80th Annual Field Conference of Pennsylvania Geologists

October 8th-10th, 2015

Hosts

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Kutztown University
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Conglomerate

Coal

And

Calamites

Geology Mining History & Paleontology of “The Region”

Schuylkill, Northumberland & Columbia Counties, Pennsylvania
Coal lay in ledges under the ground since the Flood, until a laborer with pick and windlass brings it to the surface. We may well call it black diamonds. Every basket is power and civilization. For coal is a portable climate. It carries the heat of the tropics to Labrador and the polar circle: and it is the means of transporting itself whithersoever it is wanted. Watt and Stephenson whispered in the ear of mankind their secret, that a half-ounce of coal will draw two tons a mile, and coal carries coal, by rail and by boat, to make Canada as warm as Calcutta, and with its comfort brings its industrial power.

Ralph Waldo Emerson, The Conduct of Life—“Wealth” 1860
GUIDEBOOK FOR THE
80TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS
OCTOBER 8 — 10, 2015

CONGLOMERATE, COAL, AND CALAMITES
GEOLOGY, MINING HISTORY, AND PALEONTOLOGY OF “THE REGION”
SCHUYLKILL, NORTHUMBERLAND, AND COLUMBIA COUNTIES, PENNSYLVANIA

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Group Conferee photo of the 2014 Field Conference of Pennsylvania Geologists
at Carlisle ....................................................................................................... back cover

GREAT MOMENTS IN GEOLOGIC HISTORY

Part 8 – The Eocene

Sure you’re a horse, shorty, and I’m the Lone Ranger.
See my mask? Haw, haw, haw!
ACKNOWLEDGMENTS

The Field Conference officers, organizers, and editors would like to take this opportunity to acknowledge all the hard work and effort that has gone into making this 80th Anniversary of the Field Conference of Pennsylvania Geologist come to fruition. We would like to start by thanking all the contributors and stop leaders that, in some cases, have been dreaming about this conference for years. Their drive and dedication toward the sharing of both the geological and historical significance of this region is commendable and inspiring.

Thank you:

* David DeKok, Banquet Speaker, “Centralia: How a Mine Fire Destroyed a Pennsylvania Town and Became a Worldwide Phenomenon”

A big “Thank You” goes to David DeKok, our banquet speaker, for taking the time out of his busy schedule to provide a more personal understanding of the Centralia story.

A special thanks goes out to Robin Anthony, our Road Log and Guidebook editor, for her endless patience and amazing execution of this monumental task; to Gary M. Fleeger for his thoughtful memorial of Richard P. Nickelsen, to John Harper, for continuing to provide “comic relief” on the blank back pages of the Roadlog & Guidebook, and to Thomas Whitfield for his cheerful assistance with the location maps for Day 1 and Day 2, no matter how many times we asked for changes.

Last but not least we would like to acknowledge all of the businesses listed below that make this event happen by graciously allowing us to disrupt their operations and traipse all over their property:

Thank you:

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* Corson Quarries for access to their quarry for Stop 6
* Anthracite Outdoor Adventure Area for their work with the Whaleback
* Pottsville Materials for access to Stop 8 and 9
* Reading Anthracite for access to their lands for Stop 8, 9, and 12

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INTRODUCTION

HISTORICAL CHRONOLOGY OF THE MINING INDUSTRY
IN THE SOUTHERN AND WESTERN MIDDLE ANTHRACITE FIELDS

compiled by Jon D. Inners

1742  Count Zinzendorf travels through the heavily forested, virtually uninhabited Anthracite region and bestows on it the name “St. Anthony’s Wilderness”—quite apropos considering that the Indians called it Towamensing, meaning the wild place.

1790  Necho Allen, caught at nightfall out hunting, camps under a projecting ledge at the base of Broad Mountain north of modern-day Pottsville. By the middle of the night, the fire he lights ignites the coal in the ledge—and the rest is “history.” Later Allen successfully prospects for coal and opens a small mine on Broad Mountain.

1815  Schuylkill Navigation Company chartered to create a canal along the Schuylkill River from Philadelphia to the Anthracite region.

1819  Thomas Wildey, who emigrated to the United States from Manchester, England in 1817, leads the founding of the Independent Order of Odd Fellows in North America in Baltimore. By the mid-19th century the Odd Fellows have expanded to become “the poor man’s Masonry.” In the Anthracite Region, they are particularly noteworthy because of their creation of many cemeteries for “prosperous, respectable workingmen, for family men, and for men who aspired to community betterment” (Wallace, 1980, p. 155) in the coal towns—as at Centralia.

1827  The 108-mi-long Schuylkill Canal completed from Philadelphia to Port Carbon.
      The Summit Hill Gravity Railroad at Mauch Chunk completed.

1829  Mill Creek and Pottsville Railroad connects St. Clair with Mount Carbon.
      (June) Lehigh Canal completed between Mauch Chunk and Easton.

1831  Completion of the Little Schuylkill Navigation, Railroad, and Coal Company, a 22½-mi-long railroad that connected the coal mines at Tamaqua with the Port Clinton on the Schuylkill Canal—at the time the longest railroad in America.

      Beginning of construction of the Danville and Pottsville Railroad, originally conceived by Stephen Girard, Burd Patterson, and others as a great coal-and-iron-transport route through the Anthracite region. A long plane descending through the Mill Creek gap from the top of Broad Mountain to the vicinity of St. Clair is completed early on, but the project as first projected is never completed.

      Rev. Dr. Frederick Geissenheimer successfully utilizes hot blast to smelt a small quantity of iron with anthracite at his experimental furnace in New York City, securing a United States patent.

1833  Philadelphia and Reading Railroad (P&RR) chartered.

1835  First Pennsylvania Geological Survey, under Henry Darwin Rogers (1808-1866), begins work in the Anthracite fields. Initial field studies are completed in 1841.

- 1 -
1836  Henry Carey and Burd Patterson commence the York Farm Colliery just west of Pottsville with a below-water-level slope on the 8-ft-thick Black Mine or Gate Vein, one of the first—if not the first—commercially successful slopes in the Anthracite region. It was here, too, that the furnace method of mine ventilation was used for the first time in America.

1837  The Panic of 1837, beginning in the spring, leads to a recession, which lasts for about five years and adversely affects the economy of the Anthracite region.

1839  Using ore from Mount Laffee near Wadesville, the Pioneer Furnace near Pottsville produces pig iron using anthracite for fourteen weeks without interruption—thus winning a state award of $5,000 for being the first furnace to keep an anthracite furnace continuously in blast for 3 months.

1840  (July 3) David Thomas, an immigrant Welsh ironmaker, successfully blows in an anthracite blast furnace at Catasauqua (Lehigh County). Within fifteen years more iron is being smelted with anthracite than with any other fuel.

1842  Completion of the Philadelphia and Reading Railroad’s line to Pottsville.

Because of faults and the poor quality of the coal, the York Farm and adjacent tracts becomes unprofitable—and Carey and his associates sold their interest in these lands. The operators, George and Charles Potts, went bankrupt 6 years later.

1844  Gideon Bast erects the first anthracite breaker at Wolff Creek Colliery near Minersville. Bast uses a system of steam-driven roll crushers and screen developed by Joseph Battin of Philadelphia.

