demand for coal created an economic boom and made millionaires of successful mine owners. Railroads brought city tourists to the country to enjoy the natural wonders, turning small towns into busy resorts.

Southwestern Pennsylvania was not left out of this boom. It had coal, which was highly sought to fuel the coke ovens that supplied the steel mills. Workable coal could be hard to find, but by 1900 many small, local coal mines were in operation, and geologists were actively looking for additional mineable coal beds. The boom in demand for coal was a major impetus for geologists to understand the physical and chemical properties of coals, which often vary from one bed to the next. Thus, it became important to be able to identify particular coal beds known to have desirable qualities. This entailed the correlation of strata, and the building of a stratigraphic section, in an area where much of the geology was covered by vegetation. Cover prevented direct correlation by walking out beds or connecting them by visual inspection from one exposure to the next. Thus, biostratigraphy, although that term had not yet been coined, became an increasingly important part of stratigraphic study.

Figure 1. *David White, USGS Portrait, ca. 1903 (courtesy of Confluence, Pennsylvania 101 FB Group)*

In August of 1900, a young paleobotanist from the United States Geological Survey (USGS or the Survey) named David White (**Figure 1**) visited Somerset and Fayette counties in southwestern Pennsylvania to collect fossil plants in and around the coal seams in the area. He had visited southwestern Pennsylvania before, and would visit it again, but 1900 was the only year he visited Ohiopyle, Confluence, Huston, Bidwell, Stewarton, and Indian Creek. The fossil plants he collected would help him describe the Appalachian Coalfields, and correlate the coal beds from one outcrop to another despite separation by hills or valleys, and their vegetative cover. Fossils White collected are in the collections of the Smithsonian's National Museum of Natural History (NMNH) today.

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David White went on to become head of the USGS Section on Eastern Coalfields in 1907, and Chief Geologist of the USGS from 1912-1922. He later conducted fieldwork in the Grand Canyon, funded by the Carnegie Institution, from 1927-1929. During White's 49-year career with the USGS, he became "America's foremost authority on Paleozoic stratigraphy based on fossils plants, and her leading expert on the origin and evolution of those two plant products, peat and coal" (Schuchert, 1935, p. 189).

This paper will describe White's life and career and his contributions to paleobotany and geology. It will attempt to interpret his 1900 field trip to southwestern Pennsylvania by deciphering his field notebook from that trip together with consideration of other contemporaneous sources.

David White – His Life & Career

David White was a geologist and paleobotanist at the United States Geological Survey (USGS) from 1886 until his death in 1935. He was principally known for his work correlating the coal measures of the Appalachians using fossil plants, and for being the Chief Geologist of the USGS from 1912 to 1922. His later career included fieldwork at the Grand Canyon on the Hermit Shale, and leadership positions with the National Academy of Sciences, the National Research Council, and the Geological Society of America, among other organizations. He received three honorary Doctor of Science degrees and medals from national and international scientific societies. White worked for the USGS his entire career, but was assigned to the Smithsonian Institution for a few years during the lean-budget years experienced by the USGS in the mid-1890s. He reportedly turned down opportunities for more lucrative commercial jobs and opportunities to profit from his extensive knowledge of the coalfields (Schuchert, 1935, p. 197-198).

David White was born in 1862 and was christened Charles David White (early in his career he dropped Charles and was known thereafter as David White). He was a farm boy from upstate New York who went to Cornell University on a scholarship. To supplement his income, since the scholarship only covered tuition, he learned to draw and taught drawing classes (Cornell Register, 1885-1886, p. 23). He took numerous geology and paleontology classes and wrote a thesis illustrated with his own plant drawings (Schuchert, 1935, p. 196-197). He graduated in 1886 with a degree in Natural History (Cornell Register, 1885-1886, p. 145).

It was fortunate for White that he was good at drawing; it led to an offer of employment from the USGS. In 1886 he was hired by Lester Ward, a geologist at the USGS, to draw plants for Ward's monograph of the Flora of the Laramie Group. White did well, and, in the Seventh Annual Report of the USGS for 1885-1886 (p. 124), Ward reported that, "On June 1 Mr. C. D. White entered upon the work, and has already advanced it considerably."

White was assigned additional work by Lester Ward including editing and expanding a bibliography of publications on fossil plants and an index of species and genera (Mendenhall, 1936, p. 272) – probably Ward's "Compendium of Paleobotany." White soon began studying fossil plant material, and began publishing articles and bulletins. His first publication was in 1889, "Carboniferous Glaciation in the southern and eastern hemisphere – with some notes on the Glossopteris flora" (White, 1889). His first stratigraphic paper, "On Cretaceous plants from Martha's Vineyard," was published in1890. Walter Mendenhall, a contemporary of White at the USGS, and the USGS Director from 1930 to 1943, stated that White's 1893 publication of "Flora of the outlying Carboniferous basins of the southwestern Missouri," marked the beginning of White's career in Paleozoic paleobotany, as "the successor to Leo Lesquereux," the Swiss-born paleontologist who in the latter half of the 1800s was the preeminent authority on peat and coal formation (Mendenhall, 1936, p. 273).

The USGS that White joined in 1886 had been established by the 45th Congress, only seven years earlier in 1879, to classify the public lands and examine their geological structure, mineral resources, and products. It was conceived as a vehicle to find and help exploit the vast natural resources of the United States. But, by the early 1890s, the USGS was facing challenges on two fronts. A national economic contraction led the U.S. Treasury to announce an impending deficit in 1891 for the first time in 20 years (Rabbit, 1989, p. 16), which put pressure on the budgets of all federal agencies. At the same time, the value of the Survey's scientific work was being questioned. For example, one congressman argued during the budget debate "What practical use has the Government for paleontology? What function of the Government is carried on by paleontology? Not only has the Government no use for it as government, but paleontological work is not even necessary to the proper construction of a geological map" (Rabbitt, 1980, p. 204). Ironically, these budgetary constraints helped to shape White's future, directing his work in a way that would soon prove the Congressman wrong about the value of paleobotany in the construction of geological maps.

These political and economic pressures caused changes at the USGS that altered the course of White's career in a way that determined his future professional expertise. The appropriation for the USGS in 1892 was slashed, especially for the Geologic Branch. Several geologist positions were eliminated; others had salary cuts. Lester Ward, White's boss, was demoted from the position of geologist to that of paleontologist at half his former salary. To save White's career, Ward arranged for him to work temporarily for the Smithsonian Institution's National Museum [3]. White was assigned to catalog and pack a collection of Paleozoic plants that had been donated to the museum by R.D. Lacoe (Rabbitt, 1980, p. 212). The Lacoe collection contained many of the Paleozoic plants upon which Leo Lesquereux (1879, 1880) based his benchmark "Coal Flora" published by the Second Geological Survey of Pennsylvania (1874-1895).

White wrote to F.W. True, Curator in Charge at the National Museum, on February 27, 1892, that he had arrived in Pittston, Pennsylvania on February 21, and had embarked on cataloging the Lacoe collection (White, 1892). He initially shipped 3600 pounds of material in 22 boxes back to the United States National Museum in Washington, D.C., and he estimated it would take 5 to 6 months to complete cataloging, packing, and shipping the collection. In actuality, White traveled to Pittston, Pa. many times over the next three years to list, catalog, and pack the Lacoe collection. He wrote to Lester Ward that he considered the trips an "exile" from Washington, and found the Pittston natives to be "illiterate," among other shortcomings (White, May 1894a). In another letter to Ward in December 1894, he speaks of sorting 1500 pounds of specimens a day (White, December 1894b). Despite his unhappiness with the Lacoe Collection assignment, White developed a warm personal relationship with Lacoe, corresponded with him until his death in 1901, and celebrated Lacoe's life in a moving tribute (White, 1903).

White's work with the Lacoe collection of fossils led him to develop a theory about fossil position and its importance to geologic stratigraphy. He asserted that after studying the fossil plants in the

[3] The United States National Museum was the only Smithsonian museum at the time and consisted mainly of what later became the National Museum of Natural History.

Lacoe collection he should be able to tell the age and identity of coals based on the fossil plants found in the strata associated with them. Charles Schuchert, White's friend and fellow USGS paleontologist, related that White had satisfied himself that fossil plants could be relied on to provide accurate chronologies of rock strata, but the USGS Director, Charles Walcott, thought White's conclusions should be tested in the field (Schuchert, 1935, p. 190). In 1893, White was assigned to the field party of M.R. Campbell, a USGS geologist, and they continued to work together through 1895. The USGS annual report for 1893-1894 (published in 1895) stated, "Mr. David White will be attached to the geological parties working in the coal measures of Virginia and eastern Tennessee, to aid, through his knowledge of fossil plants of the coal bearing rocks, in correlating the various coal seams of the southern Appalachians." The allocation for the work of Mr. White was $1,500 (USGS 1895, p. 24). Although Campbell was initially skeptical of White's methods, by 1896 Campbell wrote to Schuchert, "We all shared White's enthusiasm and I soon decided that I would rather trust to White's decisions than to my own tracing of formation outcrops" (Schuchert, 1935, p. 190). Campbell recalled that during four years of fieldwork he became convinced that White was correct, and that White could identify the coal beds more accurately using fossil plants than Campbell could using traditional geological methods (Campbell, 1916, p. 211). In the succeeding years, White continued his work correlating coal measures as an Assistant Paleontologist (1886-1894), Assistant Geologist (1894-1900), and Geologist (1900-1912).

In retrospect, then, White's conviction that he could correlate coal beds based on the fossil plants he found in association with them had been formed early in his career during what seemed to him at the time a terrible assignment. But this assignment in reality set him on the path to becoming a renowned expert on coal formation and coal-measures stratigraphy.

In 1907, White was appointed head of the USGS Section on Eastern Coalfields (Lyons and Morey, 1995). In the same year he hired Reinhardt Thiessen to do laboratory work on coal samples, and in 1913 they coauthored The Origin of Coal. By 1910, White was overseeing all coal and oil work east of the Mississippi, and became adept at working with the various state geological surveys, one of the skills that eventually led to him being appointed Chief Geologist in November 1912 (Lyons and Morey, 1995). White was Chief Geologist for 10 years, until 1922, including the World War I years. White believed geologists had a direct, productive role to play during the war by using scientific methods to locate scarce resources, including increasingly important oil and gas. Hugh Miser, in his Memorial of David White, said, "The geologists of the Geological Survey, working under his [White's] direction, did pioneer work in the application of geological methods to the search for oil and gas" (Miser, 1935, p. 928). The oil companies noticed, and according to the official USGS History, "So many Survey geologists who worked under his [White's] direction were recruited by oil companies after World War I that a notable portion of the leading geologists of the world on company payrolls in the 1930s were former members of the USGS" (Rabbitt, 1986, p. 136).

White had hoped to return to research after his tenure as Chief Geologist, but administrative duties at the National Research Council and the National Academy of Sciences took up much of his time. However, he did conduct fieldwork in the Grand Canyon, funded by the Carnegie Institution, in 1927-1929.

White remained an active field investigator and researcher until a stroke in 1931 disabled him physically. He continued working in the office until his death at home on February 7, 1935. White was highly regarded, and it was noted that seldom had the "death of a Survey geologist called forth so many tributes from all parts of the world" (Rabbitt, 1986, p. 359). His ashes were interred at the cemetery on the south rim of the Grand Canyon.

In the words of his colleague and friend, Charles Schuchert, "David White came to the United States Geological Survey as a draughtsman; he left it in 1935 as America's foremost authority on Paleozoic stratigraphy based on fossil plants, as her leading expert on the origin and evolution of those two plant products, peat and coal, and as the author of a theory of oil distribution that is basic to the petroleum industry" (Schuchert, 1935, p. 189).

David White's Summer 1900 Field Trip To Southwestern Pennsylvania

In 1900, David White's fieldwork included collecting fossils in western Maryland and southern Pennsylvania, including Somerset and Fayette counties in Pennsylvania. The USGS "Plans, Estimates, and Allotments" for 1900-01, stated, "In the western Appalachian region of New York, Pennsylvania, Ohio, West Virginia, and Kentucky lies the great coal field of the eastern states, with its associated oil and gas fields," and even though the states have invested large sums in their own work (notably Pennsylvania First and Second Geological Surveys), "…Nevertheless, the demand of investors for accurate information as to the conditions and districts of occurrence of various mineral resources requires additional and more detailed work" (Plans, 1900, p. 13). In the same document, White's assignment was described as:

> "In the Appalachian Field the various strata of the Coal Measures, conglomerate, sandstone, shale, and coal, are very irregularly bedded and distributed in thin overlapping layers of unequal extent. Among beds of different epochs, which differ also in economic value, there is frequently great likeness of appearance. A geologist tracing them may, therefore, be misled, and, for instance, through wrongly identifying a certain sandstone erroneously infer the depth to a certain coal or oil sand. Fossil plants, however, afford an unfailing means of recognizing each important group of strata, and they are studied for this purpose as well as to advance knowledge of extinct floras. Mr. White is charged with the investigation of fossil plants of the Coal Measures and of allied strata. His researches have been of great assistance to stratigraphic geologists and should be prosecuted to obtain precise information as to the relative age of separated coal basins and of coal beds in each basin. For Mr. White's work in the Broad Top district, about the northern and eastern margins of the Appalachian coal field in New York and Pennsylvania, and in adjacent regions, and for office work upon the collections and manuscripts, it is recommended that there be allotted the sum of two thousand five hundred and fifteen dollars" (Plans, 1900, p. 15)

In pursuit of this mission, White visited numerous locations in Maryland and Pennsylvania during the summer of 1900. The locations, listed in his field notebook "WMD & SPA including Broadtop 1900 NO.1," are shown in **Figure 2**. Southwestern Pennsylvania was only a small portion of the overall trip, but was significant for the number of fossils collected and the insight provided into White's methods and objectives during his field trips.

Although not specifically stated, we assume the amount allocated included White's salary and expenses. Other records from 1902 and 1903 indicate White's annual salary was $2,000 (Walcott, 1902), leaving $515 for expenses. This sounds like a woefully small salary, but in the same year a shirt cost 23¢, a top quality suit was $10.62, and corned beef was 8¢ a pound (Lord, 2018).

This paper will now examine White's fieldwork during this summer of 1900 in more detail. It will consider southwestern Pennsylvania in 1900, where and how White traveled, where and what fossils he collected, and the importance of his collections to the understanding of coal beds at the time and to our understanding of geologic stratigraphy today.

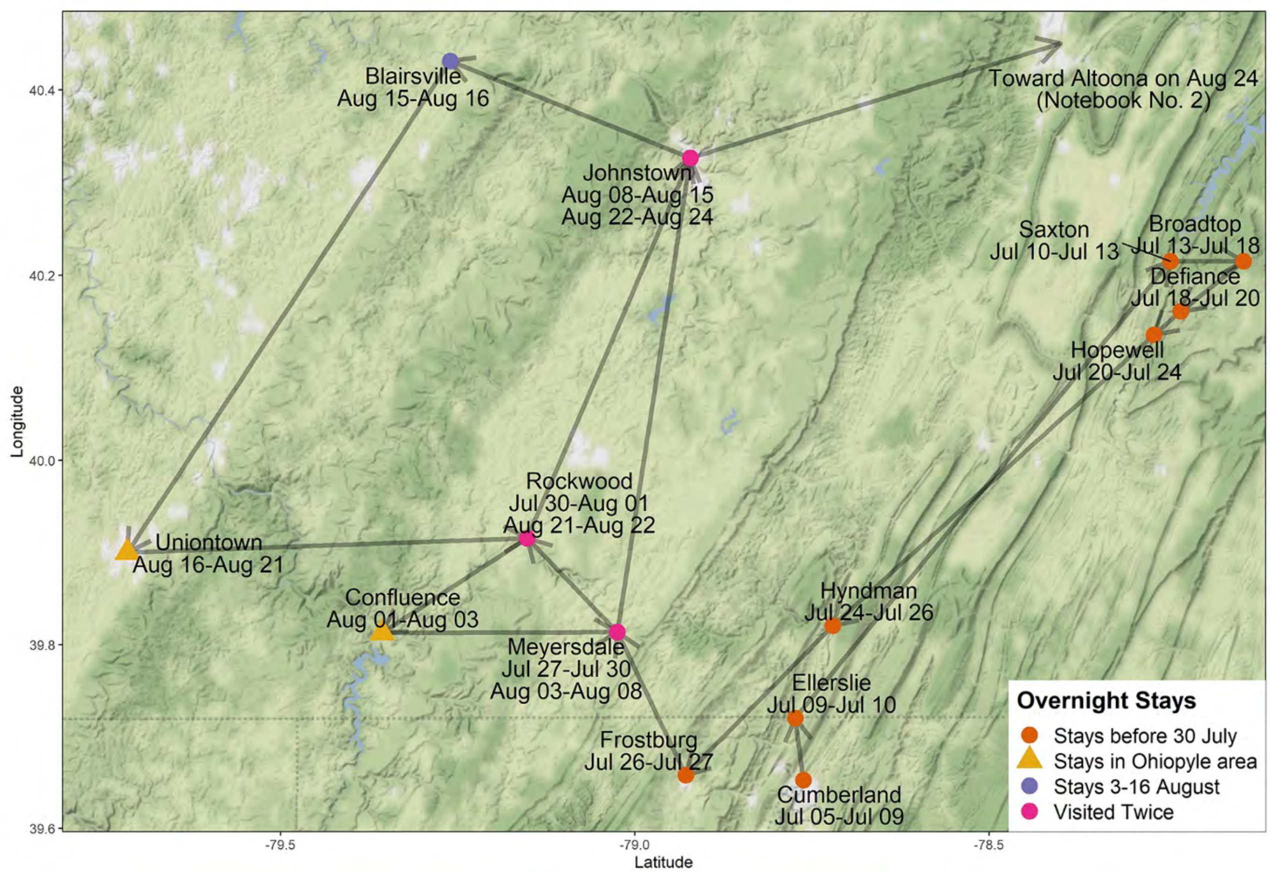

Figure 2. *White's activities and travels. Map of White's travels, July 5 – August 24, 1900.*

Southwestern Pennsylvania in 1900

The areas White visited in southwestern Pennsylvania in 1900 were home to bituminous coal mines supporting the coke ovens that fed the steel industry in the United States. There were numerous mines on the hillsides; some were small, private operations, whereas others were larger corporate enterprises. The bituminous coal fields in Pennsylvania were home to small hamlets that grew up around coal mines, as well as larger towns. As an example of a larger town, Connellsville had a population of 7,160 in 1908 (about the same as today) and featured two theaters, moving picture shows, two parks, and several saloons "well attended." Fayette City, a much smaller town on the Monongahela River near Uniontown, by contrast, numbered 1,595 souls (about three times larger than today) and had one moving picture show and two dance halls (Maclean, 1908).

Ohiopyle was a similar small town in the Fayette County mountains, surrounded by coal seams and served by the Baltimore & Ohio (B&O) Railroad. David White visited Ohiopyle twice during his 1900 field trip. The town of Ohiopyle had been established by Andrew Stewart, a former Congressman who turned down the office of U.S. Treasury Secretary to move to the mountainous area near Ohiopyle Falls. He originally planned to call the town Falls City, and championed bringing the B&O Railroad to the area. As coal and coke boomed in the Fayette County area, railroads shipped coal to the coke ovens and coke to the steel mills. Coal and lumber barons became millionaires and lived in Ohiopyle, Confluence, and Uniontown. A booming economy led to passenger trains: tourists could travel to Ohiopyle for $1 round trip from Pittsburgh or Cumberland. Over 10,000 tourists visited Ohiopyle in 1900 (Van Atta, 2002). Andrew Stewart and his sons built hotels for the tourists, including the Ohiopyle House in 1871 and the Ferncliff Hotel and Park in 1879 (McGuinness, 1998, p. 141-142). The 1900 census showed that Ohiopyle had 423 inhabitants [4].

There were coal mines in the Cucumber Run area near Ohiopyle, although the history of mining operations in the area is incomplete. Apparently larger commercial mines did not open there until the 1920s (Poellot 1975). A 1917 photograph of a small coal mine "above Cucumber Falls" shows four miners, apparently tired and dirty after a day of work (McGuinness, p. 146).

Another small town White visited in 1900 was Stewarton just north of Ohiopyle (and downstream on the Youghiogheny River, which flows north to Connellsville). Lumber harvesting was another economic engine of the area, and McGuinness (1998, p. 147) noted that "there were sawmills on every knob and hillside in these mountains during the great boom." There is no town at Stewarton today, but in 1900 it was a small town near the lumber mill owned by one of Andrew Stewart's sons, Col. Andrew Stewart.

Field Geology in Southwestern Pennsylvania in 1900

The life of a field geologist in the early 1900s required an ability to work in challenging conditions. According to C. W. Hayes in his Handbook for Field Geologists, "The first qualification is a good physique and a strong constitution… The second is adaptability" (Hayes, 1916, p. 1). David White was known to be physically fit throughout most of his life. Several commentators tell of him "running" up the four floors to his office in Washington, D.C. and carrying heavy loads of fossils from collecting sites.

White did not keep a diary during his field trips, so we have pieced together his movements in the field from his record of expenses listed in the back of his field notebooks. Based on his field notebooks and the locations of his collecting sites compiled in the USGS records, we can infer the following about his field trips in general:

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[4] Ohiopyle's largest population was 535 in 1910; in 2010 the Census recorded 59 residents.

1. He covered many miles, usually by train, with apparently numerous intermediate stops.
2. He often worked along a railroad line, examining the geology and collecting plant fossils. In many cases this would have served him well as many coal mines were along railroads or had spur lines to them, and the cuts into hillsides for the railroad right-of-way exposed rock strata.
3. When he could not reach an area by rail, he often hired a horse and wagon. Occasionally, he had to resort to other means. In a 1900 letter from the Broad Top, Pa. area to a colleague he complained, “Rode 3 miles in the hind end of a lumber wagon sitting on my trunk. There is not a livery stable within eight miles” (White, 1900a).
4. He generally stayed in hotels in larger towns near where he was collecting. There is no record of him riding on horseback or camping in the field. Whereas there is no record of exactly what he may have packed, a laundry ticket from a 1902 field trip lists clothing largely appropriate to a city environment (**Figure 3a**).
5. He packaged and shipped fossils back to Washington, D.C. numerous times during trips. Hayes’ Handbook for Field Geologists said specimens should be packed in small boxes that one person could handle and that each box should be entirely full, all interstices being filled with soft paper, excelsior, hay, or similar material, but not sawdust (Hayes, p. 81). White often recorded expenses for gunny sacks, packing material, and boxes.
6. White was flexible to the point of inconsistency. The laundry ticket mentioned above from a 1902 trip (**Figure 3a**) was found in a National Museum of Natural History drawer with collection information scribbled on the back showing his willingness to use whatever was at hand (**Figure 3b**). However, he did not consistently date or label entries in his notebook, including the places where plant fossils were collected. Even the orientation of sketches is idiosyncratic, with north often at the bottom of the page.

3a

3b

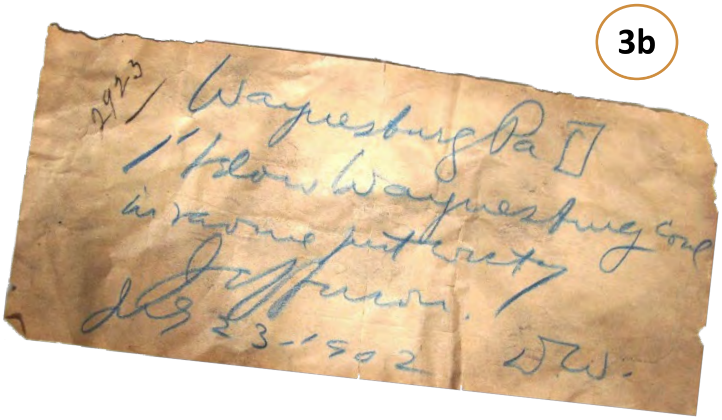


Figure 3. *a) Waynesburg Steam Laundry Ticket for D. White at the Blair Hotel for $1.00.*

b) Reverse of laundry bill, with writing from 1902, found in specimen drawer at the National Museum of Natural History.

(courtesy of Confluence, Pennsylvania 101 FB Group Page)

Because White traveled mostly by rail, he made use of a variety of railroads, and often carried timetables or affixed them in his field notes. Originally, the B&O did not run through southwestern Pennsylvania, but by 1900, when White visited, B&O tracks ran from Pittsburgh to Cumberland and from Uniontown to Connellsville.

Although the National Road, now U.S. Route 40, existed in 1900, White probably would not have traveled by automobile since this conveyance was uncommon then. However, well-to-do people in Confluence did have automobiles as early as 1900. **Figure 4** shows a photograph of "George Butler and his 1900 Buick." Automobiles would be in use by the USGS later. A letter, probably authored by White and dated August 26, 1913, requests authority to buy a Ford automobile to support a search for potash in the southwest (Smith, 1913), and by 1917 automobiles were in general use in the field by the USGS (Rabbitt, 1989, p. 28) [5].

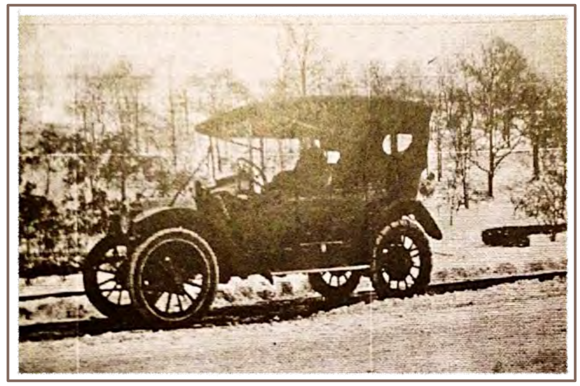


***Figure 4.** David White and his times — George Butler and his 1900 Buick in Confluence, PA (courtesy of Confluence, Pennsylvania 101 FB Group Page)*

Reconstructing David White's Summer 1900 Field Trip

Determining where White collected fossils during his 1900 field trip is important for several reasons:

1. It enhances the value of the fossil collections at the NMNH. Locality information is important to identify as closely as possible where fossils were collected because it ties the fossils to a place at which the geology can be evaluated by later investigators. It also permits the stratigraphic interpretations of the time to be evaluated in light of subsequent discoveries, and updated accordingly.
2. It enhances the value of original fieldnotes. USGS locality numbers occasionally were added after the fossils were sent back to the Museum and, therefore, the numbers appear only sporadically in White's field notebooks, and only if added later. Locating the collections accurately involves comparing descriptions in locality registers to the fieldnotes.
3. It helps us understand how fieldwork was conducted in the 1900s, the conditions under which the fossils were collected, and the importance placed on those fossils by the collector.
4. It helps us understand the historical characterizations of the fossils and the strata they were collected from.

[5] Tracing the route followed by a collector during a field trip in 1900 requires historic information on town names, highway locations, and railroad stations. Historic topographical maps from the 1920s and earlier (available from the USGS website) are invaluable for interpreting field trips in the early 1900s. They show railroads and spur lines; some mines, quarries, and forges; and historic highway routes. Modern maps can mislead since highways have changed routes, many railroads are no longer in existence, and sometimes names of towns and other places have changed.

There are several documents that allow insight into White's 1900 field season in Pennsylvania. The most relevant is his field notebook, "WMD & SPA including Broadtop 1900 NO.1", which covers July 5 to August 26. Presumably there was a notebook No. 2 for the remainder of his trip, but it has not been found. The notebook was written in pencil on paper that has become discolored ("foxed") in the 120 years since it was first written. It was scanned and enhanced to make White's faint writing easier to read. Unfortunately, it does not help with his penmanship (**Figure 5**). For the record, White was left-handed, a fact discovered from a Christmas card written to a colleague, now in the archives of Southern Methodist University.

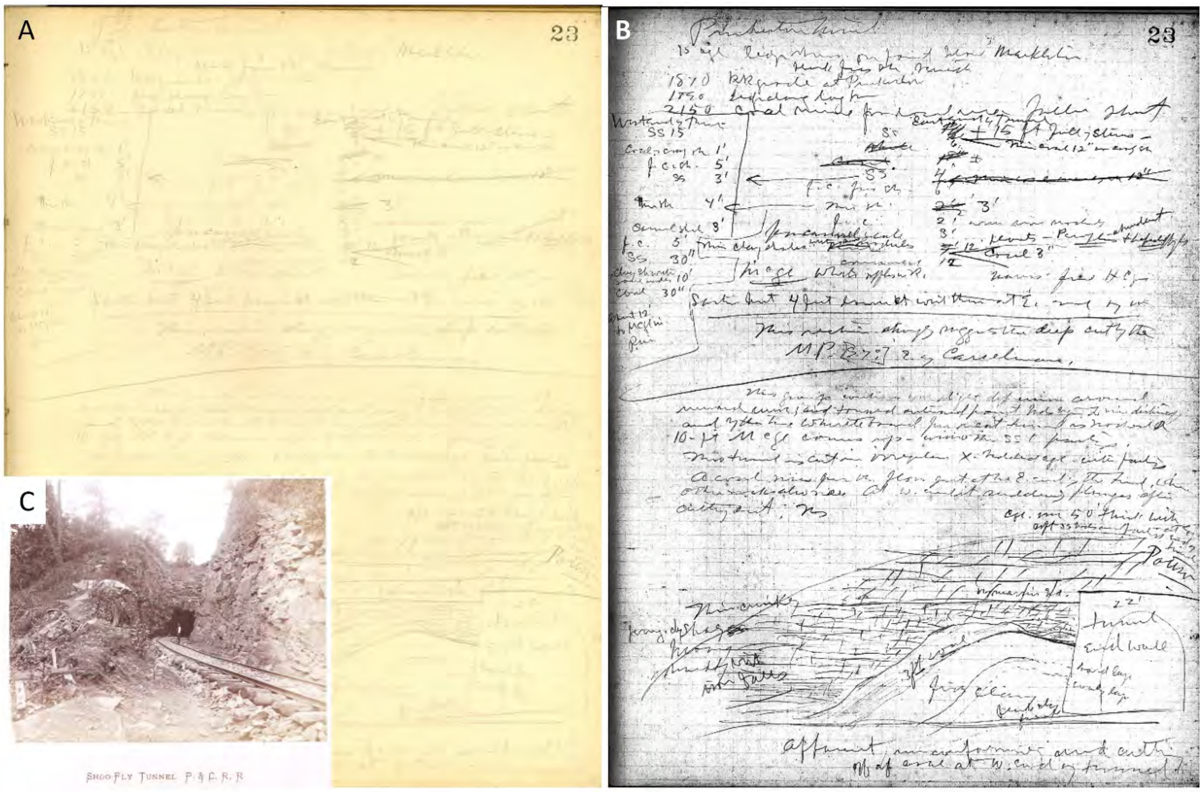
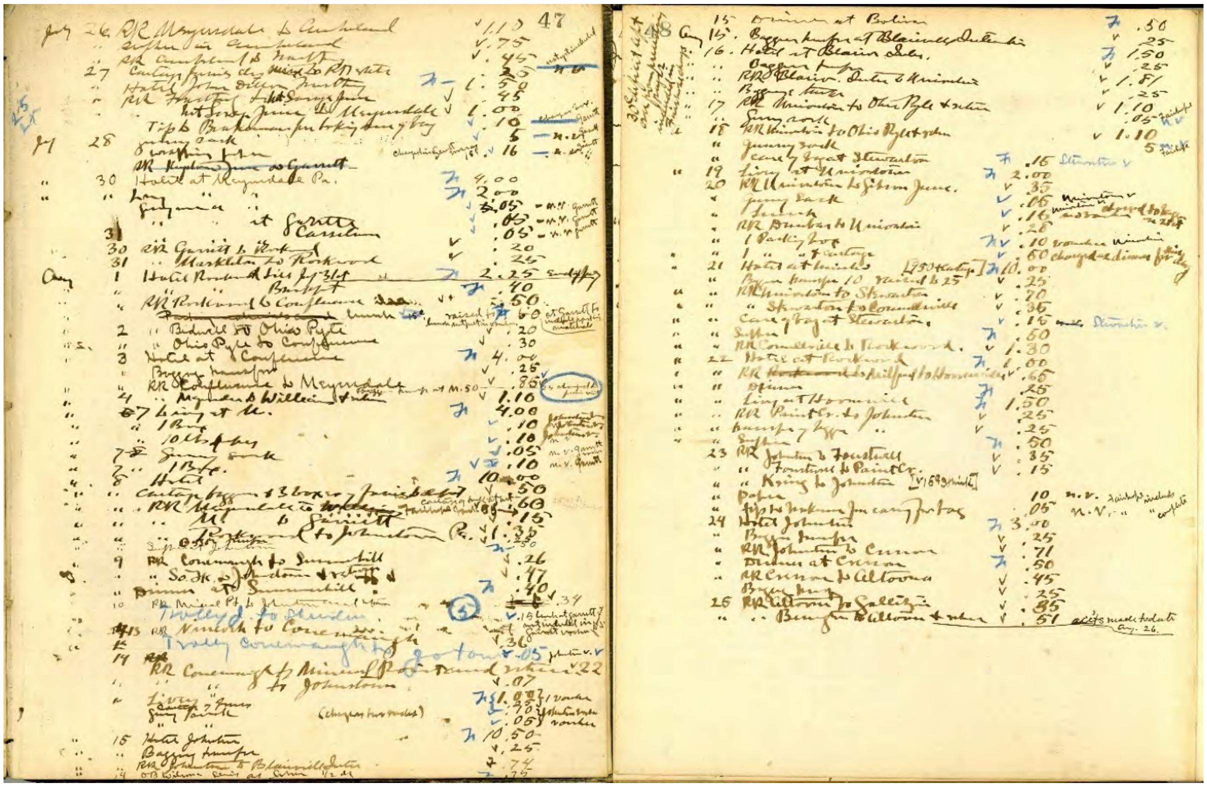


Figure 5. *White notebook page 23 as example of his handwriting.* ***A****— Original scanned version.* ***B****—Enhanced version.* ***C****—East end of Shoofly Tunnel, 1872. White's note contain a sketch of the west end of the tunnel at the bottom of page 23. Shoofly Tunnel image courtesy DeGolyer Library, Southern Methodist University.*

White's field notebook contains three types of information: his field notes, which are sometimes dated and sometimes contain sketches as well as notes and observations; his list of expenses, which are dated and serve as a record of where and when he visited locations (assuming he recorded expenses on the day he actually made them) (**Figure 6a**); and a list of boxes and bags of specimens he sent back to Washington, D.C. (sometimes listing what was in the container) (**Figure 6b**). Unfortunately, all of these records are incomplete and sometimes contradictory, but using them, together with contemporaneous railroad schedules, has allowed reconstruction of his daily activities. This reconstruction (**Figure 2**) seems to be the best fit with the available data, but other interpretations may be possible.

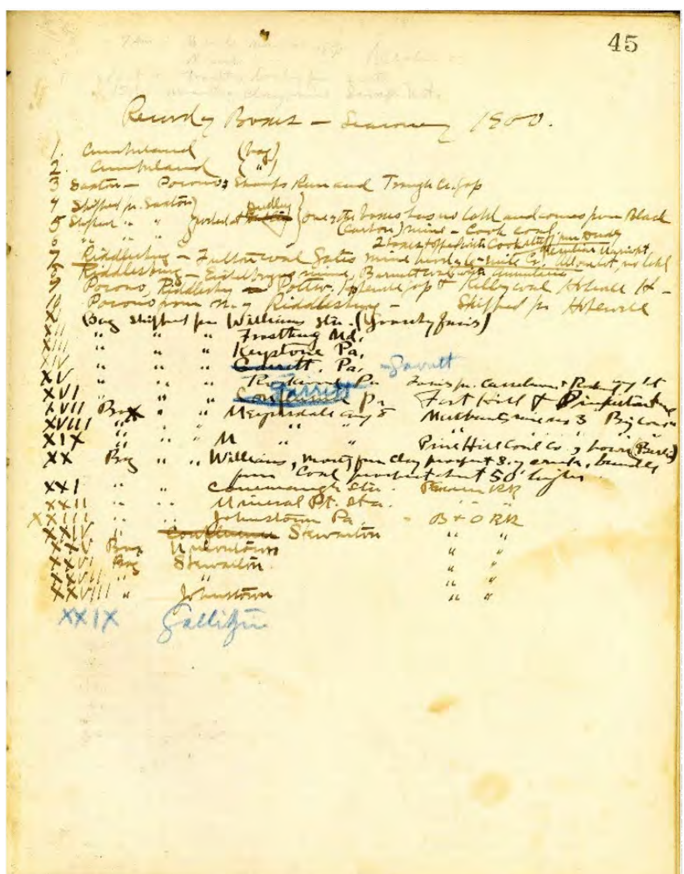


6a

Figure 6. *Lists from White's field notebook allowed reconstruction of his activities and travels.*

a) *List of White's expenses (above) on that portion of his 1900 summer trip that included the area east of Confluence to Connellsville and beyond.*

b) *List of boxes shipped, from his 1900 "WMD & SPA including Broadtop 1900 NO.1" field notebook (right).*



6b

White's Trip – Day by Day

Notebook No. 1 covers July 5 to August 26. The expenses listed in the back pages of the notebook gave a day-to-day accounting of where White was and what he was doing (**Figure 6a**). Combining this information with the field notes in the body of the notebook, which are assumed to be written in accordance with the sequence of his travels, and the listing of bags and boxes he shipped (**Figure 6b**), which are sometimes dated, yields a fairly detailed picture of his trip, although questions and inconsistencies remain. Using White's listed expenses as a guide, he left Washington, D.C. on July 5, 1900 and traveled by railroad to Cumberland, Md. White spent the first part of his trip in the Frostburg and Broad Top areas, eventually returning to Cumberland on July 26, and traveling on to Rockwood on July 30 (**Figure 2**).

His expenses show he used the railroad to travel between locations, returning to a hotel at night (hotel expenses are not listed every night, but are listed once, presumably when he checked out and paid his bill). He also sometimes used a horse, wagon and driver, and cartage. Rather than carry them with him, he frequently shipped the fossils he had collected back to Washington, D.C., apparently packed in either bags or boxes. He was an active collector and had shipped 29 bags or boxes by August 26.

White seems to have collected fossils near Rockwood and Casselman on July 30 and stayed in Rockwood that night. On July 31 he appears to have collected at the Shoofly Tunnel and a railroad cut near Fort Hill (**Figure 5c**). He then returned to Rockwood for the night. On August 1, he shipped a bag from Rockwood containing the fossils from Rockwood and Casselman. This shipment is one of the few in his notebook that has a date, as well as having the contents noted [6].

White's other activities on August 1 are less clear. His expense records, usually meticulous, show that he purchased railroad passage from Rockwood to Confluence, as would be expected as he proceeded toward Ohiopyle. But there was also an entry showing he had lunch and purchased packing material in Garrett, which is in the opposite direction. It is also possible he shipped the Shoofly/Fort Hill fossils from Garrett; the notebook entry for that shipment was edited at a later time with Confluence crossed out and Garrett written in a blue pencil (**Figure 6b**). If so, White probably had the first shipment packed and shipped it in the morning before he left Rockwood, then took the train to Garrett with the second batch of fossils where he had lunch and presumably packed and shipped the Shoofly/Fort Hill fossils. The B&O Railroad timetables (Allen, 1900, p. 446) for that day show it would be possible[7], but there is no apparent reason for such backtracking with a set of fossils. Ironically the NMNH has no record of the fossils from Shoofly or Fort Hill. If they were received they were either misplaced or attributed to another location. In any case White appears to have done little or no collecting on August 1 but finished the day at Confluence.

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[6] Since White did not make any entries in his expense record for the cost of shipping his samples, it is likely that he mailed them using what was called a Government penalty label for postage (Rabbit, 1980, v. 2, p 31).

[7] There were two trains eastbound and westbound from Meyersdale to Ohiopyle and beyond (Ohio Pyle in the timetables; Egypt, the stop after Confluence, in later timetables is listed as Bidwell – refer to **Figure 9**, this guidebook article, compare **a** and **b**) in the published Baltimore and Ohio Railroad, Pittsburg Division, timetables for July 1900 (Allen, p. 446). White's expenses do not seem to list a sufficient number of railroad tickets to cover all this traveling unless the tickets were roundtrip or multi-stop. No fare tables have been located to clarify this question.

White stayed at a hotel in Confluence on August 1 and 2, and visited the area below Confluence, at Huston and at Ohiopyle on August 2. In 1900 Confluence was a boom town with 4 hotels as well as boarding houses and rooms for rent. White did not say where he stayed, but photographs of hotels from the era show Park Hotel and Hotel Dodds (**Figure 6a, b**). A 1905 panoramic map also shows Hotel Gilchrist (**Figure 6c**).