1845  Alfred Lawton sinks a test shaft (~125 ft) down to the Primrose Vein at St. Clair.

George W. Snyder and Benjamin Haywood sink the Pine Forest Slope east of the St. Clair tract.

1846  Burd Patterson’s St. Clair furnace put in blast.

The Johns brothers, William and Thomas, begin development of the Johns Eagle Colliery in the Johns Basin north of St. Clair. The drift, tunnel and slope mine continues to operate into the early 1870’s, one of the best-run operations in the region. A new drift and slope mine was opened to the east about this time, and continued to operate as Johns Eagle Colliery until 1889.

(December 30) Fatal assault, at Delaware Mines near St. Clair, of John Reese, a Welsh miner who had recently been found “not guilty” of murdering Irishman Thomas Collahan. Irishman Martin Shay is arrested a few days later—and eventually convicted of a revenge slaying and hung. This can be seen as a prelude to what is to burst forth nearly two decades later.

1847  (February) 7 men killed in explosion at the Spencer mine in Pottsville.

1853  Enoch McGinness, with money borrowed from Henry Carey and others, extends Lawton’s test shaft down to the base of the Mammoth Vein at 450 ft (having begun the project in February 1852). The St. Clair Shaft is finally competed the next year. Earlier McGinness had developed a slope on the same vein, setting a pattern for slope-and-shaft mines in the St. Clair area (Pine Forest Slope and Shaft and Hickory Slope-Wadesville Shaft).

Benjamin and William Milnes sink the Hickory Slope on the northern edge of St. Clair.
1857  Benjamin Bannon of the *Miners' Journal* first uses the term "Molly Maguires" in reference to an alleged secret Irish organization that controlled the Democratic Party. The name originated in Ireland in the famine years of the 1830’s and 40’s and applied to peasants who retaliated against their oppressors—landlords, constables, bailiffs, etc. Who Bannon had in mind, however, was the Ancient Order of Hibernians (AOH), a secret Irish benevolent society similar to the Protestant Masons.

1858  Strikes of coal miners in Ashland and St. Clair, culminating on May 21-22 in the “Great Battle of St. Clair”—a disturbance “requiring” four companies of militia to suppress.

1859  (November) Explosion and fire in Parvin’s Slope near St. Clair, caused by failure to extend an air hole to a "trial gangway."

1860  (July 18) Explosion of “fire damp” in Enoch McGinness’s slope on the Diamond Vein on the North American Tract—the cause being, as in the case of the Parvin’s Slope, failure to sufficiently extend an air hole.

1861  Robert Allison and Benjamin Bannon found the Franklin Iron Works in Mount Carbon.

1862  McGinness discovers and successfully exploits a vein of blackband iron ore near St. Clair.

1866  Pennsylvania legislature extends to anthracite coal operators the right to maintain private police forces, a privilege previously held by railroad companies. Thus is born the “Coal and Iron” police.

        (November) Benjamin Haywood completes the Pine Forest Shaft down to the Mammoth Vein. (Sinking started in late 1864 but was delayed by water problems.)

1867  (May) The Wadesville Shaft (auxiliary to the Hickory Slope) reaches the Mammoth Vein at 663 ft, nearly 3 years after the beginning of construction.

1868  John Siney (1831-1880), an Irish immigrant via Lancashire in England, succeeds in organizing the Workingmen’s Benevolent Association (WBA) of Schuylkill County. At its peak, 30,000 miners, or four-fifths of all anthracite workers belong to an expanded WBA.

1869  Franklin B. Gowen becomes president of the P&RR and begins buying up coal lands for the railroad. He serves through tumultuous times until 1884.

        Pennsylvania legislature passes its first mine safety law (which applies only to Schuylkill County), requiring the ventilation of mines by either furnace or fan and the employment of a “mine boss” responsible for certain aspects of mine safety. Provision is also made for a single mine inspector. John Elringham, superintendent of the Pioneer Colliery in Ashland, receives this appointment.

        (September 6) Avondale Mine Disaster. Fire at the Avondale colliery of the Steuben Coal Company near Pittston kills 110 men and boys. A fire starts in a ventilating furnace and spreads to the breaker, built directly over the only entrance to the mine, and the workers are trapped underground. This is the first major mine disaster in the Anthracite fields, and no subsequent accident exacts a higher toll.

        (December 18) “Crop fall” at Stockton in the Eastern Middle field east of Hazleton swallows several houses, resulting in the deaths of 10 men, women, and children. Breast and
pillar mining of the Mammoth seam on a subvertical north-dip along the south side of the Hazleton basin results in catastrophic subsidence for nearly one-half mile along strike (see Brown, this Guidebook).

1870 (March 22) Explosion in the Potts mine at Locustdale near Ashland—5 die.
(August 28) 5 men killed in a cage fall in the Preston No. 3 mine near Girardville.

As a result of the Avondale disaster, the state legislatures strengthens the 1869 mine safety law and applies the new law to all anthracite mines. Important provisions include requiring two or more openings for shaft and slope mines and maintenance of accurate mine maps. The laws also increases the number of state mine inspectors to six.

Slate picking tables and “breaker boys” are introduced at the Hill and Harris colliery in Mahanoy City.

Franklin B. Gowen (1836-1889) becomes president of the Philadelphia and Reading Company.
Schuylkill Navigation Company leases its canal to the Philadelphia and Reading Railroad.
(March 22) “Fire damp” explosion in the Potts mine at Locustdale results in the deaths of 5 miners.
(August 28) A cage fall in the Preston No. 3 mine in Girardville kills 7 miners.

1871 Chartering of the Philadelphia and Reading Coal and Iron Company (P&RC&I Company), an expansion of the Philadelphia and Reading Railroad into ownership of coal lands in the Anthracite region. By this time P&RR is the largest company in the world.

Samuel Daddow and James Beadle invent and patent a successful safety squib (fuse).
5 die in an explosion at the Otto Red Ash mine at Branch Dale, 4 mi west of Minersville.

1873 (June 10) A fire in the Henry Clay mine at Shamokin kills 10.

(September) Collapse of Jay Cooke & Co., a banking firm tied firmly to the burgeoning railroads, leads to the “Panic of 1873,” a depression that lasts until 1879 and foments widespread labor unrest.

1874 After two decades of varying ownership and numerous disasters (floods, “firedamp” explosions, breaker fires, and roof collapses), the St. Clair Shaft Colliery is closed down by its final owners, the Philadelphia and Reading Coal and Iron Company.

1875 “The Long Strike.” A violent, five-month-long confrontation between workers and mine owners ends in a bitter defeat for the WBA. In a period of reprisals following the strike, the “Mollies” allegedly commit seven murders.

1876 “Molly Maguire” trials in Mauch Chunk (January) and Pottsville (May). At the second trial, James McParlan (alias “James McKenna), a Pinkerton spy, testifies against five men accused of murdering policeman James Yost. Franklin B. Gowen serves with the prosecution and is successful in pinning much of the terrorism rampant in the coalfields on the Ancient Order of Hibernians.

1877 (May 9) 7 men die in a methane explosion at the Wadesville Shaft, initiated by the fall of a large block of coal in the Seven-Foot vein as the men were robbing pillars in “Lundy’s gangway.” The ultimate cause of the disaster, however, was probably poor ventilation and the failure to use safety lamps.
(June 21) “Black Thursday.” Ten “Molly Maguires” executed in Mauch Chunk and Pottsville. Within a year and a half, ten more Irishmen die on the gallows at Mauch Chunk, Bloomsburg, and Sunbury.

(July 25) Shamokin uprising: hundreds of miners and railroad workers riot as a culmination in the region of the Great Railroad Strike of 1877, joining workers who had previously risen up in Reading, Sunbury, Danville, and Shenandoah—among other places—to protest poor working conditions and cuts in wages. Two are killed and 12 wounded by vigilantes hired by the local mayor.

1878 (January 1) The Knights of Labor organized in Reading, Pennsylvania.

(December 18) John “Black Jack” Kehoe, the reputed “King of the Mollies,” executed in Mauch Chunk for the murder of Frank Langdon in Audenried (Luzerne County), more than 15 years previously.

1879 (January 14) James McDonnell and Charles Sharp hanged at Mauch Chunk for the murder of Charles K. Smith in 1863, a last minute reprieve from Governor John Hartranft arriving minutes too late.

State legislature approves bill to create a State Hospital for Injured Persons of the Anthracite Coal Region at Fountain Springs near Ashland. Construction begins in May 1880 and is completed in 1882. Ashland State Hospital operates under state control until 1990, when it is turned over to private interests. It is now St. Catherine Medical Center of Fountain Springs.

(October 9) Peter McManus executed in Sunbury for the murder of Frederick Hesser, night watchman at the Hickory Run Colliery (Northumberland County) on December 18, 1874. He is the twentieth and last of the “Mollies” to die on the gibbet.

1880 Cost of buying up coal lands puts the P&RR into receivership, from which it finally emerges later in the decade.

(May 3) Explosion at the Lykens Valley mine near Shamokin kills 5.

1882 (May 24) 5 men die in an explosion at the Kohinoor mine in Shenandoah.

1884 (May 3) Fire at the Buck Ridge mine near Shamokin results in 7 deaths.

1885 (April 6) Roof fall brought on by the robbing of pillars kills 10 miners, laborers, and boys in the Cuyler Colliery at Raven Run, near Shenandoah.

1887 (April 27) Gas suffocation kills 5 miners in the Tunnel mine at Ashland.

(October 1) Another gas suffocation accident in the Bast mine at Girardville claims 5.

1889 (May 9) A mine car crashes into a cage in the Kaska William mine at Middleport, claiming 10 lives.

1891 (October 23) 7 men die in a gas suffocation accident at the Richardson mine at Glen Carbon, northwest of Minersville.

1892 (April 20) Water inundates the Lytle mine at Minersville, drowning 10 workers.

(July 23) 15 men and boys killed in a methane explosion at the York Farm Colliery just west of Pottsville.
1893  (April 1) A miner’s lamp ignites methane in the Neilson Shaft near Shamokin—the explosion kills 10 men and boys.

1894  (October 8) Fire and explosion results in the deaths of 5 workers in the shaft of the Luke Fidler Colliery at Shamokin.

          (October 11) Boiler explosion at the Henry Clay Colliery in Shamokin kills 6.

1897  (January 13) A crosshead falls in the Wadesville Shaft, killing 5.

1898  (May 26) Inundation at the Kaska Williams mine at Middleport, between Pottsville and Tamaqua, drowns 6 workers.

1900  (November 9) Explosion in the Buck Mountain mine in Mahanoy City—6 die.

1902  (May 12) Beginning of “The Great Strike”: 145,000 anthracite miners go out on strike for more than 5 months.

          (July 12) Troops are stationed throughout the Anthracite region.

          (August 14-30) Escalating labor violence, in part brought on by “goon squads” and Coal-and-Iron Police hired by the operators, culminates in a fortnight of riots, destruction, and injuries.

          (October 13) President Theodore Roosevelt intervenes and forces the miners and operators to submit their differences to arbitration by a commission agreeable to both sides. Mitchell calls off strike on October 21.

          (October 23) Most mine employees return to work.

          (November 14) Anthracite Strike Commission opens its hearings in Scranton, Clarence Darrow being the miners’ chief counsel. Hearings in Scranton and Philadelphia last three months.


          (November 26) Last of miners accept arbitration and go back to the collieries.

1903  (March 10) Anthracite Coal Commission delivers its findings after the most exhausting inquiry into the anthracite industry ever made. The miners win another 10 percent pay increase and creation of an Anthracite Board of Conciliation, but do not get recognition of the UMWA as a bargaining representative.

          This settlement marks the beginning of an 18-year period of relative peace and rising prosperity in the Anthracite fields. But stability and higher wages are bought at the cost of the monopolistic practices exposed by Socialist Scott Nearing in his *Anthracite—an instance of natural resource monopoly* (1918). For throughout this time, more than 96 percent of all anthracite coal lands are owned by the railroads, with 91 percent of the deposits owned outright—and J. P. Morgan interests control companies that transport one-third of all anthracite mined in Pennsylvania.

1904  (May 5) 5 workers die in a fire at the Locust Gap Colliery at Locust Gap, southwest of Mount Carmel.

1905  (January 31) John O’Hara born in Pottsville.

          (February 18) Haulage accident at the Lytle Mine near Minersville results in deaths of 7 men.
1911  (May 27) Explosion at the Cameron Colliery in Shamokin kills 5.

1913  (August 2, “Black Saturday”) Double explosion, probably of methane, in the deep mine of the East Brookside Colliery near Tower City claims the lives of 20 men. The accident occurred as workers were nearing the completion of a 1000-ft-long tunnel between two coalbeds, and was at first thought to involved an initiation, accidental explosion of dynamite.

1914  (May 29) Haulage accident at the Mary D mine in Mary D, southwest of Tuscarora, results in 6 deaths.

(September 16) Explosion at the Lehigh No. 4 mine kills 5.

1917  Anthracite production throughout “The Region” peaks at more than 100 million tons, mostly from deep mines.

1918-19 Influenza pandemic rages throughout the United States, as well as the rest of the world. A one-million-ton drop in anthracite production in 1918—a the height of American involvement in World War I—is due in part to the temporary shut-down of numerous collieries at the height of the pandemic in September, October, and November.

“...The mines closed down almost with the first whiff of influenza. Men who for years had been drilling rock and had chronic miners’ asthma never had a chance against the mysterious new disease; and even younger men were keeling over, so the coal companies had to shut down the mines, leaving only maintenance men, such as pump men, in charge.”

John O’Hara, “The Doctor’s Son” (1935)

1919  (July 7) Explosion at the Lansford Colliery in Lansford results in deaths of 5 workers.

1920  John Llewellyn Lewis (1880-1969) becomes president of the UMWA.

1922  (April 1-September 10) Nationwide coal strike involving both anthracite and bituminous mines (163 days). Consumers of anthracite begin to look to oil and natural gas.

1923  (February 21) 5 die in explosion at the Alliance mine in Kaska, midway between Pottsville and Tamaqua.

(June 26) Explosion at the Richards Colliery in Mount Carmel results in deaths of 5 workers.

1924  The U.S. Supreme Court orders the Reading Company to divest itself of the P&RC&I Co.

1925  (September 1) Beginning of the longest strike in anthracite history (170 days).

1926  (February 12) John L. Lewis signs pact with mine operators, effectively ending strike. The existing contract is extended for five years, but neither side really gains anything. The drift away from anthracite for home and commercial heating becomes a stampede.