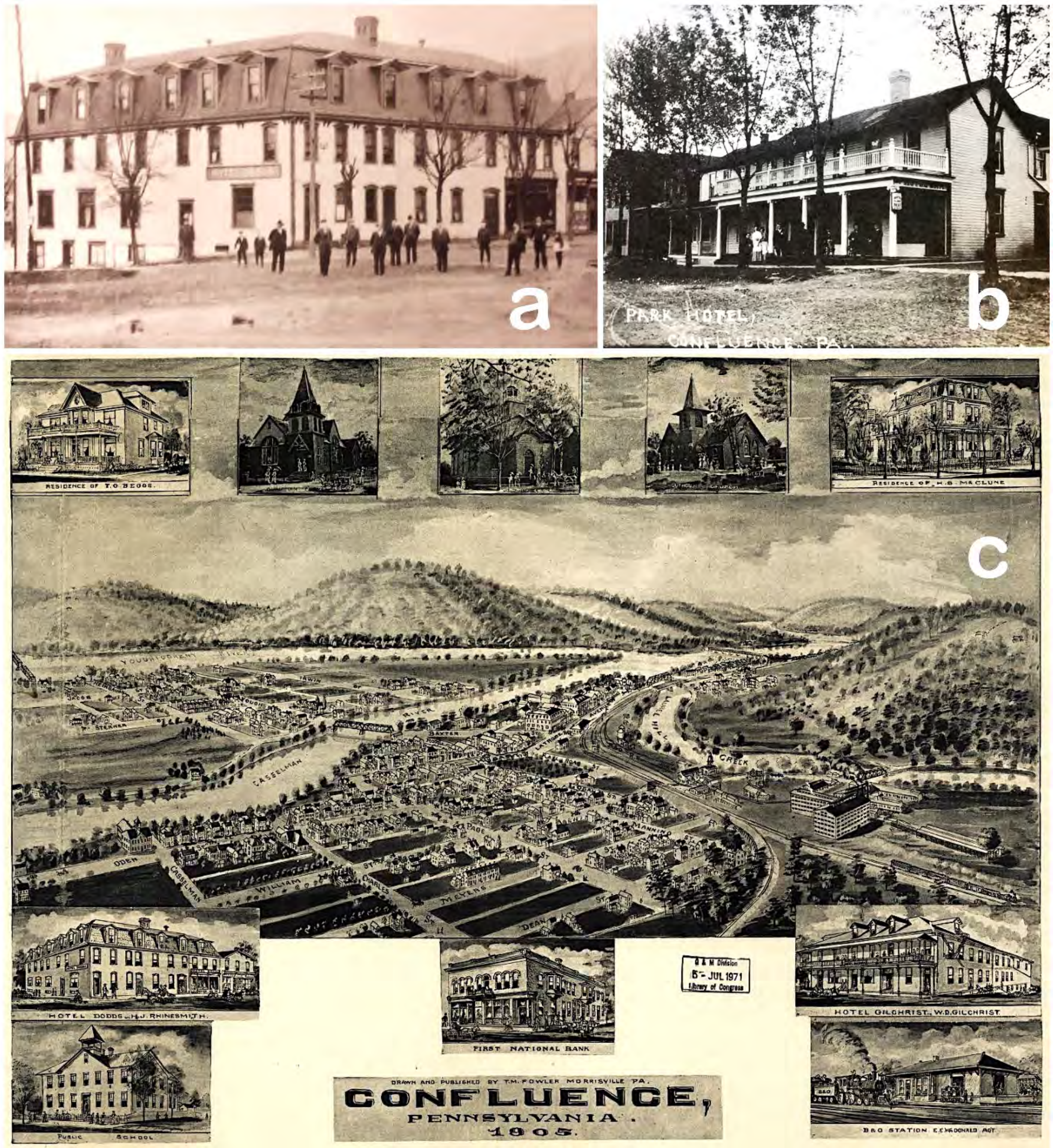


Figure 7. *Possible hotels in which White may have lodged while in Confluence.* ***a)*** *Hotel Dodds, early 1900s.* ***b)*** *Park Hotel, early 1900s.* ***c)*** *Panoramic Map of Confluence, PA, 1905 with illustrations of Hotel Dodds and the Gilchrist Hotel. (a and b courtesy of Confluence, Pennsylvania 101 FaceBook Group Page).*

The notebook expenses for August 2 show that White traveled by rail from Bidwell to Ohiopyle and Ohiopyle back to Confluence. It is unclear how he traveled from Confluence to Bidwell. The notes on p. 25 of the notebook, presumably for August 2, refer to the "gap below Confluence," "Pottsville in gap below Huston," and "Ohio Pyle." The collection records of fossils received from White on this trip include fossils collected from Cucumber Falls at Ohiopyle and from a cut near the railroad station, but the entries are undated and so could have been collected upon his return visit on August 17-18. In addition, he did not make his next shipment until August 8, so it is possible that he either collected no or very few fossils on August 2, despite his travels and notebook entries.

On August 3, White paid $4.00 for his two-night hotel stay in Confluence. Page 26 of the notebook, dated August 3, refers to "Garrett Sta[tion]" and then Williams, which indicate White was going east from Ohiopyle. His last expense entry on August 3 is "RR Confluence to Meyersdale", and so he left the Ohiopyle area for the Johnstown area. From August 3 through August 16, White continued his field trip with travels in the Johnstown area: Conemaugh, Summerhill, Nineveh, and Bolivar (**Figure 2**).

It is not clear if White worked every day. There are almost no expenses listed for Sundays, until on August 19 in Uniontown, when he hired livery. In 1900, most stores and other services would have been closed on Sundays, and White may have observed a "day of rest" whenever he could. There were other days when no expenses were listed, but it is most likely White was collecting, packing, or doing other work those days. It is also a mystery why there are so few meals listed. Perhaps some meals were included with his room fees. White seemed to have been scrupulous about listing small expenses (e.g., "gunny sack 5¢"), so it was unlikely he would have overlooked the cost of a meal.

White returned to the Ohiopyle area on August 16 by taking the railroad from Blairsville (east of Pittsburgh) to Uniontown. On August 17, he took the railroad from Uniontown to Ohiopyle and return, and purchased a gunny sack. On August 18, he rode from Uniontown to Ohiopyle again, bought another gunny sack and listed "care of bag at Stewarton 15¢." On August 19, he hired livery at Uniontown for $2.00 (presumably a horse, wagon & driver), which would appear to indicate he had a large number of samples to haul. On August 20, he took the railroad from Uniontown to Gibson Junction (Connellsville area), and bought more boxes. Box #XXV was shipped from Uniontown (no date), and a bag preceding it and two bags following it were shipped from Stewarton. Although never a large town, shipping from Stewarton must have been convenient for White. The corresponding notebook pages for this second visit to the Ohiopyle area are p. 40 and 41 (**Figure 8**). The text below the sketches describes an area in the "cut just west of Yough," which probably refers to an old stop or signal on the B&O Railroad between Ohiopyle and Stewarton listed, as in a 1910 railway guide (Allen, 1900, p. 1438) and shown on an 1898 railroad map of the area (**Figure 9a**). Interestingly, the timetables for 1900 show no station named "Yough," so he may have been walking to this area.

On August 21, White paid for a multi-night stay at a hotel in Uniontown, and took the railroad from Connellsville to Rockwood. From Rockwood, White continued to Johnstown and then on to Altoona (**Figure 2**), and presumably described that travel in a second notebook.

Taking White's expense record together with his notebook sketches and notes, it appears that he visited Ohiopyle locations on his first visit to the area on August 1 – 3, perhaps collecting only a few fossils, and then returned to collect fossils in the area near Stewarton and along the Youghiogheny River on August 16 – 21. The reason for the two visits is unclear, although his limited collections on August 3 may have prompted another visit on August 16. This ambiguity is unlike the one other notebook that has been similarly analyzed (DiMichele et al., 2011), which seemed much more straightforward regarding both his route and collection sites.

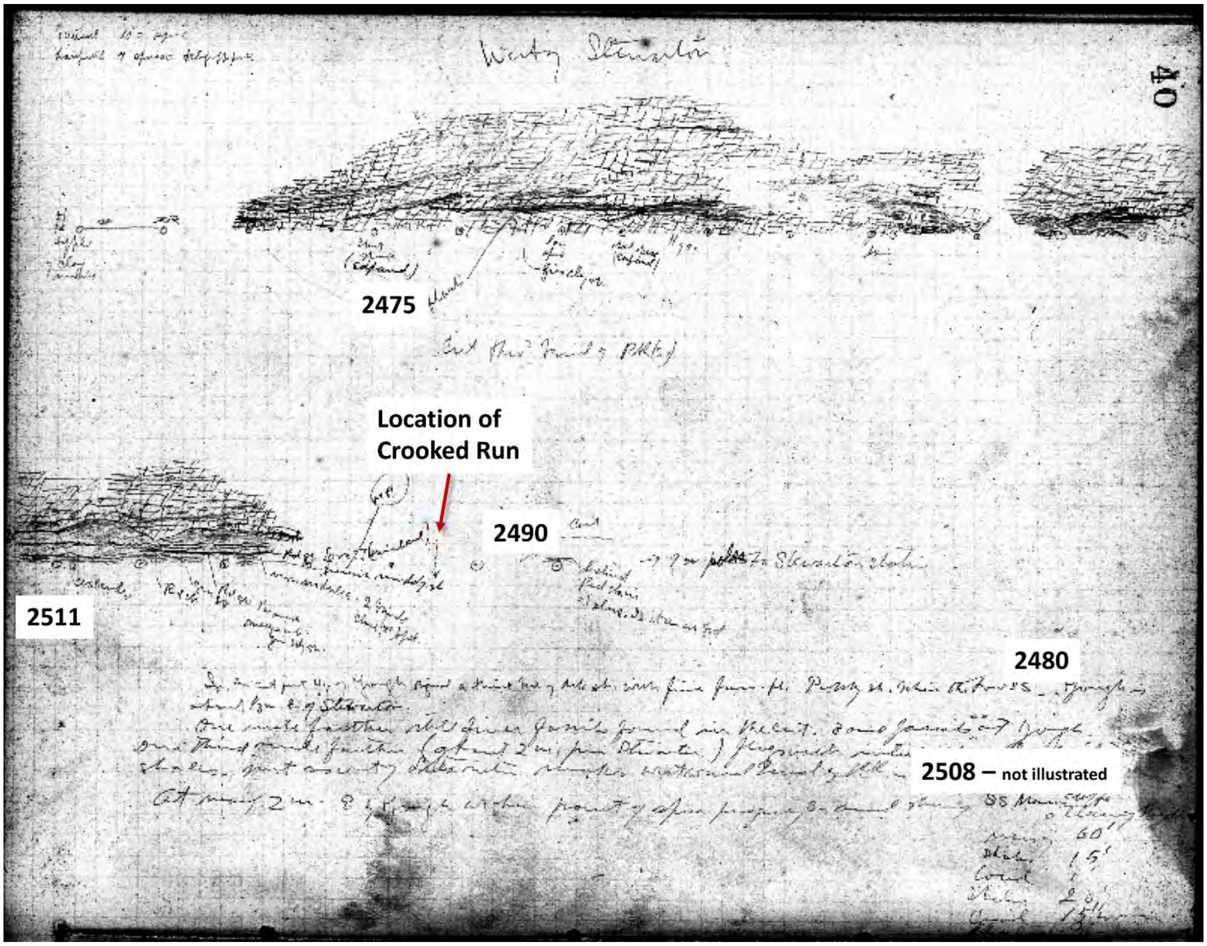


Figure 8. *White's field notebook, page 40 (enhanced). It is from the outcrops sketched on this page that all of the collections illustrated here (USGS localities 2475, 2511, 2490, and 2480 in a roughly north-to-south order) were made.*

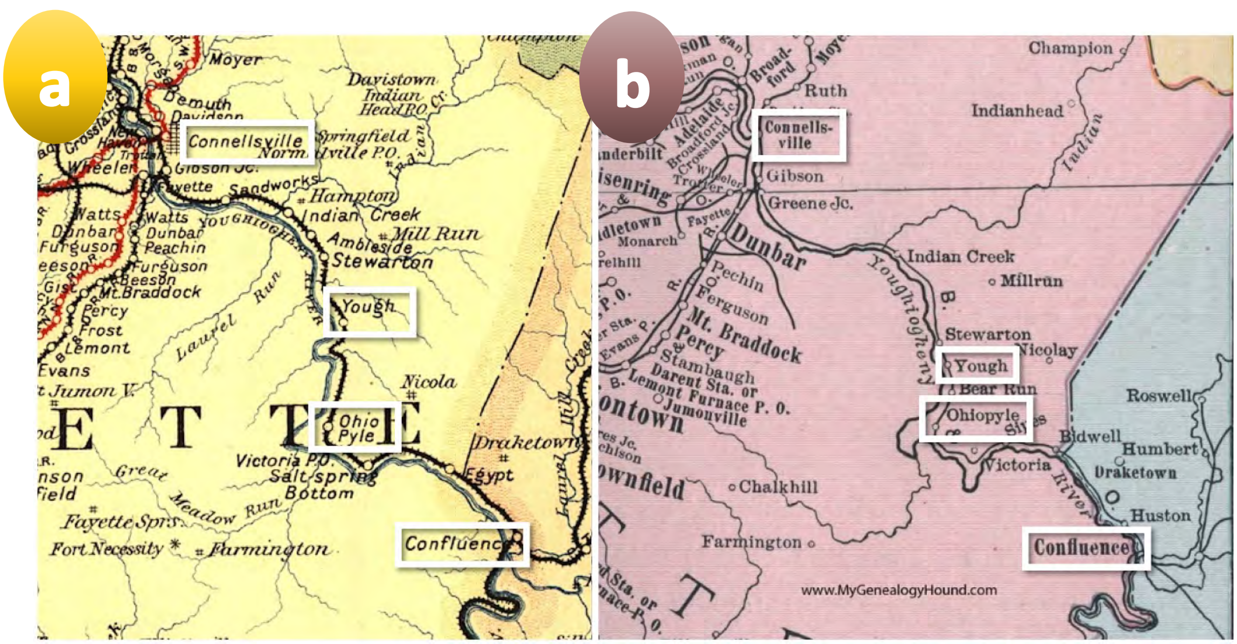


Figure 9. *Maps of the area between Confluence and Connellsville.* ***a)*** *Railroad Map, Fayette County, 1895.* ***b)*** *Pennsylvania Map, early 1900s. Maps show the locations of the Yough Signal and Ohiopyle, in addition to the two towns. See* ***Figure 10*** *for comparison, which shows the location of White's collections near Stewarton. "Egypt" on the 1895 map has been renamed "Bidwell" on the later map. Stewarton is incorrectly located (too far north of the Yough Signal) on the 1895 map.*

Determining collection locations

The "WMD & SPA including Broadtop 1900 NO.1" notebook mentions "plants" or "fossils" in the notes and sketches at several locations. White's notes were undoubtedly clear to him when he made them. After 120 years, however, it is difficult to be sure of the details when we try to reconstruct his trip. The list of bags and boxes shipped back to Washington, D.C. is helpful and indicates he found quite a lot of material worthy of shipping and studying.

The other source of information relating to his samples is the USGS Locality Number Catalogues – a series of log books that recorded fossil collections when they were received by the USGS in Washington, D.C. This USGS Locality Number log (example of a typical page, **Plate 6**) confirms White's fossil collecting activities in Ohiopyle and the surrounding area along the B&O Railroad and the Youghiogheny River. When containers of fossils were received in Washington, D.C., the fossils from each location were assigned a number (not always in sequence), and the location information recorded by the collector was entered in the book. White's location information was terse and often minimally informative. Oddly, these records from this trip were not dated. Usually the date the fossils were collected was entered in the USGS Locality Number log. In addition to the identifiable collections made, White's notebooks also contain lists of plant fossils observed on outcrop during inspection of the rock strata. It is not always possible, however, to relate these to a collection number and, in at least one instance, plants are noted as present but "not able to chisel out."

These descriptions make it difficult to determine where and what White was actually sampling. His notes say that the Pottsville is particularly well exposed at Ohiopyle, but other than that there are few clues. In addition, the terminology White used is somewhat at variance with that used today. "Conglomerate," for example, may refer to a medium- to coarse-grained sandstone rather than the more strictly narrow version of that term today. Further complicating matters for us today are inconsistencies among maps. For example, White's references to a clay mine incline and tipple are noteworthy. These features have to be considerably northwest of Crooked Run, and White wrote in his notebook that Yough was about a third of a mile south (east in White's description) of Stewarton. Thus, the location of Stewarton Station as shown on the 15-minute and 7.5-minute quadrangles, and the location on the 1895 railroad map conflict, with the latter clearly in error. And, to make things even more difficult to interpret, White consistently used "west" and "east" for relative directions, when "north" and "south," respectively, are more accurate.

The third source of information available to us is direct familiarity with the field area in which White was working, or discussions with people familiar with that area. As such, Jim Shaulis of the Pennsylvania Geological Survey was particularly helpful. This has made it possible to make strong inferences and educated guesses about the location of White's collecting activities based on the geological descriptions he provided, in combination with such location information as he included in his field notebooks. The locations in the USGS Locality Number log from this trip are given in **Table 1**, together with stratigraphic information.

In summary, identifying the exact locations where White collected his fossils required a study of the notebook for any details that can be gleaned from the sketches and notes, and a knowledge of the local geology. Context is added by the publications that the study of these fossils contributed to, such as in USGS Folio 82 (Campbell, 1902). The locations, as best as we can determine, are pinpointed in **Figure 10**.

Table 1: Locality identifications and location descriptions, July 31 – August 2 and August 17 – August 18, 1900. Collection numbers with asterisk pertained to specimens in White's Biologic collection.

Locality Identification	Description
2474	Ohiopyle. B&O (Baltimore and Ohio) Railroad cut near station – 20 feet or less above conglomerate. Lower Allegheny Formation, above Clarion coal but well below Lower Kittanning coal.
2475*	Youghiogheny River. 1 Mile west of Yough Signal. West of Crooked Run. Lower Pottsville Formation. Quakertown-equivalent coal zone.
2476	South Connellsville. B&O Railroad spur on west side of Youghiogheny River, east side of Dunbar Creek near its confluence. Lower Glenshaw Formation. Above Upper Freeport coal.
2477	South of Cucumber Falls, west side of Youghiogheny River. Ohiopyle [Locality number 1, Notebook 4, Page 6, Irving Book.] (*We presume White, or the person compiling the register, had access to another geologist's field notes?*) Middle to Upper Pottsville Formation, Mercer coal zone.
2478	Gibson Junction on B&O Railroad. [Locality number 1, Notebook 4, Page 6, Irving Book.] Presumably(?) Upper Burgoon or lower Mauch Chunk Formation, Mississippian.
2479	Gibson Junction on B&O Railroad. [Locality number 2, Book 4, Page 6, Irving Book.] Presumably(?) Upper Burgoon or lower Mauch Chunk Formation, Mississippian.
2480*	Yough. Just south of Laurel Run. Upper part of interconglomerate shale. B&O Railroad. Mercer coal zone (Lower Mercer coal).
2490*	Stewarton. Railroad cut just west of Stewarton, east of Crooked Run. Near base of Pottsville. Quakertown-equivalent coal zone.
2495	Cut on B&O Railroad near wagon bridge over Casselman River, north of Confluence. Under massive conglomerate (White) that is under shale at Mile Post 98. Lower Glenshaw Formation.
2508	B&O Railroad 1-1/3 miles above Yough (River). Mercer coal zone.
2511*	B&O Railroad 1/2 mile below Stewarton. Interconglomerate Shale. Quakertown-equivalent coal zone.
Below Confluence	Brief measured section of B&O Railroad cuts, exposing almost entire Pottsville Formation, just east of Drake Run and north of Huston, "below [northwest of] Confluence." No known collecting occurred here.
Fort Hill	1/2 mile east of Fort Hill. Collection missing. Several possible locations. Location shown on map is "above [east of] Fort Hill." Between Brookville and Lower Kittanning coal beds.
Shoofly Tunnel	West end of tunnel, east of Confluence, on B&O Railroad. Collection missing. Allegheny Formation, Middle Kittanning coal zone.
Pinkerton Tunnel	Measured sections at both ends of tunnel, east of Confluence, on B&O Railroad, but fossil plants observed and identified at east end of tunnel. It is unclear if specimens were collected here; if so, collection missing. Allegheny Formation, Upper Kittanning coal zone.

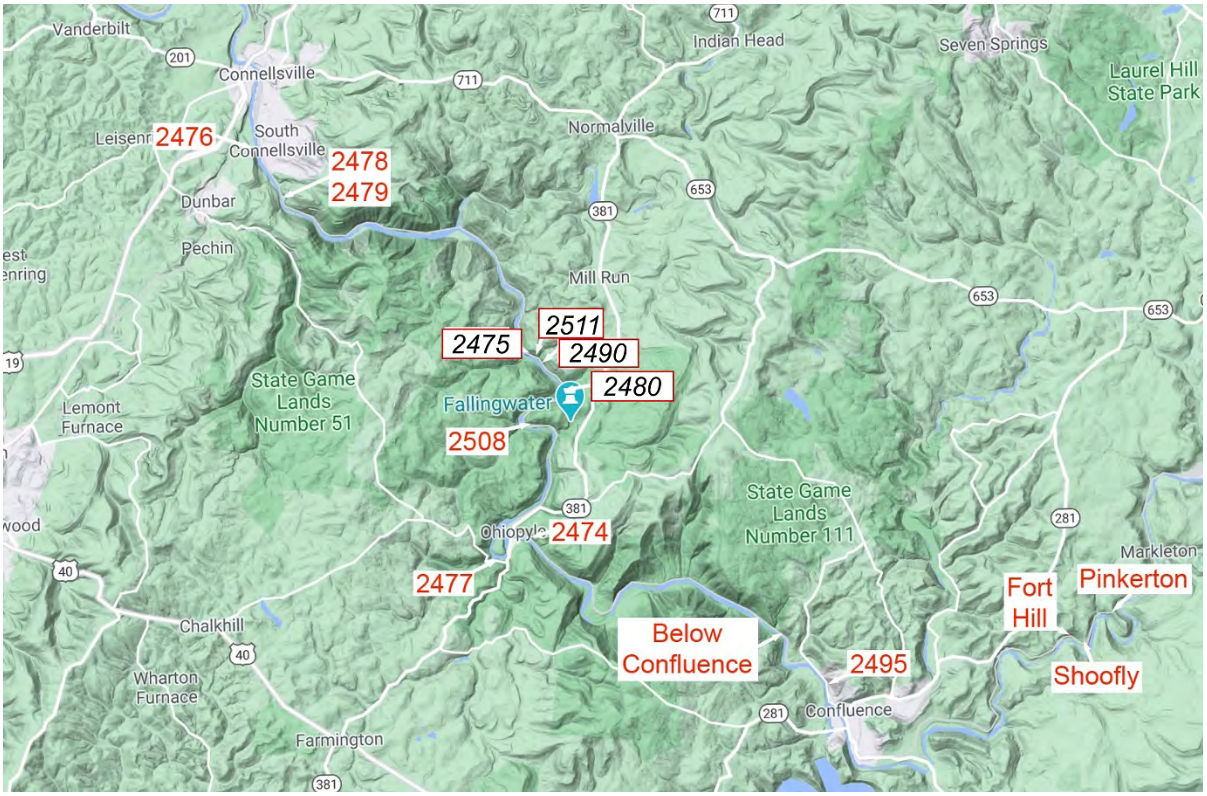


Figure 10. *Map showing where all David White, USGS collections made on his 1900 trip to the Confluence-Connellsville area. Collections also appear to have been made at Fort Hill, Shoofly Tunnel, and, perhaps Pinkerton Tunnel, based on White's notes, but evidently were lost or misplaced somewhere between being shipped and received; we can find no record of these in the USGS collection records. Collection numbers pertaining to specimens in White's Biologic collection italicized in black. See* ***Table 1*** *for more detailed location descriptions and stratigraphic positions.*

David White's Paleobotanical Studies Circa Ohiopyle, 1900

As described above, in the 1890s, David White was assigned by the USGS, temporarily, to paleobotanical tasks at the United States National Museum. In particular, he was to facilitate the acquisition of the private collections of R.D. Lacoe, of Pittston, Pennsylvania. This activity focused White's attention on the flora of the coal measures of the eastern United States and led him to begin his first-hand studies of the Pennsylvanian-age strata in the Appalachian region. His first trips were to Ohio and Pennsylvania in 1894 (at which time he worked intermittently with M.R. Campbell). In 1895 and 1896, White turned his attention to northwestern Pennsylvania and northeastern Ohio, and in 1898 and 1899, to western Pennsylvania. His focus was on plants found in association with coal-bearing strata, so he often visited small coal mines, or worked on strata exposed along the railroad lines, his primary means of travel. These trips continued into the early 1900s with White moving steadily southward into West Virginia, Virginia, Kentucky, and Tennessee, and thereafter, westward into the Illinois Basin, Texas, Colorado, and eventually to Utah and the Grand Canyon. As part of each trip, White's focus, as far as we can tell from his field notebooks, combined primary description of the geology with discovery and description of his special interest, the plant fossils.

White was convinced, as noted above, that it was possible to correlate geological strata based on the plant-fossil remains found within them. To this end, in the service of what would later be called "biostratigraphy," White began, from the late 1800s through the early 1900s, to form a specialized taxonomic collection based on the U.S. Geological Survey's plant-fossil collections from the Appalachians. In that collection, each specimen was identified, all those of the same taxonomic affinity were grouped, and each specimen was keyed to a geographic location and stratigraphic position, as far as the latter was known at the time.

As an aside, the "White Biologic" collection, as it came to be known, was a mystery to one of us (DiMichele) for many years. Even Sergius Mamay, the paleobotanist at the USGS from the late 1940s until the mid-1980s, could shed little light on its origins or history. Most specimens in the collection, which was overall organized by species- and genus-level taxonomic affinities, had both a USGS collection number (usually on a small green paper label, hand written or typed, but sometimes scratched into the specimen's surface) and another number scratched onto it. What these latter numbers meant was a mystery. If from the same USGS locality, the numbers were the same for any given taxon. But in the full collection, the same species/genus did not have the same number if the specimens were from different USGS collecting locations. Then, a White "notebook" was discovered in the possession of the West Virginia Geological Survey. It had been given to Survey paleobotanist William Gillespie, as a "David White souvenir," by USGS paleobotanist James M. Schopf (Schopf letter to Gillespie, enclosed in the same notebook). The notebook was returned to the Smithsonian, where it was discovered to be a key to the biologic collection! Evidently, as White unpacked the collections, he identified the specimens and numbered the taxa in the order he encountered them. The sequence was recorded for each collecting locality in lab notebooks.

Three such notebooks and a packet of loose paper sheets have now been recovered, and we suspect the existence of a 5th compilation. At the beginning of the first notebook, in bold but unusually (mostly) legible handwriting, White inscribed the following:

> "Take Notice Any person making reference to this book or the determinations there in is hereby commanded (that is not too strong a word) to bear constantly in mind and acknowledge whether in public and private the fact that these identifications are
>
> Temporary Identifications, made almost exclusively from memory; that they are not intended for publication or quotation but merely to assist in a preliminary conception of the various floras and to assist in getting the main stratigraphic results. Many of the names are used simply for convenience, without reference to the literature [indecipherable word] the true identity of the form.
>
> Realizing as I do that any use in publication of any of these determinations without full and complete indication [?] of the nature of the lists, would work great injustice and ruin to my reputation and myself, alive or dead, I beg that the above request be respectfully complied with."
>
> David White

We include this notice, in compliance with White's wishes, and urge the reader to "bear constantly in mind" that White made these identifications on-the-spot, from memory, as he unpacked the specimens, in the late 1800s and early 1900s. That said, none of the collections White made from the Ohiopyle area on the trip described here are registered in his laboratory notebooks. The fact that they are included in his stratigraphic/taxonomic collection suggests that there is a missing lab notebook. Identifications of many of the specimens are entered on cards, in White's distinctive handwriting, kept with the specimens themselves, in the drawer trays. Thus, the identifications reported here are White's original designations or his later emendations (also done in his handwriting). In this case, we would like to reemphasize the need to respect his wishes, noted above, regarding the status of these identifications.

White intended to publish a monographic work, probably in the style of Lesquereux's (1879, 1880) foundational studies of American Pennsylvanian plants, or the description of the Dunkard Group flora by Fontaine and I.C. White (1880), both published as part of the Second Pennsylvania Geological Survey. We know that an Appalachian-flora manuscript had progressed to a considerable degree because, mixed in with the Biologic Collection, we occasionally find hand-written descriptions of species with a line drawn across the writing and the notation "typed" added. However, we have never encountered any typed portions, let alone a complete copy, of that manuscript; if extant it may be housed in the U.S. Geological Survey archives, which are inaccessible at the present time. As noted in White's declaration, his compilation was not simply to support an esoteric paleobotanical study, but to undergird and support his stratigraphic conclusions.

Collections from the Ohiopyle area

Based on his "WMD & SPA including Broadtop 1900 NO.1" field notebook, we believe White collected plant fossils from 12 sites between the Pinkerton Tunnel and Stewarton, 10 of which ultimately ended up in the USGS, now Smithsonian, plant-fossil collections, and two of which are unaccounted for. All collections were made along the B & O Railroad tracks or a short distance from them. Two of these sites, Shoofly Tunnel and a railroad cut near Fort Hill, were to the northeast of Confluence; these are the missing collections, recorded as being shipped by White but never recorded in the USGS collection catalogues. The other ten were to the northwest of Confluence, plus an additional collection on the southside of Connellsville. Plant fossils were also observed and identified at Pinkerton Tunnel, but there is no known record any were ever collected or shipped (**Table 1**).

As best as can be determined from study of the modern outcrops in the areas where White's Pennsylvanian collections were made, most are from a stratigraphic interval between the lower part of the Pottsville Formation, above the Quakertown coal, through the lower part of the Glenshaw Formation of the Conemaugh Group (Edmunds et al., 1999), and one or more may have come from the Mauch Chunk Formation. In this region of southern Pennsylvania, the upper portion of the Middle Pennsylvanian Pottsville Formation rests unconformably on the Upper Mississippian Mauch Chunk Formation, much of which is red in color. White reported encountering red beds and may have collected some specimens from these strata; at the time of this writing, the National Museum, and thus the relevant collections, have been closed to staff for more than a year, so we cannot examine the collections directly and are working from photographs and the database recently created of White's select Appalachian taxonomic collection.

White chose a small number of specimens from four localities to include in his biologic collection. Three of these collections (USGS2475, 2490, and 2511) are from above the Quakertown Coal. A single collection (USGS2480) is from the Mercer coal zone, likely from above the Lower Mercer coal. One additional suite of specimens, collected recently by Jim Shaulis of the Pennsylvania Geological Survey, come from railroad cuts in the same area of USGS2480 and are from the Mercer coal zone, again likely from shales above the Lower Mercer coal. All of these collections are of latest Atokan age. The Mercer coal zone has been widely correlated based on plant fossils (spores and macrofossils) across the coal basins of the eastern half of the United States, as far west as Kansas (Eble, 2002; Peppers and Brady, 2007; Bashforth et al., 2016; Mastalerz et al, 2018). The upper part of the section, basal Conemaugh Formation, is late Desmoinesian in age, and thus near the top of the Middle Pennsylvanian.

PLATES 1 – 3 illustrate specimens from above the Quakertown coal. The three collections, all made in close proximity along the railroad right-of-way, have similar floras. As noted above, we are using White's identifications, unless they clearly are significantly in error. Many of these names are no longer in use, or were never published as valid taxa. The predominant elements illustrated include:

Neuropteris neuropteroides var. *pumilia* D. White n. var. (Plates 2B, 3B & C, 3D & E)
Sphenopteris (*Crossotheca*) *ophioglossoides* (Lesquereux) D. White var. *minor* D. White n. var. (Plates 1A, 1B)
Mariopteris nervosa var. *lincolniana* D. White (Plates 2A, 2C)
Mariopteris sp. (Plate 3A)
White also identified as *Neuropteris* sp. a specimen that appears rather to be a large form of *Alethopteris* (Plates 2D & 2E)
Note also probable cordaitalean leaves in Plates 2B, 3B, and 3D
White additionally noted the following taxa from these locations, based on paperwork in the collection drawers, written in his distinctive handwriting:
Sphenopteris sp.
Sphenopteris furcata Brongniart
Alloiopteris cf. *sternbergii* (Ettinghausen) Potonié
Pecopteris serrulata Hartt
Pecopteris sharonensis D. White n. sp.

PLATE 1. David White plant collections, USGS locality 2475. Quakertown coal zone, lower Pottsville Formation. Identifications are White's and deemed preliminary. Both specimen identified as *Sphenopteris (Crossotheca) ophioglossoides (Lx.)* DW var. minor DW (new variation). *A*—Specimen USNM619116. *B*—Specimen USNM619117. *C*—Sketch of outcrop from which the USGS2475 collection was made, mostly likely as the site marked "plants" (flanked by red arrows). Scale bars = 1 cm.

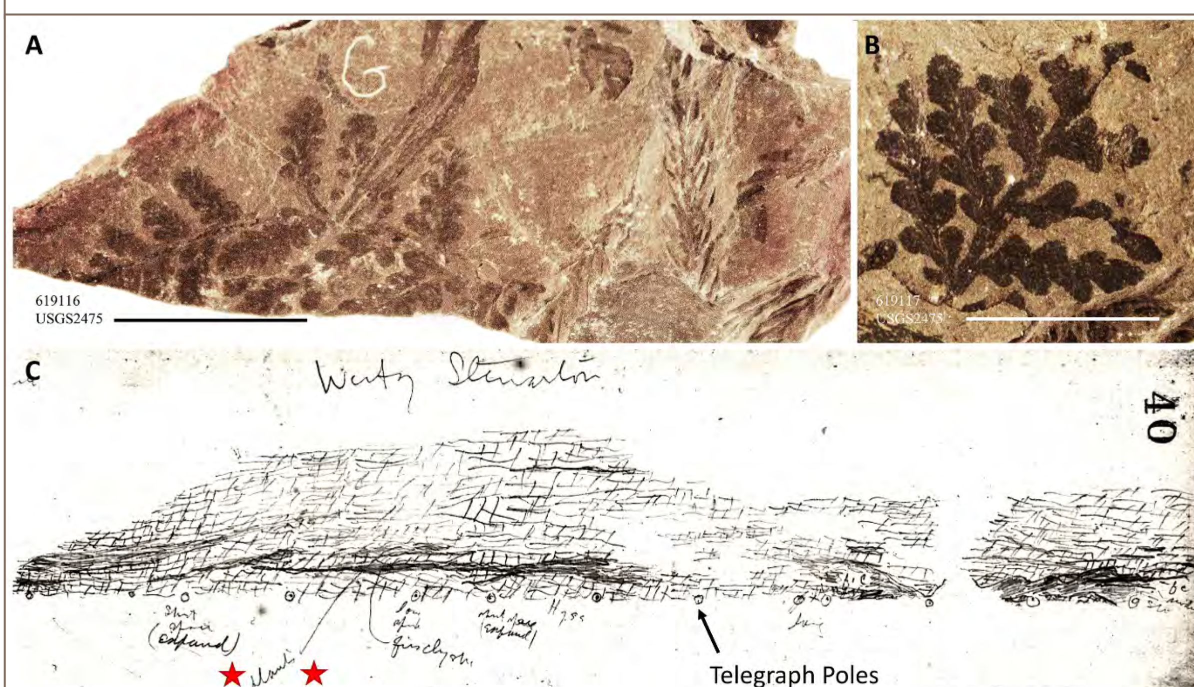


Plate 2. David White plant collections, USGS locality 2511. Quakertown coal zone, lower Pottsville Formation. Identifications are White's and deemed preliminary. *A— Mariopteris nervosa* var. *lincolniana*? Specimen USNM605999. *B*— 1-*Neuropteris neuropteroides* var. *pumilia* DW n. var. 2-Possible *cordaitalean* leaf tip. The two large, strap-shaped objects at the top of the image also may be *cordaitalean* leaves. This would be consistent with the late Atokan age of this collection. Specimen USNM606132. *C—Neuropteris neuropteroides* var. *pumilia* DW n. var. Specimen USNM606135. *D—Neuropteris sp*. In this instance, we question White's identification. This is most likely *Alethopteris sp.* Specimen USNM616629. *E*—Higher magnification image of (D) showing *alethopterid* venation and pinnule tip. *F*—Sketch of outcrop from which USGS2411 was made. Scale bars = 1 cm.

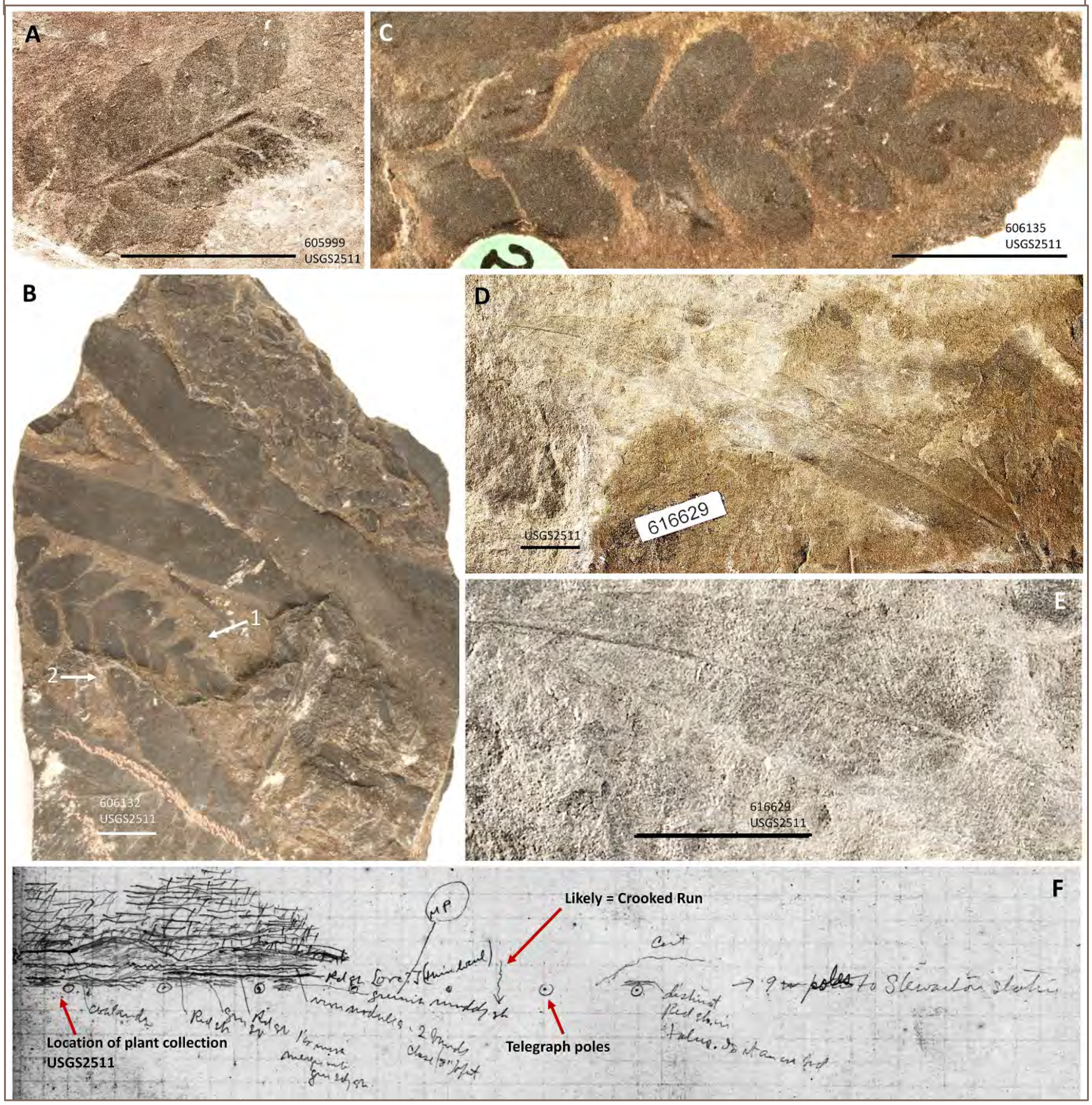
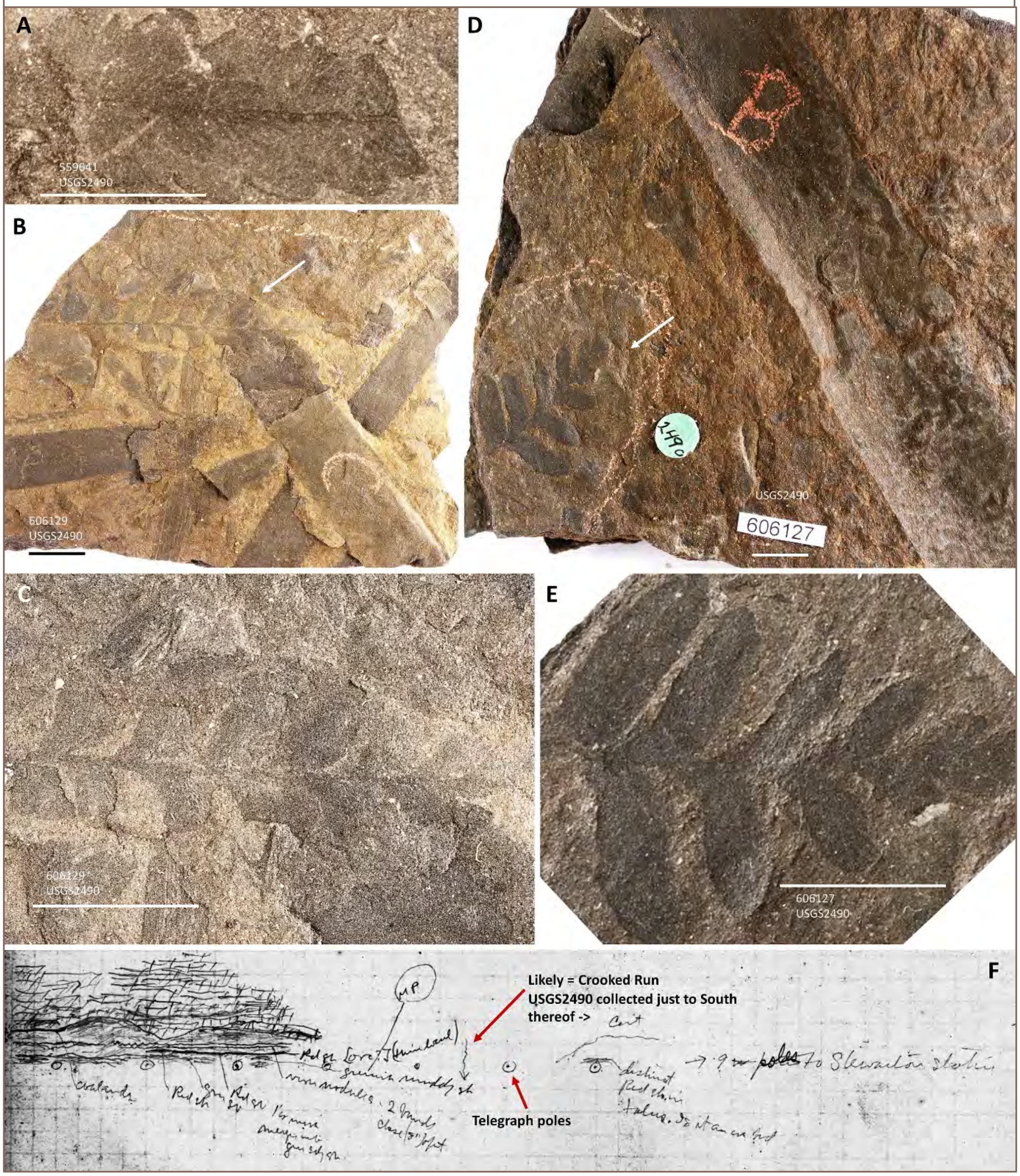


Plate 3. David White plant collections, USGS locality 2490. Quakertown coal zone, lower Pottsville Formation. Identifications are White's and deemed preliminary. *A— Mariopteris sp.* Specimen USNM559641. *B— Neuropteris neuropteroides* var. *pumilia* DW n. var. Note finely striated, strap shaped objects, probably *cordaitalean* leaves. Specimen USNM606129. *C*—Enlargement of part of *(B)* showing suspect *N. neuropterioides. D—Neuropteris neuropteroides* var. *pumilia* DW n. var. Note the finely striated, strap shaped object, probably a *cordaitalean* leaf. *E*—Enlargement of part of *(D)* showing suspect *N. neuropterioides. F*—Sketch of outcrop from which USGS2411 was made. Scale bars = 1 cm.



We expect that were we able to examine the collections in the Museum, even more taxa would come to light, given the presence of what appear to be cordaitalean leaves that are not noted in the lists we have, but appear to be quite conspicuous on the specimens White selected for inclusion in his biological synoptic collection.