(May 6) Explosion in the Randolph Colliery at Port Carbon kills 5.

1928  Due to hard times and high unemployment, “work equalization” emerges as a major issue in the Anthracite fields.
1930  (August 8) 8 miners working on reopening an old slope are killed in a roof fall in the Gilberton mine at Gilberton.

1933  J. L. Lewis gains recognition of the UMWA as the official bargaining agency for all coal miners in the country. The practice of using scrip to pay miners is also abolished.

1935  (January 21) 13 die in an explosion in the Gilberton mine at Gilberton.

1936  Contract gives miners an increase in wages and also contains a work-equalization clause that commits operators to employ as many of their mineworkers as possible.

1937  As depression deepens, more than 12,000 men are involved in illegal bootleg operations throughout the Anthracite region.

1938  (April 27) Explosion in the No.1 Slope at Pottsville—8 die.

1942  Bill passed by Congress authorizing the construction of a $450,000 research laboratory in the Anthracite region. The project is designed to "determine how anthracite markets may be regained, maintained, and expanded, and to advance the health and safety of the workers in anthracite mining." It falls victim to wartime neglect and is never accomplished.

1943  (April 27) Beginning of a series of short wartime strikes sanctioned by the UMWA that brings on federal takeover of the nation’s coal mines under Secretary of the Interior Harold Ickes.

  (September 24) Deadly methane explosion in the Primrose (old Lytle) Mine of the M&S (Moffet and Schrader) Coal Company at Primrose (near Minersville) claims the lives of 14 men. (Note that accidents resulting in multiple deaths had also occurred in this mine in 1892 and 1905.)

1947  Canal is officially closed, as the State of Pennsylvania begins filling it in an effort to clean up the Schuylkill River.

1950  (June 12-October 25) Fifteen core holes drilled along the path of the “Conowingo Tunnel,” a proposed 102-mile long drainage tunnel that would have extended from Glen Lyon in the Northern field, through Sheppton in the Eastern Middle field, and Pottsville, to Chesapeake Bay. This is perhaps the last great scheme devised to revitalize the dying anthracite industry.

1956  The P&RC&I Company changes its corporate title to the Philadelphia & Reading Corporation, of which Reading Anthracite is one of its many operating divisions.

1957  St. Clair Coal Company shuts down mining operations.

1960  About this time, surface-mine production of anthracite first exceeds deep-mine production.

1961  The Philadelphia & Reading Corp. divests itself of its anthracite interests, selling the Reading Anthracite Co. to its present owners.

1962  Daniel J. Flood, U.S. representative from the Wilkes-Barre area, ushers the Flood Amendment through Congress. This requires the use of anthracite or coke in all military installations in West Germany, even if natural gas or fuel oil is cheaper.
1968  Reading Anthracite closes Pine Forest stripping east of St. Clair.

1972  (January 1) Surface Mining Conservation and Reclamation Act of 1971 goes into effect. Anthracite strip mines placed under backfilling and reclamation requirements similar to those of bituminous mines.

1973  Arab oil embargo.

1977  (March 1) An inrush of water from old mine workings inundates the Porter Tunnel Mine of the Kocher Coal Company near Tower City, causing the deaths of 9 miners, the injury of 3, and the entrapment of 1, who is eventually rescued. 71 miners escape through air emergency escapeways.

    Anthracite Task Force formed in an effort to increase production and expand markets for "hard coal."

1979  (January 12) Governor Milton Shapp signs a posthumous pardon for "Black Jack" Kehoe, a belated acknowledgment of the injustices that prevailed at the "Molly Maguire" trials 100 years before.

    OPEC oil-price increase causes government action to encourage use of anthracite in place of fuel oil. Production rises for a few years, but then begins to fall again.

1999  Reading Anthracite sells St. Clair tract to private developers (Wal-Mart, etc.) for erection of Coal Commerce Shopping Center.

2015  80th Field Conference of Pennsylvania Geologists descends upon “The Region”

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INCLINED PLANES IN THE PENNSYLVANIA ANTHRACITE
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Introduction

The common every day ramp takes on many forms, from the ramp letting you drive your mower onto the trailer to sidewalk ramps required by the ADA for handicapped access to the marvels of 19th Century engineering, the inclined plane railroads used to move coal from the valleys over the mountains to the canal systems of the 1800's and eventually to the railroads as they supplanted the canals.

Definition: An inclined plane is a flat supporting surface tilted at an angle, with one end higher than the other, used as an aid for raising or lowering a load. The inclined plane is one of the six classical simple machines as defined by Renaissance scientists.

The Anthracite Region of Pennsylvania is situated in the Valley and Ridge Province of the Appalachian Mountains. The coal deposits are located in the synclinal basins in the valleys and in synclines across the broad mountain tops. As the canal systems did not extend very far into the mountains it was necessary to find ways to bring the coal to the canals. Thus the need for a multi-stage integrated transportation system to bring the anthracite to the New York and Philadelphia markets required forward thinking individuals and companies to come up with solutions to not only increase the tonnage to market but to reduce transportation costs.

The 18th Century was a period of rapid advancements in technology brought about by the Industrial Revolution and many of those advancements found their way into the operation of the inclined planes found in the Anthracite. The earliest planes used horse and mule power to move the coal cars both up and down the inclines. This method was quickly supplanted by rope connected to steam and hydro power. The rope was soon replaced by chain and finally by wire rope.

In the 1800’s the railroads were restricted to steam power and were not capable of surmounting the grades required to cross the mountains. However, stationary steam engines were not restricted in size as were the locomotives so they were rapidly adapted to provide the power to the hoists used by the inclined planes to pull the loaded coal cars up the inclines.

In this paper we will enumerate and document the known planes built in the Pennsylvania, the dimensions of the planes, periods of operation and their location and use in the Anthracite Fields of northeastern Pennsylvania to move coal to market.

List of Incline Planes

The very first inclined plane of note was the Switchback Gravity Railroad from Summit Hill to Mauch Chunk. It was created when rails were applied to the all downhill “Stone Turnpike” in 1827. A “Back Track” that was completed in 1845 created an 18-mile loop with two stationary steam engines atop Mt. Pisgah and Mt. Jefferson allowing cars and passengers to return to Summit Hill. We are leaving discussion of this plane for another paper and will be concentrating on the other planes that we have found during our research.
The next documented use of inclined planes as part of the transportation system to deliver anthracite coal to the east coast cities is by the D&H Gravity Railroad in 1829 from Carbondale in Lackawanna County to the canal head in Honesdale, Wayne County. The last plane in operation was the Owl Hole Plane near Eckley in eastern Luzerne County. It was still in operation in the 1960s at Gerry Gatti’s Owl Hole Pit operation. The last major plane in operation was the Ashley Plane which was closed in 1948 when it was displaced by diesel locomotives.

Below is a list of the inclined planes that we have found in our research. They are in chronological order from start of operation:

1) Delaware and Hudson Canal Company Gravity Railroad (D&H Gravity Railroad) – Northern Field: The D&H opened in 1829 and was in service until 1899.

2) Room Run Plane\textsuperscript{2,3,4} – Southern Field (Bohlin, 1980; Baker, 2015): Operation started in 1830 and remained in service until 1870.

3) Wadesville Plane\textsuperscript{3,4} – Southern Field (Baker, 2015): The Wadesville Plane opened in 1834, its closure date is undocumented although we can surmise that it was replaced by railroad at some point before the opening of the new “Mahanoy” Plane in 1862.

4) Buck Mountain Railroad\textsuperscript{2} - Eastern Middle Field (Bohlin, 1980): The Buck Mountain opened in 1836 and remained in operation until the Great Flood of 1862.

5) Ashley Plane – Northern Field\textsuperscript{2}: Construction started on the Ashley Planes in 1837. They opened for operation in May 1843 and remained in service until 1948.

6) Pennsylvania Coal Company Gravity Plane – Northern Field\textsuperscript{2}: The PCC Gravity Plane opened in 1850 and remained in service until 1885.

7) Gordon Plane – Southern Field\textsuperscript{3,4}: The Gordon Planes started operation in 1855 and remained in service until 1895.

8) Penn Haven Planes – Eastern Middle Field\textsuperscript{2}: The Beaver Meadows and Hazleton Railroad opened the Penn Haven Planes in the mid-1850s and they remained in service until 1879.

9) Mahanoy Plane – Western Middle Field\textsuperscript{2}: The second Mahanoy Plane opened in 1862 and remained in service until September 1932.

10) Owl Hole Plane – Eastern Middle Field: Service period unknown although it was still in use in the mid 1960’s to remove coal from the Owl Hole pit.

**Incline Planes of the Anthracite Detailed Descriptions**

There is little information remaining for some of the inclined planes listed so we are going to initially discuss the four that we can find only minimal information detailing them.

**#2 Room Run Plane – Southern Field\textsuperscript{2}**

The Lehigh Coal and Navigation Company built the Room Run Plane to connect their operations in Nesquehoning to the canal at Mauch Chunk, both in Carbon County. As previously noted it operated from 1830 to 1870.
#3 Wadesville Plane – Southern Field

Easier access to the Shenandoah and Mahanoy coal measures was desired in the early 19th Century. One of the first ventures to supply the transportation needs of the coal companies was undertaken by the Danville and Pottsville Railroad which developed the Wadesville Planes to traverse the Broad Mountain to connect the northern Schuylkill coal deposits from the Shenandoah and Mahanoy fields being brought to Girardville to the canal at Port Carbon.

The system consisted of six inclined planes covering a 5.5 mile distance. It was designed as a counterbalanced system where the loaded descending cars, whose speed was controlled by brakes, lifted the empty cars back to the top of the plane. It also included an 800 foot tunnel as part of the #1 Plane. Construction started in the early 1830’s and planes opened for operation in 1834.\(^2,5\) It quickly became an only-descending operation and received coal from the measures around Frackville until 1835 as a major disaster occurred during the opening of the original 1834 “Mahanoy” plane when the hoisting mechanism and drum house self-destructed resulting in multiple injuries and at least one death. The counterbalanced system for the “Mahanoy” plane was replaced by a 90-HP steam engine\(^2\) during the re-build. As a result its initial operation was a failure and ended in 1836\(^5\).

The system was rebuilt in 1844 and operated until it was supplanted by the new “Mahanoy” Plane in 1862.

#4 Buck Mountain Railroad - Eastern Middle Field\(^2\)

The Buck Mountain Railroad was developed in the 1830’s and consisted of four planes starting at Rockport, Carbon County. It was approximately four miles long and included a tunnel. The tunnel was only large enough to pass the 1-1/4 ton coal cars then in use. The Great Flood of 1862 destroyed much of the infrastructure and it was not repaired.

#10 Owl Hole Plane – Eastern Middle Field

Little is known of origins of this plane and it is believed to have started as a component of the Buck Mountain Railroad. What is known is that it was still in use in the mid-1960’s to remove coal from the Gerry Gatti’s Owl Hole operation. It was 300 to 400 feet in length. The Owl Hole operation was located in Foster Township, Luzerne County. (Figures 1 and 2)

![Figure 1. Photo used with permission of Jon D. Inners, PG, PA Geological Survey (Retired)](image-url)
The remainder of the planes have been studied and documented in more detail than the previous four planes so we are providing an abridged version of their details and we recommend looking at the source documents (see References) for much more detailed information and many more photographs and maps of these inclined planes.

#1 Delaware and Hudson (D&H) Canal Company Gravity Railroad – Northern Field

The Delaware and Hudson Canal Company\(^2\), \(^6\), \(^7\) pioneered the use of inclined planes in the United States when it opened its well-documented gravity railroad to use in 1829. The route originated in Carbondale, Lackawanna County, and traveled over five ascending inclined planes to the Rix's Gap in the Moosic Mountains. The ascending planes were powered by stationary steam engines and the railroad then used gravity for the descending planes using three self-acting, or counterbalanced, planes to travel the remaining distance to the canal head at Honesdale on the Lackawaxen River in Wayne County.

John Bloomfield Jervis designed and built this railroad for coal and passengers; it opened the anthracite trade from the eastern part of the northern field to the Hudson River and New York City. Between 1841 and 1866 this railroad was extensively altered by engineer James Archbald increasing the number of planes from 8 to 28. It remained in operation until 1899. (Figures 3, 4)

The D&H gravity plane system was continuously extended and upgraded throughout its life. The first extension occurred when the White Oak Run Mine was opened in Archbald, Lackawanna County. Ten years later in 1858, additional mines at Olyphant, Lackawanna County, were opened and planes to service the mine were built. The final extension of the planes occurred in 1860 with an extension to the Providence mines north of Scranton, but instead of gravity, the D&H decided to use narrow gauge steam locomotives to move the cars to the gravity plane at Olyphant.

Technological advances produced changes in the design and operation of the planes throughout the operating period of the D&H starting with the changeover from the original iron chains used to move the cars along the planes with the more reliable hemp rope. This change was caused by the frequent failure of the iron chains to the point that blacksmith forges were maintained along the planes to facilitate rapid repairs. The hemp rope was replaced in 1858 by wire rope manufactured by the Roebling Company (of Brooklyn Bridge fame, but before that he...
was the builder of choice of the D&H for the aqueducts carrying the D&H Canal over the Lackawaxen River and the Delaware River at the village of Lackawaxen, PA.)

Figure 3. "D&H-Gravity-1829 Carbondale" by Jim Irwin - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:D%26H-Gravity---1829-Carbondale.png#/media/File:D%26H-Gravity---1829-Carbondale.png

Figure 4. "D&H Gravity - 1829 Honesdale" by Jim Irwin - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:D%26H_Gravity_-_1829_Honesdale.png#/media/File:D%26H_Gravity_-_1829_Honesdale.png

The final improvement to the system was the switchover from the original strap iron rails to "T"-rails.
While the D&H and PCC Gravity Planes took coal to the New York market from the Lackawanna fields and upper Luzerne fields around Pittston, the southern portion of the Northern Field in Luzerne County did not have the ability to access these transportation systems.

The Lehigh Coal and Navigation Company (LC&N) looked to fill this need for the coal companies from the Wilkes-Barre / Nanticoke area by providing access the LC&N’s Lehigh Canal at White Haven through the construction of the Ashley Planes from Ashley, Luzerne County to the rail head at the Solomon Gap in Mountain Top, Luzerne County. They started construction of the Lehigh & Susquehanna (L&S) Railroad from White Haven which included the Ashley Planes in 1837 with the planes going into operation in May 1843. They remained in operation until 1948 making them the longest-lived inclined plane operation in the Anthracite.