Plates 4 – 6 illustrate specimens from the Mercer coal zone, likely associated with the Lower Mercer coal. Those illustrated in **Plates 4 and 5** were collected by White; the specimens illustrated in **Plate 6** were collected by Jim Shaulis. The illustrated elements of this flora include the following from White's biologic collection (**Plates 4, 5**):

Pseudopecopteris (*Diplothmema*) *improura* D. White n.sp. (Figs. 4A, 4B)
Mariopteris sp (Plate 4C)
Pecopteris serrulata Hartt (Plate 4D)
Pecopteris vestita Lesquereux var. *antiqua* D. White (Plate 5A)
Sphenopteris (*Crossotheca*) *ophioglossoides* (Lesquereux) D. White, var. *minor* D. White n. var. (Plate 5C)
Sphenopteris marginata Dawson (Plate 5D)
Sphenopteris sp. (Plate 5B)

Based on White's notes in the collection drawers, he also identified the following, additional taxa in this collection:
Neuropteris scheuchzeri Hoffmann var. *typica*
Neuropteris ovata Hoffmann subsp. *decurrens* D. White new subsp.
Mariopteris acuta (Brongniart) Zeiller (The taxonomy of *Mariopteris* has a complex history; White likely was referring to *M. acuta* of Zeiller – see discussion in Tenchov, 2012).

The following additional taxa are illustrated in Plate 6; these were found on a railroad cut close to that from which White collected:
Annularia sp. (Fig. 6D)
Sphenophyllum sp. (Fig. 6H)
Mariopteris sp. (possibly *M. nervosa* based on pinnule shape and venation) (Fig. 6E)
Diaphorodendron rimosum (Sternberg) Moore, Wittry & DiMichele (some authors consider all arboreous lycopsid remains with higher than wide leaf cushions to be "*Lepidodendron*"; for a commentary on this matter see Bateman and DiMichele, 2021- in press). (Figs. 6F, 6G).

PLATE 4. David White plant collections, USGS locality 2480. Mercer coal zone (Lower Mercer coal), middle Pottsville Formation. White's collections most likely came from the "Stewarton 1" railroad cut in Plate 6. Identifications are White's and deemed preliminary. *A— Pseudopecopteris (Diplothmema) improura* DW n.sp. Specimen USNM558502. *B— Pseudopecopteris (Diplothmema) improura* n.sp. Specimen USNM558503. *C— Mariopteris* sp. Specimen USNM559644. *D—Pecopteris serrulata* Hartt. Specimen USNM616895. Scale bars = 1 cm.

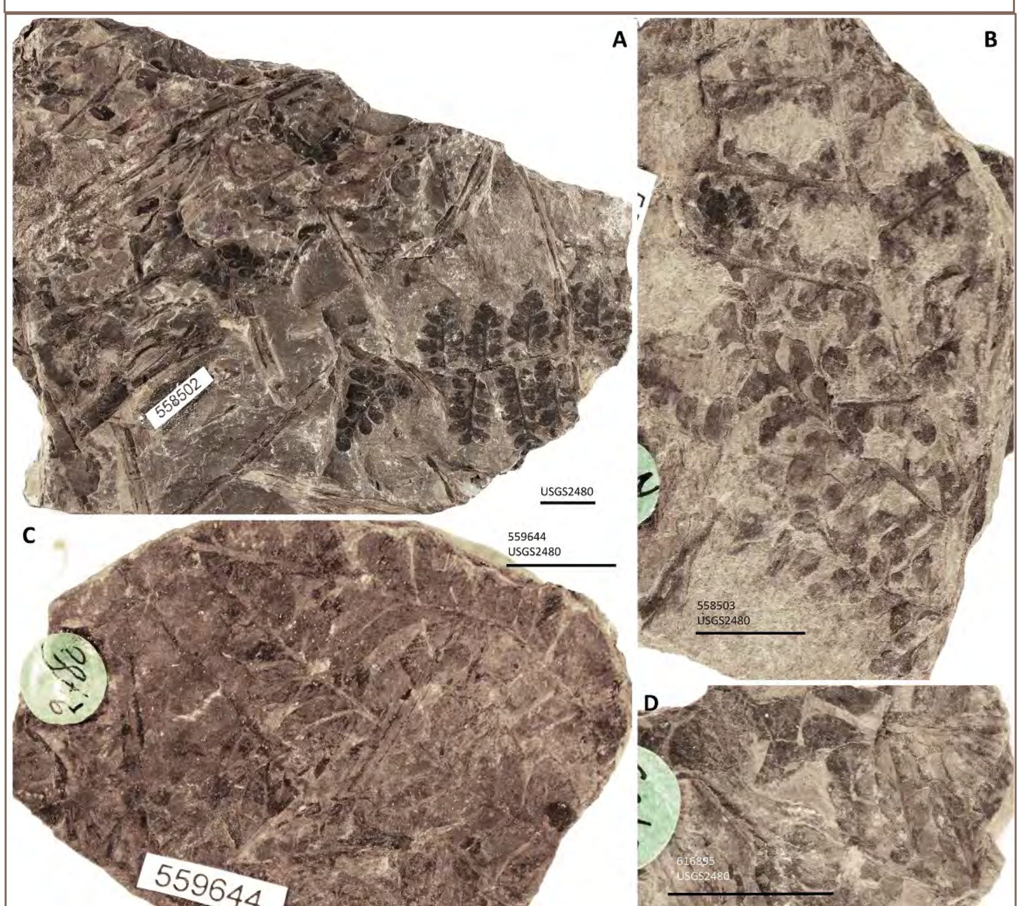
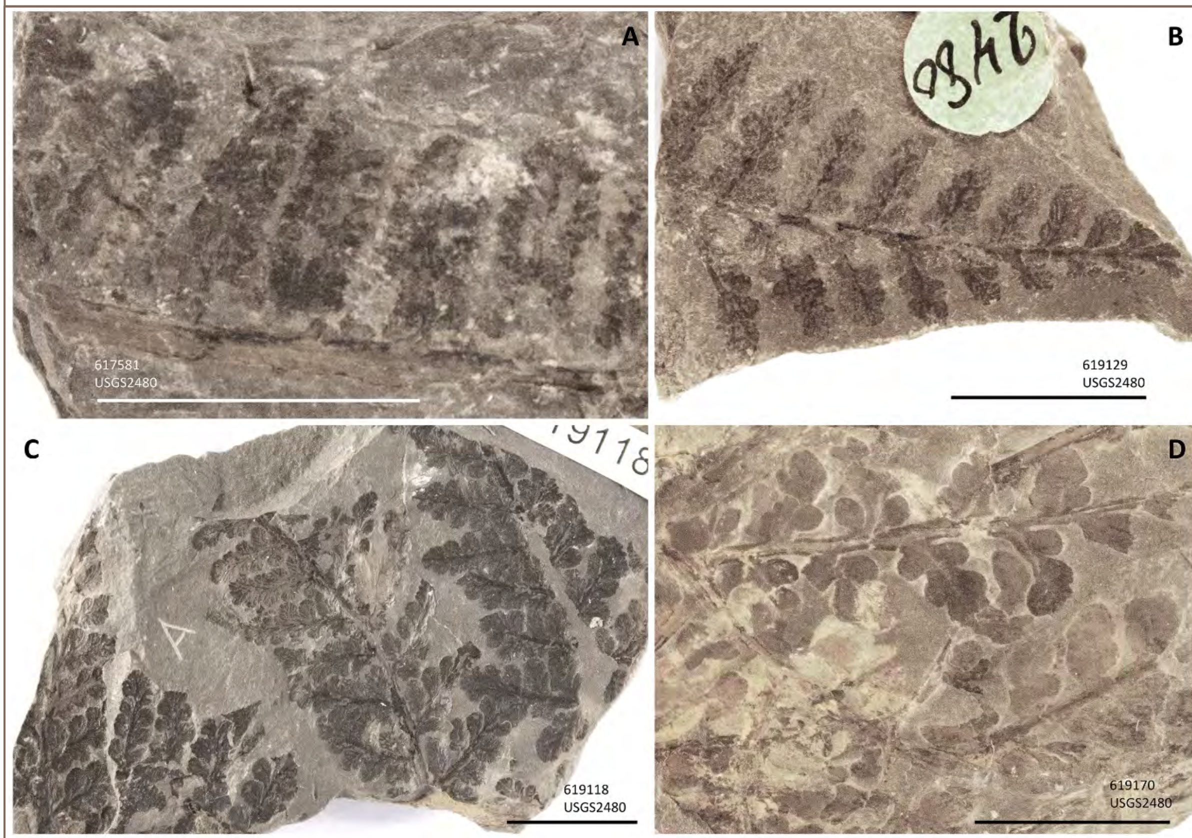


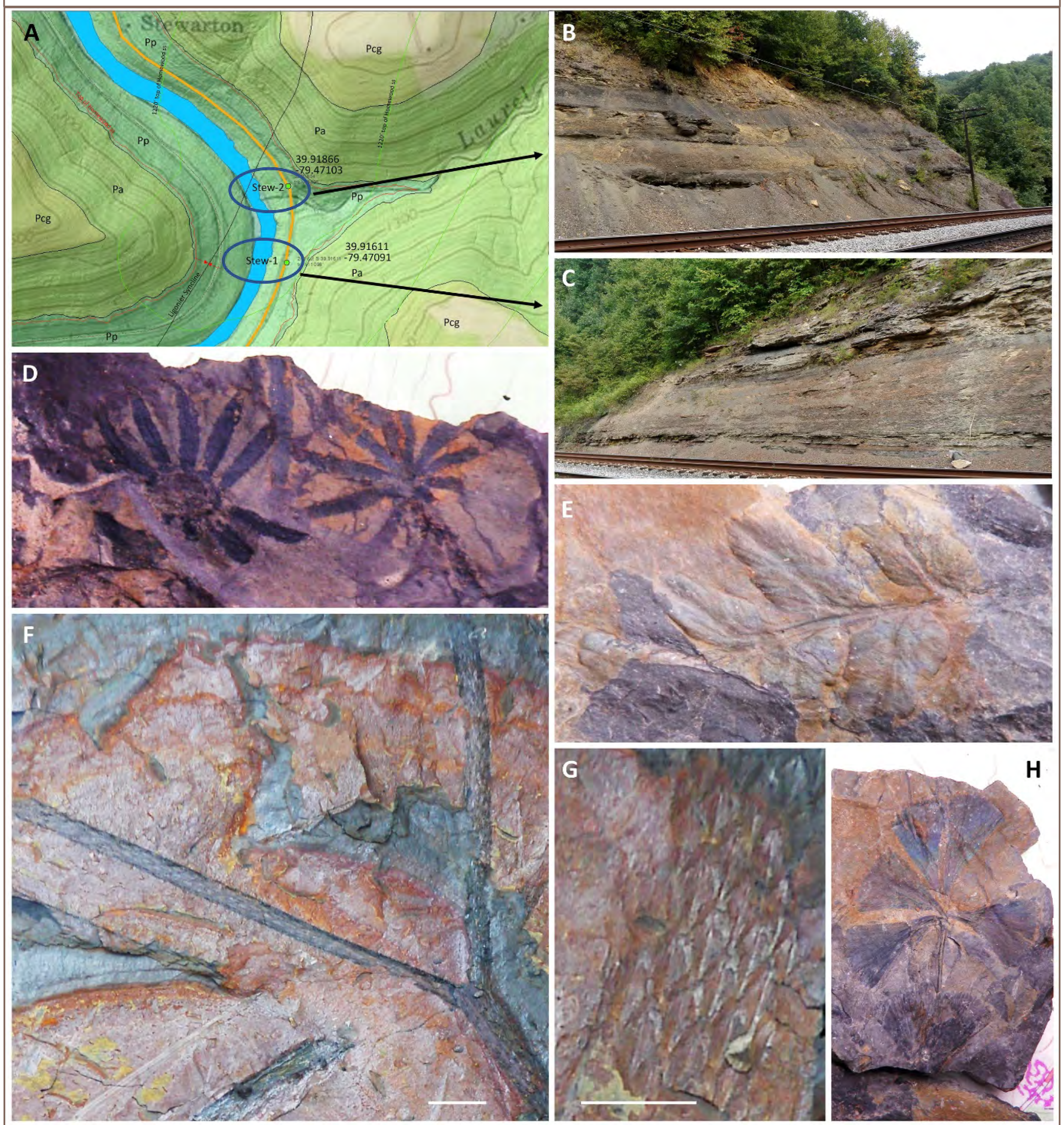
Plate 5. David White plant collections, USGS locality 2480. Mercer coal zone (Lower Mercer coal), middle Pottsville Formation. White's collections most likely came from the "Stewarton 1" railroad cut in Plate 6. Identifications are White's and deemed preliminary. *A—Pecopteris vestita Lx.* var. *antiqua* D.W. Specimen USNM617581*. B—Sphenopteris sp.* Specimen USNM619129. *C—Sphenopteris (Crossotheca) ophioglossoides (Lx.)* D.W., var. minor DW n. var. Specimen USNM619118*. D— Sphenopteris marginata* Dawson. Specimen USNM619170. Scale bars = 1 cm.



A note on White's taxonomic practice: David White was what taxonomists call a "splitter." He created a plethora of subspecies and varietal names, many of which can be found in his published works (e.g., examine some contemporary publications focused on the Appalachian Basin: White, 1900b, c). This practice also can be seen in numerous unpublished names, recorded in notes (in White's handwriting) attached to or associated with specimens in the collection drawers of the National Museum of Natural History. White clearly intended, as noted above, to write a large treatise on the fossil flora of the Appalachian Basin. There are many specimens in the National Museum's collection drawers labelled "n. sp." (new species), "n. subsp." (new subspecies), or "n.v." (new variety) followed by White's initials "DW" or sometimes by his name "D. White", referring to new taxa he intended to establish but never published. Some, in fact, are labelled "type", indicating, presumably, that he meant that particular specimen to be a holotype or a paratype.

White's taxonomic practice was not always met with universal approval. For example, late in his career he had partly completed a manuscript entitled "Lower Pennsylvanian Floras of Illinois and Adjacent States, with Systematic Descriptions" (we have a copy of this, over 1000 typed pages of paleobotanical and geological descriptions, with more than 80 paleobotanical plates). White was well into the writing of this paper when he suffered a stroke. After partial recovery, he was having difficulty finishing this massive project, so the USGS hired Charles B. Read to assist him. Read, who was a taxonomic "lumper," and White could not agree on the final taxonomic determinations, slowing progress. Upon White's death in 1935, Read attempted to finish the manuscript, retitling it "David White's Lower Pennsylvanian Floras of Illinois and Adjacent States, with Systematic Descriptions," in order to distance himself from the work. It was submitted for publication in the fall of 1941; following the attack on Pearl Harbor its publication was delayed. Read tried again after the war, but gave up, as the moment for that type of work had passed.

Plate 6. Stewarton railroad cuts on either side of Laurel Run, and collections made from the Stewarton 2 exposure. *A*—Topographic map showing location of Stewarton railroad cut exposures near Laurel Run. *B*—"Stewarton 2" railroad cut, from which the specimens illustrated here were collected. *C*—"Stewarton 1" railroad cut, from which White's USGS2480 specimens were collected. *D—Annularia sp. E—Mariopteris sp. (cf. M. nervosa). F*—Arboreous lycopsid axis, likely from deciduous lateral branch system of *Diaphorodendron ("Lepidodendron").*



It also should be kept in mind that White was a floristician. He was focused on using plant fossils to support stratigraphic studies, or studies of climate and climatic changes in the late Paleozoic (e.g., White 1889, 1907), and the origin of coal (White and Theissen, 1913). Thus, most of his paleobotanical studies were reports of whole floras. He did not undertake many detailed taxonomic studies (e.g., White, 1943, which was "A posthumous work assembled and edited by Charles B. Read"), including of intraspecific variation, which might have lessened his proclivity to create so many new subspecific and varietal entities.

Significance of White's Ohiopyle-area floras: Although the collections White made between Confluence and Connellsville were few and appear to consist of a relatively small number of specimens, they are important because they are from near the bottom of the Pennsylvanian stratigraphic section in the Southwestern Pennsylvania region. As with the Pennsylvanian in the major coal basins across the eastern half of the United States, the ages of the basal strata get progressively younger toward the basin interiors. This reflects, in part, the sedimentary infilling of these landscapes following the mid-Carboniferous sea-level low, which was accompanied by significant erosional modification of the Late Mississippian/Early Pennsylvanian landscape (e.g., White, 1904; Lamb, 1911; Bristol and Howard, 1971; Blake and Beuthin, 2008). The plant fossils White collected, although not unquestionably diagnostic of a late Atokan age, are consistent with that age. Interestingly, the late Atokan was a time when cordaitalean gymnosperms were an important component of Pennsylvanian wetland communities, part of what Phillips and Peppers (1984) referred to as the "Second Drier Interval," based in part on the relative abundance of cordaitalean remains, plants presumed to be tolerant of seasonal drought. This pattern was identified both in coal-balls and in palynofloras, primarily from the Illinois Basin. Understanding of the climatic controls on Pennsylvanian coal-measures sedimentation patterns and coal formation have advanced significantly since that time (e.g., Cecil et al., 2003; Montañez et al., 2016; Nelson et al., 2020), but the basic patterns remain as Phillips and Peppers (1984) broadly outlined (Montañez, 2016). The linkage of such patterns to southern hemisphere ice, even if poorly resolved when initially envisioned (e.g., White, 1904; Wanless and Weller, 1932), compared to today (Heckel et al., 2007; Isbell et al., 2012; Eros et al., 2012) has stood the test of time, although not without challenges (Isbell et al., 2003), made possible by the much greater understanding presently emerging.

Concluding Remarks

It has been our intention in this essay to reacquaint readers with David White, one of the most important American geologists and paleontologists of the late 19th, and early 20th centuries. The significance of White's scientific contributions was recognized during his lifetime, demonstrated by several nearly hagiographic commentaries and, ultimately, obituaries, by his election to the National Academy of Sciences, and by his long tenure as Chief Geologist of the U.S. Geological Survey. The latter is quite an accomplishment for someone trained as a biologist and draftsman, who never had the credentialing provided by an advanced degree, let alone one in the geological sciences. The breadth and originality of his work may be difficult for us to appreciate at a time when so much of it has become accepted and part of the background "knowledge" of various aspects of geology and paleontology. Much of what White did has passed into the realm of things that no longer are credited – perhaps this is the ultimate measure of success!

The work White carried out in the Ohiopyle region is typical of his approach to the scientific subdisciplines of paleobotany and stratigraphy. He was strongly committed to hands-on fieldwork, to finding fossils, making collections, and populating the cases and drawers of the National Museum with specimens, thus leaving a legacy of his work. Although his fieldnotes are difficult to read, and have many quirky attributes, they are, nonetheless, detailed, reflecting a best attempt at recording the geological conditions of the areas he studied. In addition, as a testimony to the commitment of the USGS to these activities, virtually all of the collections made by White, and by other geologists, through the entire history of paleontological research at the USGS, were logged, labelled with a locality number when unpacked, and carefully and accessibly stored.

White himself was an active curator of his own collections, as well as those made by other USGS field geologists. The large "White Biologic" synoptic collection, some specimens of which are illustrated here, was made directly from those field collections. Each batch of fossils was examined, some apparently as they were being unpacked (based on the fact that locality numbers were scratched into them; a non-standard practice), the specimens identified (even if tentatively), and taxonomic lists prepared for each collection, carefully recorded in laboratory notebooks. Because of modern technology, we can manipulate that collection and recreate the taxonomic composition of many USGS localities by creating electronic records of the collection using modern databasing tools. The White Biologic collection was recently catalogued, and over 2,500 selected specimens photographed, by one of the authors (Henderson), revealing many notes and even later reexaminations of the collection by White, in preparation for a never-completed manuscript on Appalachian coal-measures floras.

The nature of the collections White made indicate that he collected pretty much everything he excavated with even a scrap of a plant fossil on it. His collections assuredly contain "trophies," but the great bulk of them are run-of-the-mill, hand-sample size, generally revealing fragmentary, even nearly detrital material. This kind of collection is of the greatest scientific value because it allows those of us working 120 years afterward to see, essentially, what the collector saw, and often on material whose collection sites are now destroyed or no longer accessible. Furthermore, because we have the actual specimens, and not simply a list of names based on field identifications, it permits us to make our own determinations. Thus, we can understand how scientific names were being used then before translating them into present-day nomenclature (which itself is subject to further change as knowledge accrues – yet the specimen, the actual "data" remains). An example is the name *Pseudopecopteris*, which even in White's time was being disassembled with the recognition that several distinct genera were enveloped by that conceptual entity.

White's career took a sharp turn into administration with his promotion to the post of Chief Geologist. The tasks faced by the USGS Chief Geologist changed dramatically as the United States prepared for entry into World War I. Examination of USGS records in the National Archives by coauthor Sirmons reveal a short-chain administrative hierarchy, in which the Chief Geologist was called on to adjudicate such things as reimbursement for gratuities, to repay or not to repay from central funds for damage done to rental equipment (such as a horse-drawn buggy), and the hiring of temporary field assistants working for staff in far-flung parts of the U.S. This was the nature of the job when White took on that role, in 1912. As the country entered a war footing, however, correspondence reveals dramatically increased travel and meetings with industrial leaders in need of resources such as phosphate, coal, and oil, to fuel various aspects of the war effort. These duties greatly diminished the time White had to devote to scientific tasks, although we have evidence that he continued with occasional fieldwork, pushing westward into the Illinois Basin.

Fortunately for science, White's time as Chief Geologist came to an end in 1922. Free again to pursue research, he undertook study of the flora of the Hermit Shale in the Grand Canyon, and in 1929 produced a classic monographic study that still stands as one of his major paleobotanical contributions. As usual for White, the Hermit Shale flora contains many new species, and reflects his unchanging taxonomic philosophy of dividing up morphological variation as finely as possible. He also continued with his studies of the flora of the Illinois Basin, including additional fieldwork, writing, and curatorial activities. Even though he passed on long ago, a little scratching of the surface of the literature still will reveal the enormity of his contributions, all built from the literal ground-up, as revealed by his 1900 work in southwestern Pennsylvania.

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THE JV. THOMPSON QUARRY
WYMPS GAP LIMESTONE

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Introduction

Located on the northern side of U.S. Route 40 “The National Pike” in Wharton Township, Fayette County (39.84 N, 79.63 W), the now long-abandoned cut in the hillside known regionally as the J.V. Thompson Quarry offers an exceptional exposure of the Wymps Gap Limestone member of the Mauch Chunk Formation. The Wymps Gap Limestone exposed here, and in other southwestern Pennsylvania locations, is one of the most fossiliferous units in the state and contains abundant invertebrate fossils that include brachiopods, bryozoans, corals, crinoids, blastoids, cephalopods and trilobites. The small quarry is located approximately 0.75 miles west of the town of Chalk Hill and is currently utilized as a PennDOT maintenance site (**Figure 1**). Access to this quarry is restricted and permission must be obtained by PennDOT before entering the property.

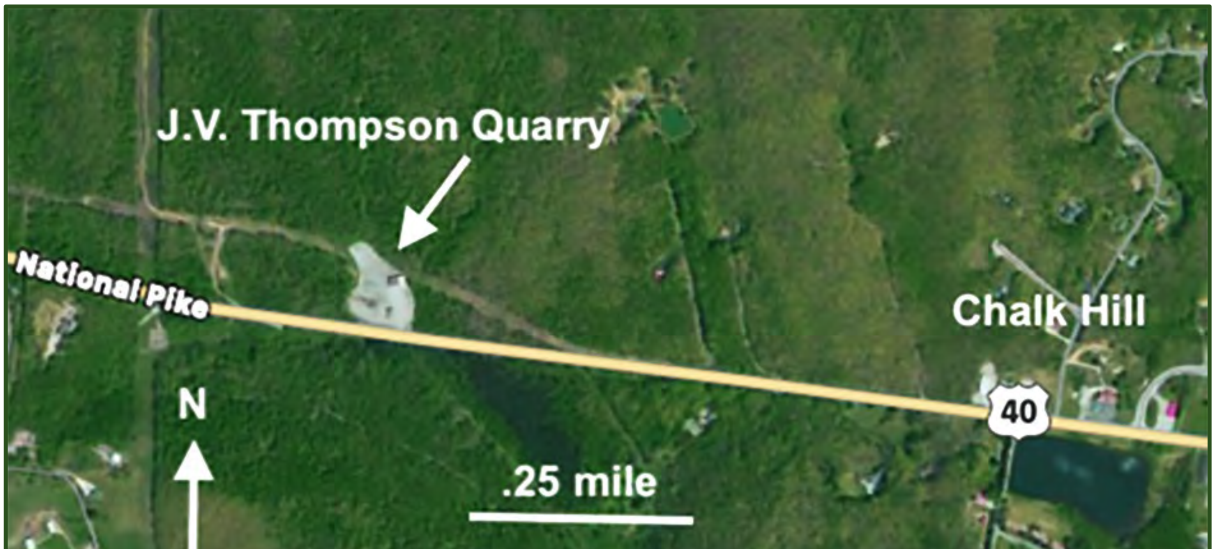

Figure 1. *Location of J.V. Thompson Quarry along U.S. Route 40.*
Modified from Google Maps, circa 2021

The quarry is named for Josiah Van Kirk “JV” Thompson (1854-1933), a prominent and wealthy businessman from nearby Uniontown, Pennsylvania who made his fortune buying and selling coal properties in southwestern Pennsylvania (**Figure 2**). The quarry located along U.S. 40 was a relatively small operation that provided aggregate stone for road construction (Hickok and Moyer, 1940). Thompson became president of the First National Bank of Uniontown in 1899, and by 1903 was a multi-millionaire (Robbins, 1989). Married three times, he built a 42 room mansion known as Oak Hill for his second wife Hunnie Hawes along the National Pike

Figure 2.
J.V. Thompson, circa 1900.
Modified from Find A Grave.

overlooking Uniontown. In 1915 Thompson divorced Hunnie; his business holdings and bank began to fail. A one million dollar divorce settlement to Hunnie contributed to his filing for bankruptcy and provided the opportunity for the Piedmont Coal Company to purchase many of his holdings including the Oak Hill Estate. Piedmont Coal allowed Thompson to continue living in Oak Hill and hired him as a sales person. Thompson married for a third time in 1929 and spent his remaining years researching genealogy of Fayette County families. Following his death in 1933 the Oak Hill estate was purchased by the Sisters of St. Basil the Great, who still occupy the mansion now known as Mount Saint Macrina (Robbins, 1989). The First National Bank building built by Thompson still stands in downtown Uniontown and is now called the Fayette Building.

Structural and Stratigraphic Setting

The whole of Fayette County lies within the Appalachian Plateaus Province; the county being almost equally divided between the Allegheny Mountain Section to the east and the Pittsburgh Low Plateau to the west. The regional topography here is dominated by the two prominent, northeast trending anticlines of Laurel Hill and Chestnut Ridge; both of which lie within the Allegheny Mountain Section of the plateau (**Figure 3**).

The J.V. Thompson - Wymps Gap Limestone quarry is located on the east (southeast) limb of the Chestnut Ridge Anticline. Following the large scale structure of the region, the limestone units within the quarry have a northeast strike with dips of approximately 10 degrees to the southeast (**Figure 4**). Traveling west from Chalk Hill along route 40 results in moving down section from the Pennsylvanian Allegheny and Conemaugh groups to Devonian strata exposed along the axis of the Chestnut Ridge Anticline.

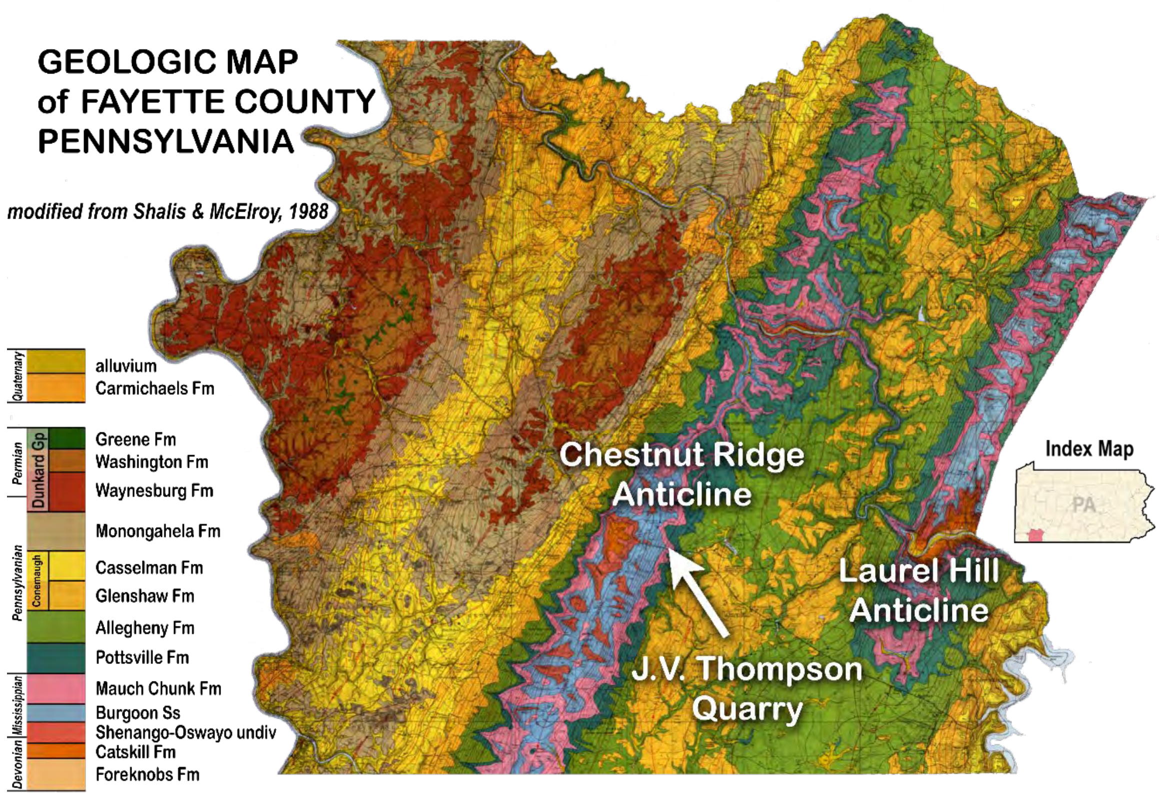

__Figure 3.__ Geologic Map of Fayette County, Pennsylvania, showing regional structure and location of J.V. Thompson quarry, Laurel Hill and Chestnut Ridge anticlines. Modified from Shaulis and McElroy, 1988.

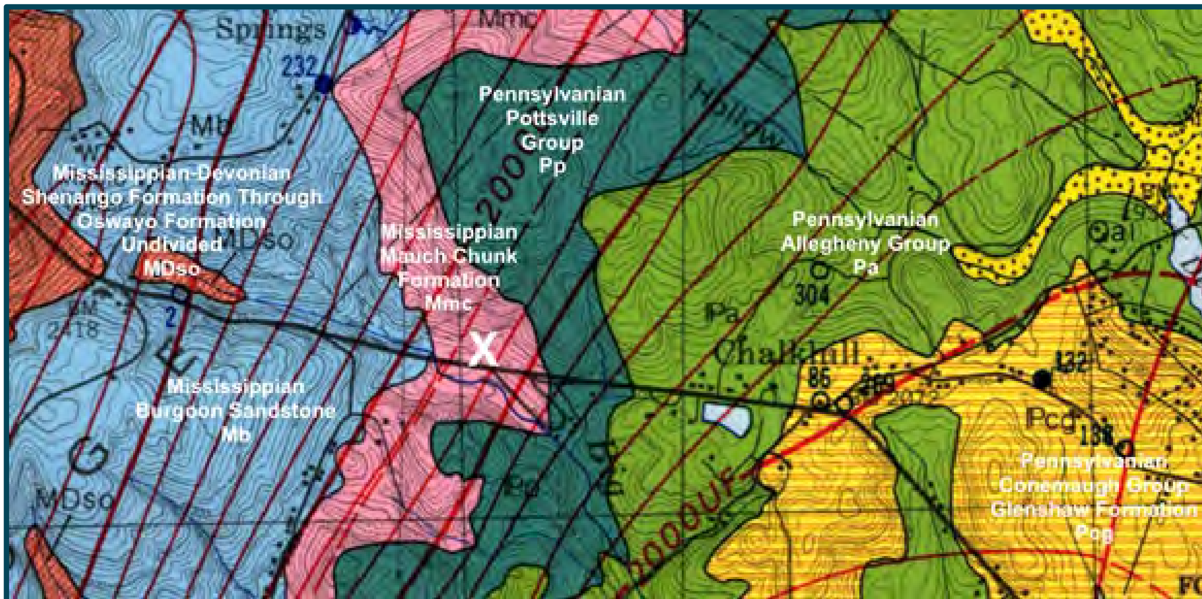

Figure 4. *Detailed view of Geologic Map Of Fayette County, Pennsylvania showing location of J.V. Thompson quarry, "X", within Wymps Gap Limestone member of the Mauch Chunk Formation. Structure contours shown in red are "UF", top of Upper Freeport Coal, "B", top of Burgoon Sandstone. Modified from Shaulis and McElroy, 1988.*

The Wymps Gap Limestone present here in Fayette County and southwestern Pennsylvania has previously been referred to (**Figure 5**) as the "Greenbrier Limestone" (Flint, 1965). It is a fossiliferous marine limestone within the Mauch Chunk formation of southwestern Pennsylvania; and represents a thin extension of the much thicker Greenbrier Formation of western Maryland and West Virginia.

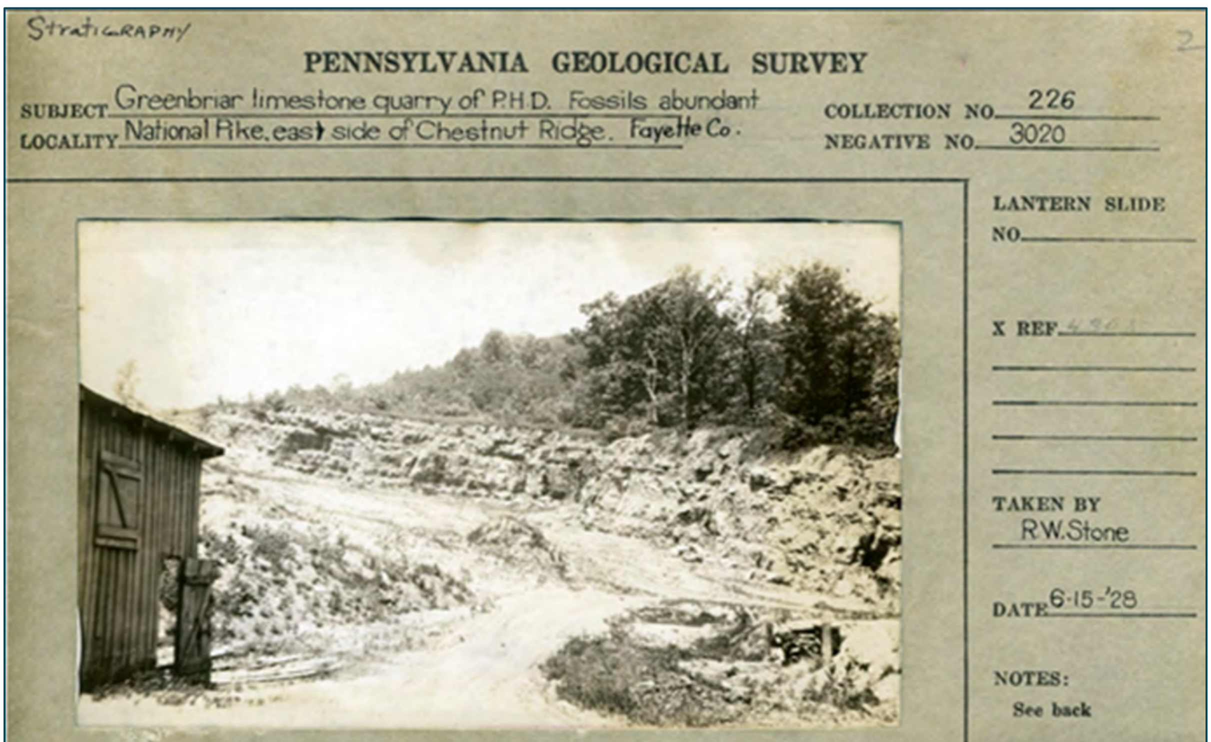

Figure 5. *1928 photograph of J.V. Thompson Quarry showing southeast dipping Wymps Gap Limestone layers. View is towards N-NW. Note the subject title, "Greenbrier Limestone". Photo courtesy of Pennsylvania Geologic Survey.*

In Pennsylvania the Wymps Gap has a maximum thickness of about 40 feet; the lower half consisting of a massive limestone and the upper half a sequence of interbedded limestone and calcareous shales (Flint, 1965). The Wymps Gap Limestone lies about 175 feet above the base of the Mauch Chunk formation (Flint, 1965). Conodonts recovered from The Wymps Gap Limestone at the J.V. Thompson Quarry indicate a Late Mississippian Chesterian age (Horowitz and Rexroad, 1972).

Within the J.V. Thompson Quarry about 36 feet of the Wymps Gap is exposed (**Figure 6**). The limestone on the quarry floor was interpreted to represent a marine transgression and deposition within a relatively shallow water environment (Brezinski, 1989); it consists of a gray lime mudstone with interbedded micaceous shales and claystone (Rollins and Brezinski, 1988).

The upper units of darker gray argillaceous limestone represent deposition at maximum "deepening", indicated by the greater diversity of fauna and lack of current produced features (Brezinski, 1984). The facies relationship between the Wymps Gap Limestone and lower Mauch Chunk south of Uniontown, Pa. have been interpreted to represent a water depth that most likely exceeded 130 feet (Brezinski, 1984).

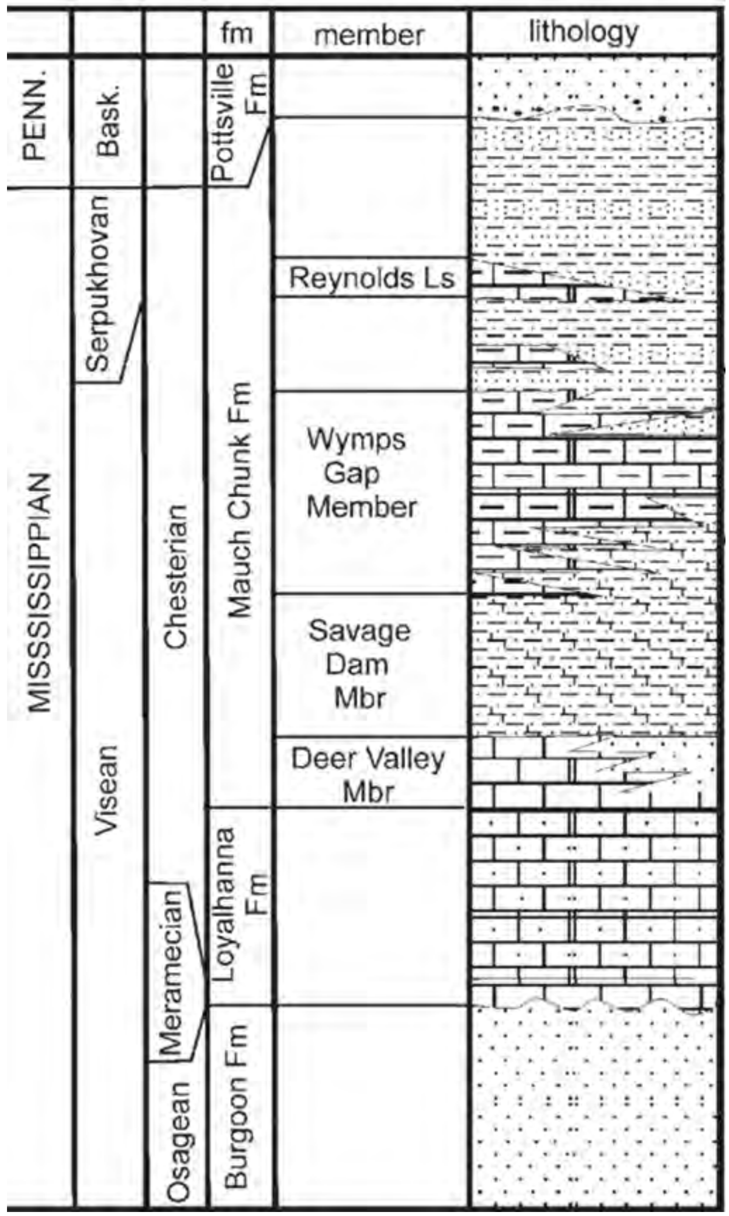

Figure 6. *Stratigraphic column showing Mauch Chunk Formation in southwestern Pennsylvania and position of Wymps Gap Limestone member. Modified from Carter, J. L., Kollar, A. D., and Brezinski, D. K.,2008.*

Fossils

Invertebrate fossils are very abundant within the quarry, and are often found weathered out and easily recovered from within the small talus slopes or on the quarry floor. The small Mississippian trilobites Kaskia and Paladin can be found here, as well as numerous fragments of crinoids that include spines, calyx plates stems and less frequently a complete calyx. At least three different genera of bryozoans; Fenestella, Polypora, and Septopora can be found within the shales and quarry floor limestones (Simonsen,1981). Brachiopods are quite numerous, and the quarry is the type locality for a new brachiopod species, Phyricodothyris lauriegrahamae (**Figure 7**) that is known only from the Wymps Gap Limestone here in southwestern Pennsylvania and Maryland (Carter, Kollar, and Brezinski, 2008).

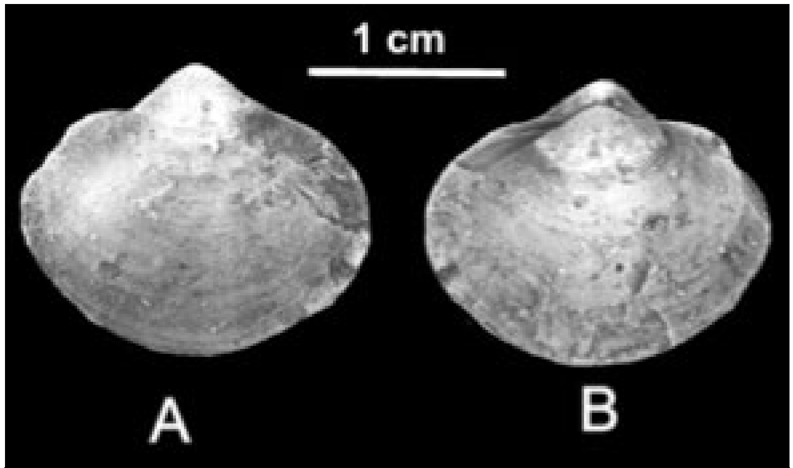

Figure 7. *The brachiopod Phyricodothyris lauriegrahamae (holotype CM 55291), J.V. Thompson Wymps Gap Limestone quarry. Ventral (A), dorsal, (B). Modified from Carter, Kollar, and Brezinski, 2008.*

A final bit of incentive for the fossil collectors here at the J.V. Thompson quarry hoping to find that exceptional trilobite, brachiopod or crinoid. Here is a complete crinoid calyx (Figure 8-8), perhaps *Platycrinites,* with arms and pinnules that I collected here at the quarry in the fall of 1973.