To quote Annie Bohlin from her History of the Ashley Planes, 1843- 1948: “The Ashley Planes are noteworthy for their pioneer engineering, their longevity, and their relatively undisturbed remains.”

The original design consisted of a series of three double-track inclined planes. Starting in Ashley Plane #3 followed Solomon Creek through a rock cut located just above the last coal outcropping and crossed over the creek near the Solomon’s “lower falls.” It traveled a distance of 4,894 feet with a grade of 5.7% rising to an elevation of about 900 feet above MSL. From that point there was a downgrade plane for 850 feet dropping to an elevation of 892 feet at the base of Plane #2. Plane #2 was directed to the southwest at a grade of 8.6% for a distance of 3,775 feet. It rose from the 892 foot elevation to 1,250 feet above MSL. At this point the cars were horse or mule drawn along a level plane for a distance of approximately 3,000 feet to the base of Plane #1. From here the final plane travelled 4,361 feet at a rise of 9.3% to an elevation of 1,681 feet above MSL at Solomon Gap. At this point the cars passed over a weigh scale and moved onto the L&S Railroad for its travel to the Lehigh Canal at White Haven, Luzerne County.

When the Great Flood of 1862 almost completely destroyed the “Upper Grand” of the Lehigh Canal, the Pennsylvania legislature soon after passed an act prohibiting the reconstruction of the canal, but they did grant the LC&N a charter to extend its L&S railroad from White Haven to Mauch Chunk. A year later on March 16, 1864 the terms of the charter were extended to include a railroad from Mauch Chunk to Easton. Upon its completion in 1868, the LC&N now had an all-rail route from Ashley to New York via the L&S and a connection with the Central Railroad of New Jersey at Phillipsburg, New Jersey.

As with each of the other long-lived plane operations, technological improvements were incorporated into the upgraded designs. In the 1860’s the Planes’ alignment and technology were
revised, most importantly of which was the realignment of Plane #2 so that the 3,000 foot level plane was removed and the need for horse/mule drawn cars was eliminated. In 1871 the Central Railroad of New Jersey leased the Lehigh and Susquehanna Railroad from LC&N including the Ashley Planes, so the modifications in 1908 and 1909 in which the planes were nearly rebuilt was designed and constructed by the Central Railroad of New Jersey. Concrete replaced much of the original stone foundations. Bridges were reinforced and many engineering changes were made to the operation of the planes. The improvements to the planes made in 1909 allowed them to operate without major repairs until the 1940’s.

Another important change to the operation of the Ashley Planes was to build the “Back Track” from Solomon Gap through Laurel Run to Wilkes-Barre bypassing the Ashley Planes. It was completed in 1867, the same year that the Lehigh Valley railroad also completed its own line to Wilkes-Barre. The reason for the Back Track was not to replace the Planes, but rather to supplement them and give the L&S a competitive advantage over the newly-completed Lehigh Valley Railroad. Until the construction of the Back Track both freight and passenger traffic was laboriously raised and lowered on the Planes, the tracks operating in opposite directions. However, once passenger traffic, westbound freight tonnage, and empty coal cars returning to the mines were transferred to the Back Track, both tracks of the Planes were pressed into all-eastbound freight and coal traffic (Figures 5 through 7). The Planes were a more economical and faster method of raising tonnage from the Wyoming Valley covering only about two and one-half miles compared to the twelve and one-half mile long Back Track.
Building on the success of the D&H Gravity Railroad to transport anthracite coal to the New
York market, the Pennsylvania Coal Company (PCC) started construction of its own Gravity Plane
Railroad from its mines at Port Griffith (Pittston, Luzerne County) to the D&H Canal at Paupack
Eddy (Hawley, Wayne County). The gravity railroad was opened for service in 1850.

Pennsylvania Coal Company Gravity Railroad consisted of 22 separate lift planes and at 47
miles long it is considered the longest gravity railroad in the world (Figures 8 through 10 show
remains of various infrastructure). The PCC railroad design consisted of two tracks, an
eastbound “loaded” or “heavy” track and a westbound “light” track. These tracks did not
always share the same right-of-way and at times diverged by up to three miles. The loaded
track was 46.7 miles in length with twelve planes and the light track was 43.6 miles with ten
planes. Since the PCC Gravity Plane was built later the design included a mix of stationary
steam engines and three water-wheel powered (later replaced by steam engines) hoists with
steel cable instead of rope or chain that the earlier planes used.

The lift from Port Griffith to the Moosic Mountain east of Dunmore, Lackawanna
County, consisted of eleven planes covering 19 miles. At approximately 1,100 feet from the top
of Plane 11 the railroad passed through the ridge via a 755 foot tunnel and then completed the trip
to the D&H canal at Paupack Eddy along a single 28 mile long plane.
The PCC had to use its rival’s D&H Canal to complete the route to the New York market until 1863 when the Erie Railroad completed a rail link between Hawley and Lackawaxen allowing the gravity cars to be transferred directly to the Erie Railroad bypassing the D&H Canal.

The beginning of the end of the PCC Gravity Plane came in 1885 when PCC decided to begin construction of the Erie & Wyoming Railroad roughly paralleling the light track route. The last gravity coal train trip on the PCC was made on December 18, 1885.

**#7 Gordon Plane – Southern Field**

The Gordon Planes in Schuylkill County (Figures 11 and 12) were built by the Mine Hill and Schuylkill Haven Railroad to cross the Broad Mountain approximately 5-1/2 miles to the

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**Figure 11. Stereoscopic View of Mine Hill Railroad, looking up Gordon #2 Plane**

**Figure 12. Stereoscopic View of Mine Hill Railroad, looking up Gordon #1 Plane**
southwest of the Mahanoy Plane. Two planes with a combined lift of about 750 feet were placed into operation in 1855. These planes were principally designed by R. A. Wilder and remained in service until 1895.

We presume the following photographs in Figure 13 show the remaining foundations for the hoist house and associated buildings at the top of Plane #1. They are located on the north side of SR4007, the Gordon Mountain Road, coming down the Broad Mountain into the Borough of Gordon, Schuylkill County.

![Figure 13. Remaining foundations for buildings at the top of Plane #1. Photos by John Ackerman, Jon Inners for scale](image)

**#8 Penn Haven Planes – Eastern Middle Field**

The Beaver Meadows and Hazleton Railroad opened the Penn Haven Planes in the mid-1850s and they remained in service until 1879. In 1850, the transport of coal from the eastern middle field needed to reach Josiah White’s “Upper Grand” section of Lehigh Coal and Navigation’s Lehigh Canal. Until 1850 the only way to reach the canal was by the Buck Mountain Railroad’s gravity plane. Then the Beaver Meadow and Hazleton Railroad (BMHRR), the first steam railroad built in Pennsylvania, was built to carry coal to the Penn Haven Plane (Figure 14) to open up the Hazleton and Jeansville Basins, Luzerne County, and the Beaver Meadows basin in Carbon County. There is conflicting information about where the BMHRR loaded the coal to the canal boats. It could be at Penn Haven, but John S. Koehler11, Collector and Historian of Weatherly, PA, indicates that the BMHRR took the coal by steam locomotive to Parryville, Carbon County where it connected with the Lehigh Canal. This conflict may be explained by the Great Flood of 1862 causing the abandonment of the northern “Upper Grand” portion of the Canal and both depictions of the canal terminus may be true.

![Figure 14. The Penn Haven Planes and the Lehigh Coal and Navigation Company’s coal wharves as they looked from across the river two years prior to the 1862 flood. Photo from collection of Robert F. Archer11](image)
The first incline was built in 1850 to try to overcome the continual rockslides and floods of the steep ravine leading from Weatherly to the gorge. The plane was 1,200 feet long and rose over 450 feet in elevation. The first plane installed was the one on the right in Figure 3-14 with two lines. Designed as a counterbalanced system, one loaded car was lowered which in turn pulled an empty car up the hill.

The second incline, a four-track plane (Figures 15 & 16), was built by the Hazleton Railroad in 1859 but it was to be short-lived.

The June 6, 1862 flood uncovered a fatal flaw in White’s grand dream. The “Upper Grand” Canal contributed to its own demise in that the dams needed to feed the locks were not structurally adequate to contain the heavy June rains, and dams breached releasing devastating tidal waves of flood water that burst dam after dam downstream resulting in the great flood and subsequent loss of life.

John J. Leisenring Jr., then Superintendent of the LC&N Company estimated that 200 people lost their lives between White Haven and Lehighton. The state legislature stepped in and prohibited the LC&N Company from rebuilding. Figure 17 shows remaining walls of the engine house.
The use of the Penn Haven Planes ended in 1879 when a new railroad grade was built and allowed direct rail connection from Hazleton to the tracks at the Penn Haven Junction.

**#9 Mahanoy Plane – Western Middle Field**

By the mid-1850’s approximately 75% of the coal in the Middle Field north of the Broad Mountain originated in the Mahanoy & Shamokin valleys. These loads were carried to the top of Broad Mountain by the original Mahanoy Plane portion of the Wadesville/Mahanoy combination by a hoisted inclined plane and then down its southern slope on gravity planes with a 3% grade covering 5.5 miles to the railroad connection at St. Clair.

As higher production rates increased the need for new methods to move the coal to market were needed. The existing combination of planes was limited by the watershed summits, the mountain’s steep slopes and narrow valley cuts on the slopes. The very heavy grades and the rough alignment of tracks of the original design presented problems in the movement of the cars, so the Mahanoy and Broad Mountain Railroad carefully studied the system to find a more efficient solution. This led to the building of the second Mahanoy Plane in 1862 situated just to the west of Robinson’s original "Mahanoy". It was originally designed to handle small cars then in use. The plane rose 350 feet from the valley floor to the summit at Frackville, Schuylkill County, with a maximum grade of 22%. The Mahanoy and Broad Mountain Railroad was purchased by the Philadelphia and Reading Railroad in 1871. Figure 18 show structures of the Mahanoy Plane as they look today.

*By the mid-1850's approximately 75% of the coal in the Middle Field north of the Broad Mountain originated in the Mahanoy & Shamokin valleys.*

![Photos by John Ackerman, Jon Inners for scale](image)

*Figure 18. Left photo shows coal bins at terminus of Mahanoy Plane. Right photo shows foundation and structure of hoisting house.*
Similar to the D&H Gravity Railroad, events allowed for technological improvements to be made over the life of the Mahanoy Plane. A fire in 1868 resulted in the original 2,500-horsepower engines to be replaced with 6,000-horsepower engines that increased the lift rate to as many as 900 loaded cars a day. Again in 1884 the Mahanoy Plane was remodeled and by 1895 after the Gordon Plane was abandoned, a greater volume of business along with the need increased for cars with increased capacity led to continuous 24 hour a day operation of the Mahanoy Plane. In 1910, the plane was rebuilt to allow three loaded cars to be hauled up the mountain every three minutes, allowing over 1,400 loaded cars of coal to be sent to market daily.

The "second" Mahanoy Plane (Figure 19) remained in operation until September, 1932, when the control of the operation was taken by the Baltimore and Ohio Railroad and last large scale inclined plane operation in the Pennsylvania Anthracite was closed down.

Summary

For over 100 years a primary component of the integrated transportation network for moving anthracite coal from the mines to the markets in Philadelphia and New York was the inclined plane railroad. Since the technology levels in the 1820’s had not reached the point where a steam locomotive was capable of surmounting the grades found in the Valley and Ridge Province to pull a loaded train up a mountain, the development of a multi-stage transportation system was needed. Forward thinking individuals and companies came up with the inclined plane as part of the solution when combined with the canal system and early steam engines to not only increase the tonnage of coal to market but to reduce transportation costs from mine to market and earned the inclined planes its place as an integral part of our Anthracite heritage in fueling the Industrial Revolution.
As previously noted, we recommend checking out the source documents in the following References for much more detailed information and many more photographs and maps of the inclined planes listed in this article.

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THE MAHANOY AND GORDON PLANES

Walter J. Payne, Pennsylvania Department of Environmental Protection (PADEP) – Environmental Cleanup-Brownfields Redevelopment, SE Regional Office

Introduction

Both of these inclined plane systems were constructed to move Anthracite coal from the Western Middle Coal Fields to transportation nodes and markets south of the Broad Mountain. These planes were operational during the early days of the Industrial Revolution when Anthracite was in demand.

The Gordon Planes

Anthracite coal production in the Mahanoy Basin lagged behind that of the Shamokin Basin to the west, and was concentrated around the Ashland area initially. In 1854 a new breaker was erected to prepare anthracite for shipment out of the basin over the Mine Hill and Schuylkill Haven Railroad, which eventually became the Reading Railroad. This line was completed in 1854, with the first shipment from the Pioneer Colliery to the railroad in September of that year. The route of this railroad was to the south, up and over the Broad Mountain via the Gordon Planes.

The planes were constructed in a naturally occurring wind gap in the Broad Mountain south of Gordon (Figure 1). The top of the mountain is 717 feet in elevation at this point.

Figure 1. Foot of the Gordon Plane at the Gordon Rail Yard.
This passage consisted of two separate planes. One beginning at the edge of the Gordon Rail Yard (Figure 2) extending 5,048 feet over a 313 foot rise and the second, at the top of the first, extending 5,105 feet over a 404 foot rise to the peak of the Broad Mountain. The average capacity of these planes was 105 cars per hour, and the cost of hoisting in 1878 was 4.89 cents per ton. Nearly 2,000 cars, equal to 10,000 tons, have been passed over these planes in a single day. Total tonnage in 1877 was 1,546,330 tons. The Gordon Planes were put into operation in 1854 and abandoned in 1896.

Figure 2. Stereo Image of the foot of the Gordon Plane showing the cable connections

Figure 3 shows tracks located between Plane Street and West Plane Street in Gordon.

Figure 3. Mid-grade stereo photographs of the Gordon Plane. These tracks were located between Plane Street and West Plane Street in Gordon
PA Route 4007 crosses the mountain along the former route of these planes. The Country Inn and Suites is located on this road atop the Broad Mountain.