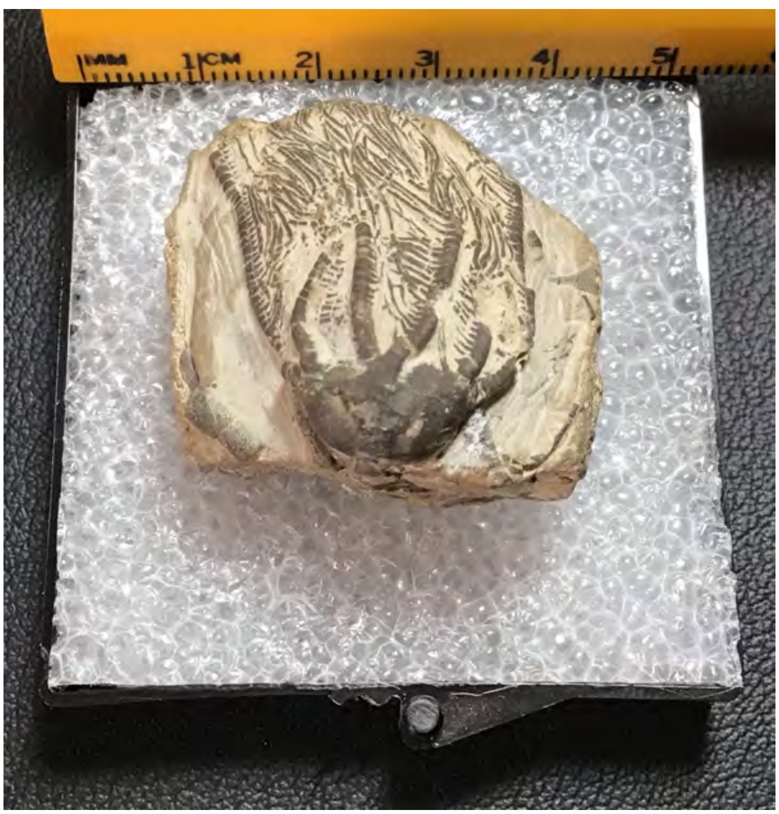

Figure 8. *Crinoid from the collection of S. Lindberg. Found at the J.V. Thompson quarry in the fall of 1973. Photo by S. Lindberg*

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GEOLOGY OF JUMONVILLE GLEN

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Introduction

Some historians point to the events here on May 28, 1754 as a major factor that ignited the French and Indian War (1755-1763). At this location, Lt. Colonel George Washington and his company of 40 Virginians attacked an encampment of French soldiers led by Ensign Joseph Coulon de Villers de Jumonville. De Jumonville identified himself as the detachments commander of Fort Duquesne at the "forks of the ohio" some 40 miles to the west (NPS) was wounded and later killed by the Mingo chief Tanaghrisson called the "Half King" by the English who regarded him as an ally (Anderson 2000). Retribution for this killing led to the battle of Fort Necessity and subsequently had a domino effect that led to the Seven Years War in Europe. This Seven Years War (1756-1763) is considered by many historians as the first true World War (Anderson 2000). Battles during this conflict occurred on five continents, involving fourteen countries. Anderson (2000) Map 1 lists 20 associated conflicts or battles of the Seven Years' War. In western Pennsylvania, this includes George Washington's expedition (1753), Fort Necessity (1754), General Edward Braddock' defeat at Battle of Monongahela (1755), General John Forbes expedition to Fort Duquesne (1758) and Colonial Henry Bouquet's expedition to quell the uprising known as Pontiac's Rebellion along Brushy Run in Westmoreland County, Pennsylvania (1763)[1].

The night before the battle at Jumonville Glen a steady rain felt as Washington and his patrol arrived near daybreak at the Iroquois allies' camp led by Monacatootha and a small band of Mingo warriors led by Tanaghrisson who reported on the French and Indian encampment at the glen. Washington positioned his troops on top of the large rocks above the French camp (refer to Figure 3C showing the "rock city" above the glen in the geology section of this report). The British fired two volleys down on the awakening French who returned a few shots before attempting to retreat into the shelter of the trees. This escape route for the thirty-odd Frenchman was blocked by Tanaghrisson and his warriors who returned to the clearing now pinned down by the English muskets. At this moment, an officer called for quarter and Washington ordered his men to cease firing. After Tanaghrisson took his hatchet to Jumonville's head, killing him, Washington formed his men around the twenty-one surviving prisoners and took them to safety. The Half King's warriors scalped and stripped the thirteen corpses, decapitating one and impaling its head on a stake (Anderson 2000). One naked barefoot warrior hid behind the trees during the fight and escaped to Fort Duquesne to report the battle (Fort Necessity National Park Plaque).

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[1] Other battles in ascending order from 1754 to 1765, Nova Scotia (1754), Hudson River-Lake Champlain-Richelieu River Corridor (1755, 1757, 1758-1760), Mohawk Valley-Lake Ontario-Upper St. Lawrence Valley (1756, 1758, 1760), Battle and Siege of Minorca (1756), Central European Operations (1756 – 1762), Operations in Bengal and Battle of Plassey (1757), Siege of Louisbourg (1758), West African Expedition (1758), Québec and the Upper St. Lawrence Valley (1759-1760), The Eastern Caribbean (1759,1761-1762), British Naval Operations from Gibraltar (1758 – 1759), British Operations on the Coast of France (1757-1759, 1761), Upper Great Lakes (1759, 1764), The Cherokee War (1759 – 1761), Operations on the Coromandel Coast (1758-1760), Newfoundland Expeditions (1762), Conquest of Manila (1762), and Pontiac's Rebellion (1763 – 1765).

Geology

Jumonville Glen is on the crest of Chestnut Ridge Anticline. The exposed ledge of sandstone that surrounds the glen consists of strata that earlier workers assigned to the Pocono Formation (Campbell, 1902). In this area, Laird (1941) considered this interval of rock to be assignable to what he called Sandstone J. He correlated Sandstone J to the Burgoon Sandstone of Butts (1904). The Burgoon is the youngest early Mississippian unit in southwestern Pennsylvania. It is overlain by the late Mississippian Loyalhanna Limestone, and underlain conglomeratic sandstones of the Berea and Cussewago (Brezinski, 1999).

At this location, the Burgoon consists of massive, cross-bedded, micaceous, coarse-grained sandstone with a few interbeds of thin-bedded siltstone and laminated shale (**Figure 1**). Plant fragments are common, and no marine fossils are known. Laird (1941, fig. 1) proposed that the Burgoon Formation was as much as 300 feet thick in the vicinity of the Summit. The coarse texture and pervasive trough cross-bedding has led Bjerstedt and Kammer (1988) to suggest the Purslane Formation of Western Maryland and equivalent Burgoon Formation of southwestern Pennsylvania originated as a channel-phase fluvial sandstone. Although the coarser texture of the Purslane led these authors to suggest a braided fluvial depositional environment, the relatively good sorting of the Burgoon Formation at Jumonville suggests a meandering fluvial, probably point bar, environment.

Figure 1. ***(A)*** *Weathered trough cross-bedded, fluvial sandstone of the Burgoon Formation at Jumonville. (**B**) Medium, cross-bedded sandstone of interpreted point-bar origin, weathered along joint faces.*

Matchen and Kammer (2006) correlated the Burgoon Formation of western Pennsylvania with the Black Hand Sandstone of central Ohio. These authors interpreted the Black Hand Sandstone as an incised valley fill deposit. The Black Hand's sinuous distribution, localized thickening, and coarse texture sharply contrast the enclosing marine strata of the Cuyahoga Formation. Kammer and

Matchen (2008) suggested that the Burgoon Formation of Pennsylvania, Purslane Formation of Maryland, and Big Injun of the West Virginia subsurface represented a basin-wide shallowing event that was equivalent to the Black Hand incision. This regression, they believed, was the result of a global sea level drop concurrent with a high-latitude glacial event that marks the Kinderhookian-Osagean boundary within North America's early Mississippian.

The ledges of the Burgoon Formation that we see at Jumonville Glens bear the joints that result from the late Alleghenian orogeny and the up-lifted and folding of Chestnut Ridge (**Figure 2A**). These fractures were important avenues of groundwater movement and frost action. During the Pleistocene the pervasive fractures in the Burgoon strata here forces blocks of sandstone apart to form an incipient "rock city." Rock cities are common periglacial features within the Laurel Highlands. The massive sandstone of the Pottsville and, less commonly, Burgoon formations become separated along persistent jointing. Prolonged freeze-thaw during the Pleistocene forced these blocks apart to form the so-called rock city. The blocks of sandstone are reminiscent of city blocks, while the spaces between them are suggestive of avenues and streets (**Figure 2B**).

Figure 2. (A) *Joint surface along which water accumulates and passes. (**B**) Rectangular pattern of fractures with the Burgoon Formation. Note that not all joint faces are separated into the incipient "rock city."*

The detached massive, cross-bedded sandstone of the Burgoon Formation at Jumonville were created by the above-described periglacial actions. These events were illustrated by Brezinski and Kollar (2005) (**Figure 3 A-D**). Individual sandstone blocks became detached along fractures and joints that have concentrated water (A). These fractures were wedged apart by ice during intense freezing of during the Pleistocene (B). The underlying permafrost allowed the blocks to move downslope by freezing and thawing (C).

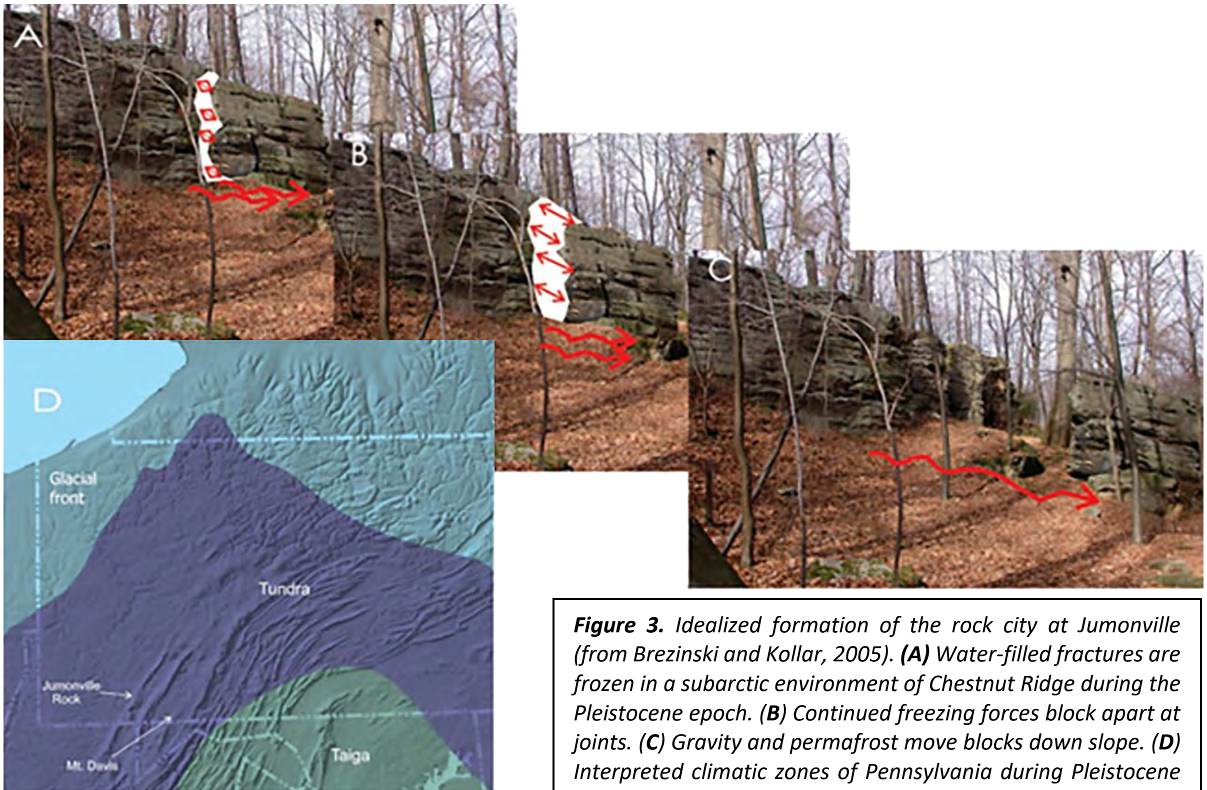

Figure 3. *Idealized formation of the rock city at Jumonville (from Brezinski and Kollar, 2005). **(A)** Water-filled fractures are frozen in a subarctic environment of Chestnut Ridge during the Pleistocene epoch. (**B**) Continued freezing forces block apart at joints. (**C**) Gravity and permafrost move blocks down slope. (**D**) Interpreted climatic zones of Pennsylvania during Pleistocene glacial maxima. Glacial distribution from PAGS map 59, biome based on Guilday (1971, fig. 4) and Martin and Neuner (1978).*

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LAUREL CAVERNS
GEOLOGY, MORPHOLOGY AND SPELEOGENESIS

KATHERINE W. SCHMID – PENNSYLVANIA GEOLOGICAL SURVEY

Abstract

Laurel Caverns is a popular commercial cave in southwestern Pennsylvania. This cave formed on the western side of the Chestnut Ridge Anticline in carbonate bedrock sandwiched between two aquitards. Development of the cave was controlled by the silica-rich composition of the carbonate bedrock as well as strong bedrock jointing, faults and the dip of the anticline. Because of the silica-rich composition of the Loyalhanna Limestone, the cave formed through a process known as phantomization. First dissolution of the carbonate cement formed zones of greater permeability along faults and joints in the bedrock and along the contact between the Loyalhanna Limestone and the impermeable Burgoon Sandstone. After dissolution of the carbonate cement, insoluble grains remained preserving the original bedding – this is referred to as phantom bedrock. Groundwater flow removed this phantom bedrock and this process was facilitated by the dip of the bed.

Laurel Caverns contains network maze passages, mostly straight passages trending down the dip of the bedding, large rooms, and curvilinear trunk passages. Groundwater movement along joints led to the development of network maze passages. An increase in the dip of the bedrock facilitated phantom bedrock removal in the down-dip passages. Groundwater transport along thrust faults allowed water to reach the contact of the Loyalhanna Limestone and the Burgoon Sandstone. Dissolution of the carbonate cement and later removal of the insoluble grains at this contact led to collapse of bedrock blocks which led to the formation of rooms and trunk passages.

Introduction

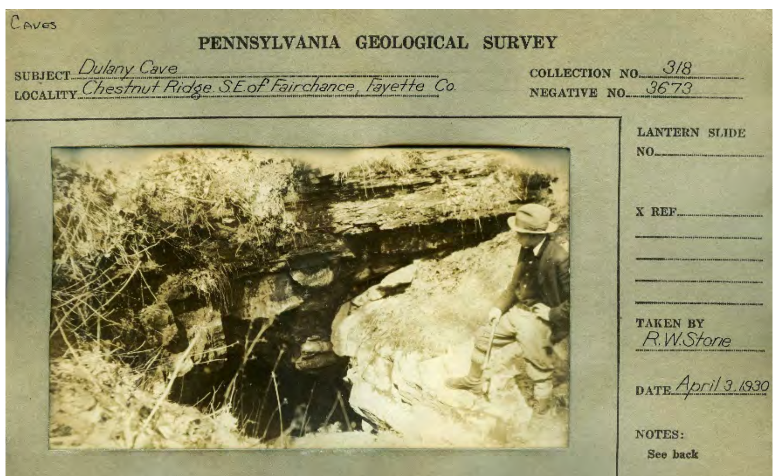

Figure 1. Laurel Caverns, originally known as Dulany Cave. (archive from Pennsylvania Geological Survey, photo, Stone, 1930)

Laurel Caverns is a popular commercial cave in southwestern Pennsylvania. Travelers have been visiting here since at least the early 1800s (Ellis, 1882; Schmidt, 1976). The earliest recorded exploration of this cave was memorialized in an article by John Paxton that was published in 1816 in the American Telegraph of Brownsville PA (Stone, 1932). Back then, the cave was known as Dulany Cave (**Figure 1**) after the farmer who owned the cave and gave access to tourists (Campbell, 1902; Stone, 1932). Other spellings of this name include “De Laney”, “Delany”, “Delaney“ and “Dulaney” (Stone, 1932). Dave Cale, current owner of Laurel Caverns, led the first guided tour of the commercial cave in 1964 (Patrick, 2004).

This cave formed on the western side of the Chestnut Ridge Anticline (**Figure 2**) in a 50-foot (ft) thick carbonate sequence at the base of the Mauch Chunk Formation (**Figure 3**). This carbonate sequence includes the Loyalhanna Limestone and the Deer Valley Limestone. The Loyalhanna Limestone is not a pure carbonate; it is an arenaceous limestone to calcareous sandstone known for its conspicuous high-angle crossbedding. The Deer Valley Limestone is a much purer carbonate composed mostly of detrital calcite sand (Flint, 1965). The bedrock dips about 14 degrees on the western side of the anticline, and the carbonates are sandwiched between two aquicludes that restrict groundwater movement to and through the carbonates.

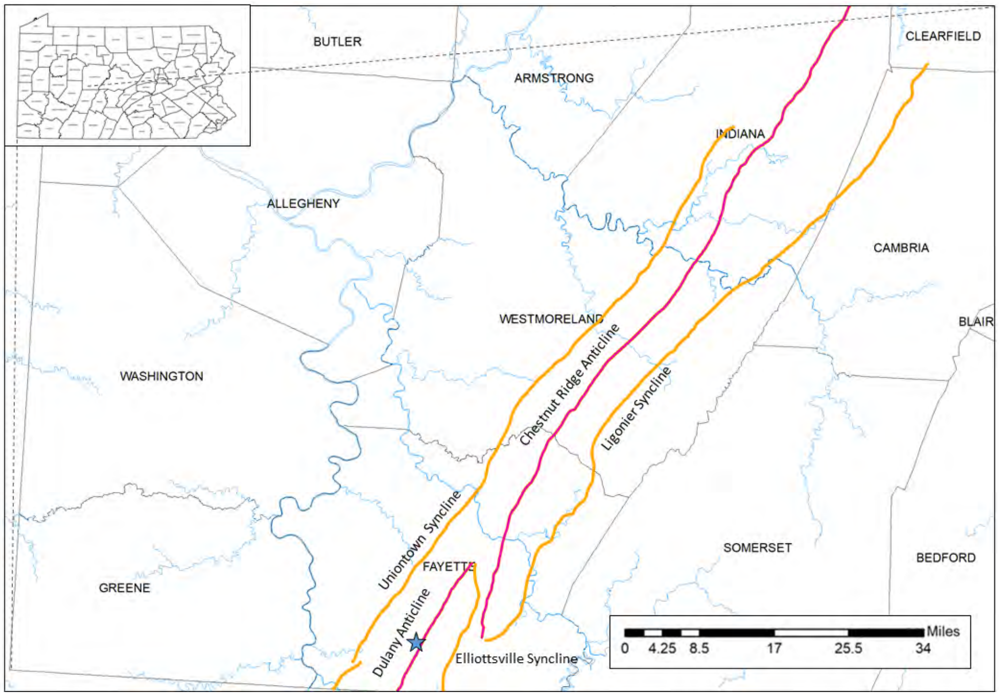

Figure 2. *Location of Laurel Caverns on the western flank of the Chestnut Ridge Anticline in southwestern Pennsylvania. Anticlines are shown in pink and synclines are shown in yellow. The location of Laurel Caverns is marked by a blue star. Anticline and syncline locations are from Faill, 2011.*

A recent map shows Laurel Caverns to be 4.1 miles (mi) long and 476 ft deep (Maurer, 2021). As it descends from the crest of Chestnut Ridge Anticline, Laurel Caverns is divided into four sections with distinct passage trends and morphologies (**Figure 4**). From highest elevation to the lowest, these sections are the Upper Maze Cave, the Middle Cave, the Flue and the Lower Cave (**Figure 5**). The Upper Maze Cave includes a network of passages close to Loyalhanna Limestone outcrops on the ridge. The Middle Cave is composed of large trunk passages that trend down the dip of the bedrock. The Flue contains several thrust faults and consists of large rooms, network maze passages and a low wide passage known as the Upper Flue. The Lower Cave consists primarily of branching trunk conduits and some joint-controlled maze passages.

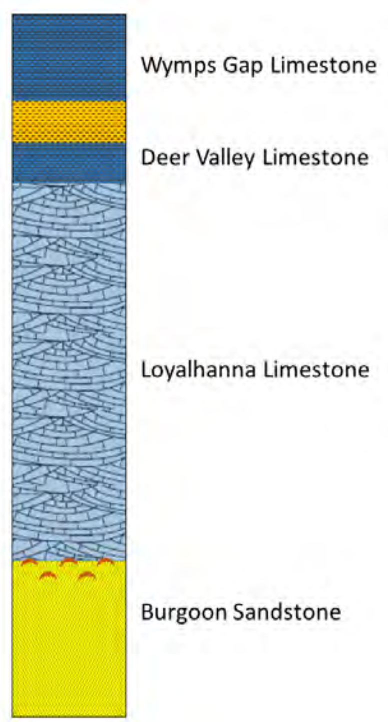

Figure 3. *Stratigraphy of the carbonates on the Mauch Chunk Formation. In southwestern Pennsylvania, the Loyalhanna Limestone rests unconformably on top of the Burgoon Sandstone. In Laurel Caverns, iron concretions are observed at the top of the Burgoon Sandstone. The clastic layer between the Wymps Gap and Deer Valley limestones is unnamed in Pennsylvania.*

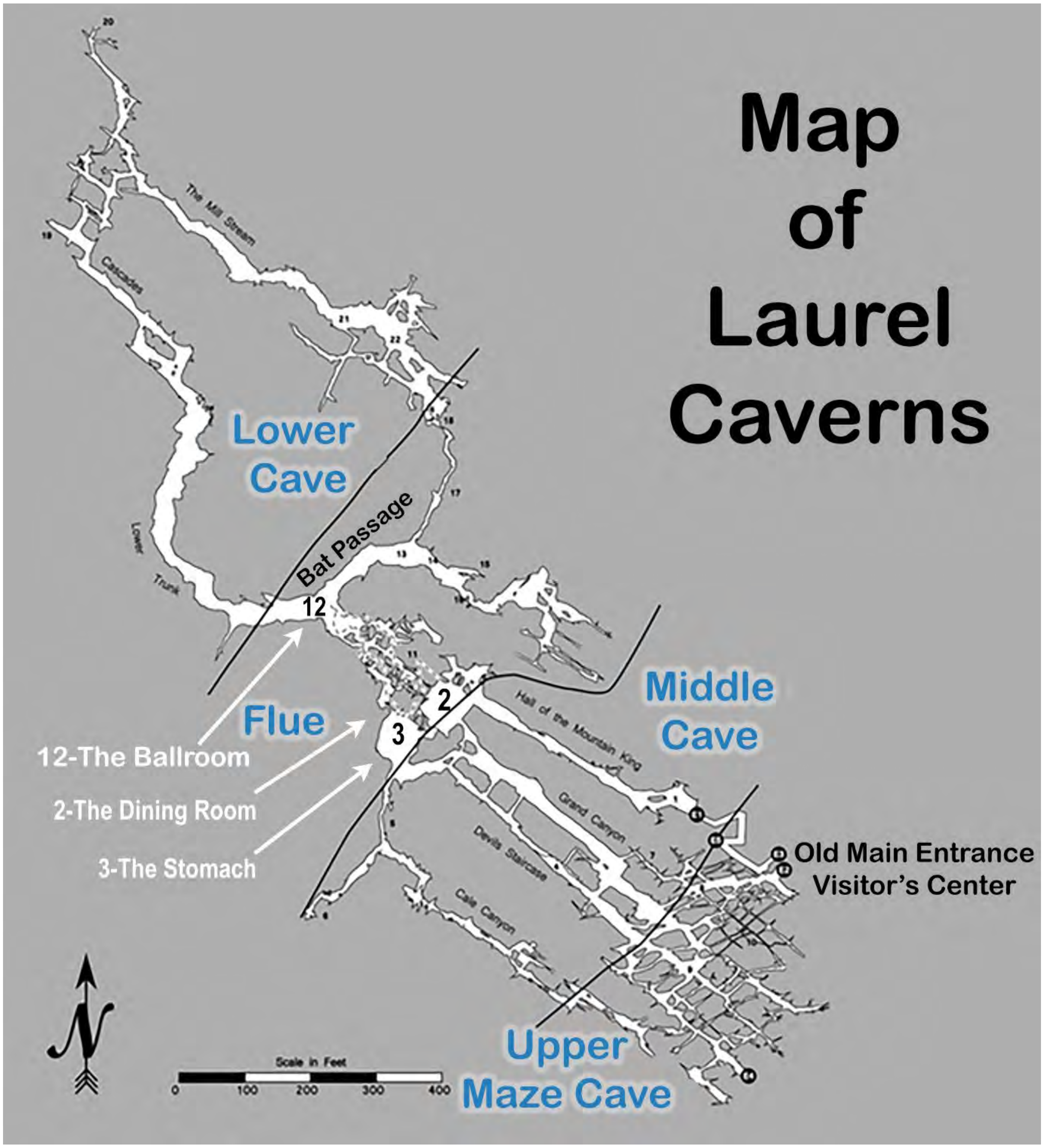

Figure 4. Map of Laurel Caverns. 2 is the Dining Room. 3 is the room known as the Stomach. 12 is the Ballroom.

Victor Schmidt (1974, 1976) studied Laurel Caverns and made some observations. He noted that the large passages are almost always dip passages. Strike passages are usually smaller and associated with maze sections. The principal zone of faulting is in the mid-section of the cave. The large rooms and breakdown areas are associated with shallow angle thrust faults. These faults run parallel to each other and to the axis of the anticline. They dip from the axis at angles near 30 degrees.

The fault zone seems to separate stratigraphically higher and lower passages. Trunk passages follow the dip at the bottom of the limestone. Schmidt concluded that the cave formed rapidly because the cave follows modern topography, and that the dip passages are the largest because their steepness facilitates greater water flow. Schmidt's interpretations do not explain why the strike and dip passages are close to the same size in the Upper Maze section nor the paucity of strike passages in Middle Cave[1].

Karst sciences have evolved considerably since Victor Schmidt's study of Laurel Caverns in the 1970s. For example, an entire volume on how caves form, titled *Speleogenesis*, was published in 2000, Arthur Palmer published *Cave Geology* in 2007 and the third edition of *Encyclopedia of Caves* was published in late 2019. In addition, more Laurel Caverns data have been collected by researchers and caving enthusiasts. Ryan Maurer drafted a new map of the cave in 2021, which extends the length of the cave by about a mile as new passages have been discovered and/or excavated since the studies in the seventies. Along with this map, Ryan Maurer and Hope Brooks collected many strike and dip measurements and found that the dip of the bedrock varies between the Upper Maze Cave and the remaining sections. This variation is only a couple degrees but seems to have had a significant influence on cavern development. These new data have led to a revised interpretation regarding the formation of Laurel Caverns.

Laurel Caverns formed in multiple stages. First, dissolution of calcite cement in the siliceous Loyalhanna Limestone formed zones of higher permeability along joints and fractures in this unit and along its contact with the underlying impermeable Burgoon Sandstone – this process is known as phantomization (Wray and Sauro, 2017). However, the cavern could not form until the insoluble quartz sand grains were removed. A sandy spring at the contact of the Burgoon Sandstone and the Loyalhanna Limestone is a probable outlet for these grains. Removal of grains along joints opened network maze type passages. Removal of grains along the contact between the Loyalhanna Limestone and Burgoon Sandstone led to collapse of large bedrock blocks that opened large room and trunk passages.

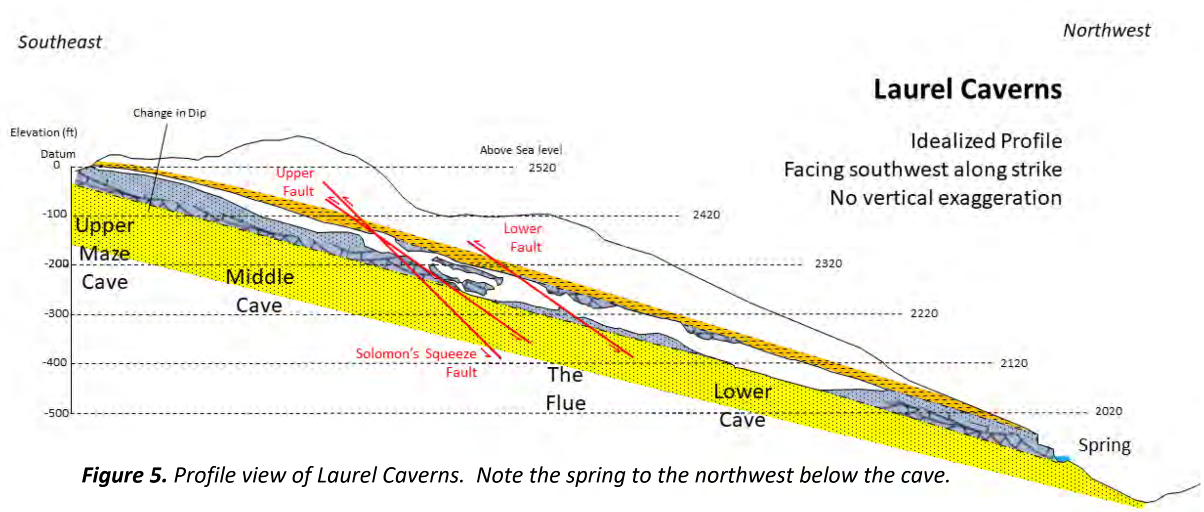

Figure 5. *Profile view of Laurel Caverns. Note the spring to the northwest below the cave.*

[1] Victor Schmidt's results first appeared in a paper at an informal karst conference held in Morgantown, West Virginia in 1974. This was apparently the first description of what much later became a major topic in papers published in Europe, but with no reference to Vic's work, which remained unknown to most people (Palmer, 2021 per comm). Palmer (2007) mentions his overlooked pioneering work.

Geographic Location

Laurel Caverns is located in Fayette County, Pennsylvania, on the western limb of the Chestnut Ridge Anticline (**Figure 2**). The Chestnut Ridge Anticline rises in northern West Virginia and runs to the northeast, trending roughly North 20 degrees East (N-20-E). In central Fayette County, the anticline plunges and resurfaces before continuing northeast into Westmoreland County. South of the Youghiogheny River in Fayette County, the Chestnut Ridge Anticline is also known as the Dulany Anticline (Campbell, 1902) – named after Laurel Caverns as the cave was called in 1902 (**Figure 1**). The crest of Dulany Anticline rises some 2,600 ft from the trough of the Uniontown Syncline to the west and brings up with it Mississippian carbonates of the Mauch Chunk Formation (**Figure 3**). These carbonates are exposed in narrow bands along the slopes of the Dulany and Chestnut Ridge anticlines (Hickok and Moyer, 1940). It is in these carbonates that Laurel Caverns (**Figures 4 & 5**) developed.

Geology

Stratigraphy

The Mauch Chunk Formation occurs throughout western, central and parts of northeastern Pennsylvania. It is thickest in central eastern Pennsylvania, where it ranges from 4,000 to 6,000 ft (Edmund, 2008). In central eastern Pennsylvania, the Loyalhanna Limestone member of the formation is found near the middle of the Mauch Chunk sequence (**Figure 6**). The Loyalhanna Limestone covers a large area of Pennsylvania extending from the southwestern to north-central Pennsylvania (Edmunds, 1993, Behr, 2020). Nondeposition and/or erosion are responsible for the varying amounts of clastic sediments from the Mauch Chunk found above and below the Loyalhanna Limestone in northern and southwestern Pennsylvania and neighboring states (Edmunds, 1993, 2008).

In southwest Pennsylvania, the basal carbonate in the Mauch Chunk Formation is the Loyalhanna Limestone (**Figure 3**). The Loyalhanna Limestone is an arenaceous limestone to calcareous sandstone known for its conspicuous high-angle crossbedding. Butts (1904) named the Loyalhanna Limestone for its exposures along Loyalhanna Creek in Westmoreland County. In Pennsylvania, the composition of the Loyalhanna Limestone averages about 50% detrital quartz sand (Brezinski, 1999) and in Fayette County, the composition ranges from 21% silica (SiO2) and 75% calcite (CaCO3) to 54% silica and 39% calcite (Hickok and Moyer, 1940). Much of the sand originated from the Burgoon Sandstone where it was eroding to the north (Edmunds and others, 1979; Brezinski, 1999).

Going up section, the next carbonate in the Mauch Chunk Formation is the Deer Valley Limestone (**Figure 3**), named by Flint (1965). The type section of the Deer Valley Limestone occurs at the head of a valley about a mile southwest of Mount Davis, the highest point in Pennsylvania. This carbonate is much purer than the Loyalhanna Limestone. The majority of the Deer Valley Limestone is at least 90% calcite, 33% of which is detrital microfossils (Flint, 1965).

The clastic layer between the Deer Valley and Wymps Gaps limestones is unnamed in Pennsylvania. It correlates to the Savage Dam member in Maryland which is between the Alderson and Loyalhanna limestone members of the Greenbrier Formation (Edmunds, 1993).

The next carbonate in the sequence is the Wymps Gap Limestone. Historically, this limestone was referred to as the Greenbrier limestone, but because the bed is just a thin finger of the much thicker Greenbrier Formation to the south in West Virginia, Flint (1965) gave this bed a unique name. This bed correlates to the Alderson Limestone in Maryland and West Virginia (Edmunds, 1993).

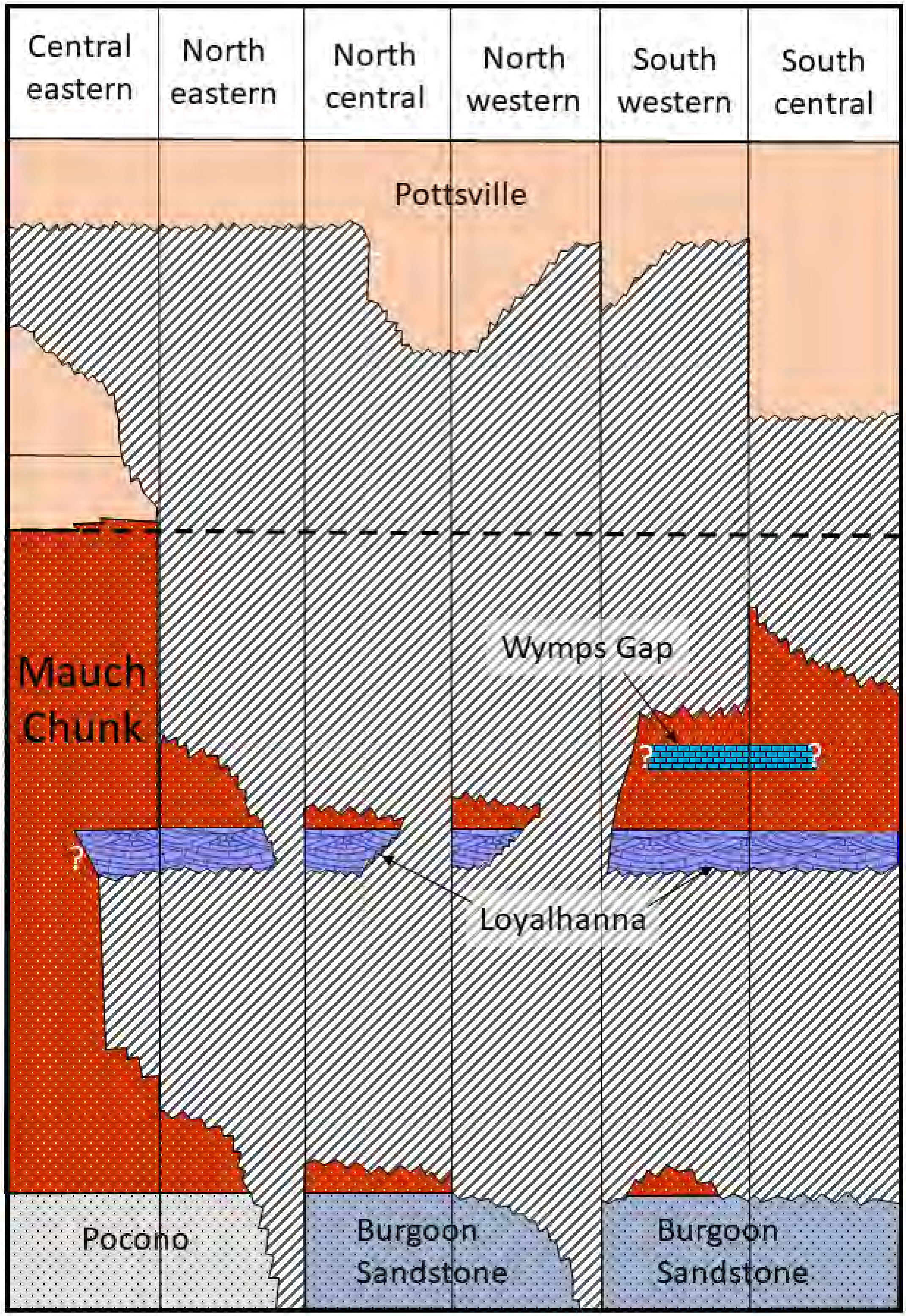

Figure 6. *Mississippian to lower Pennsylvanian correlations across Pennsylvania. (Modified from Edmunds, 1993 and Edmunds, 2008). The heavy dashed line denotes the Mississippian – Pennsylvanian unconformity. Bed thicknesses are not shown to scale.*

Prior to deposition of the carbonates, erosion had leveled the surface to a broad, flat plain (Edmunds, 1993). This set the stage for a shallow marine sand complex to be deposited over a large region covering parts of Maryland, Ohio, Pennsylvania and West Virginia (Edmunds, 2008). Deposition likely fluctuated over this broad area during the time of deposition. Portions of the siliciclastic sediments in the Loyalhanna Limestone may have passed through an eolian stage prior to transgression of the shallow inland sea (Edmunds, 2008).

The carbonates of the Mauch Chunk Formation were deposited in a deltaic environment about 330 million years ago in this broad, shallow inland sea which at times was turbulent (Salver, 1962; Flint, 1965; Edmunds, 1993) (**Figure 7**). The landmass at the time was about 25 degrees south of the equator and moving northward (Edmunds and others, 1979; Scotese, 2013). Rapid fluctuations in sea level and river discharge created a highly variable depositional environment which, in turn, produced a highly variable sequence of carbonates and clastics. In most of southwestern Pennsylvania, the Mauch Chunk carbonates occur in a roughly 120 ft thick sequence and serve as the basal units for the Mauch Chunk Formation. These carbonates rest unconformably on top of the Burgoon Sandstone. Essentially these are far-reaching tongues of the limestone-rich Greenbrier Formation to the south – the marine and sandy carbonates of Figure 7 (Brezinski, 1999). These strata transition from thick marine carbonates in West Virginia, to unconformity-bound marine carbonates in Fayette County, Pennsylvania, to non-marine terrigenous strata in northeastern Pennsylvania (Brezinski, 1999, Carter, 2019) (**Figures 6 and 7**).

Figure 7. *Depositional setting of the Loyalhanna Limestone (modified from Edmunds, 1993 and Behr, 2020).*

Erosion of the uplifted Burgoon Sandstone to the north provided much of the sand present in the Loyalhanna Limestone. Orogenic source rocks to the east-southeast provided most of the clastics in the overlying Mauch Chunk shales and sandstones (Edmunds and others, 1979; Brezinski, 1999).

Note the marine carbonates deposited as the Greenbrier in southern West Virginia.

The depositional environment of the Loyalhanna Limestone has been debated for decades. Some researchers believe that the Loyalhanna Limestone is an eolian deposit (e.g., Butts, 1924; Hickok and

Moyer, 1940; Berg, 1980; Ahlbrandt, 1995), while others believe it is a submarine deposit (e.g., Salver, 1962; Gallagher, 1984; Behr, 2020). The steep crossbedding angles observed in the Loyalhanna have been used as evidence for eolian deposition. According to Ahlbrandt (1995), the range of crossbedding angles is consistent with eolian deposits such as barchan, transverse ridge and blowout dunes. Salver (1962) and Gallagher (1984) referred to the flume experiments performed by McKee (1957), which showed that subaqueous sand deposits may have crossbedding angles up to 25 or 30 degrees. However, McKee's experiments were performed in stream-flow tanks and may not account for sediment compaction after deposition (McKee, 1957). The angularity and poor sorting of the grains is cited as evidence for a submarine deposit (Salver, 1962; Flint,1965; Gallagher, 1984; Behr, 2020). Ahlbrandt (1995) reported that the bimodal sorting and subangular grains is evidence of dune and interdune deposits. The scarcity of fossils in the Loyalhanna Limestone is cited as evidence for eolian deposition (e.g., Ahlbrandt, 1995). However, marine fossil fragments including echinoderms, bryozoans and brachiopods have been identified in the Loyalhanna Limestone (Hickok and Moyer, 1940; Salver, 1962; Edmunds, 2008).

The Loyalhanna Limestone of Laurel Caverns is a 50-ft thick, massive, gray to light-blue, siliceous limestone with dark crossbedding. A higher concentration of insoluble material tends to be present in the coarser bands. This leads to differential erosion, making the individual beds and crossbedding more visible (Hickok and Moyer, 1940) (**Figure 8**). When exposed to moisture, the calcite cement dissolves, leaving the sand grains behind in situ. These sand grains retain the original bedding. This sand, when oxidized, becomes light tan, with higher concentrations appearing a darker brown color (**Figure 9**). In the Lower Cave, water flow exposed fragments of iron concretions at the top of the Burgoon Sandstone. Cavern development exposed these concretions but did not occur below them.

Figure 8. *Crossbedding in the Loyalhanna Limestone. Note mechanical pencil for scale. Photo by Arthur and Margaret Palmer.*

A transgressive marine event deposited the Deer Valley Limestone on top of the Loyalhanna Limestone at the caverns. The contact between the Loyalhanna and Deer Valley limestones is gradational. Typically, the contact between the top of the Deer Valley and the clastics above is well defined. A short period of clastic deposition deposited a 4-ft thick calcitic sandstone above the Deer Valley before producing one final unit of marine limestone – the Wymps Gap. The base of the Wymps Gap Limestone is gradational, although it is rarely visible in Laurel Caverns. In this vicinity, it is 15-ft thick and dark gray to black. It weathers to a light gray, or almost white, color and is highly fossiliferous. Deep in the cave, red, blue and tan calcitic siltstones, shales and sandstones of the clastics higher in the Mauch Chunk Formation are exposed (**Figure 10**).

Figure 9. *Above: a typical passage in the Upper Maze section of the cave showing how the siliceous limestone weathers out as the calcite cement dissolves leaving behind the silica grains. Note how the bedding in the solid walls continues through the weathered sand (darker) in the middle of the photo. Picture from Arthur and Margaret Palmer.*

Figure 10. *Left: the rainbow canopy in the lower cave exposes different red, blue, and tan calcitic siltstones, shales, and sandstones of Mauch Chunk clastics above the carbonate. These clastics were sourced from the mountains to the east. Photo by Ryan Maurer.*

Structure

Chestnut Ridge is a doubly plunging anticline that trends northeast-southwest. In Fayette County, the Youghiogheny River crosses the anticline at a sag in the anticline known as the Youghiogheny Saddle (Iannacchione and Coyle, 2012). The rise of the ridge south of the Youghiogheny Saddle is known as Summit Dome (Iannacchione and Coyle, 2012). Laurel Caverns formed within the Summit Dome section of the anticline (**Figure 11**). The entrance to the caverns is near the crest of the Chestnut Ridge – Dulany Anticline where the slope begins to steepen (McElroy, 1988). At the entrance, the top of the Burgoon Sandstone is just above an elevation of 2,600 ft Mean Sea Level (MSL) and from there, it dips 14.8 degrees to the west. This dip contributes to Laurel Caverns being the deepest mapped cave in Pennsylvania (Häuselmann, 2019; Gulden, 2020).

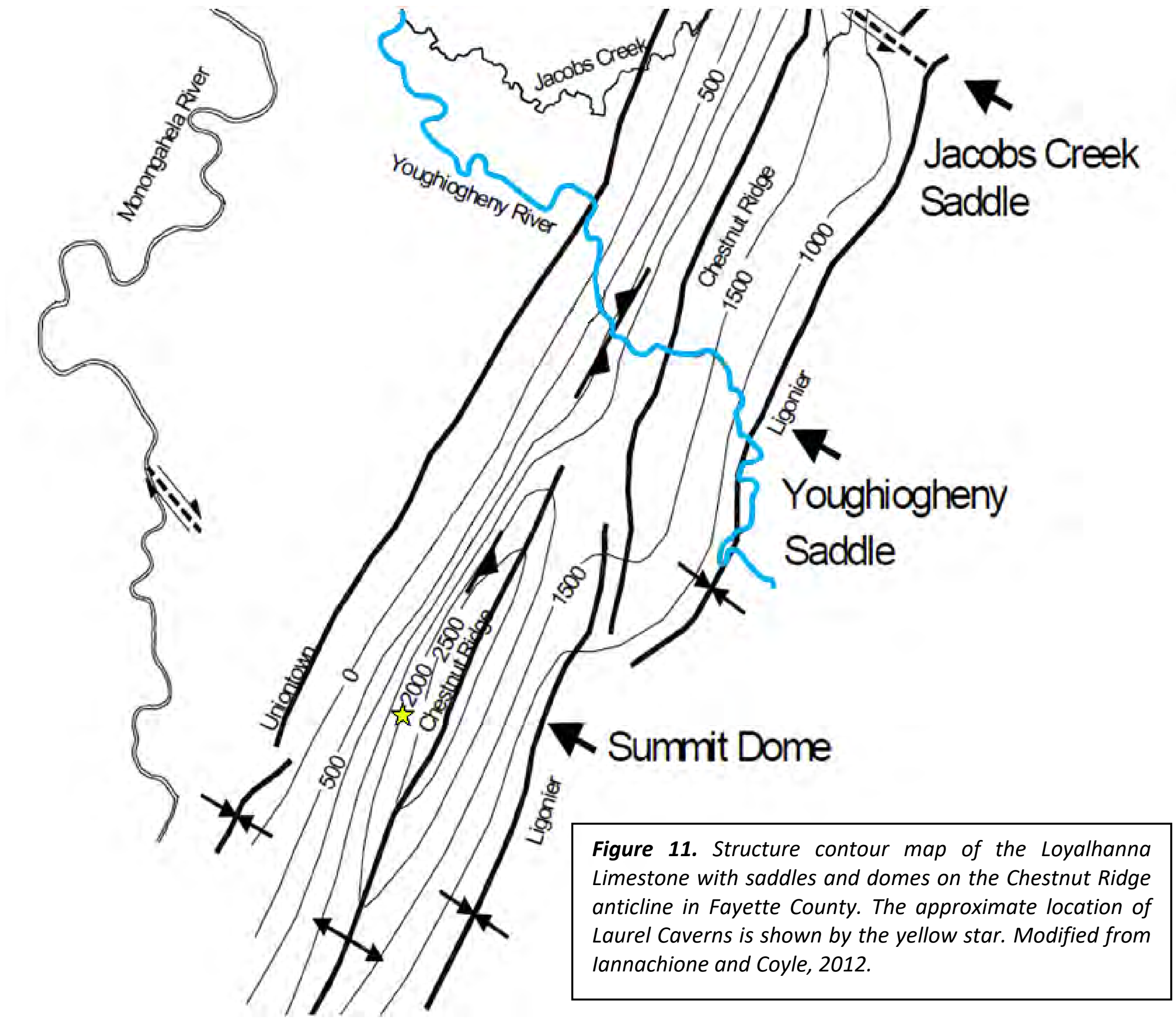

Figure 11. *Structure contour map of the Loyalhanna Limestone with saddles and domes on the Chestnut Ridge anticline in Fayette County. The approximate location of Laurel Caverns is shown by the yellow star. Modified from Iannachione and Coyle, 2012.*

The Chestnut Ridge Anticline is a structurally complex feature with thrust faults throughout the Devonian section and up into parts of the Mississippian section (Scanlin and Engelder, 2003). Indeed, thrust faults have been observed in Laurel Caverns. To understand the complex formation of the Chestnut Ridge Anticline, one must look far back in the geologic history of the Appalachian Basin. The Appalachian Basin is in many ways a 'type section' for the Wilson cycle (Ettensohn, 2008), the plate tectonic cycle of extension and contraction between periods of ocean formation and collision between tectonic plates. Jacobeen and Kanes (1974) modeled how these different periods of extension and contraction controlled deformation of the strata (**Figure 12**). Their model considered the different mechanical strengths and behaviors of the subsurface rock layers. After extensional faulting in the early Cambrian, strata were laid down with relatively uniform thicknesses throughout the Cambrian and Ordovician. Compression from the east followed, causing these rock layers to slide over the lower clastic unit that had been deposited on the unconformity on top of Precambrian basement rocks. When the strata encountered a bump caused by basement faulting, a ramp fault formed. Further compression from the east caused additional thrust faulting. When this thrusting encountered the ramp fault, stresses were reoriented and multiple high-angle splay thrusts formed (Jacobeen and Kanes, 1974). Strata above these high-angle thrusts, including the Mauch Chunk Formation, deformed into tightly folded and faulted structures.

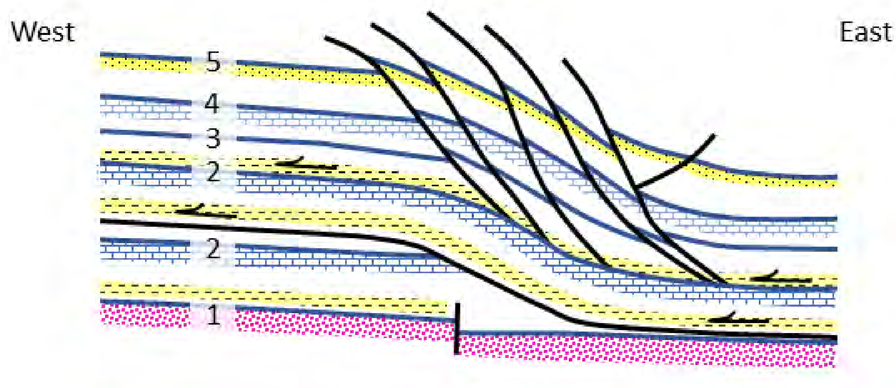

Figure 12. *Model of subsurface deformation in the Broadtop Synclinorium (modified from Jacobeen and Kanes, 1974). In this model, Jacobeen and Kanes broke the subsurface up into multiple lithotectonic units. 1: Precambrian crystalline basement rock was faulted during extension in the early Cambrian. 2: Mechanically competent strata that act as a rigid beam and are involved in broad structures and large overthrust sheets. Note the repeat of this section to the west. 3: Incompetent shaley unit that is not strong enough to transmit horizontal stresses. Stress in this unit causes sliding, small-scale faulting, and flow folding. Note all the thrust faulting initiating from the top of the rigid strata (2) beneath this unit. 4: Strata that tend to fail as an imbricate thrust sheet. 5: Clastic strata – strata above this layer are not shown in this model and tend to deform into tightly folded and faulted structures (Jacobeen and Kanes, 1974).*

Laurel Caverns Description

Laurel Caverns formed in dipping carbonate beds trapped between two aquitards on the western flank of the Chestnut Ridge Anticline. Häuselmann (2019) noted that many of the deepest caves in the world formed under these same conditions. Well-developed joints in the carbonate bedrock, faults in the anticline and variations in composition of the carbonate beds make Laurel a complicated cave.

Laurel Caverns is a telogenetic cave, that is, a cave formed by meteoric water. Rainwater enters the cave from localized point-sources and from widespread diffused entry. Groundwater movement in telogenetic caves concentrates along of high permeability such as fractures or joints in the bedrock and/or along the bedding planes (White and Culver, 2019; White, 2019). Indeed, groundwater movement has been observed both along the joints and faults and at the contact of the Loyalhanna Limestone and the Burgoon Sandstone in this cave.

As the caverns descend from the crest of the anticline, Laurel is divided into four sections with distinct passage trends and morphologies. Trending northwest from highest elevation to the lowest, these sections are the Upper Maze Cave, the Middle Cave, the Flue and the Lower Cave. **Figure 4** shows the cave in plan view, with heavy black lines delineating the sections. **Figure 5** shows the four sections of the cave in profile view, with the larger faults labeled.

Upper Maze Cave

Visitors to Laurel Caverns enter the Upper Maze section from the visitor's center. This section consists of a network maze of passages close to where the Loyalhanna Limestone surfaces along the ridge (**Figure 13**). Water enters this section of the cave through joints in the bedrock and the upper termini of passages near the surface. This network of mostly straight passages follows joints trending about N-50-E and N-60-W. Bedrock in this section of the cave dips 10.6 degrees. Passages typically have a smooth and undular shape with sandy floors and a distinct "V" in the ceiling. Crossbedding is well-developed in the Loyalhanna Limestone, and angles as high as 30 degrees have been observed in these passages.

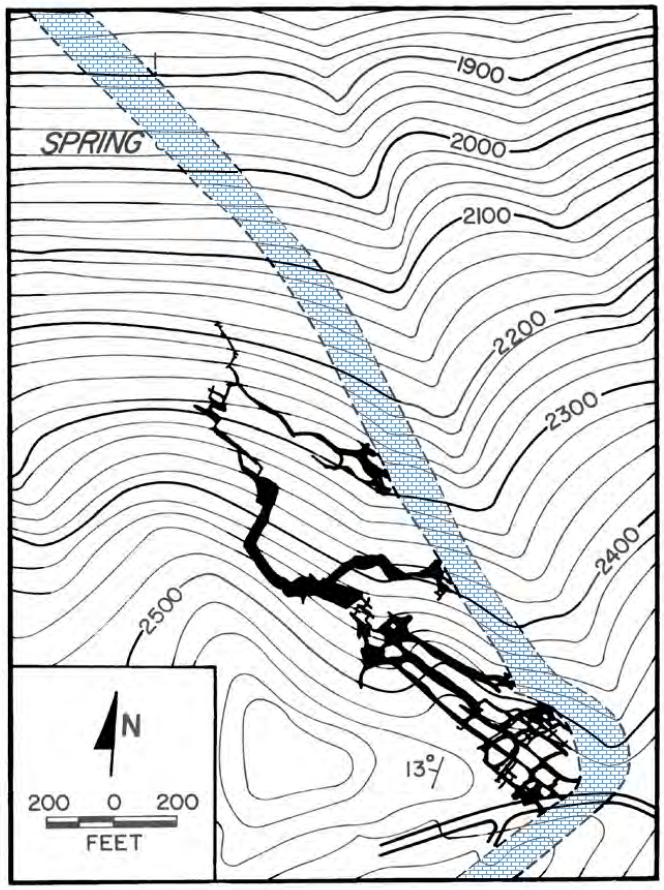

Figure 13. *Map of Laurel Caverns plotted on a topographic map of the region with the outcrop of the Loyalhanna Limestone shown in blue. Modified from Schmidt (1974).*

Passages in this section of the cave commonly trend along joints near the orientation of the dip or the strike of the bedrock. Dip-oriented passages are generally Texas-shaped, and strike-oriented passages are rectangular (**Figure 14**). These morphologies result from the phantomized Loyalhanna washing away in the dip direction but not the strike direction. The passage cross-sectional areas are strike- and dip-dependent, irrespective of the passage's distance from the surface. Dip-oriented passages have an average cross-sectional area of 12 square ft, and strike-oriented passages have an average cross-sectional area of 3.5 square ft (**Figure 15**).

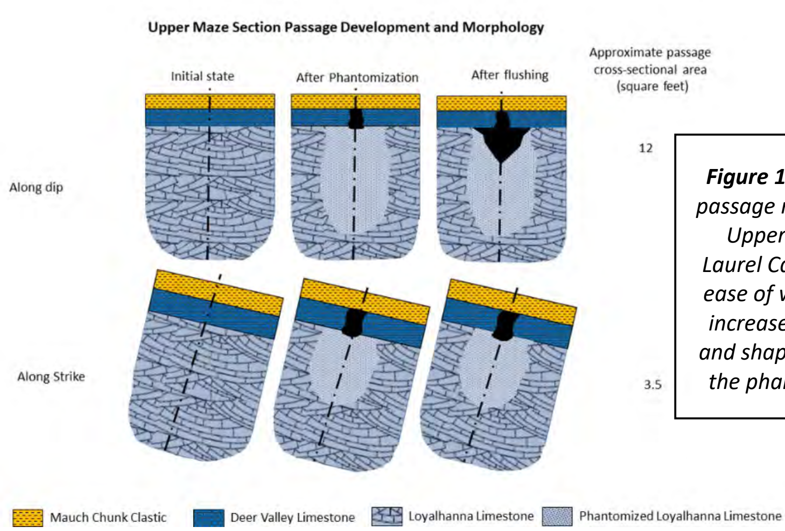

Figure 14. *Development of passage morphologies in the Upper Maze section of Laurel Caverns. The greater ease of waterflow downdip increases the passage size and shape by washing away the phantomized bedrock.*

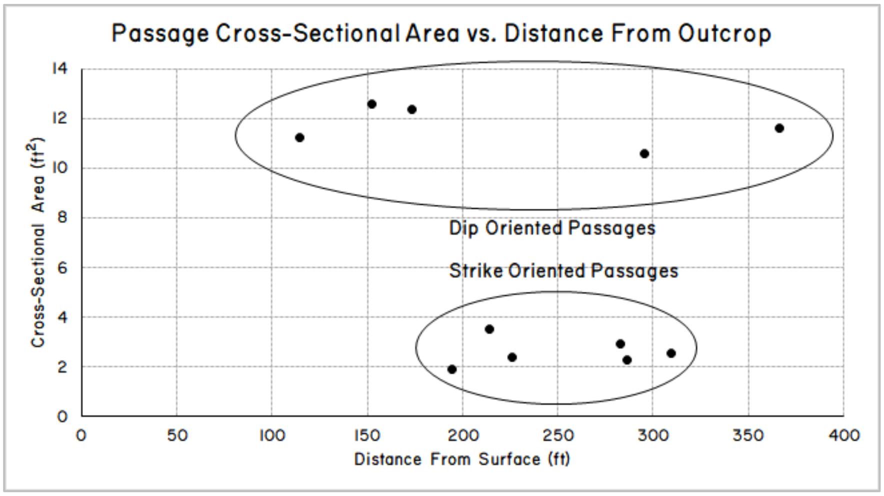

Figure 15. *Passage cross-sectional area versus distance from the surface outcrop in the Upper Maze section of Laurel Caverns.*

Middle Cave

Beyond the Upper Maze section are four mostly straight, joint-controlled passages trending down-dip N-60-W (**Figure 4**). In these passages and below, the bedrock dips 15.7 degrees. The change in dip from the Upper Maze Cave to these trunk passages occurs along a line trending about N-40-E. Before addition of sediment to level the floor for tourism, these passages had a canyon shape – that is, they had a large height to width ratio (**Figure 16**). These passages descend into rooms known as the Stomach and the Dining Room where thrust faults are first encountered.

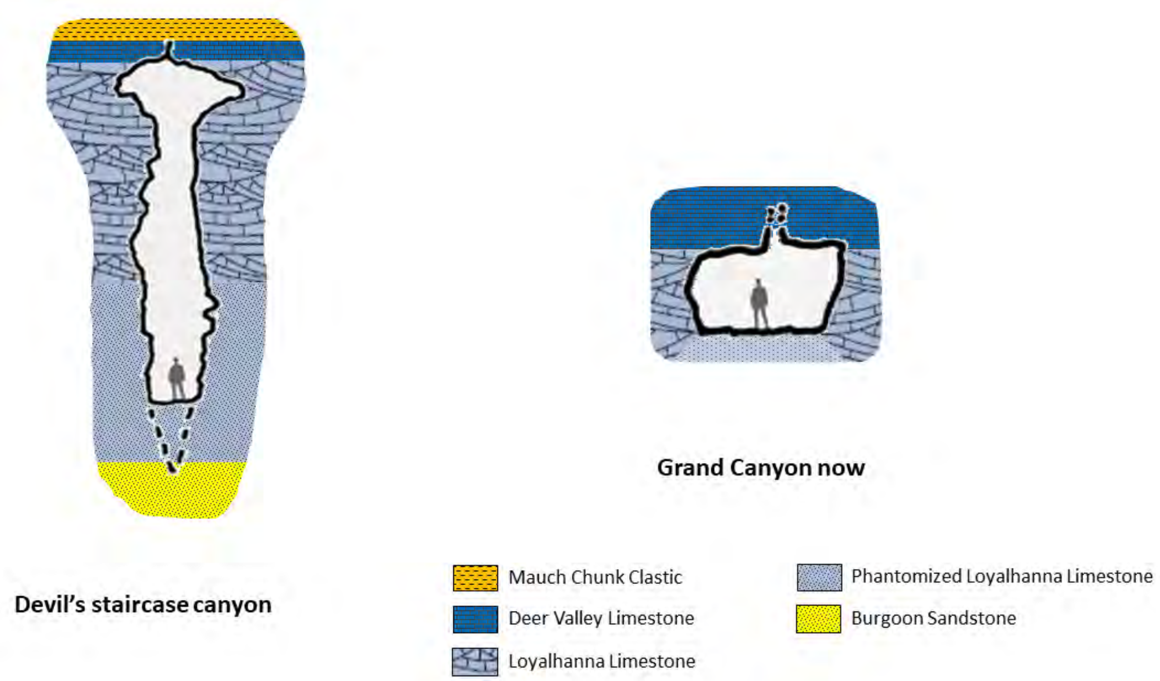

Figure 16. *Canyon passages in the Middle cave section of Laurel Caverns. The Devil's staircase canyon is on the left. On the right, the Grand Canyon passage has been modified for tourism. Note the joints at the top center of each passage. Passage profile modified from Maurer, 2021.*

The cross-sectional areas of the trunk passages in Middle Cave decrease steadily with greater distance from the outcrop (**Figure 17**). The Hall of the Mountain King is the northern-most passage and is the closest to the surface outcrop of the Loyalhanna Limestone. Cross-sectional areas of this passage range from 140 to 185 square ft. Toward the southwest, the next passage is the Grand Canyon, with cross-sectional areas ranging from 110 to 120 square ft. The next passage is the Devil's Staircase, with cross-sectional areas of 60 to 90 square ft. Cale Canyon, the farthest passage from the surface, was excavated by cavers and did not exist when Schmidt published his map of the cave (Schmidt, 1976). This passage has a cross-sectional area of about 80 square ft. These dimensions are from a recent survey of the cave (Maurer, 2021) and do not represent the dimensions prior to modification for tourism.

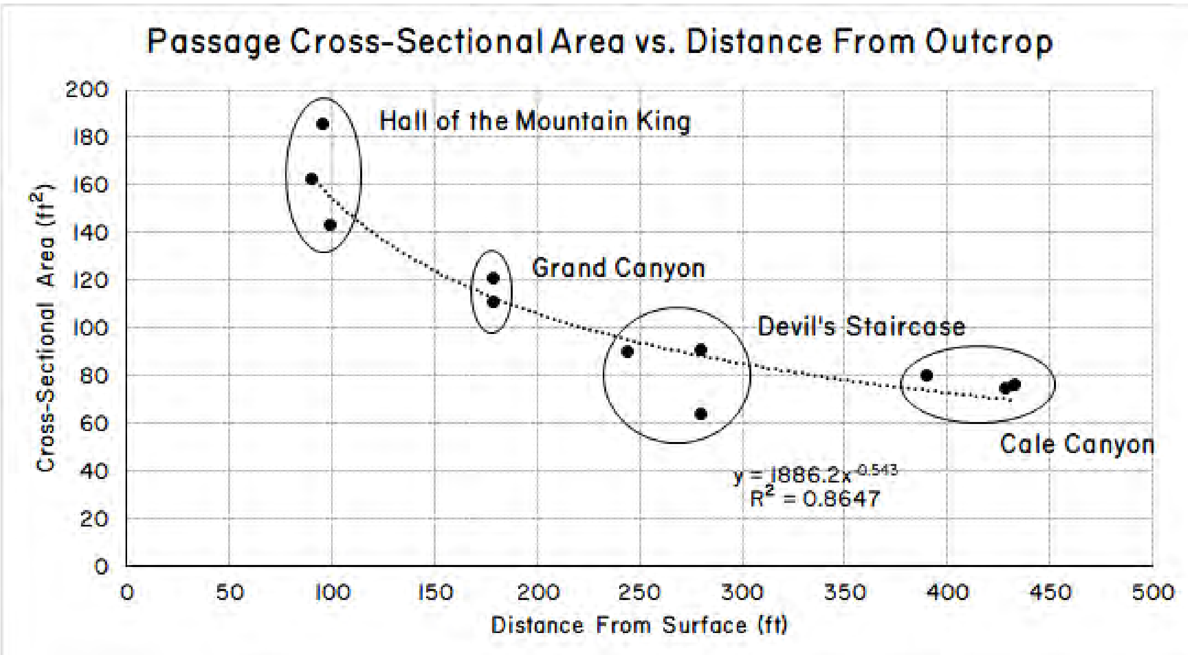

Figure 17. *Plot of passage cross-sectional area versus distance from the Loyalhanna Limestone outcrop.*

Flue Section

Multiple faults penetrate the cave section known as the Flue. This section is bounded by the Upper Fault and the Lower Fault. The Upper Fault is known as such because it is encountered at a higher elevation in the cave even though it is situated stratigraphically beneath the Lower Fault (**Figure 5**). These two faults and most of the smaller faults in the cave trend at about N-30-E and dip 35 degrees northwest. Solomon's Squeeze Fault is the exception to this; this fault trends N-7-E and dips roughly 45 degrees west. Conduits in the Flue consist of large rooms, network maze passages and a large wide passage known as the Upper Flue. The Upper Flue is nearly 200 ft long and up to 80 ft wide but is only 2 to 3 ft high. Passages in the Flue mostly trend down-dip and in the same direction as the trunk passages in Middle Cave. The passage through the middle level of the Flue varies from a steep, twisty canyon-style passage to a slanted passage not quite high enough to accommodate an average standing adult. This passage has been widened for ease of visitor access.

The streams originating in the Upper Maze Cave, visitor center and Hall of the Mountain King areas all coalesce in the Flue section. At the lower end of the Flue, the stream joins the Bat Passage stream and runs down the Lower Trunk to join up with the Mill Stream in the Lower Cave. Water also enters this section of the cave along the fault lines.

Lower Cave

The Lower Cave consists of curving trunk passages and joint-controlled passages. The curving trunk passages include the Lower Trunk and the southeast end of the Mill Stream passage. These passages range from 40- to 80-ft wide and 15- to 25-ft high. Long straight passages in the Lower Cave trend down-dip at about N-60-W. The Cascades and The Mill Stream are dip passages and they are about 25-ft wide and 6- to 50-ft high. Cross-passages in this section trend N-24-E.

Summary of Cave Pattern

Palmer (2000) defined how cave patterns are controlled by a combination of the distance of flow of water to a soluble rock, the amount of discharge from a passage, and the radius of the conduit. Where the discharge is low, passage enlargement is slow. Also, passage development tends to be slower the farther from the water source, the surface in this case. Passage development is fastest closest to the source of the water and in passages with the greatest discharge, for example, passages trending down-dip. Despite flattening the floors for ease of visitor access, these trends can be seen in Laurel Caverns. For example, **Figure 15** shows how the passage cross-sectional areas in the Upper Maze section are strongly dependent on whether the passage is strike- or dip-oriented; **Figure 17** shows how passage cross-sectional areas vary with distance from the surface; and **Figure 18** shows that passage cross-sectional area varies linearly with orientation relative to strike throughout the cave.

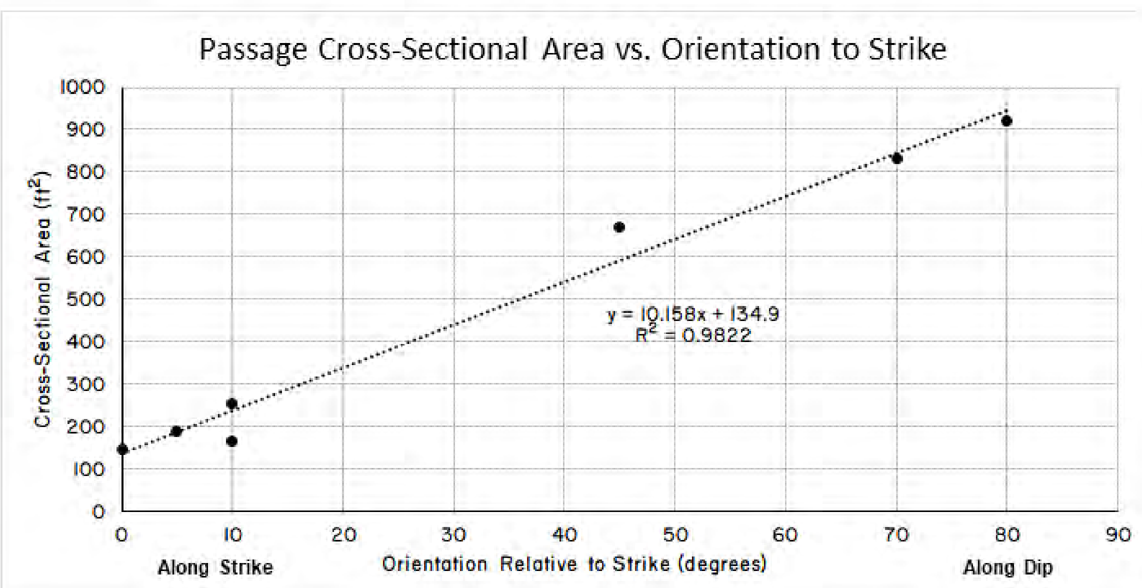

Figure 18. *Passage cross-sectional area versus orientation relative to strike. Passages trending along strike have the smallest cross-sectional areas while passages trending along dip have the greatest cross-sectional areas. This relationship is linear with an R^2 value of 0.9822 when looking at the passage orientation with respect to strike in degrees.*

Speleogenesis

Basics of Cave-Formation

Caves can form through a variety of processes ranging from mechanical to chemical dissolution. Mechanical processes include bedrock being fractured and moved by tectonic processes and/or gravity (White and Culver, 2019). Caves formed by these processes are known as tectonic caves. Differential erosion of bedrock layers at the surface may also create cave-sized openings (for example, Meadowcroft Rock Shelter). The most common caves are formed by dissolution of the bedrock by groundwater (White and Culver, 2019). Most of the caves in Pennsylvania are solutional. Solution caves most often form in limestone or dolomitic bedrock (White and Culver, 2019) as meteoric water sinking through the soil horizon becomes acidic and dissolves the carbonate bedrock. When bedrock has low permeability, groundwater transport is mostly through fractures and bedding planes in the rock that have higher permeability than the surrounding bedrock (White and Culver, 2019; White, 2019).

Multiple factors control how solutional caves form and their resulting geometry. These include local hydrology, lithology, structures, geochemical setting and topography (Gabrovšek, 2019). In a relatively homogenous bedrock, water saturation controls the morphology of passages as the cavern forms. Cave passages that form in the phreatic (saturated) zone typically have low overall gradient and a more tubular shape (Palmer, 2019). Cave passages that form in the vadose (unsaturated) zone have continuously descending profiles that consist of canyon passages interrupted by vertical shafts (Palmer, 2019).

Solution caves may also form in gypsum, salt or somewhat insoluble rocks such as quartzite or iron ore (White and Culver, 2019). These different lithologies lead to a range in karstification processes that rely on a combination of primary chemical and secondary mechanical weathering. Terms used for karst processes on bedrocks ranging from mostly carbonate to mostly silica include ghost-rock karstification, phantomization, and arenization. Ghost-rock karstification is the term used when not all the carbonate components are removed by chemical weathering. A less soluble fraction remains as the carbonate cement is dissolved. This less soluble fraction may contain sparitic crystals, fossils, quartz grains or clay minerals (Dubois and others, 2014). Phantomization is the term used for multicomponent rocks that are composed of minerals of varying solubility such as granites, arkoses, or carbonate-cemented sandstones (Wray and Sauro, 2017). As in ghost-rock karstification, a less soluble fraction remains after the more soluble components of the rock are removed by chemical weathering. Finally, arenization occurs when fluids with a high pH dissolve quartz overgrowths or cement in quartz sandstones or quartzites (Wray and Sauro, 2017). With such a high silica content, caves in the Loyalhanna Limestone are generally formed through phantomization, while conduits in the more carbonate-rich Wymps Gap and Deer Valley limestones may have formed through ghost-rock karstification.

Solution caves may have an upper zone known as epikarst perched above the main vadose zone (Klimchouk, 2000; Klimchouk, 2004). Klimchouk (2004) defines epikarst as the uppermost weathered zone of carbonate bedrock that has porosity and permeability significantly greater than the bulk rock mass below. Fractures may act as leakage paths from the epikarst zone to the vadose zone (Klimchouk, 2004). Epikarst cannot exist unless there is already an established vadose zone. Stress release and physical weathering are essential to initiating epikarstic development. The thicknesses of epikarstic zones vary greatly, but are generally less than 50 ft thick (Klimchouk, 2004).

Speleogenesis at Laurel Caverns

Laurel Caverns is primarily a solutional cave, but tectonic processes and gravity have also played a significant role in forming sections of the cave. Laurel Caverns formed in the Summit Dome of the anticline. Extensive cave development has occurred in domes in the Chestnut Ridge Anticline. Uplift of the domes led to erosion which lessened the confining stresses on the joints. Joints in the limestone were then further widened by dissolution of the carbonate cement (Iannacchione and Coyle, 2012).

The Upper Maze Cave formed under perched phreatic conditions in the epikarst zone. Water entered this section of the cave through the widened joints in the bedrock and the upper termini of passages near the surface. This water dissolved the carbonate cement but left insoluble sand grains. This process created 'phantom passages' (**Figure 9**). The remaining sand grains retain the original bedding and jointing of the bedrock and is referred to here as phantom bedrock. The groundwater was dispersed along joints via capillary action and resulted in passage formation along both strike and dip-oriented joints. The resulting passages have a smooth and undular appearance suggestive of phreatic development. Water flow removed the phantom bedrock resulting in different passage shapes in the two different orientations (**Figure 19**).

Strike and dip measurements by Ryan Maurer and Hope Brooks show that the dip of the bedrock in the Upper Maze Cave is 10.6 degrees. This dip increases to 15.7 degrees when at the upper end of the Middle Cave.

Figure 19. *Typical passage profiles in the Upper Maze Cave. Note the bedrock joints near the center of each passage. The profile of a dip passage is shown on the left. Water flowing down-dip has washed away some of the phantom bedrock at the base of this passage. The profile of a strike passage is shown on the right. Due to the lack of waterflow, the phantom bedrock makes flow floor in this passage. Passage profiles modified from Maurer, 2021.*

The passages in Middle Cave are all dip passages which, prior to modification for tourism, were canyon-shaped (**Figure 16**) similar to vadose passages in other caves. The fact that these passages trend down-dip and are steeper than passages in the Upper Maze section increased the rate of groundwater flow in the passages which resulted in larger passages (Schmidt, 1974).

The Flue is an extremely complex area formed via both solutional and tectonic processes. The Flue likely first formed as a network maze along joints and minor faults associated with the Upper and the Lower Faults. This development is evident throughout the middle of the three vertical levels of the Flue. The thrust faults serve as a path for water down to the contact with the impermeable Burgoon Sandstone, which led to removal of the (no longer cemented) phantom bedrock beneath these passages. It appears that the entire Flue section between the Dining Room, Ball Room, Hall of the Mountain King and Grand Canyon slumped 2-4 ft vertically downward around joint-bound blocks. This formed a large, wide, tectonic passage in the ceiling called the Upper Flue which is nearly 200 ft long, up to 80 ft wide, but only 2 to 3 ft tall. The Middle Flue experienced extensive tectonic alterations during this slumping and the entire middle section is a labyrinth of giant breakdown slabs with some solutional features.

Lower Cave formed primarily through a process of undercutting and block slumping after removal of the phantom bedrock. As in the Flue, joints also controlled the formation of some passages in this section of the cave. Below the Upper and Lower faults, water flows primarily occur along the contact between the Burgoon Sandstone and the Loyalhanna Limestone. The curving trunk passages formed primarily through a process of undercutting along the Loyalhanna-Burgoon contact and slumping of blocks (**Figure 20**).

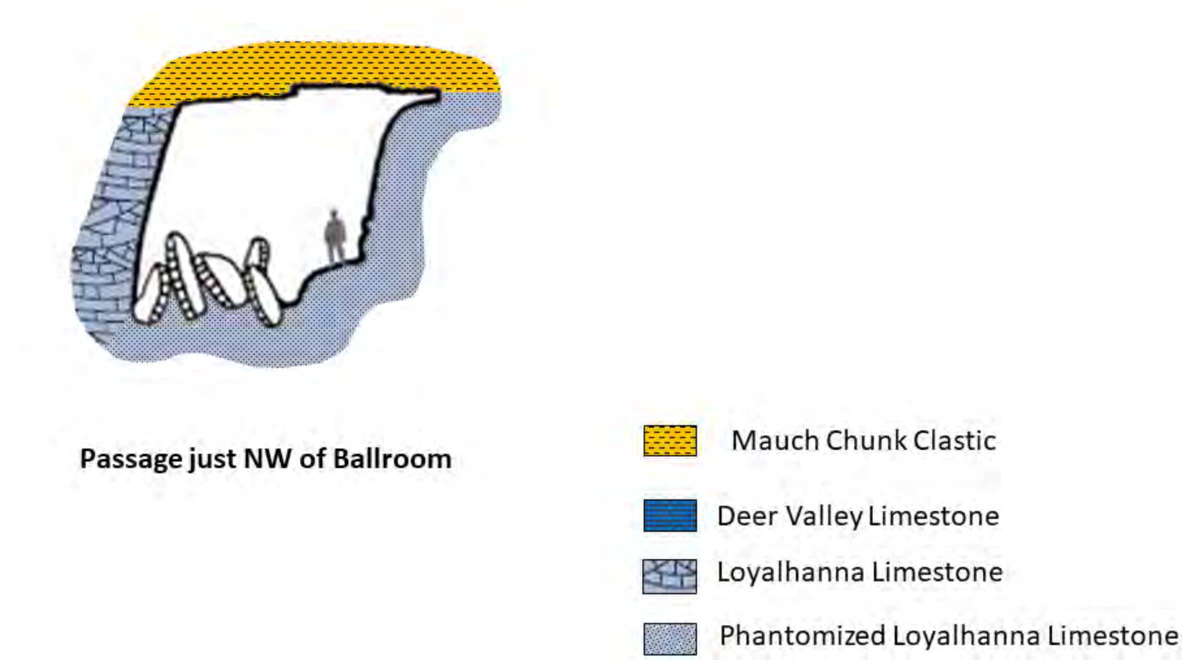

Figure 20. *Profile of a passage just northwest of the Ballroom below the Flue. Note the collapse of bedrock has exposed the sandstone in the Mauch Chunk formation in the ceiling. There are no joints associated with this passage. This passage is just beneath the Lower Fault. The passage is over 60-ft wide and is 26-ft high at this location. Passage profile modified from Maurer, 2021.*

Figure 21 shows a passage profile from the northwest end of the Mill Stream passage. This passage has an obvious joint in the ceiling and the Burgoon Sandstone forms the floor of the passage. Water flows along the contact with the Burgoon Sandstone in this passage.

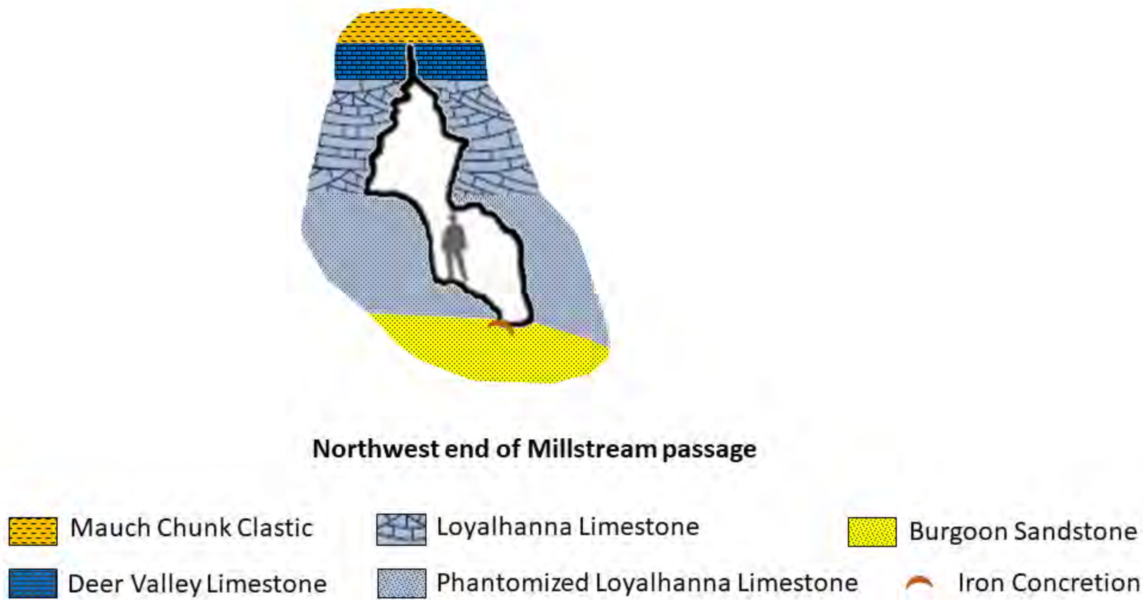

Figure 21. *Profile of dip passage at the northwest end of the Mill Stream passage. Note the bedrock joint in the Deer Valley limestone at the top of this passage. The Burgoon Sandstone forms the floor of this passage. Note the iron concretion at the Burgoon contact. Passage profile modified from Maurer, 2021.*

Conclusions

Laurel Caverns is a complex cave. A combination of solution and tectonic processes controlled the development of this cave. These processes were complicated by the high silica content in the Loyalhanna Limestone. In a process known as phantomization, cavern development first began by dissolution of the calcite cement in the siliceous Loyalhanna Limestone. This dissolution formed zones of higher permeability along joints and fractures in the bedrock and along the contact between the Loyalhanna Limestone and the impermeable Burgoon Sandstone although the groundwater did not reach this contact above the thrust faults. The cavern could not form until the (no longer cemented) phantom bedrock had been removed. A sandy spring at the contact of the Burgoon Sandstone and the Loyalhanna Limestone is a probable outlet for this phantom rock.

The deepest part of the cave, Lower Cave, formed first. This is the section of the cave that is closest to the sandy spring. Cavern development formed primarily through phantomization – a process of solution undercutting the bedrock and blocks slumping after removal of the silica grains by water flow. Much of the water in this section of the cave was sourced from the thrust faults in the Flue section. Water flow was concentrated at the contact between the Loyalhanna Limestone and the underlying impermeable Burgoon Sandstone. As the insoluble sand grains washed out of the cave, large blocks of Loyalhanna Limestone slumped, forming large rooms and branching trunk passages. This also facilitated the removal of sand grains along joints which opened the network maze passages that exist in Lower Cave.

Passages in the Flue first formed as network maze passages with passage orientations controlled by joints and minor faults in the bedrock. Faults in this section of the cave allowed groundwater to reach the contact between the Loyalhanna Limestone and the Burgoon Sandstone which lead to dissolution of the calcite cement in the Loyalhanna Limestone at this boundary. Removal of the resulting phantom bedrock led to later slumping which formed a large, wide, tectonic passage in the ceiling called the Upper Flue between the dip-oriented joints that formed the Hall of the Mountain King and Grand Canyon passages. This slumping combined with the dip of the anticline likely gave room for the phantom bedrock to wash out of the down-dip trending passages of Middle Cave.

The Upper Maze Cave was the last section of the cave to form. This section is a good example of epikarst, the uppermost zone of carbonate bedrock with enhanced permeability. After removal of the phantom bedrock, Middle Cave became an established vadose zone. When the phantomized joints of the Upper Maze Cave connected with the down-dip passages of Middle Cave, groundwater was able to remove the residual phantom bedrock in the Upper Maze Cave.

Laurel Caverns formed along the flank of an anticline in carbonate bedrock sandwiched between two aquitards. At first glance, this looks like a relatively simple situation in which to form a cave. However, this was complicated by the silica-rich composition of the carbonate bedrock as well as prominent joints in the bedrock, faulting in the anticline, and the dip of the beds. The silica-rich composition of the Loyalhanna Limestone forced the cave to be formed through the process of phantomization. First dissolution of the carbonate cement formed zones of greater permeability along faults and joints in the bedrock and at the contact between the Loyalhanna Limestone and the impermeable Burgoon Sandstone. This dissolution created phantom bedrock which was later removed by groundwater flow. The dip of the anticline facilitated removal of the phantom bedrock by groundwater. Transport along the thrust faults allowed the water to reach the contact of the Loyalhanna Limestone and the Burgoon Sandstone. Low on the side of the anticline, the Lower Cave was closest to an outlet for removal of the insoluble silica grains and this section of the cave formed first. Next, the Flue formed in the section of the cave with the most thrust faults. Slumping in the Flue allowed the phantom bedrock in the Middle Cave to wash away and this in turn allowed the phantom bedrock in the Upper Maze Cave to wash out.

Acknowledgements

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NATURAL GAS STORAGE
IN NORTH SUMMIT STORAGE FIELD

John A. Harper – Pennsylvania Geological Survey, retired

Introduction

Anyone driving along Skyline Drive at the crest of Chestnut Ridge between Laurel Caverns and US 40 would have to be completely unobservant to not notice the multitude of unusual looking equipment hiding in plain sight in clearings on both sides of the road. This equipment belongs to a natural gas storage field called North Summit, part of what once was a series of old natural gas-producing fields and pools on the ridge.

One of the more accessible gas storage well sites lies on the northwest side of Skyline Drive approximately 2 km (3.5 mi) northeast of Laurel Caverns. The well site includes a variety of equipment surrounding a gas storage well originally drilled as a producing gas well (**Figure 1**). This is the Dominion Transmission Inc. #1 R. E. Eberly gas storage well, originally drilled on the William Johnson lease between September 1, 1938 and April 6, 1939 as the New Penn Development Co. #1 Indian Creek Coal & Coke Company gas well (drilled in partnership with William T. Snee). It was the third well drilled by the partnership. Although originally planned as a Middle Devonian Oriskany Sandstone well, by March 11, 1939 it was producing about 900 thousand cubic feet of gas (Mcfg) from 35 m (115 ft) into the Middle Devonian Huntersville Chert. When the well finally reached the Oriskany Sandstone at 2,165 m (7,103 ft), they found the sandstone was dry. The well produced for many years before Consolidated Natural Gas Corp. (CNG) acquired the lease and converted it to gas storage in the early 1990s.

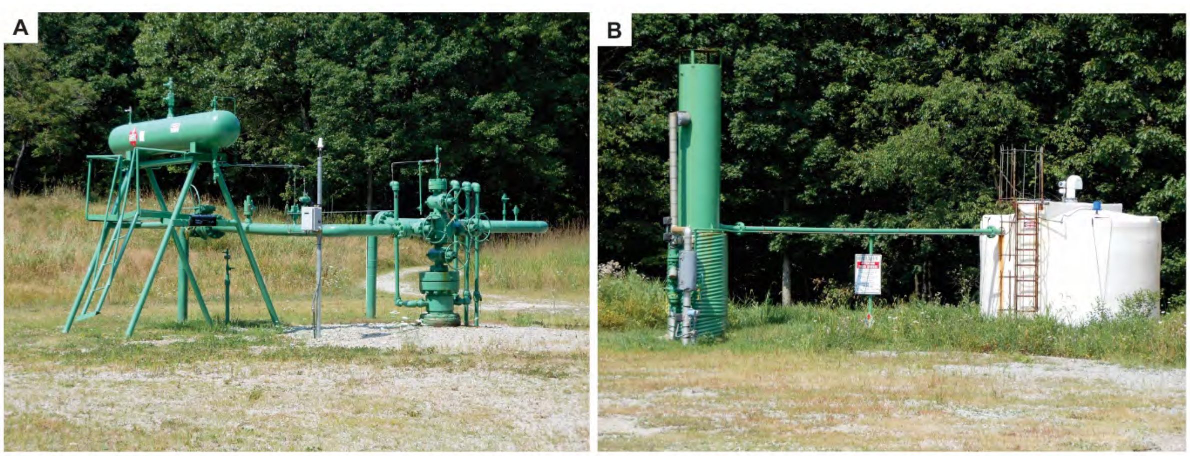

Figure 1. *Photographs of the Dominion Transmission Inc. #1 R. E. Eberly gas storage well (API# 3705100093-R) and attendant equipment. This originally was the New Penn Development Co. #1 Indian Creek Coal & Coke Co. producing gas well, drilled in 1938 and 1939. Left – the gas well's "Christmas tree" is on the right; Right – a fluids separator and storage tank*

North Summit Storage Field

North Summit Storage field (**Figure 2**) is located about 6.5 km (4 mi) southeast of Uniontown on the Chestnut Ridge anticline. Summit field, as it was originally called, was discovered in 1937 with the completion of the Snee and New Penn #1 Leo Heyn well near the Summit Inn on US 40 (**Figure 2**).

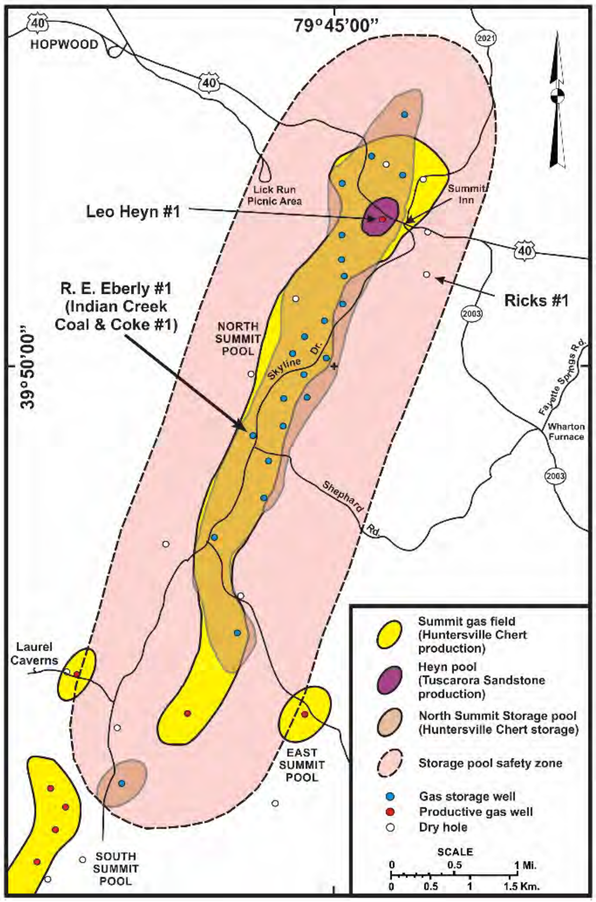

Figure 2. *Map of North Summit Storage field (based on Shumaker, 2002, and files of the Pennsylvania Geological Survey). Wells mentioned in the text are identified.*

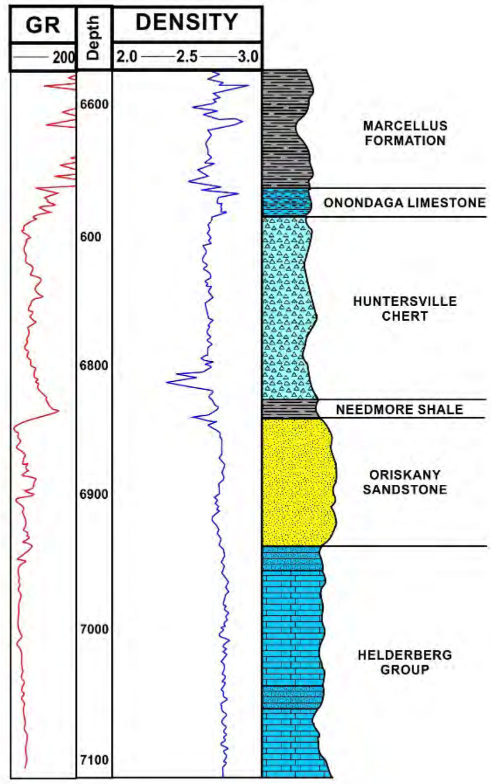

Figure 3. *Stratigraphic section from the Middle Devonian Marcellus Formation to the Lower Devonian Helderberg Group in the North Summit Storage field (modified from Shumaker, 2002). The original target of drilling in the area was the Oriskany Sandstone, but gas was found instead in the fractured Huntersville Chert.*

Discovery of the field was the result of the anticlinal theory (Galey, 1985), which states that oil and gas should be found by drilling at the crest of an anticline (Galey, 1985). The Heyn well was spudded using a cable-tool rig on the topographic crest of the mountain and was completed on April 23, 1937 with an initial open flow of 2,000 Mcfg and a pressure of 4,478 psi at a depth of 2,015 m (6,611 ft) in the Middle Devonian Huntersville Chert (Figure 3). With that discovery, development of the field proceeded rapidly, with 14 producing wells and several dry holes defining the limits of the reservoir. In 1943, the Heyn well was drilled deeper to 2,139 m (7,019 ft), then to 2,576 m (8,450 ft) in 1944. Tests reported 100 Mcfg containing hydrogen sulfide in the Helderberg limestones at 2,189 to 2,195 m (7,183 to 7,200 ft) and 650 Mcfg at 2,225 to 2,239 m (7,300 to 7,345 ft) in the Upper Silurian Tonoloway (below the Helderberg). These shows were not enough for a commercial well, however, so in 1964, the well was once again deepened, this time to 3,527 m (11,571 ft) to test the Lower Silurian Tuscarora Sandstone. The well supposedly flowed 2,000 Mcfg in the Tuscarora after hydraulic fracturing, but the gas tested at only 865 BTU. Normally, natural gas has a BTU value of about 1,000 with a composition that includes greater than 90% methane, a few percent ethane, and trace amounts of other hydrocarbons. The Tuscarora gas had only 82% methane and 2% ethane. Fully 15% of the gas composition was nitrogen, whereas in a normal natural gas the nitrogen content typically is less than 1%. Between the high nitrogen content and other troubles with the well, it was plugged and abandoned on August 16, 1964. In 1967, another Tuscarora test was conducted in the Snee #1 Ricks well, which was deepened to 3,670 m (12,041 ft) on the east flank of the surface fold about 1.6 km (1 mi) southeast of the Heyn well (**Figure 2**).

Subsequent drilling on Chestnut Ridge discovered additional pools on separate fault blocks, prompting the original producing area to be called North Summit pool in Summit field. The North Summit pool was converted to natural gas storage during the 1990s by Consolidated Natural Gas Company (CNG). It is now operated by Dominion Transmission, Inc. Natural gas is pumped into the reservoir in the off-peak season and stored for periods of peak usage. An extensive series of pipelines connects the field with suppliers in the southwest and consumers in the northeast.

Stratigraphy

The primary producing and storage formation in North Summit field is the Middle Devonian Huntersville Chert (**Figure 3**). This formation occurs primarily in western Pennsylvania and West Virginia, with the best development south of Clarion and Jefferson counties, Pennsylvania. In general, the formation grades eastward into the Needmore Shale, northward into the Clarence Member of the Onondaga Limestone, and westward into the Bois Blanc Formation. Lithologically, it is typically microcrystalline, massive, and hard, varying from translucent to opaque, and in color from white to dark brown and dark gray. It commonly includes some dolomite, quartz, glauconite, pyrite, calcite, and trace fossils (Flaherty, 1996). Sherrard and Heald (1984) considered the Huntersville to be of biogenic origin because of the large quantities of sponge spicules present throughout the formation. Because it lacks feldspathic and pyroclastic material, a volcanic origin is unlikely. Basan and others (1980) suggested the formation resulted from diagenetic replacement of carbonate sediment, indicated by replacement of skeletal calcite, relict carbonate fabrics, and gradation from solid chert to siliceous limestone (and to nodular chert in the Bois Blanc to the west.) The Huntersville varies in thickness from less than 30 m (100 ft) near the northern limit in Forest and Elk counties to more than 76 m (250 ft) in Greene County, Pennsylvania, and Monongalia County, West Virginia.

The Lower Devonian Oriskany Sandstone acts as a secondary reservoir throughout most of the area where the Huntersville Chert occurs. It is typically a light gray, medium- to coarse-grained quartz sandstone. The grains commonly are cemented with calcite or silica (Edmunds and Berg, 1971; Flaherty, 1996). The formation ranges from about 5 m (17 ft) thick in the northern and western parts of western Pennsylvania to 73.5 m (241 ft) thick in southeastern West Virginia, averaging 20.7 m (68 ft) (Flaherty, 1996).

Geologic Structure

Campbell (1902) described and named the Chestnut Ridge anticline based on surface stratigraphic units found on the topographic ridge. Structural relief at the surface is about 914 m (3,000 ft) into the Uniontown syncline on the northwest, but only about 610 m (2,000 ft) into the Ligonier syncline on the southeast (Cathcart and others, 1939; Shaulis and McElroy, 1988). Surface rocks basically are unfaulted, but Hickok and Moyer (1940) found a small southeast-dipping reverse fault along old US 40 on the west flank of the fold and Shumaker (2002) found a small, west-dipping reverse fault in the Mauch Chunk and Loyalhanna section at a quarry about three miles northwest of Summit. Joints in the exposed sandstones and limestones on the anticline form an orthogonal system (Hickok and Moyer, 1940). Coal cleats are close to parallel with joint trends in other rocks.

At depth, the gas reservoir is complexly faulted. Gwinn (1964) provided a structural map of the area (**Figure 4**) and a generalized cross section across the anticline to the south of North Summit Storage field (**Figure 5**) and indicated that the thrust faults in his diagram extend northward through the storage field. Gwinn (1964) emphasized the concept that Oriskany and Huntersville reservoirs were broad folds formed from fault sheets thrust over a depressed core. This model of a broad surface fold,

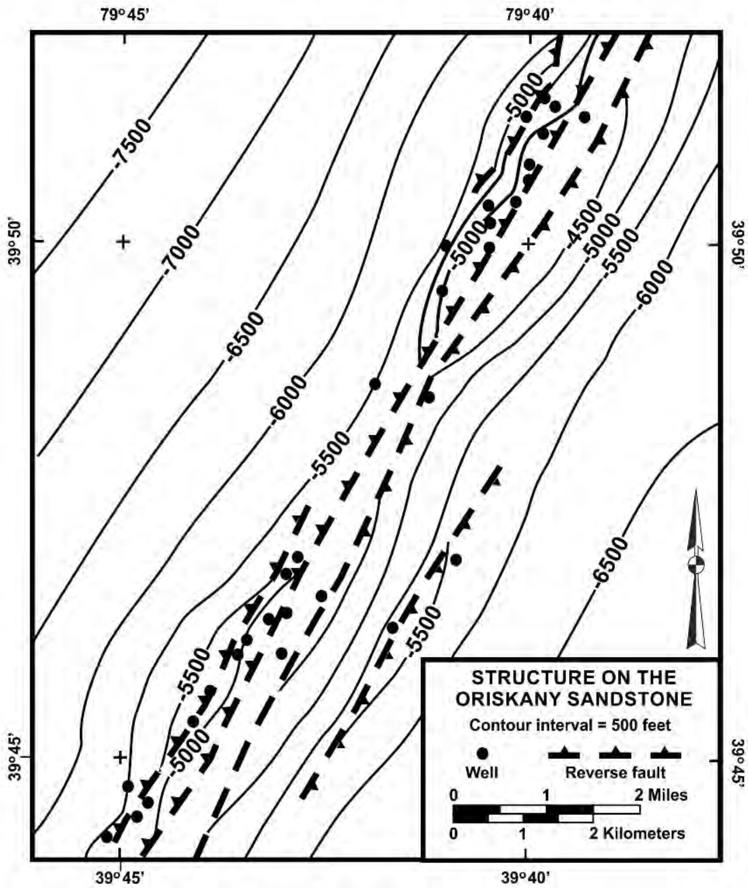

Figure 4. *Subsurface structure map of the North Summit Storage field and South Summit pool area on Chestnut Ridge anticline. Redrawn from Gwinn (1964).*

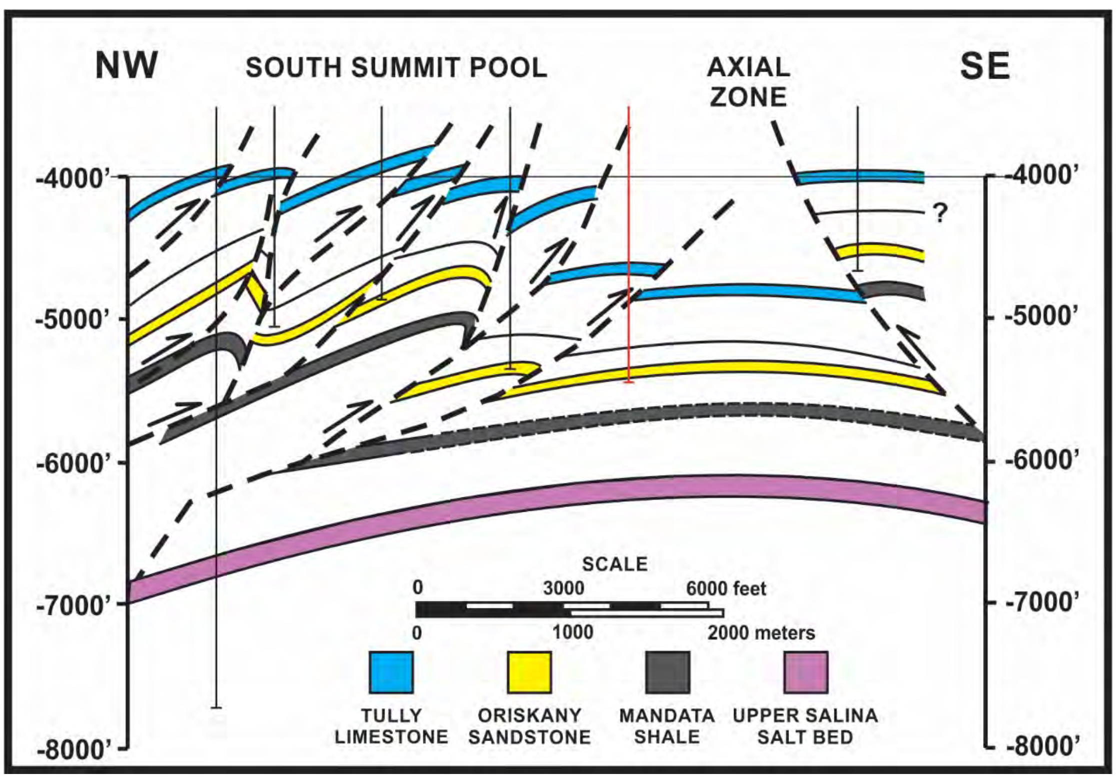

Figure 5. *Cross section of Chestnut Ridge at South Summit pool south of North Summit Storage field showing Vinton Gwinn's concept of Appalachian Plateau folds. At depth, the anticline is interpreted as a graben overstepped by thrust sheets splaying off the detachment fault in the Upper Silurian Salina salt beds. Redrawn from Gwinn (1964).*

cored by outward-dipping flank thrusts adjacent to a relatively undeformed and depressed axial zone, has been widely accepted for Appalachian Plateau anticlines for many years (see for example, Harper, 1989; Harper and Patchen, 1996).Gwinn's cross sections suggest that rocks above the Salina detachment deformed as a single lithostructural unit. Gwinn also indicated that Oriskany and Huntersville gas in Appalachian Plateau structures was trapped by sealing faults in an imbricated reservoir. Interpretations vary regarding the stratigraphic level of the primary detachment horizon under the Allegheny Mountains. Gwinn (1964) suggested that the Chestnut Ridge anticline is detached at the level of both the Upper Ordovician Utica and Reedsville shales and the Salina salt beds. He also postulated that those folds detached in the Utica and Reedsville determine the location of folds above the Salina salt beds in the Allegheny Mountains of Pennsylvania and West Virginia. In addition, Shumaker (2002) pointed out that shales of the Middle Cambrian Rome Formation form an important basal detachment horizon in high-relief folds of the Allegheny Mountains adjacent to the Allegheny Front in West Virginia, so this detachment should not be ignored.

Shumaker (2002) used new data, particularly new seismic sections and modern geophysical logs run by CNG in both old wells and newly drilled ones, to reinterpret the structure of Chestnut Ridge anticline at the level of the Huntersville Chert and Oriskany Sandstone. His analysis showed that Gwinn's (1964) faulted and depressed axial zone is actually an anticlinal fold (compare **Figure 5** with **Figures 6 and 7**). The crest of the subsurface anticline follows the crest of the surface anticline!

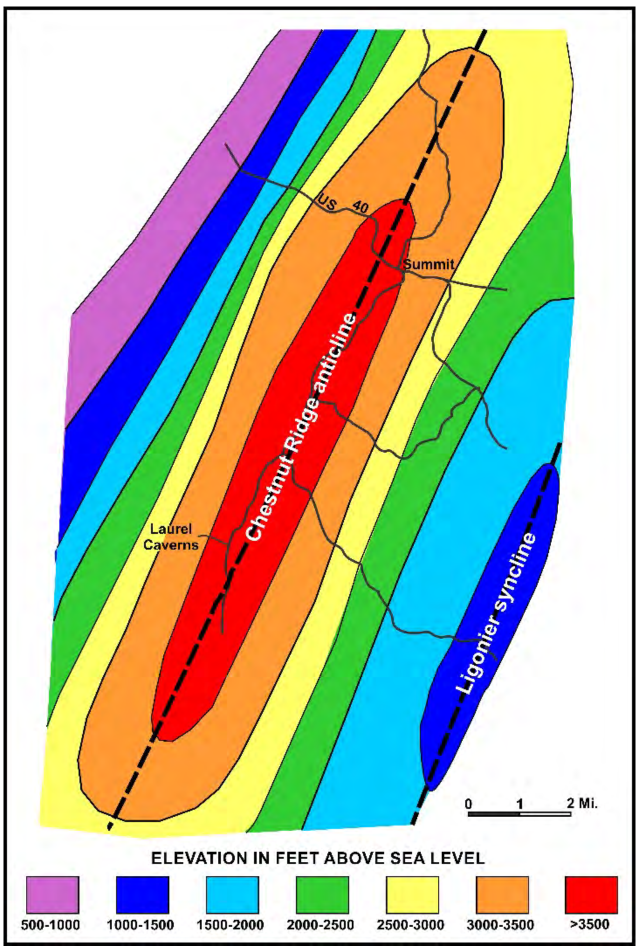

Figure 6. Surface structure of Chestnut Ridge southeast of Uniontown. Structure contours on the Middle Pennsylvanian Upper Freeport coal, Allegheny Formation, are estimated in most places. Based on Shaulis and McElroy (1988) and Shumaker (2002).

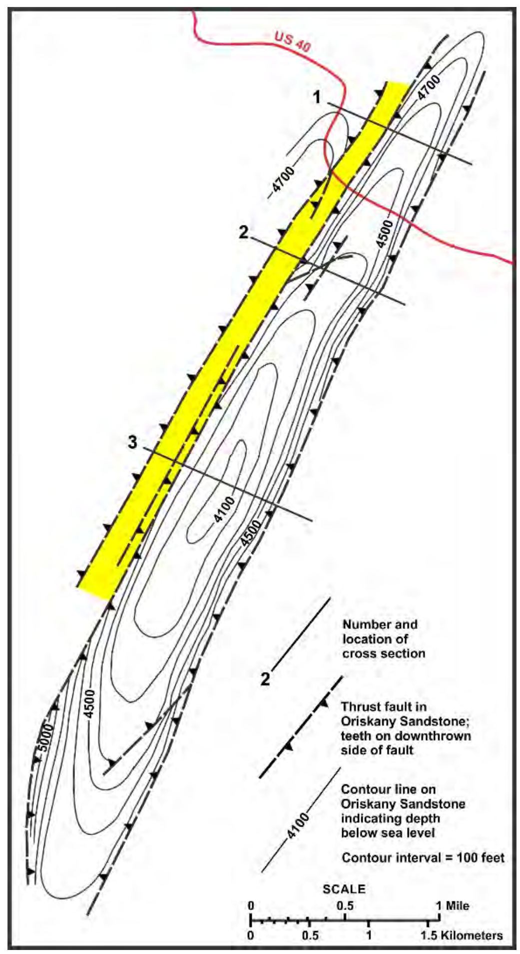

Figure 7. Structure map of Chestnut Ridge on the Lower Devonian Oriskany Sandstone (modified from Shumaker, 2002). Compare with Figure 6. Numbered lines represent cross sections shown in Figures 8 to 10.

New data from several wells confirm the presence of a structural high west of the central anticline, but that they are separated by a deep structural low (**Figure 7**). Shumaker (2002) provided three cross sections of the anticline interpreted from all of the new data (**Figures 8 to 10**) that show Chestnut Ridge is far more structurally complex at depth than previously suspected. Mull these illustrations over for a while and see if you develop a headache!

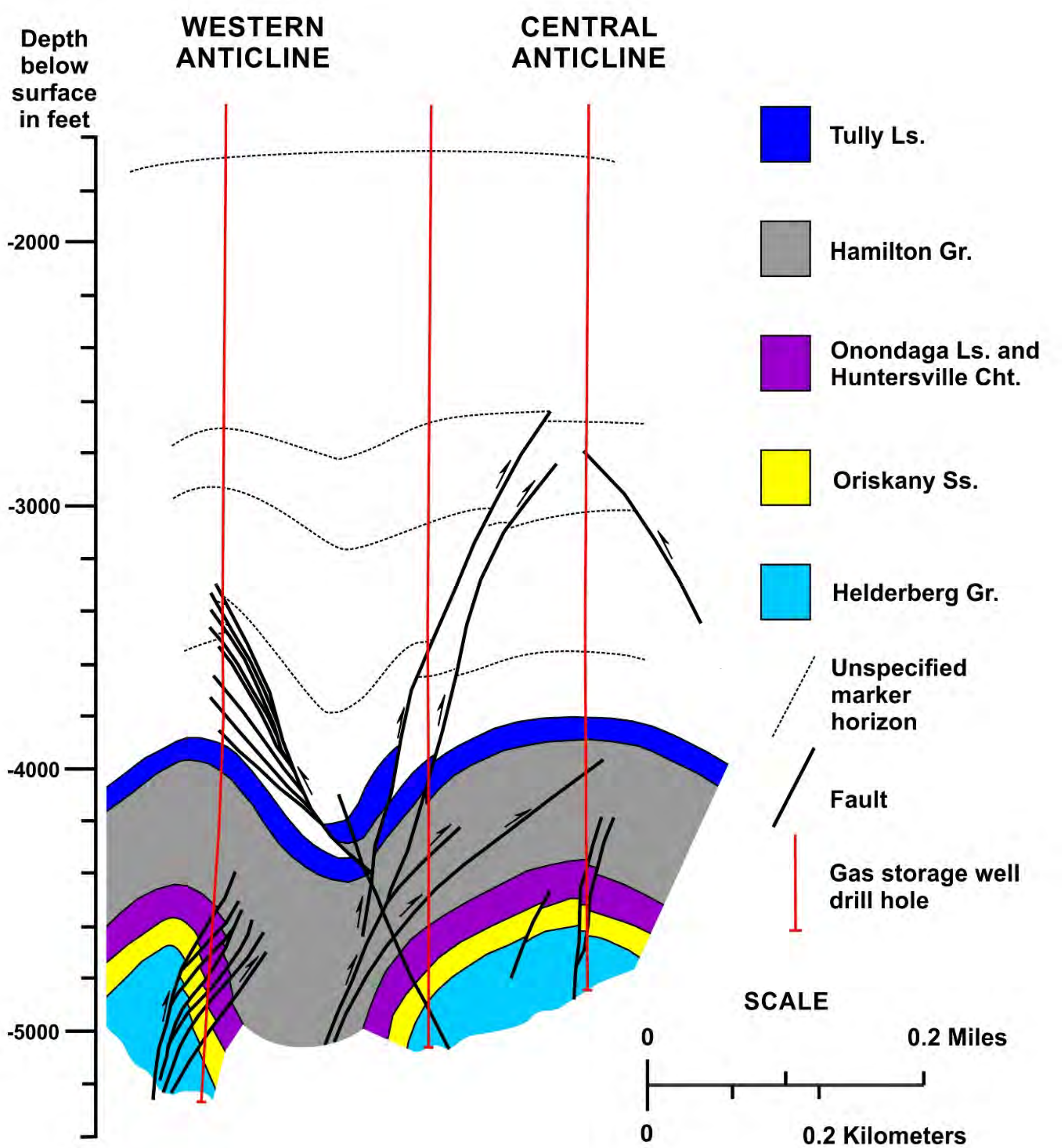

Figure 8. *Cross section 1 (see Figure 7 for location). Redrawn from Shumaker (2002).*

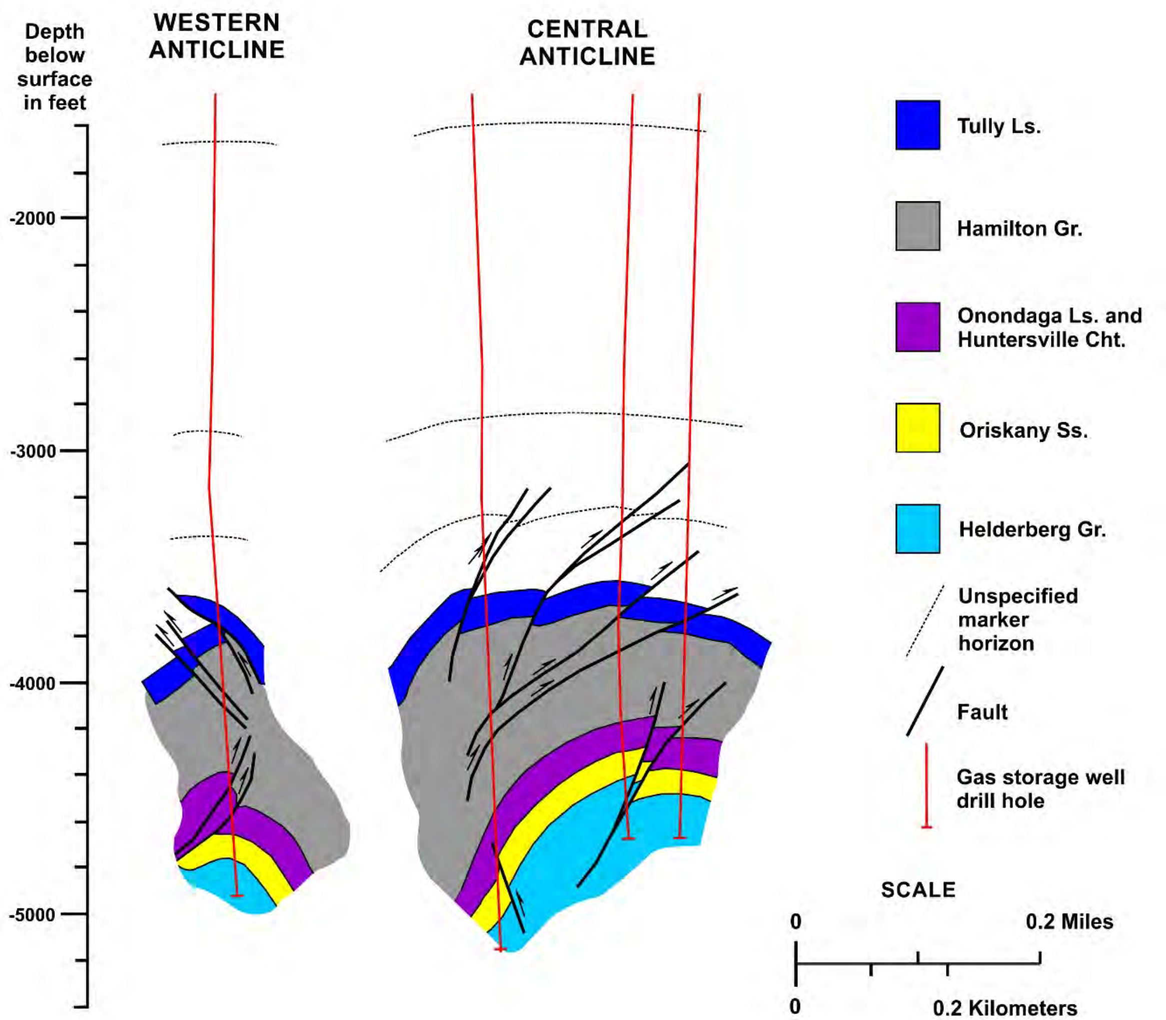

Figure 9. *Cross section 2 (see Figure 7 for location). Redrawn from Shumaker (2002).*

The strata above the Middle Devonian Tully Limestone are far less deformed than the rocks below it. Wiltschko and Chappel (1977) suggested that most of the deep faults splaying off the Salina detachment were absorbed by the Upper Devonian shales and did not extend above the Tully. Although the frequency of faulting is far less at the surface than at depth, there are faults in the shallow (Pennsylvanian and Mississippian) strata along Chestnut Ridge. Whether these are extensions of the Lower and Middle Devonian faults, or are merely mimicking them, is unknown.

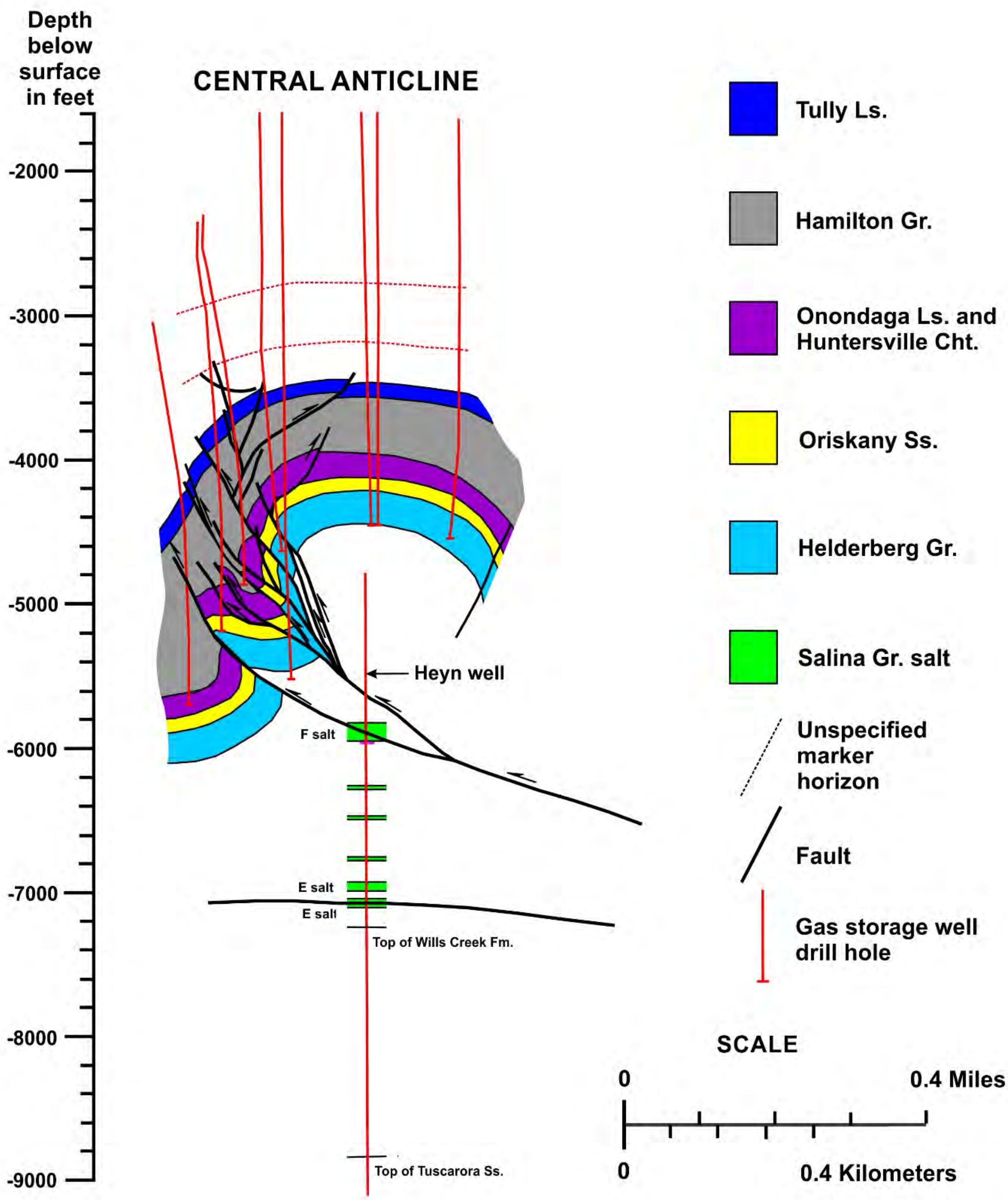

Figure 10. *Cross section 3 (see Figure 7 for location). Redrawn from Shumaker (2002).*

Acknowledgments

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We wuz drillin' through a purty thick lime rock at
300 feet when the bit hit a cavern apparently used
by the local brewery fer housin' their storage vats!
Now nobody gives a damn what the price of oil is!

BAKERSVILLE QUARRY

NEW ENTERPRISE STONE & LIME CO.

ROUTE 31, JEFFERSON TOWNSHIP, PENNSYLVANIA

CHRISTOPHER COUGHENOUR AND STEPHEN LINDBERG – UNIVERSITY OF PITTSBURGH, JOHNSTOWN

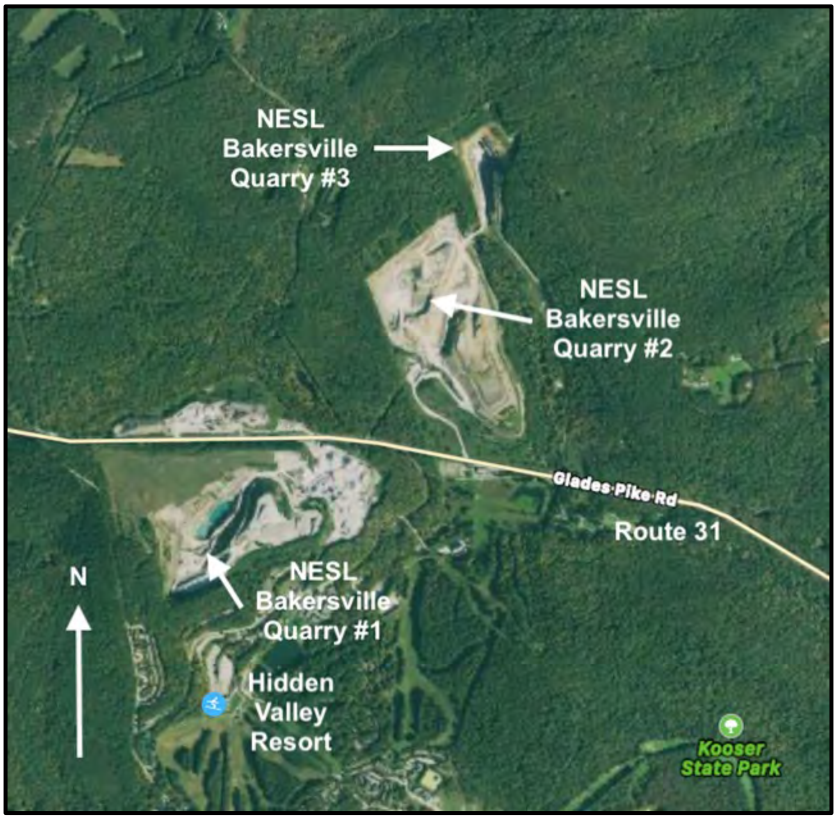

Figure 1. *Location of NESL Bakersville, Pa. quarry along route 31 west of Somerset, Pa. showing location of Bakersville quarries 1,2, and 3. Modified from Google Maps, (2021).*

Introduction

The New Enterprise Stone & Lime Co., Bakersville Quarry is located on Route 31, Jefferson Township, Pennsylvania (**Figure 1**). The target unit is the Loyalhanna Limestone and the facility consists of three quarries; Bakersville #1 was first quarried in the 1940's and is currently inactive. Some Burgoon Sandstone was also quarried here. Bakersville #2, also inactive, was supplanted by Bakersville #3 which is the first subsurface mining operation onsite. Strata exposed at the Bakersville quarries include the Upper Mississippian Burgoon Sandstone (an upper Pocono Formation equivalent), and the lower units of the Mauch Chunk Formation, including the desired Loyalhanna Limestone member (**Figure 2**).

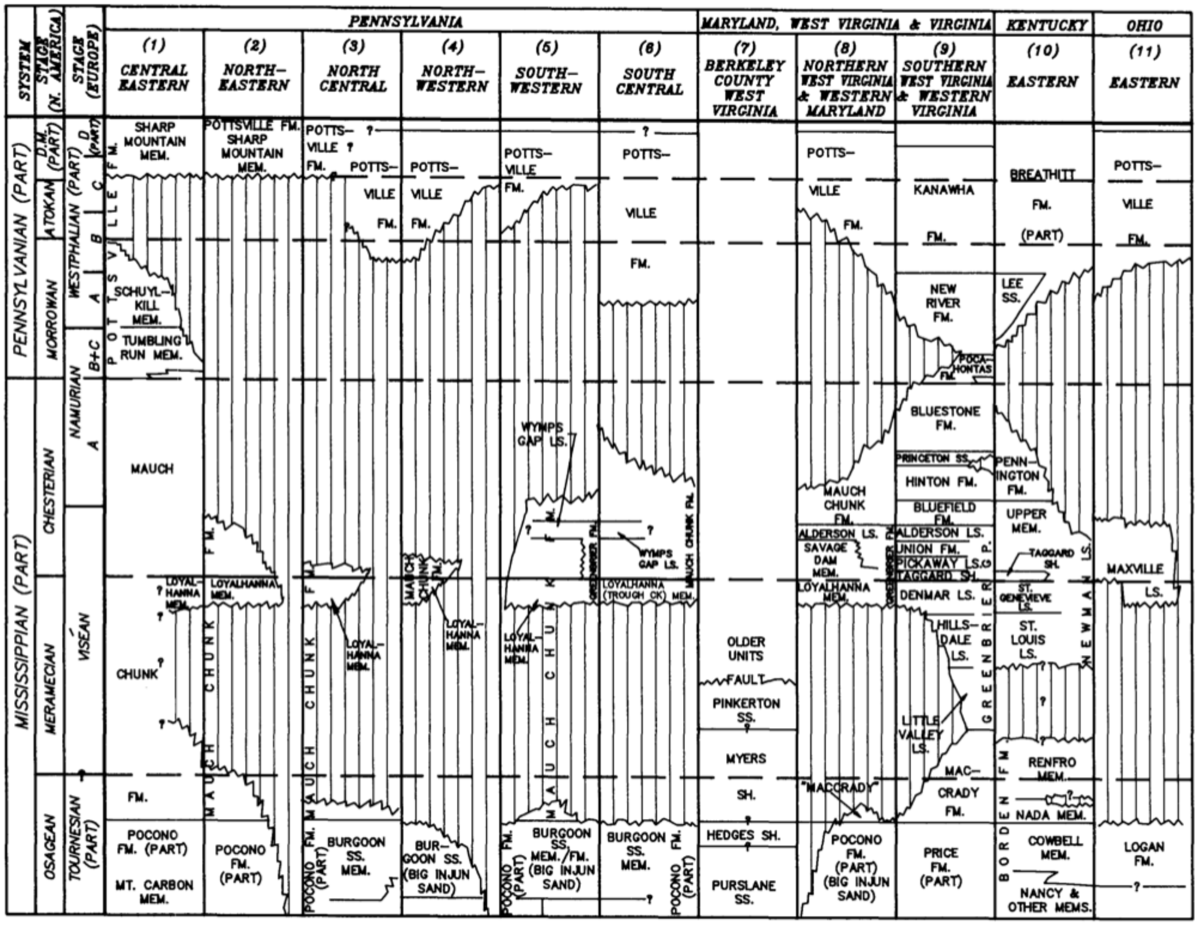

Figure 2. Stratigraphic column showing correlations between Middle and Upper Mississippian and Lower and Middle Pennsylvanian within the central Appalachians. Modified from Edmunds et al., (1979).

Mississippian Stratigraphy at Bakersville

The Burgoon Sandstone (at Bakersville #1)

The basal unit exposed at the first quarry is the Burgoon Sandstone, named for the thick exposures found along railroad tracks in Sugar Run Valley near Horseshoe Curve in Blair County, Pennsylvania (Butts, 1904). Butts (1904) described the Burgoon at the type locality as a "…coarse and very thick-bedded gray sandstone…". It generally exhibits prominent cross-bedding and scour-fill sequences with basal lag (Harper & Laughrey, 1987). The unit is generally ~100-300 ft thick.

At Bakersville #1, the uppermost 25 feet of Burgoon SS are exposed (**Figure 3**). Three lithofacies are recognized at this quarry:

Facies 1 is predominantly a blocky, quartz-rich, buff-colored sandstone with some decimeter-scale gray micaceous sandstone interbeds that exhibit thin, flaggy partings in float. Visible thickness above the quarry floor varies from ~2.5-3.5 m.

Facies 2 contains shale rip-ups as part of an intraformational shale cobble breccia embedded in a micaceous sandstone (litharenite) of a grayish-green color (**Figure 4**). Maximum thickness (at east-facing highwall) is ~2.5 m. Elongated rip-ups show strong preferential orientation (~horizontal). At Bakersville #1, facies 2 lies atop an apparent concave bounding surface visible in the east-facing highwall.

Facies 3 is a lighter gray colored sandstone (sometimes weathered to reddish brown) that generally displays massive bedding. It tends to form large blocks in outcrop and total thickness is about ~2.5 m thick here.

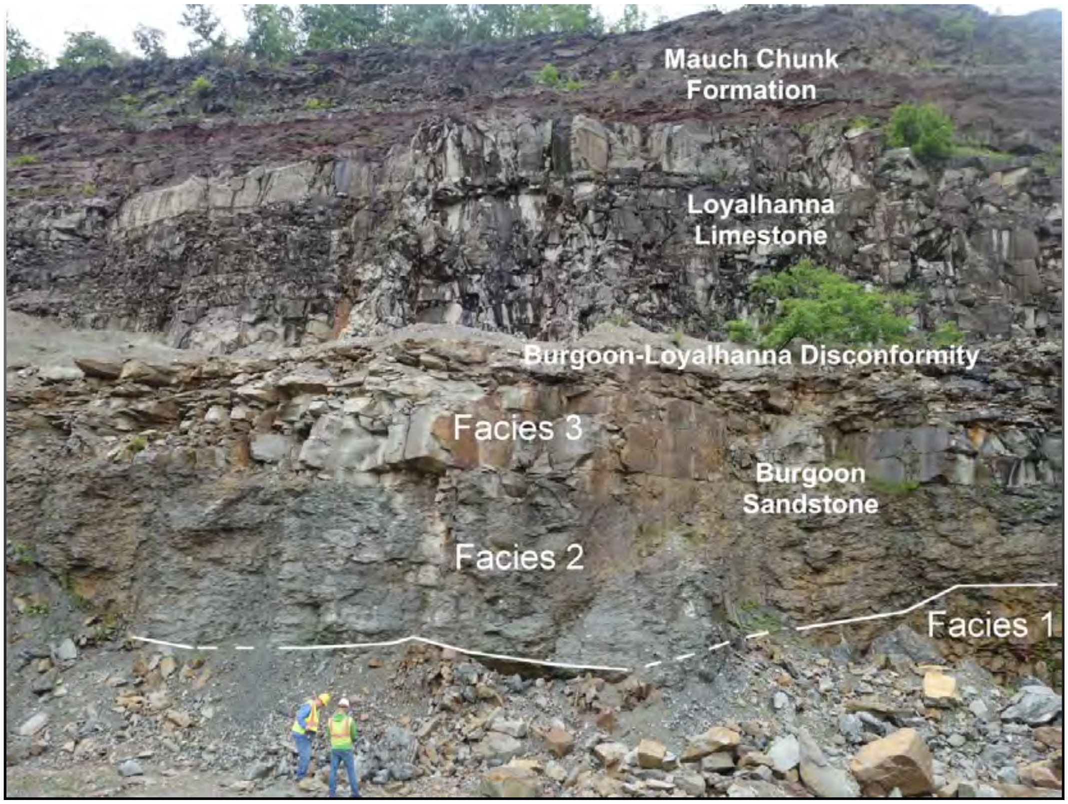

Figure 3. *Bakersville #1 quarry showing Burgoon Sandstone, Loyalhanna Limestone and lower beds of the Mauch Chunk Formation. Photo by C. Coughenour, June, 2021.*

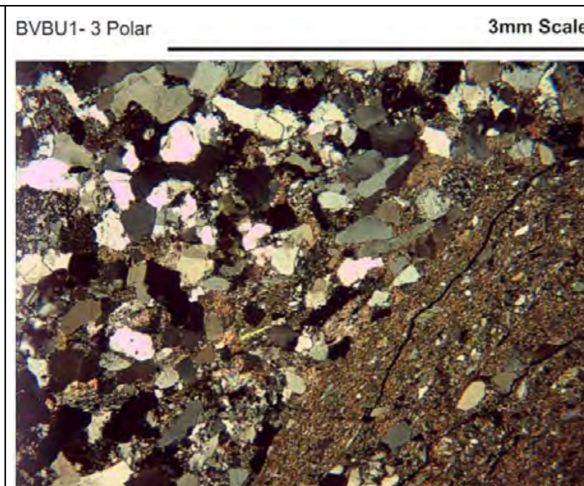

Figure 4. Left: *Talus at base of Bakersville #1 showing facies 2 shale rip-ups as part of an intraformational shale cobble breccia. Length of pencil 14 cm. Photo by S. Lindberg, June, 2021.* ***Right:*** *Photomicrograph under polarized light of facies 2, showing litharenite matrix to the left and shale intraclast on right. Photo by C. Coughenour and J. Breyer of PA Geological Survey thin section.*

The depositional environment of the Burgoon SS appears to be that of a sandy, bedload-dominated system. Overall, there is predominance of sands and general lack of extensive fine-grained deposits generally associated with well-developed overbank environments associated with meandering. Fossils are primarily seed fern fragments. Scour-fill sequences with basal lags are common, such as that in facies 2 overlying a 5th order concave bounding surface (channel erosional surface). Paleocurrent analysis (Pelletier, 1958) shows paleocurrents moving west from eastern source areas. All this suggests the Burgoon was deposited in a sandy, bedload-dominated system. Cotter (1978) assumed a braided fluvial complex, while Edmunds et al. (1979) suggested an anastomosing deltaic sequence.

Burgoon-Loyalhanna Ages and Boundary

The Burgoon SS has few fossils for biostratigraphic age placement. Pteridosperm ("seed fern") remnants, originally thought to be Triphyllopteris which date to the Osagean Stage, are no longer assigned to the genus. Strata underlying the Burgoon SS (unconformably) are earliest Kinderhookian (Harper & Laughrey, 1987), leaving the poorly-constrained likely age range for the Burgoon sometime between ~350-340 Ma (i.e. between the later Kinderhookian, through the Osagean, and possibly into the early Meramecian).

The Loyalhanna LS interval in Pennsylvania has generally been placed in the latest Meramecian to mid Chesterian Stage (~335-325 Ma) based on lithostratigraphic correlations with the Greenbrier Fm in northern West Virginia and western Maryland (see Edmunds, 1993). Conodont-based ages from the region and correlative units (e.g. Greenbrier Fm) yield an early to mid Chesterian age (see Ahlbrandt, 1995).

The Burgoon-Loyalhanna contact is generally thought to be disconformable in south-central and western PA with a sharp change in lithology, perhaps representing a gap of ~5 million years in the record based on evidence outlined above for depositional ages (note: a few areas in the region are reported to show a conformable boundary; see Brezinski, 1989).

The Loyalhanna Limestone

The Loyalhanna Limestone member of the Mauch Chunk Formation was named for exposures along Loyalhanna Creek in Westmoreland County, Pennsylvania (Butts, 1904). At Bakersville and other locations across southwestern Pennsylvania the Loyalhanna often lies disconformably on the Burgoon Sandstone. With an average thickness of 60-70 feet here in the region, the Loyalhanna is easily recognizable. as a grayish green to light gray "sandstone", varying from calcarenite (>50% carbonate) to calcareous sandstone (<50% carbonate). At outcrop scale, 1 facies predominates and is composed internally of large-scale cross-beds (foresets), while set surfaces are generally curvilinear yielding trough/festoon cross-bedding. Differential weathering accentuates bedding on older exposed surfaces as carbonate is dissolved and color is altered to brown (at Bakersville #1). Loyalhanna-type facies have numerous interbeds with red mudstones near the top of the mineable Loyalhanna interval, with red beds forming laterally discontinuous lenses initially and tending to more laterally extensive deposits higher in section.

Depositional environment for the Loyalhanna has long been debated. One hypothesis states that the Loyalhanna is marine in origin, and was deposited on a estuarine shelf as a sand wave complex by strong tidal currents, helping to explain the presence of marine invertebrates in some locations (e.g. Brezinski, 1989). The unit has also been interpreted as representing an aeolian sand "sea" based on interpretation of sand flow toes and similar features in outcrop (e.g. Ahlbrandt, 1995).

At Bakersville the Loyalhanna Limestone is the primary unit being mined for use as aggregate stone in the production of hot asphalt mix. PennDOT rates the Loyalhanna Limestone as having a superior Skid Resistance Level (SRL) of "E" when used for bituminous wearing surfaces on roadways with Average Daily Traffic (ADT) of 20,000 and above (PennDOT, 2021). New Enterprise Stone and Lime is a major supplier of Loyalhanna Limestone aggregate to PennDOT.

Mauch Chunk Formation

Named for the exposures in the vicinity of Mauch Chunk (Jim Thorpe), Carbon County, Pennsylvania, the lower units of the Mauch Chunk Formation are well exposed in all three Bakersville quarries, with approximately 40 feet exposed in each quarry. The lower Mauch Chunk here in southwestern Pennsylvania consists of the interval between the bottom of the Wymps Gap Limestone member and the top of the Loyalhanna Limestone. The lower Mauch Chunk consists of marine and nonmarine units characterized by gray-green sandstones of the Loyalhanna member interbedded with red brown and gray green mudstones (Brezinski, 1989). The interpreted environment of deposition for the Mauch Chunk alternates between alluvial plain, fluvial channel, intertidal, subtidal, supratidal and beach..

Bakersville #3 Subsurface Mine

The Loyalhanna Limestone at Bakersville #3 has an approximate thickness of 60 feet. Measurements based on drill holes indicate a strike of N14E and dip of 2.9 degrees to the southeast (Stairs). The lengthy process of permitting for Bakersville #3 subsurface Loyalhanna Limestone mine began in 2009 with surveying, coring and hydrological assess-ment overseen by Earthtech, Inc of Somerset, PA with Ryan Stairs, P.G. as principal geologist. In 2011-2012 the permits were cleared for mining; and active removal of the Loyalhanna began in 2015. The permitted mining area covers 209 acres (**Figure 5**).

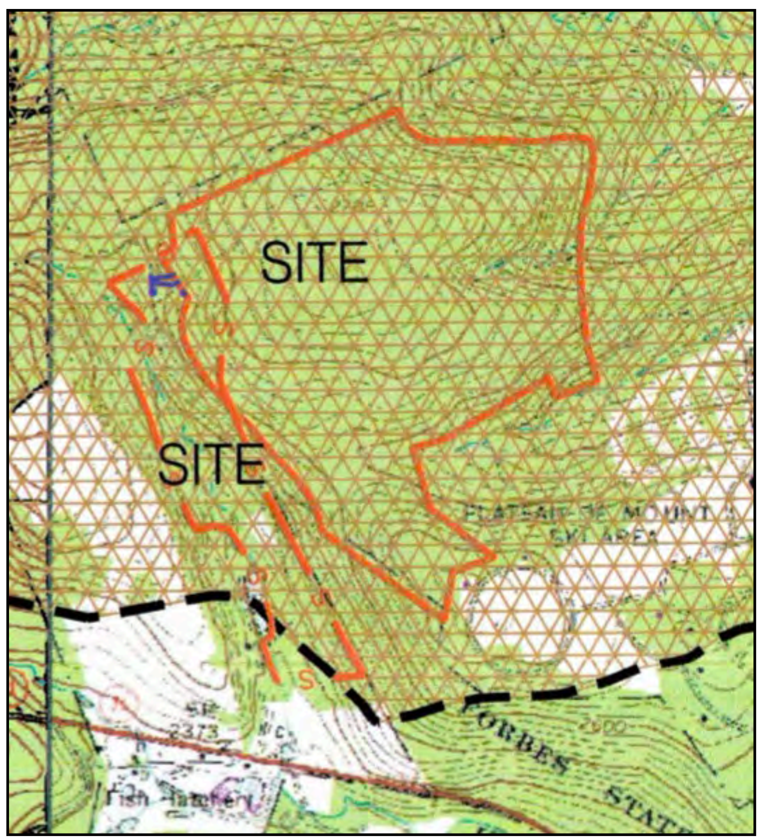

Figure 5. *Portion of the USGS 7.5 Minute Bakersville, Seven Springs PA Quadrangle showing location of Bakersville #3 mine. Dashed red line indicates surface permit area. Solid red line indicates underground permit area. Map courtesy of Ryan Stairs, Earthtech Inc., 2009.*

The subsurface mine is accessed by two, 20 foot high, horizontal drift entry-exit tunnels at the base of the highwall (**Figure 6**). An accessory tunnel providing air circulation to the mine is located to the north of the mine entries. Mining progresses in the classic “room and pillar” method in which the Loyalhanna is removed in a systematic pattern that leaves roof supporting pillars of at least 50 square feet (**Figure 7**). The upper 25 feet of the Loyalhanna is currently mined, leaving a minimum of 10 feet of Loyalhanna roof between the base of the Mauch Chunk lower units to account for sporadic lenses of red mudstones/shales that make unstable roof materials. Eventually the mine will “ramp down” to access and remove the lower 25 feet of Loyalhanna. Production from Bakersville #3 varies with market demand, with recent production ranging from 1500 to 3000 tons/day and averaging 750,000 tons per year (Claycomb and Stairs, personal communication). The small thrust fault visible within the highwall was unexpected, and missed during the coring that took place as part of the mine permitting. The presence of this fault required extensive roof bolting to stabilize the Loyalhanna in the area of the mine entries (Claycomb).

Figure 6 *Subsurface mine map showing Bakersville #3. Entry - Exit tunnels indicated at base of highwall shown by red line. Main entries and crosscuts are shaded, roof supporting pillars are shown striped. Map courtesy of Ryan Stairs, Earthtech Inc., 2021.*

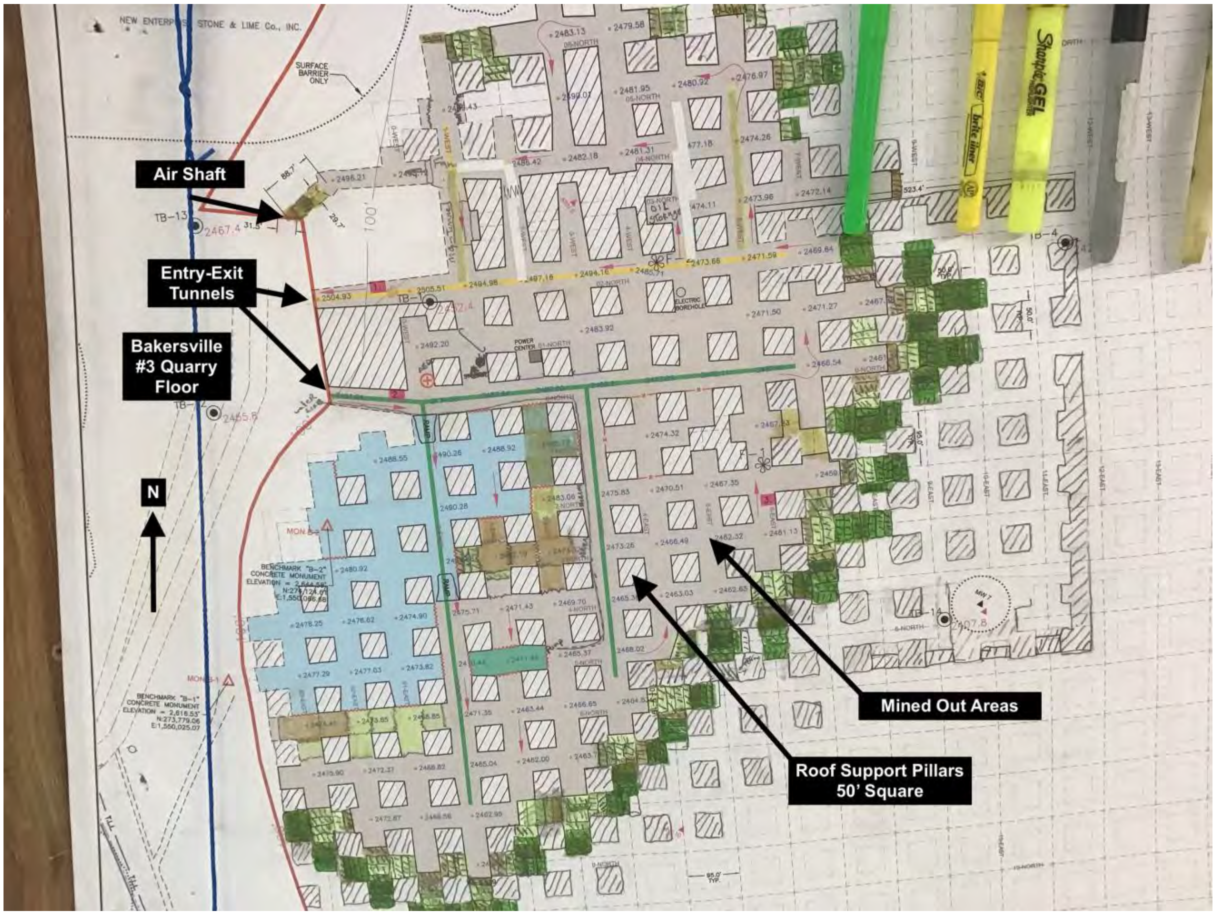

Figure 6 *Subsurface mine map showing Bakersville #3. Entry - Exit tunnels indicated at base of highwall shown by red line. Main entries and crosscuts are shaded, roof supporting pillars are shown striped. Map courtesy of Ryan Stairs, Earthtech Inc., 2021.*

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COOPER SPRINGS

(BEALS HATCHERY)
LAUREL RIDGE STATE PARK

MIKE MUMAU – PARK MANGER, LAUREL HILL STATE PARK
RYAN STAIRS, P.G. – VICE PRESIDENT/OPERATIONS MANAGER EARTHTECH, INC.
JIM SHAULIS - PENNSYLVANIA GEOLOGICAL SURVEY

Introduction

In late 2011, the park learned of an opportunity to potentially acquire a 30 acre parcel adjacent to Forbes State Forest and Laurel Ridge State Park with unique water resources , one of those being "Cooper Spring "which was part of the Beals Hatchery property. (**See Figures 1 & 2**). After nearly 6 years of hard work, due diligence and negotiation, the Western PA Conservancy was able to acquire the parcel and convey to the Bureau of State Parks. This property provides significant water quality protection and features 2,500 feet of frontage on Shaffer Run, a major tributary to Laurel Hill Creek. An average of approximately 1.4 million gallons of water per day flow from four natural artesian groundwater springs located on the property. The property also includes forested wetlands adjacent to the springs. The permanent conservation of the forests, wetlands and springs on this property will play an important role in protecting water quality and quantity in Laurel Hill Creek, a significant ecological and recreational asset for the Laurel Highlands region (**Figure 3**).

Figure 1 *is a photo of Cooper Spring located at the headwaters of Shaffer Run, GPS, 40.084,-79.231 NAD 83.*

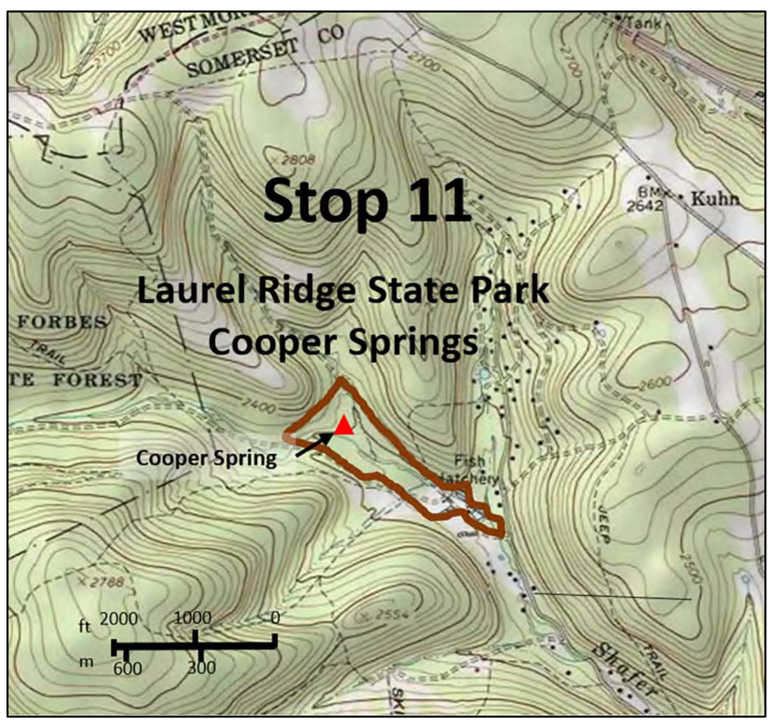


Figure 2 *shows the location of the Laurel Ridge State Park Cooper Springs site located at the base of the headwater valleys of Shaffer Run.*

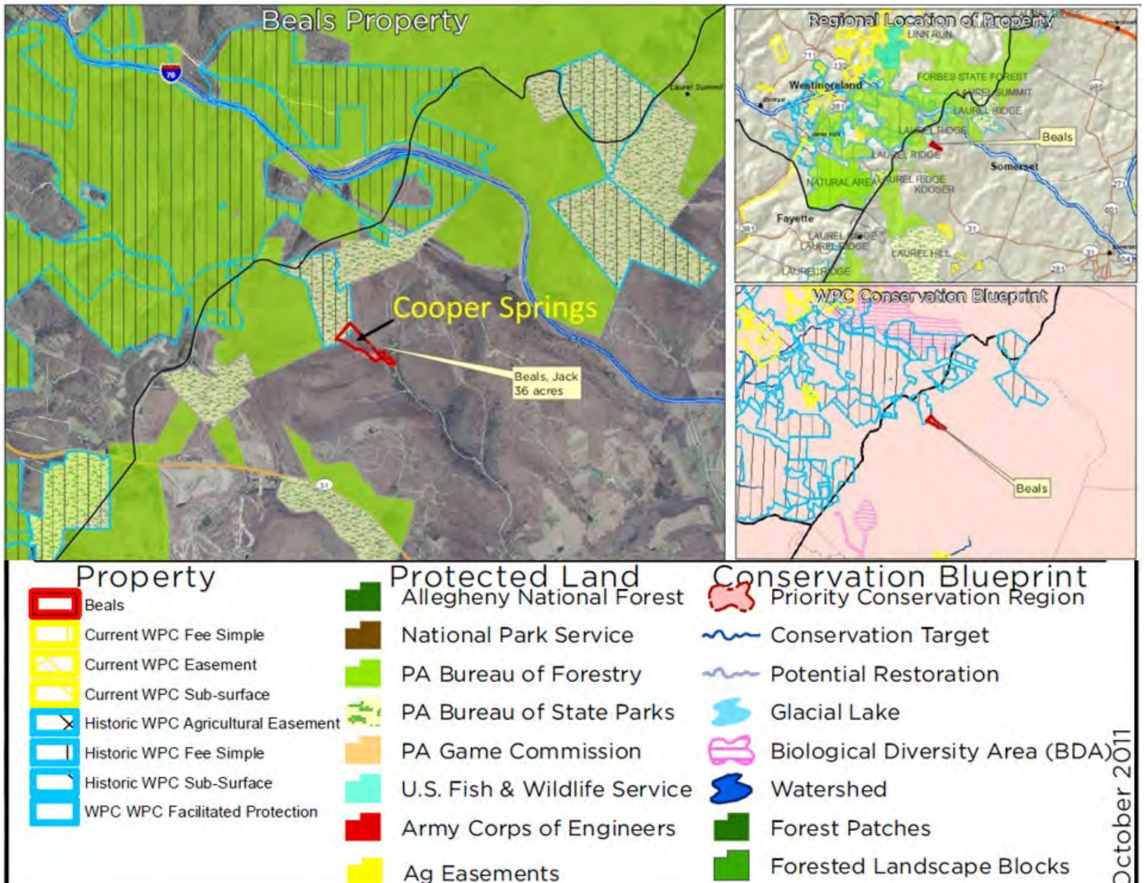


Figure 3 *is a map showing the location of the Cooper Springs addition to Laurel Ridge State Park and nearby existing public lands.*

Ultimately, the 5-10 year plan is to remove all hatchery related infrastructure and return this critical upper headwater area into a more natural system (**Figure 4**). The hope would be to transform the current hatchery infrastructure into a more naturalized stream channel that also has some flood plain built into help alleviate the channelizing/velocity of water during rain events. The downstream area has sustained significant damage to the roadway as a result of this condition.

Figure 4 *is a photo from 2019 of the Beals Hatchery raceway on the left and the head waters of Shaffer Run above the hatchery, on the right.*

Hydrology and Water Quality

There are several natural artesian springs on the property. Hydrologic studies show that these are based in the sandstone in the upper portion of the Burgoon formation, Casselberry (1993), Deason (2003). In 1940 a trout hatchery was constructed and operated until 2003. Both the quality and quantity of the spring water was also found suitable for public consumption without treatment, which therefore made it a potential source for bulk-load facility for bottled water. An analysis done for the water at the Cooper Springs site shown in **Table 1**. The springs can produce 200 to 300 gpm, or 300,000 gal/day. Cooper Springs can even get up to 1000 gpm during the wet seasons of the year.

Table 1. shows the chemical analyses of several of the springs located on the Cooper Springs site

Date Sampled	Coliform Colony Count Per 100 ml	Lab pH	Alkalinity To pH 4.5 Mg/l as CaCO3	Acidity To pH 8.2 Mg/l as CaCO3	Fe Mg/l	Mn Mg/l	Al Mg/l	Ca Mg/l	Mg Mg/l	Sulfate Mg/l	Suspended Solids Mg/l	Spec Cond	Hard-ness Mg/l	Total Dissolved Solids Mg/l
Spring (Cooper)														
1/20/03	8	7.1	23	neg	<0.005	<0.02	<0.1	12.8	0.9	10	<5	81	35.7	38
House Spring														
1/27/03	5	6.4	25	neg	<0.005	<0.02	<0.1	14.1	1.0	10	<5	84	39.3	58
Top Spring														
1/27/03	TNTC	7.0	27	neg	<0.005	<0.02	<0.1	13.9	1.0	10	<5	87	38.9	60
Hill Spring														
1/27/03	TNTC	6.5	22	neg	<0.005	<0.02	<0.1	12.3	1.0	10	<5	77	34.8	54
Averages		6.8	25	neg	<0.005	<0.02	<0.1	13.6	1.0	10	<5	84	38.0	52

(data from Geochemical Testing Labs)

The excellent quality combined with the high volume of water made it an attractive business venture. The springs can fluctuate seasonally, so looking for a more dependable supply, a groundwater production hole was drilled and installed in 2006 that had an artesian flow, which tapped into the same source as the springs. Using Very Low Frequency geophysical surveys, a well was located at an intersection of fractures that extended to depths of 300 feet near the main spring house. This well produced 108,000 gals of spring water per day (Evers,2008). Water produced from this well met all the EPA drinking water standards and US Food and Drug Administration requirements for labeling as spring water. However, because of the amount of water that would have been removed from the aquifer to make it an economical undertaking, the permit was not approved by DEP in 2009, siting the potential to significantly diminish the flow to Shaffer Run.

Permitting of a large underground mining operation of New Enterprise Stone and Lime Company on the Loyalhanna limestone member of the Mauch Chunk Formation up dip from this unique water supply was carefully studied before it was approved by DEP. There were concerns that the mining operation would negatively impact both the quality and quantity of water in the Shaffer Run watershed. Hydrologic studies completed for permitting showed that the Loyalhanna limestone in the area of the proposed mine had little water bearing capacity. A thick sandstone at the top of the Burgoon formation constitutes the aquifer that conveys the regional groundwater Casselberry (1993), Deason (2003), below the mineral to be mined, the Loyalhanna limestone. The regional aquifer is structurally controlled and is likely to flow in a southeasterly direction towards Shaffer Run and Laurel Hill Creek. On the surface above the mine, groundwater flows in perched aquifers via the fractures and bedding planes primarily in the Mauch Chunk formation, eventually discharging into the stream valleys. No aquifers would be affected by the underground mining of the Loyalhanna limestone in this area since the mining plan included a 10' (3m) thick roof barrier of limestone. Pump tests on the monitoring wells showed that fractures in the Loyalhanna Limestone are generally closed at a depth of over a hundred feet. Monitoring wells also showed only small amounts of recharge in the Loyalhanna limestone and therefore significant groundwater would not be encountered during the mining operation. Any water entering the mine that needed to be removed would be put back into the regional aquifer in the top of the Burgoon formation via injection well(s). In summary, mining would occur below the perched water table of the Mauch Chunk formation and above the regional water table of the Burgoon formation (DEP, 2010). Continuous monitoring has been done since underground operations began a few years ago and no negative impact has been observed. **Figure 5** is a geologic map showing the location of the permitted mining operation and the Cooper Spring area, along with a cross section showing the relationship of the geologic strata for the mine and the Cooper Springs area.

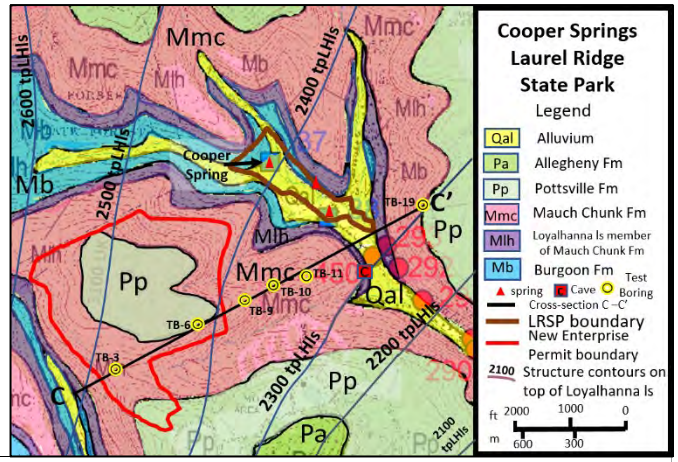
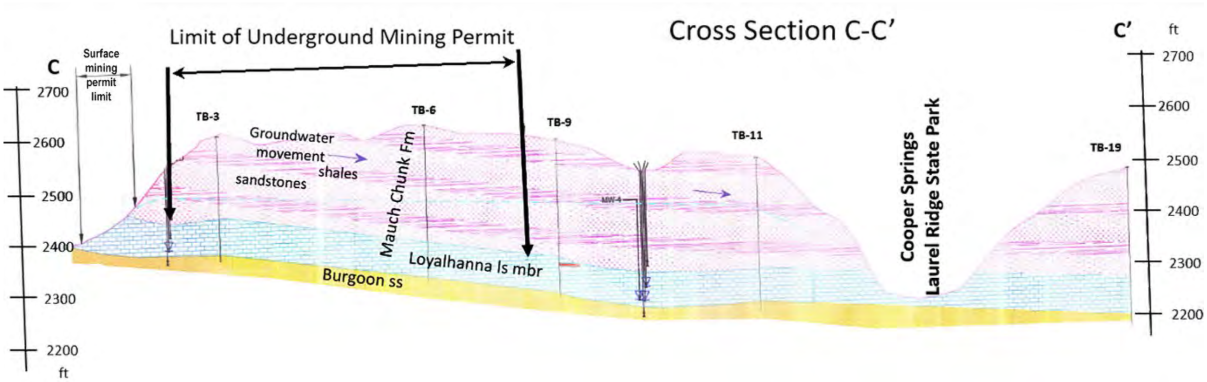


*Figure 5 is of geologic map (McElroy,2000) modified by Shaulis, showing the local geology and spring sites, **above**, and cross section C-C', **below**. Cross-section complied by Stairs, R., Earthtech Inc., 2010), modified by Shaulis.*



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FAYETTE COUNTY'S PIONEERING IRON INDUSTRY

John A. Harper[1], Albert D. Kollar[2], Normal L. Samways[3], and David J. Vater[4]
Albert D. Kollar – Carnegie Museum of Natural History

Introduction

Iron was a basic necessity in the early history of the United States. Horseshoes (as well as nails to keep them on a horse), pots and pans, axes and other hand tools, plow shares, wagon wheel rims, and a host of other items were made of iron, and the constant need for additional items kept the iron makers busy all year round. Small stone blast furnaces utilized abundant local raw materials: 1) sandstone masonry to build the furnace and associated infrastructure; 2) fireclay to make refractory bricks that lined the interior of the furnace; 3) iron ore, primarily siderite but also some hematite and bog ore; 4) limestone to use as flux in the furnace; 5) charcoal for fuel, requiring cutting thousands of acres of timber (coal for making coke eventually replaced charcoal so the coal mining industry saved the local forests from complete destruction!); and 6) local streams that provided water to power the blast equipment in the furnaces and, in some cases, were a source of transportation for raw materials to the furnaces and subsequent iron products to market.

Fayette County played a major role in the history of the iron industry in the late 1700s and into the 1800s long before Pittsburgh became a major industrial center. Local iron ores were mined extensively and used in the numerous charcoal blast furnaces scattered throughout the area. Eventually, coke replaced charcoal as a fuel, ores from the upper Great Lakes area supplanted the lower quality local ores, and new processes greatly improved the production of iron and steel.

What would life in western Pennsylvania have been like without the abundance of local natural resources and the intrepid people who exploited them? An ordinary cast-iron skillet might have cost a small fortune because it would have to have been shipped from eastern Pennsylvania or some other state. Without plentiful coal resources, western Pennsylvania would not have attracted the diverse ethnic populations that became our ancestors. Without abundant water, Pittsburgh would never have become the Steel Capital of the World. It was fortuitous that the abundant raw materials, and the people who had the foresight to exploit them, became essential parts of western Pennsylvania history.

Early Iron Manufacturing

The iron industry expanded in western Pennsylvania during the early 19th century because the demand for iron products increased with the population. By 1811, Fayette County had 27 iron works that supplied iron products to Pittsburgh, the Ohio River Valley, and beyond. Pittsburgh became western Pennsylvania's focus for secondary iron works such as forges, foundries, and rolling mills that fabricated an extensive range of iron products produced in blast furnaces in Fayette County and elsewhere.

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[1] Pennsylvania Geological Survey, retired.
[2] Carnegie Museum of Natural History
[3] LTV Steel Co. Inc., retired. Deceased.
[4] Pittsburgh, PA

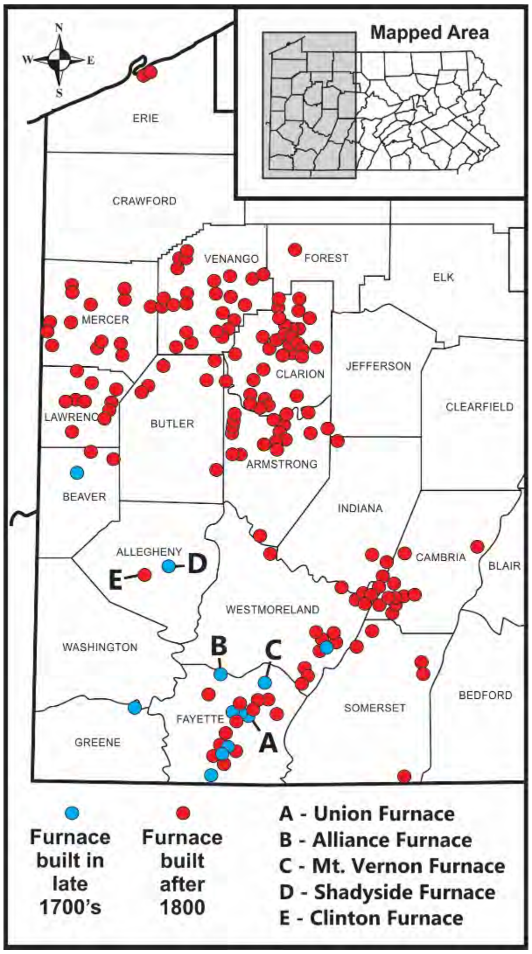

Figure 1. *Map of western Pennsylvania showing locations of historic iron furnaces built before 1860 (from Samways et al., 2014).*

The early iron industry constructed more than 180 charcoal blast furnaces in western Pennsylvania before 1850 (**Figure 1**). More than 30 were built before 1830 in Fayette and Westmoreland Counties, 10 in the 1700's alone. The first iron furnace constructed in western Pennsylvania was either the Union Furnace in Dunbar, Fayette County (Figure 1, location A), or the Alliance Furnace near Perryopolis, Fayette County (Figure 1, location B). Both were built around 1789 (see below). Another early furnace in Fayette County was the Mount Vernon Furnace, built in Bullskin Township in 1798 (Figure 1, location C). Most of these early furnaces were located on the west side of the Chestnut Ridge anticline close to deposits of iron ore. One exception, the Shadyside Furnace in Pittsburgh's Shadyside neighborhood (Figure 1, location D), was built in 1793, but was only in operation for a year because of a lack of easily accessible local ore. After 1830, the majority of new furnaces were concentrated in Armstrong, Clarion, and Venango counties as other local iron ore deposits were exploited.

Figure 2 illustrates how a typical charcoal blast furnace, such as those built in the late 1700s and early 1800s, operated. It consisted of a sandstone stack that resembled a hollow, truncated pyramid

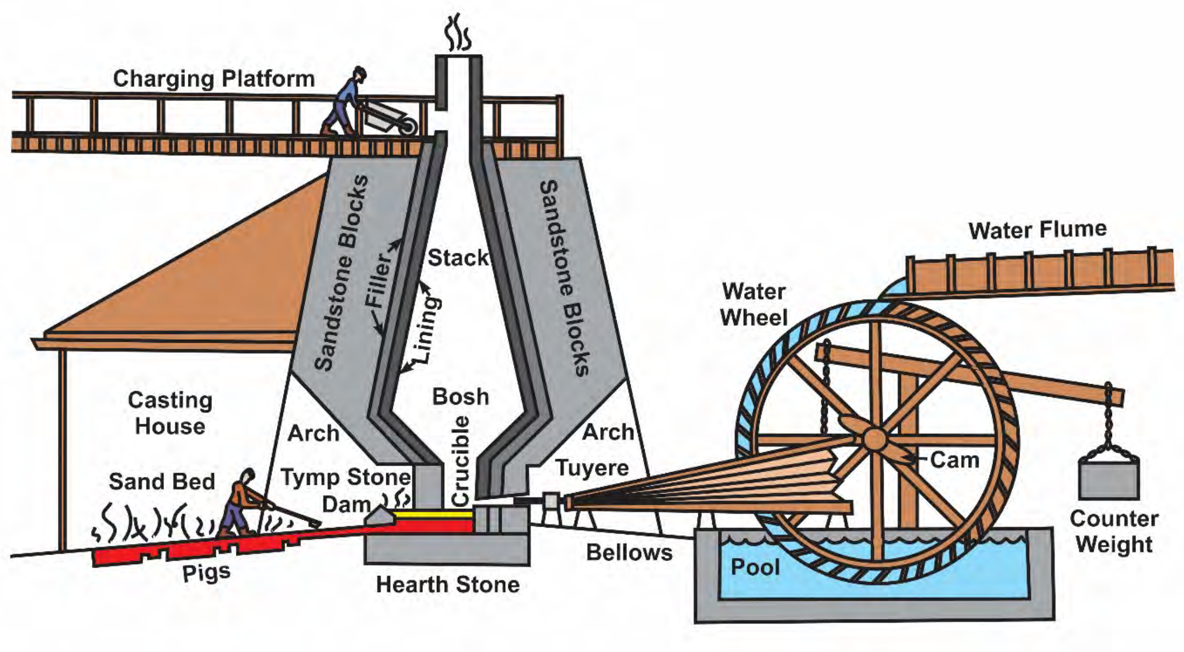

Figure 2. *Schematic diagram and terminology of typical charcoal iron furnace (from Samways et al., 2014). Red – molten iron; yellow – slag. Drawing modified from original by David J. Vater.*

approximately 9 m (30 ft) high. It was usually constructed of local sandstone blocks and lined with refractory fireclay bricks or blocks to protect the furnace walls. The furnace was continuously charged at the top with iron ore, limestone, and charcoal (later, coal or coke) for fuel (Samways et al., 2014). While the charge materials descended towards the bottom of the furnace, hot carbon monoxide gas, generated by the combustion of charcoal with air, transformed the iron ore into liquid iron at temperatures in the order of 815 to 1,370°C (1,500 to 2,500°F). The air, provided by water-powered bellows, was blown into the furnace through tuyeres (blowpipes) located at the bottom of the furnace. The water that powered the bellows typically came from nearby ponds or dammed streams that flowed through a sluice to the water wheel (**Figure 2**), then back to the stream. The limestone acted as a flux to remove impurities from the ore, forming a liquid slag. Every six hours or so, the furnace was tapped by opening a refractory-sealed hole in the hearth area. Liquid iron flowed into parallel rows of depressions in the cast house floor that, when solidified, vaguely resembled piglets attached to a sow – hence the name "pig iron." Solid pig iron was processed into bars by successive reheating and forging to produce stock for making nails, wheel rims, tools, etc. Alternatively, liquid iron was removed in ladles and cast in molds into articles such as pots and stoves (cast iron products).

Raw Materials

The bedrock of western Pennsylvania provided abundant raw materials to the early iron industry in the form of iron ores, limestones, coals, fireclays, and sandstone, and the area had vast hardwood forests for producing charcoal and numerous streams for powering the furnace bellows. An early 1800s charcoal blast furnace produced about two tons of pig iron per day. Each ton of produced iron required a total charge of approximately three tons of iron ore, two tons of limestone, and 2.6 tons of charcoal. In the latter half of the 1800s, iron production spawned major support industries such as coal mining, coke making, and refractory industries that also utilized the coal and fire clay resources of the region.

Iron Ore

Until 1880, Pennsylvania produced more iron ore than any other state in the nation (Brown and Ehrenfeld, 1913). Despite this statistic, there generally was not enough ore produced in the state to supply all the iron furnaces and foundries, and most ore was imported to meet local demand. Iron ore was discovered in Fayette County before 1792.

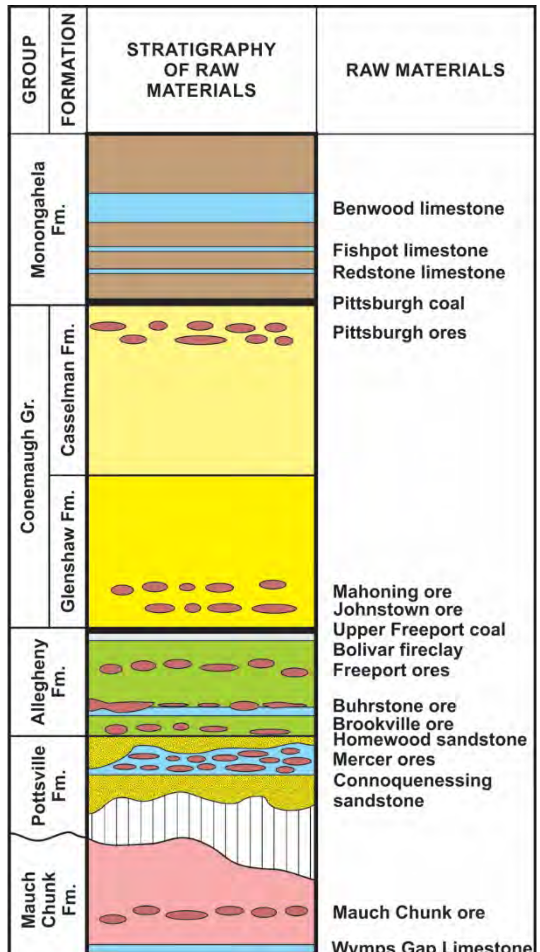

Figure 3 *Generalized stratigraphic column for western Pennsylvania, showing iron ores, limestones, sandstones, coals, and fireclays (from Samways et al., 2014).*

The readily available iron ores in western Pennsylvania were primarily siderites, although some hematite (kidney ore) and goethite or bog iron ore do occur in places in the area. See below for more information on these ores. The principal ores used in the Fayette County furnaces included the

Mercer ores from the Pottsville Formation and Johnstown ores from the Glenshaw Formation (**Figure 3**). These rocks are exposed along the western slope of Chestnut Ridge (**Figure 4A**). One furnace on the east slope of Chestnut Ridge used what was purported to be Mississippian Mauch Chunk ore (**Figure 3**), although the actual identity of the source formation is in doubt (J. Shaulis, pers. comm., January, 2018). In contrast, furnaces in counties such as Armstrong, Clarion, and Venango primarily used the Buhrstone and Freeport sideritic ores from the Allegheny Formation (**Figure 3**) where they are exposed in stream valleys carved into the otherwise flat-lying rocks of western Pennsylvania (**Figure 4B**). The iron content of these ores varies from 30 to 40%. It was only when the Lake Superior hematite ores, containing in excess of 50% iron, became readily available through rail and water transportation that the iron-making industry shifted to the Pittsburgh area. The Clinton Furnace (**Figure 1**, location E) on the south shore of the Monongahela River across from downtown Pittsburgh, was the first of these, with operations beginning in 1859 (**Figure 5**).

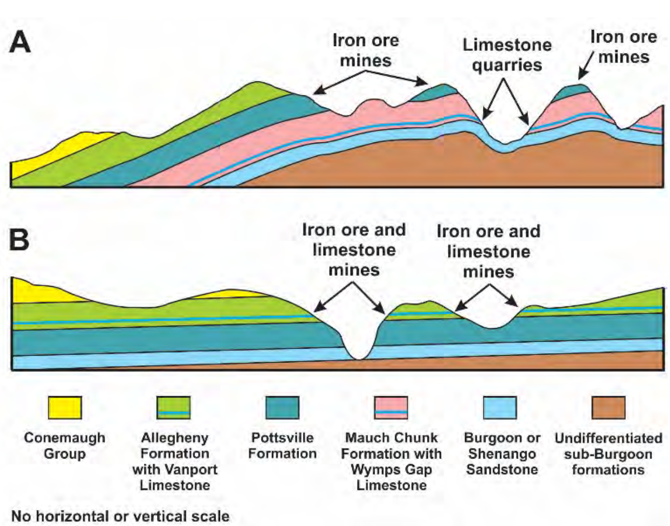

Figure 4. *Cross sections of western Pennsylvania showing effect of geologic structure and topography on locations of raw material deposits. A – Along Chestnut Ridge. B – Northwestern Pennsylvania. From Samways et al., 2014.*

Figure 5. Old Clinton Furnace*, an undated oil painting by famous Pittsburgh artist John Kane (from Wiki∞.org, 2021). St. Mary of the Mount Church on Mount Washington overlooks the furnace, which was situated on the south shore of the Monongahela River across from downtown Pittsburgh, approximately where Highmark Stadium and the Gateway Clipper Fleet currently are located.*

Flux

Limestone, the flux material, occurs extensively throughout western Pennsylvania. Deposits close to the furnace operations along Chestnut Ridge include the Redstone, Fishpot, and Benwood limestones of the Monongahela Formation, and Wymps Gap Limestone of the Mauch Chunk Formation (**Figure 3**). The Vanport Limestone of the Allegheny Formation (**Figure 3**) was the primary source of limestone for northwestern Pennsylvania furnaces.

Fuel

Prior to 1840, 100% of the iron produced in western Pennsylvania was made using charcoal as a fuel, which in turn required vast quantities of wood. For example, in the 1840's, an annual statewide iron production level of 100,000 tons consumed approximately 15,000 acres of forest (Samways et al., 2014). After 1840, alternative fuels such as anthracite and coke were introduced that gradually reduced the need for charcoal.

Coke, made from coal, eventually replaced charcoal as the fuel in the western Pennsylvania furnaces. In the 1800s, coke was produced primarily in beehive ovens (**Figure 6**) by heating bituminous coal at temperatures ranging from 900 to 1,100°C (1,650 to 2,000°F) to drive off volatiles, leaving a fused-carbon structure. Because of the local availability of vast quantities of the Pittsburgh coal, a premium coal for coke-making (**Figure 3**), the Connellsville area in Fayette County became the center for coke production in meeting the needs of the iron industry. Although there were only 26 beehive ovens in operation in the area in 1855, the number increased rapidly to 3,000 in 1873 and 20,000 in 1900 when the industry produced more than 10 million tons of coke from nearly 15 million tons of Pittsburgh coal.

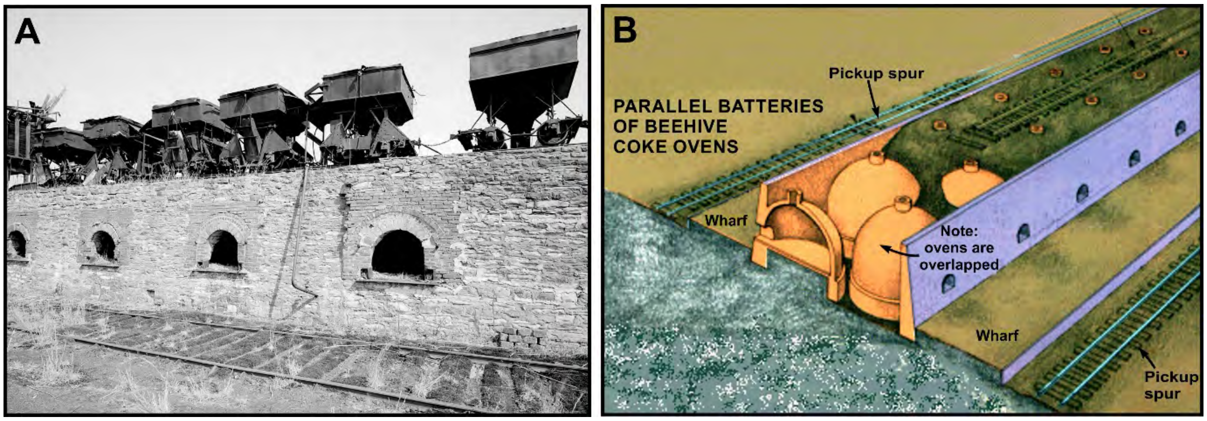

Figure 6. *Beehive coke ovens.* ***Left*** *– Historical coke ovens that are part of the Shoaf Historic District in Fayette County (Library of Congress, Prints and Photograph Division HAER: PA,26-SHO, 1-3).* ***Right*** *– Diagram of beehive coke oven construction (from Washlaski, 2008).*

Refractories made from fireclay provided protective linings for furnaces and coke ovens exposed to destructively high temperatures often in excess of 1,100°C (2,000°F). The refractory industry, whose roots also began in western Pennsylvania, is sometimes referred to as "the hidden industry;" it played a major but unrealized role in the growth of the coke, iron, and steel industries. The predominant raw materials for refractory brick are fireclay, sandstone, and ganister (orthoquartzite). Fireclay ($Al_2O_3 \cdot 2SiO_2$) is widely distributed throughout western Pennsylvania, usually in association with coal beds where it formed from the soils that supported the coal-forming plants. The Bolivar fireclay of the Allegheny Formation (**Figure 3**), for example, a premium fireclay that has been mined locally for the manufacture of refractory bricks, occurs a few feet below the Upper Freeport coal bed. This claystone is an intensely weathered and leached paleosol that contains much higher levels of iron and silica than do the flint clays of the lower Allegheny and upper Pottsville formations (Brezinski and Kollar, 2011). Fireclay products, in addition to lining blast furnaces, are used extensively in coke ovens. Siliceous refractories from sandstone containing 90 to 96% SiO_2 were produced from the Homewood and Connoquenessing sandstones of the Pottsville Formation (**Figure 3**), and ganisters containing more than 98% SiO_2 occur in the mountain ridges in central Pennsylvania (primarily the Lower Silurian Tuscarora Formation). Silica bricks are used in the higher temperature regions of a coke oven. The magnitude of the demand for refractory products and, consequently, for raw materials such as fireclay and sandstone, is illustrated by the requirements of the coke industry. For example, close to 5,000 refractory bricks were used in the initial construction and rebuild of a single beehive oven. Thus, the 20,000 ovens in operation in 1900 required more than 100 million refractory bricks (Samways et al., 2014). More recently, in 1996, 80,000 tons of brick were needed for the construction of a new 268-oven facility. And, in 2012, 2.4 million bricks were laid in the construction of U.S. Steel's new 84-oven coke battery at the Clairton coke plant near Pittsburgh (Samways et al., 2014).

Western Pennsylvania Iron Ores

As stated previously, the primary ore used in western Pennsylvania iron blast furnaces during the early days of the industry was siderite (**Figure 7A**), principally in the form of nodules and other irregular masses in argillaceous and calcareous strata.

Siderite

Siderite nodules typically are finely crystalline, break with a sharp conchoidal fracture, and are bluish-gray in color where they have not been weathered. They commonly contain about 30% to 40% iron and more than 0.15% phosphorus (Inners, 1999). Fayette County's siderite comprises two types: 1) siderite nodules imbedded in shale and clay; and 2) limestone beds replaced by siderite. In some places, the iron limestones appear to have been enriched at the surface, but the iron content typically diminished only slightly away from the outcrop (Hickok and Moyer, 1940).

Western Pennsylvania siderite deposits typically consist mostly of nodules in shales associated with marine limestones, but there are exceptions. Black band ores are siderite nodules associated with coal beds, usually found within, or, more typically, above the coal (Stout, 1944), usually in non-marine rocks. Hickock (1939) stated that there are many outcrops of siderite in the strata above the Pittsburgh coal in Pennsylvania, but the beds are not extensive, and the nodules are scattered and are commonly high in phosphorus. The Buhrstone ore of the Vanport Limestone (Allegheny Formation) is an extensive siderite deposit that is confined mainly to the top of the limestone. This deposit resulted from the partial replacement of the limestone by meteoric waters bearing iron leached from the overlying shales. The ore, although very thick in places, is confined to the zone of weathering.

Other Ores

Of lesser importance were limonite (also called brown ore), goethite, hematite, and bog ore. Pyrite and other iron sulfides and iron silicates such as chamosite, glauconite, and greenalite also occur in western Pennsylvania rocks, but were not important in the early iron industry. Limonite (**Figure 7B**) typically occurs from the alteration of siderite, but has also been known to occur due to the decomposition of impure iron-bearing limestones or by precipitation of soluble iron salts in wetlands and coal mine runoff. Goethite (**Figure 7C**) often forms through the weathering of other iron-rich minerals, so it is commonly found in soil and other low-temperature environments. Hematite, the most important iron ore in the world, typically

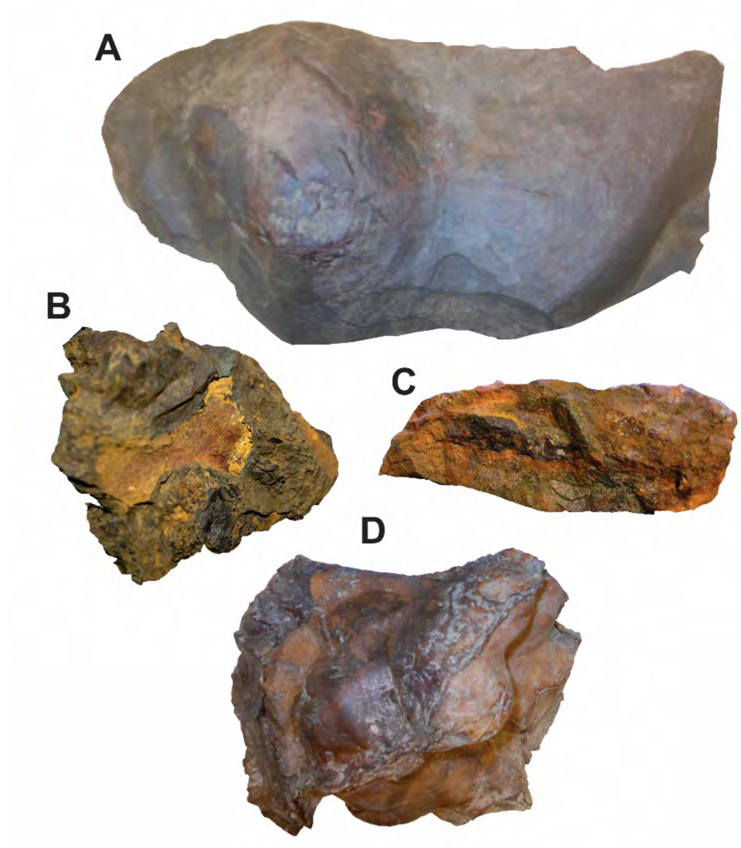

Figure 7. *Examples of sedimentary iron ores that occur in Fayette County.* ***A*** *and* ***D*** *are in the collections of the Carnegie Museum of Natural History (CM).* ***A*** *– Siderite (CM58021).* ***B*** *– Limonite.* ***C*** *– Goethite.* ***D*** *– Hematite, specifically "kidney ore" (CM58022)*

occurs in western Pennsylvania as "kidney ore" (**Figure 7D**), named for its similarity in appearance to an internal organ. Kidney ore forms as a precipitate in cavities. Chemically precipitated hematite such as this can be relatively uncontaminated with clay or host rock inclusions, and it has a higher purity. Kidney ore supposedly was the primary ore used at Wharton Furnace (see below). Unfortunately, analyses of this ore apparently were never performed. Bog ore also forms through precipitation as the iron present in rocks and soils becomes separated from the parent material by acids from decaying organic matter, is held in solution and then deposited by surface and groundwater in wetlands and other low-lying areas (Stout, 1944).

Origin of Siderite

Siderite concretions of the type used in the early iron industry in western Pennsylvania formed in an aqueous environment after the deposition of sediment (Woodland and Stenstrom, 1979). The iron was deposited between sediment grains or within pore spaces in the rock by circulating iron-bearing waters. Precipitation of iron can occur prior to lithification of the sediments, during diagenesis, or after lithification. Woodland and Stenstrom (1979) determined that the most likely source of iron would have been from migrating fluids flushing through the sediments.

> *Water draining peat bogs will be relatively high in Fe++ ions because decaying plant material lowers pH and Eh, thus increasing the total concentration of Fe++ ions. Gruner (1922) and Oborn and Hem (1961) have shown that microbial activity on organic matter is important in releasing iron from soils. The effects of lateral diffusion should be reflected in a strong zonation of concretion growth with high population adjacent to the source area. There is insufficient evidence to demonstrate any such zonation.* (Woodland and Stenstrom, 1979, p. 86-87)

As such, geochemical factors such as temperature, pressure, Eh, pH, iron concentration, and type and amount of organic matter are critical factors during precipitation (McGuire, 2012).

Also critical would have been the effects of biogeochemical activity, particularly by bacteria. Johnson et al. (2004) felt that the evidence was overwhelming that biological processing of redox-sensitive metals (e.g., Fe) is probably the rule in surface and near-surface environments, rather than the exception. Iron oxide produced by Fe(II) oxidation is an important sink for Fe released by terrestrial weathering. Dissimilatory microbial reduction of Fe_2O_3 (a process microbes use to conserve energy through oxidizing organic or inorganic electron donors and reducing a metal or metalloid; this process enables the organisms to create electrochemical gradients that provide the chemical energy required for growth (MicrobeWiki, 2012)), coupled with oxidation of organic carbon and/or H_2, is an important process by which it is reduced in both modern and ancient sedimentary environments. In fact, relatively recent microbiological evidence by Vargas et al. (1998), coupled with a great deal of geochemical data, suggests that microbial reduction of Fe_2O_3 may have been one of the earliest forms of respiration on the planet (Johnson et al., 2004).

There are significant differences between siderites found in continental settings and those in marine environments. "Fresh-water" siderite is often relatively pure, having greater than 90 mol percent $FeCO_3$, whereas marine siderites always are very impure, having extensive substitution of Mg and Ca for Fe in the mineral lattice. Also, marine siderite generally contains less Mn and has a higher Mg/Ca ratio than "fresh-water" siderite (Mozley, 1989). The differences between the two seem to reflect the fact that marine sediments generally undergo a more extensive period of sulfate reduction than do "fresh-water" sediments (Mozley and Wersin, 1992). The compositional variations seem to result from differences in the chemistry of early marine and meteoric pore waters; early marine pore waters generally have higher Mg^{2+}/Ca^{2+} ratios and contain less Mn^{2+} and Fe^{2+} and more Ca^{2+} and Mg^{2+} than meteoric waters.

The exposure of the iron-bearing rocks to weathering can alter the mineral form of the iron. For example, siderite within the subsurface often changes to limonite at the outcrop where weathering is most likely to occur. The famous Buhrstone ore at the top of the Vanport Limestone of northwestern Pennsylvania generally is 15 to 30.5 cm (6 to 12 in) thick (Butts, 1906), but in places, weathering of the bed resulted in fairly thick pockets of sedimentary limonite (Inners, 1999).

Siderite in Fayette County

The iron ores of Fayette County occur at specific positions within the stratigraphic record. In general, there are six primary ore-bearing horizons named the Pittsburgh, Mahoning, Freeport, Brookville, Mercer, and Mauch Chunk ores (**Figure 3**).

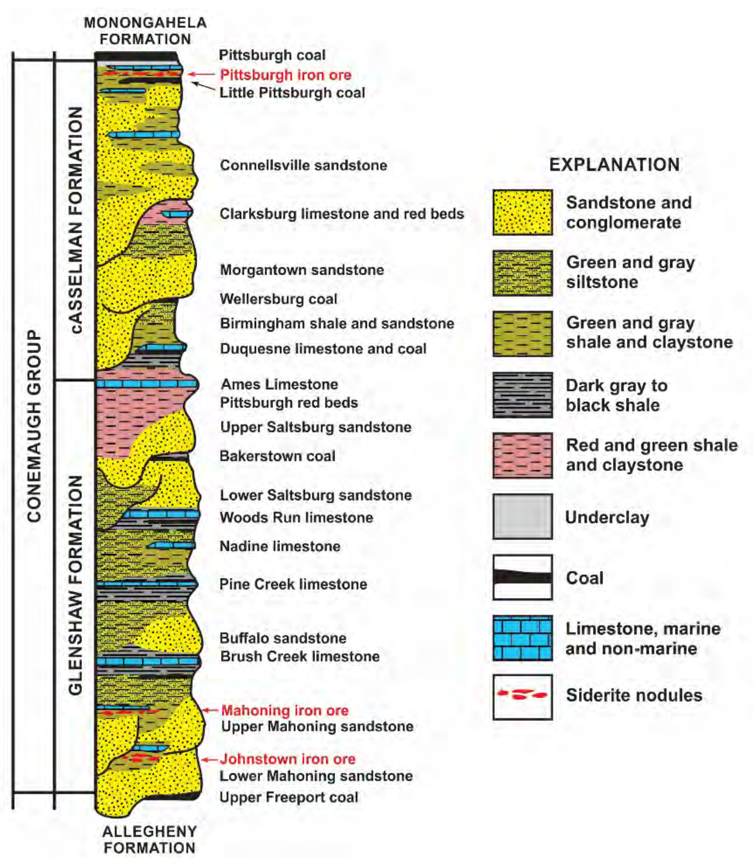

Figure 8. *Generalized stratigraphic section of the Conemaugh Group in western Pennsylvania, indicating the location of major iron ore beds (in red). Redrawn from Harper and Laughrey (1987).*

Pittsburgh Ore Beds – The Pittsburgh ore occurs within the Casselman Formation of the Conemaugh Group, lying about 1.2 to 1.8 m (4 to 6 ft) below the Pittsburgh coal and above the Little Pittsburgh coal (**Figure 8**). They appear in various beds that the miners named Blue Lump, Condemned Flag, Big Bottom, Bed Flag, and Yellow Flag (McCreath, 1879). Hickock (1939, p. 11) stated that siderite occurs in the underclay of the Pittsburgh coal as four thin beds that are persistent throughout a large part of the county. Analyses of the ore found it averaged 35% to 40% iron and was low in phosphorus and sulfur. It is well developed along the Monongahela River near Point Marion and extends across the county to the area around Uniontown. The ore beds were explored as deep as 245 m (800 ft) underground where they appeared to be fairly consistent in quality. Analyses of seven Pittsburgh ore samples found the iron content to range from 29% to 42% (Stevenson, 1877; see **Table 1**). These ores were important resources for the Oliphant Furnace in Georges Township and Lemont Furnace in South Union Township (Hickok and Moyer, 1940). A few thin beds of nodules occur scattered through the upper Casselman Formation below the Pittsburgh ore, but they are found only locally and were not considered important.

Table 1. Chemical analysis of the Pittsburgh ores (from Hickok and Moyer, 1940). Analyses were made by A. S. McCreath and D. McCreath, chemists with the Second Geological Survey of Pennsylvania in the late 1800's.

	1	2	3	4	5	6	7
Iron	33.350	39.000	42.116	35.500	35.800	35.400	20.200
Sulfur	0.155	0.011	0.041	0.145	0.047	0.319	0.415
Phosphorus	0.072	0.089	0.070	0.042	0.083	0.069	0.268
Insoluble residue	13.860	5.790	4.415	7.450	9.560	10.450	19.240

Mahoning Ore Beds – The Mahoning ores generally occur at two horizons, one directly above the Mahoning sandstone (Johnstown ore) and the other higher in the section (Mahoning ore) (**Figure 8**). Hickok and Moyer (1940) speculated that they probably represent sideritic phases of two Mahoning limestones. The ores occur as solid beds in some places, and are entirely missing in others, but more commonly they occur as siderite nodules in shale or clay. They were mined at Lemont Furnace in South Union Township, Fairchance Furnace in Georges Township, and Springhill Furnace in Springhill Township (Hickok and Moyer, 1940). Stevenson (1877) reported analyses of five samples of the ore from Fayette County contained from 3.5% to 32% iron (**Table 2**).

Table 2. Chemical analysis of the Mahoning ores (from Hickok and Moyer, 1940). Analyses were made by A. S. McCreath, D. McCreath, and Professor C. F. Chandler, chemists with the Second Geological Survey of Pennsylvania in the late 1800's.

	1	2	3	4	5
Iron	32.02	18.000	11.100	3.49	5.04
Sulfur	-----	0.026	0.313	-----	-----
Phosphorus	0.20	0.261	0.018	0.12	0.10
Insoluble residue	0.85	18.190	26.090	52.35	21.25

Freeport Ore Beds – The Freeport ores also comprise two sets of beds within the upper part of the Allegheny Formation (**Figure 9**) – the upper bed, occurring at the level of the Upper Freeport limestone, was an important ore on the west side of Chestnut Ridge whereas the lower bed, occurring at the level of the Johnstown cement bed between the Upper and Middle Kittanning coals, was more important east of the ridge. Inners (1999) called this the Kittanning ore, which name is used here. Hickok and Moyer (1940) considered both ores to be "surface ores" for the most part, that is, they occur as limonite at the surface, but become very lean deeper in the subsurface. For example, Hickok and Moyer (1940) listed one sample from underground in Springhill Township as having only 4.2% iron. The Upper Freeport limestone ore was mined on Jacobs Creek in Tyrone Township, near Dunbar Furnace in Dunbar Township, at the Springhill furnaces in Springhill Township, and on Deckers Creek in West Virginia. The Johnstown cement bed ore was mined at Furnace Run and Springhill Furnace, Springhill Township. Hickok and Moyer (1940) documented the iron contents of the Upper Freeport ore ranged from 26.5% to 40.8% at the surface, and of the Johnstown cement bed ore ranging from 28.3% to 38.1% (**Table 3**).

Brookville Ore Beds – The Brookville ores consist of two or three thin beds lying close to the Brookville coal near the base of the Allegheny Formation (**Figure 9**). The best ore lies either directly on the coal or 3 to 3.6 m (10 to 12 ft) above it. The ore found below the coal is very thin and mostly non-economical. The Brookville ore had been mined on Mount Creek near the Vernon mines in Dunbar Township, near Dunbar Creek, near Coolspring Furnace in Union Township, and near Springhill Furnace in Springhill Township. It was never mined east of Chestnut Ridge, although Hickok and Moyer (1940) found traces of it in outcrops near Ohiopyle. The ore apparently was never analyzed.

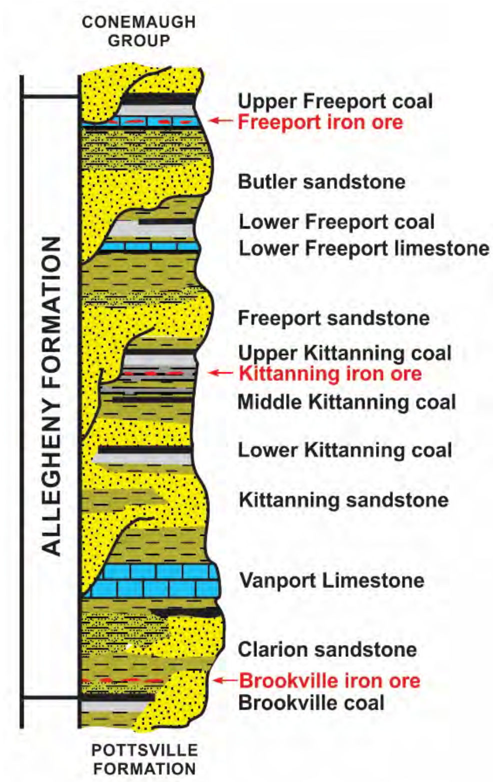

Figure 9. *Generalized stratigraphic section of the Allegheny Formation, indicating the location of major iron ore beds (in red). See Figure 8 for explanation of lithologic symbols. Redrawn from Harper and Laughrey (1987).*

Table 3. Chemical analysis of the Freeport ores (from Hickok and Moyer, 1940). Analyses were made by A. S. McCreath and Professor C. F. Chandler, chemists with the Second Geological Survey of Pennsylvania in the late 1800's.

	1	2	3	4	5	6	7
Iron	31.23	4.21	26.500	40.750	28.300	33.900	38.100
Sulfur	-----	-----	0.090	0.278	0.079	0.333	0.159
Phosphorus	1.04	0.01	0.046	0.229	0.137	0.302	0.115
Insoluble residue	16.92	3.85	13.810	5.120	13.885	18.690	9.250

Mercer Ore Beds – The most important iron ores found in Fayette County are part of the Mercer member of Pottsville Formation (**Figure 10**). Several beds of good ore occur around the Mercer coals below the base of the Homewood sandstone. Stevenson (1877), who documented their existence west of Chestnut Ridge, misidentified them as being within the Mauch Chunk Formation (his Umbral series). He apparently was convinced that the Homewood sandstone, which is massive on the western flank of the anticline, comprised the entire Pottsville; he did not recognize the Connoquenessing sandstone lying below it. The Mercer ore beds range from 15 to 46 cm (6 to 18 in) in thickness. Although they typically are siderite ores, at the outcrop they tend to be limonitic. Several large mines along the west flank of Chestnut Ridge provided large amounts of ore to the major blast furnaces in the county. The most important mines included the Vernon mines on Mounts Creek near Mt. Vernon Furnace, the Dunbar mines on Dunbar Creek near the Union and Dunbar furnaces, the Lemont mines near Lemont Furnace, the Coolspring mines on Shutes Run, the Fairchance mines near the Fairchance

Furnace, and the Springhill mines near Springhill Furnace. Stevenson (1877; also Hickok and Moyer, 1940) provided generalized stratigraphic sections of some of these mines. Analyses of the Mercer ores by the Second Geological Survey of Pennsylvania indicated that iron contents of the ores ranged from 31.1% to 41.4% (**Table 4**).

Mauch Chunk Ore Beds – Thin beds of hematitic iron ore 2.5 to 5 cm (1 to 2 in) in thickness occur near within 4.5 m (15 ft) from the top of the Mauch Chunk Formation (**Figure 10**) along the eastern flank of Chestnut Ridge south of the Youghiogheny River (Hickok, 1939). According to Inners (1999), they also extend eastward into Bedford and Huntingdon counties. Hickok and Moyer (1940) stated that these ores had never been mined, but qualified that by stating that one of the beds near Wharton Furnace was 0.15 to 0.6 m (0.5 to 2 ft) thick and was actually mined extensively on the Wharton Furnace property. These ores apparently were never analyzed.

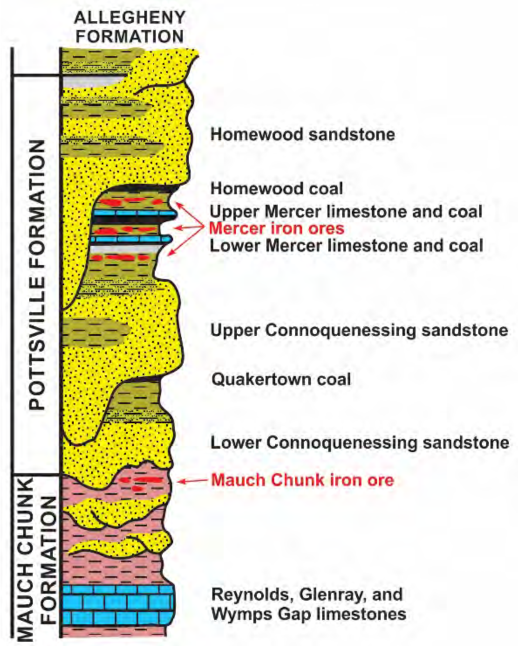

Figure 10. *Generalized stratigraphic section of the Pottsville Formation and upper portion of the Mauch Chunk Formation, indicating the location of major iron ore beds (in red). See Figure 8 for explanation of lithologic symbols. Redrawn from Harper and Laughrey (1987) and Brezinski (1989).*

Table 4. Chemical analysis of the Mercer ores (from Hickok and Moyer, 1940). Analyses were made by A. S. McCreath, D. McCreath, and Professor C. F. Chandler, chemists with the Second Geological Survey of Pennsylvania in the late 1800's.

	1	2	3	4	5	6	7	8	9	10
Iron	39.77	41.400	35.823	41.000	31.100	32.010	37.440	36.200	35.664	31.200
Sulfur	-----	0.184	-----	0.191	0.086	-----	-----	0.107	Tr.	0.253
Phosphorus	0.22	0.151	0.030	0.120	0.103	Tr.	0.250	0.154	0.008	0.120
Insoluble residue	12.98	6.430	15.568	6.810	25.960	22.150	12.000	12.980	16.700	21.930

Some Significant Early Fayette County Iron Furnaces

There is some disagreement about which was the first iron furnace west of the Alleghenies. Three blast furnaces, the Alliance, Union, and Fairfield furnaces, were built around the same time in the late 1790s. Swank (1878, p. 51; 1892, p. 214), Ellis (1882, p. 235), and the Pennsylvania Historical and Museum Commission (PHMC, 2011) all claim the first to be put into production was Alliance Furnace in 1790, followed about 16 months later by Union Furnace. Heald (1990), however, stated that pig iron was not produced at Alliance Furnace until 1792, which would make Union furnace the first producing iron furnace in western Pennsylvania.

Union Furnace

Union Furnace (**Figure 11**) was located on Dunbar Creek in Dunbar Township, four miles southwest of Connellsville. According to Heald (1990), it was built in 1789 by Isaac Meason (see below) and was the first furnace to produce iron west of Allegheny Mountain. It was a small stack, estimated to be 3.6 m (12 ft) high built into the hillside at creek level with a 1 m (3.5 ft) bosh. It is said to have been capable of producing only ¾ tons of pig iron daily (Parks, 2010a) but apparently was a financial success, supposedly because Dunbar iron was in great demand for its excellent quality. The ironworks consisted of the furnace, a forge, and two sawmills. Meason abandoned this furnace within three years and built a second, larger stack on a level terrace on the southeastern floodplain of Dunbar Creek. Meason, Moses Dillon, and John Gibson formed a company that also operated two local forges, a gristmill, a sawmill, two blacksmith shops, and a shoe and harness shop (Heald, 1990). Iron ore for the furnace was mined from an outcrop about 25 m (80 ft) above creek level which, considering the approximate location of the furnace, probably was a Mercer ore. Products included tea kettles, fire grates, Franklin stoves, andirons, wagon parts, mill parts, and clock weights, as well as sugar kettles for Louisiana plantations. A 1794 advertisement in the Pittsburgh Gazette indicated that the furnace also produced well-assorted castings for £35 ($93.33) per ton. Meason eventually bought out his partners and formed the Union Iron Works.

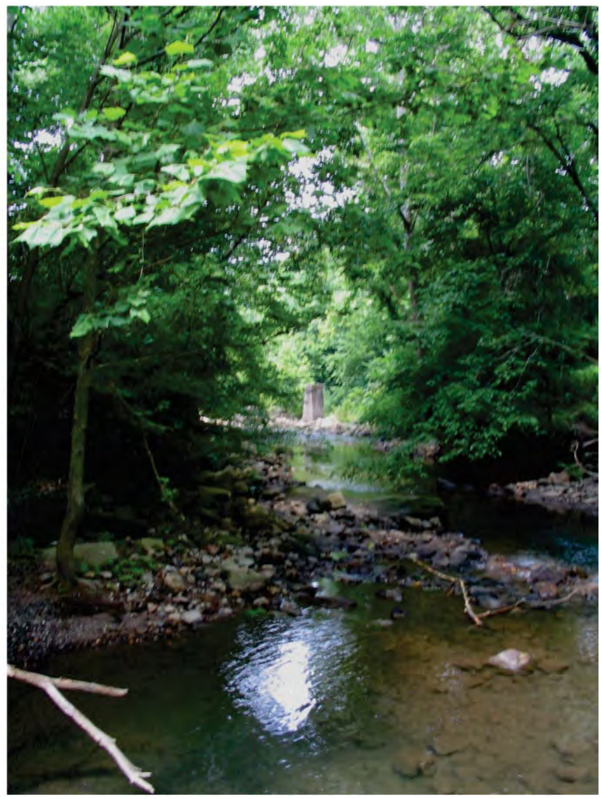

Figure 10. *Photographs of the remains of Union Furnace 1 and 2.* ***Left*** *– A few cut stone blocks on the hillside above Dunbar Creek indicate the location of Union Furnace 1.* ***Right*** *– Scattered sandstone blocks on the south shore of Dunbar Creek indicate the location of Union Furnace 2. Photos from Parks, 2010a.*

Alliance Furnace

Alliance Furnace, located on Jacobs Creek in Perry Township was built and operated by Turnbull, Marmie and Company. Peter Marmie, who lived nearby in Westmoreland County, was in charge of the furnace. Alliance furnace is often considered to have been the first iron furnace west of Allegheny Mountain. Heald (1990) documented a Fayette County Road Docket that listed the existence of the furnace in June 1789, but further stated that it was only under construction at that time and was not put into blast until sometime between 1790 and 1792. After it went into blast, it produced pots, kettles, and other hollowware that settlers in the area needed to cook and process food, as well as cannon shot and shells for General "Mad Anthony Wayne's" troops when they fought against Native Americans during the Northwest Indian War in 1795. By 1793, however, the company was in financial straits because some of their clientele refused to pay, and by 1802 the furnace was out of blast, never to return (PHMC, 2011). **Figure 12** is a historic photo of the old abandoned stack.

Mt. Vernon Furnace

Another furnace constructed and operated by Isaac Meason, who also owned the two Union furnaces as well as Dunbar Furnace at Dunbar, and Ross Furnace in Westmoreland County, was Mt. Vernon Furnace in Bullskin Township (**Figures 13 and 14**). According to Swank (1878), Meason built this furnace prior to July 1800, and then rebuilt it in 1801; it was probably in construction between 1795 and 1800 (Parks, 2010b). An iron lintel above the main opening has the letters "MT VN 1801".

The abundance and excellence of raw material found in the rock formations along the west side of Chestnut Ridge, plus the vastness of the forests in the late 1700s and early 1800s and the presence of Mounts Creek made this site an excellent choice for constructing a furnace. In addition to the furnace, the Mt. Vernon works also had mills to cut lumber and grind feed for the animals. Woodsmen cut the trees and work horses dragged them from the forests to the mill where they were cut into smaller pieces. Those pieces were then stacked and covered with earth, and ignited to make charcoal to fuel the furnace. The timber lands were cut over every 25 years (Bullskin Township Historical Society, 2018). The forest was in its second growth of timber by the time the furnace went out of blast in 1830 (Swank, 1878, gives the date as 1824; Parks, 2010b, said 1825). Iron from the furnace was used to cast molded products that were transported to Connellsville for shipment down the Youghiogheny River. Products from the furnace made their way by water as far away as Louisiana (Bullskin Township Historical Society, 2018).

The Mt. Vernon ore mines, located in the hills to the east of the furnace, operated from 1795 until 1830. The Mercer ores (**Figures 3 and 10**) supplied the siderite from beds generally ranging from 0.2 to 0.5 m (0.5 to 1.5 ft) thick (Stevenson, 1877; Hickok and Moyer 1940). These ores were relatively high in iron (Table 5), although not nearly as high as other kinds of ores (magnetite – 72% iron; hematite – 70% iron; goethite – 63% iron). Following the demise of the furnace, the mined ore was shipped to the Charlotte Furnace in Scottdale, Westmoreland County, via a narrow gage railroad until the 1880s (Bullskin Township Historical Society, 2018). The mine openings were completely collapsed by the time Hickok and Moyer (1940) examined the area in the 1930s, and not much is left of them today.

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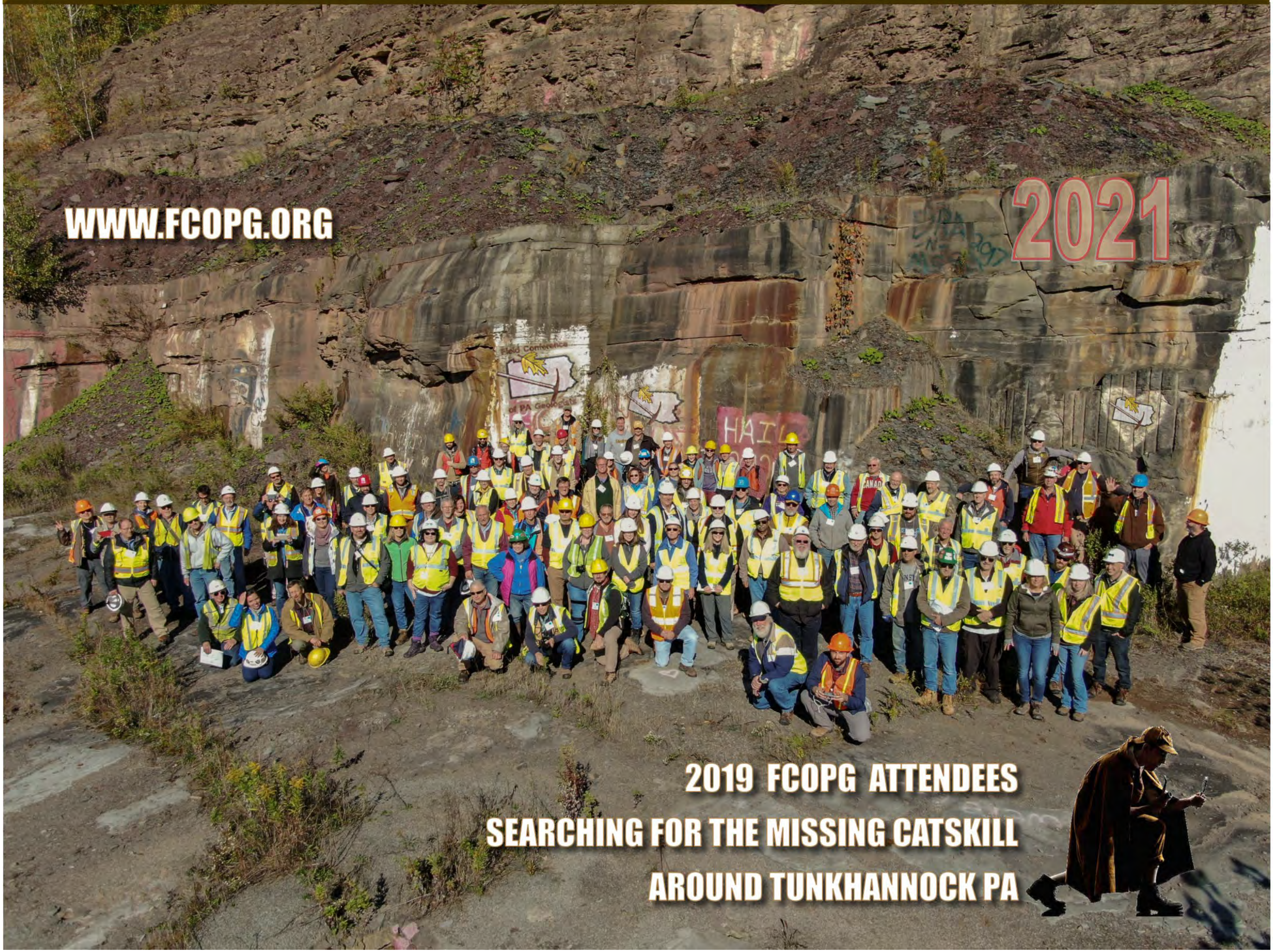
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