**The Mahanoy Plane**

Construction began in 1859 by the Mahanoy & Broad Mountain Railroad, and was completed by 1861. The Mahanoy and Broad Mountain Railroad leased the plane (shown in Figure 4 as it passes through the village of Mahanoy Plane) to the Philadelphia and Reading Coal and Iron Company shortly after its construction, which became the Reading Railroad. Using this plane reduced the transportation distance by 12 miles compared to other routes. Empty cars were returned to the foot of the plane by existing rail routes. The average number of cars hoisted per hour was 130 at a cost of 2.66 cents per ton of coal. The largest yearly tonnage of the plane was 2,015,098 in 1877. The largest daily tonnage was 2,533 cars, equal to 12,665 tons.

![Figure 4. View of the inclined plane from the village of Mahanoy Plane.](image)

This plane extended 2,460 feet with a rise of 524 vertical feet (Figure 5). The slope was 28% at its steepest section. Capacity was 800-900 cars / day. A 2,500 horsepower stationary steam engine at the top of the slope was used through 1868 when it was lost in a fire. New 6,000 horsepower engines were installed and were operational through 1932 when operations ended.

Over 70 years of service it hoisted 1,376,400,000 tons of coal over the mountain and claimed the lives of 148 men.

Partial ruins of the old engine house, at the top of the plane, can be found over the crest of the hill at the corner of North Balliet and High Streets adjacent to the municipal baseball fields in Frackville.
This plane was memorialized in 2007 by the placement of a historical marker along the southbound lanes of PA Rt. 924 as it enters Frackville from Shenandoah (Figure 6).

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Ashland Historical Society,
318 W Centre Street, Ashland, PA 17921

Frackville Free Public Library,
56 N Lehigh Avenue, Frackville, PA 17931
Introduction

From the middle to late nineteenth century, the anthracite coal industry of eastern Pennsylvania experienced rapid growth and consolidation to become one of the most economically important enterprises in the United States. Anthracite played a pivotal role in the American Industrial Revolution and was recognized as a fuel of choice in transportation (locomotive steam engines), manufacturing (iron and steel making), and domestic use (heating and cooking). In addition to business practices and supply-and-demand considerations, growth and success in the anthracite mining industry were contingent upon a practical understanding of the geology of the anthracite coalfields and the specialized methods of coal extraction unique to the region’s geology.

Of the many individuals who contributed to this understanding during the nineteenth century, one of the most noteworthy and successful was Peter W. Sheafer (1819–1891)—geologist, surveyor, mining engineer, businessman, and philanthropist (Figure 1) — who maintained his office and home throughout his career in Pottsville, Pennsylvania, the heart of the Southern Anthracite coalfield (Figure 2). Patriarch of a prominent Schuylkill County family, Sheafer contributed much to the business, educational, social, and cultural fabric of his community and beyond. He was also politically astute, which served him well in various endeavors, particularly his support of the Pennsylvania Geological Survey.

Background and Education

Peter Wenrich Sheafer\(^1\) was the eldest child of Henry and Mary (née Wenrich) Sheafer and member of a remarkable entrepreneurial family. He was born on March 31, 1819, in Halifax, Dauphin County, Pennsylvania. His father Henry was one of the pioneer coal operators in the western end (“fish tail”) of the Southern Anthracite coalfield, having been one of the founders and

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\(^1\) Sheafer’s middle name is frequently misspelled “Wenrick.”
subsequent superintendent of the Wiconisco Coal Company in 1831 (mining the Lykens Valley anthracite coals of the Pottsville Formation). Henry also helped organize and became president of the Lykens Valley Railroad, which was completed in 1834, to provide transportation of the Lykens Valley coals to market.

Figure 2. Map of the Anthracite region, eastern Pennsylvania, with names of principal coalfields. Bold letter "P" denotes location of Pottsville (modified from Eggleston and others, 1999, p. 458)
Peter Sheafer received his formal education at local schools in Dauphin County and thereafter attended Oxford Academy, a private educational institution in Oxford, Chenango County, New York, where he took additional coursework. Although smart and capable, Sheafer never attended college, as he appears to have been too restless and practical minded, wanting to get on with his career. (His parents certainly supported higher education, as Peter’s younger brother William Scott Sheafer (1837–1908) later graduated from Yale University.) His very close friend J. Peter Lesley (1819–1903) would later note that Sheafer’s mundane approach of expression when writing, whether for business or pleasure, could “be ascribed to his lack of youthful classical training” (Lesley, 1891, p. 41). Yet, Sheafer’s lack of formal higher education was no impediment to his acquisition of the skills and training needed to attain success in the career he chose. Again, it was Lesley (1891, p. 41–42) who observed:

“I even doubt that the lack of technical school training in his [Sheafer’s] profession as civil and mining engineer was at any time an obstacle in his path of life. He learned enough to join his experienced father in earlier enterprises; and in after ones his intercourse with business men and technical books and professional experts supplemented his own experiments and kept his intellectual ability abreast of the public needs of each succeeding year.”

**Early Career and Work with the First Geological Survey of Pennsylvania**

Upon completion of his studies at the Oxford Academy, he went to work for his father and took particular interest in the Lykens Valley coal measures. However, within a year or so, in 1837, Peter Sheafer applied for a position as a “sub-assistant” on the First Geological Survey of Pennsylvania (1836–58) and was hired by Henry D. Rogers, State Geologist. Rogers undoubtedly recognized the need to acquire staff with some experience in anthracite geology, as anthracite coal was becoming increasingly important to the iron industry in Pennsylvania, and the state legislature specifically directed him to report on coal and iron in its second-year appropriation to the Geological Survey (Rogers, 1838; Gerstner, 1994).

Sheafer was only 18 years old when he started working for the First Survey and was assigned to assist James D. Whelpley of Philadelphia, who also joined the organization the same year. Rogers was focusing his efforts at that time on the geology of the folded structure of the Appalachian region, which encompassed central and northeastern Pennsylvania, and it appears in this regard that Whelpley and Sheafer spent most of their time in Schuylkill County in 1837. The following year, Whelpley and Sheafer were assigned to survey the geology of Rogers’ newly created District 2 (of his six subdivisions of the state), which included the anthracite coalfields. The assistants were now expected to devote more of their time to topographic mapping in addition to their geologic investigations. Gerstner (1994, p. 82) noted that:

“in spite of the need to give more time to other areas, the anthracite regions of the second district remained critical to Rogers because of their importance to the state’s economy and also because of his research into the geological dynamics of the area. He promised to let Whelpley and Sheafer hire as much additional help (probably coal surveyors working in the area) as possible, and Rogers spent as much of his time as he could manage in this area as well.”
Although he enjoyed his time and work experiences with the First Survey, Sheafer resigned his commission by early 1839 to return to work for his father and begin “a career in coal mining operations as a consultant and mining engineer” (Gerstner, 1994, p. 88). Meanwhile, J. Peter Lesley, later State Geologist of the Second Geological Survey of Pennsylvania (1874–95), was hired and assigned to work with Whelpley in the second district. With Whelpley’s resignation several months later in June 1839, Rogers entrusted Lesley alone to carry out the geologic and topographic surveys of the second district. Sheafer and Lesley had little or no opportunity to interact at this time (Lesley, 1876), although they later became intimate, lifelong friends. As of 1842, fieldwork on the First Geological Survey was suspended, owing to the lack of a new appropriation brought on by legislative dissatisfaction with Rogers’s inability to complete the Survey with the final report on time (as originally stipulated in the enabling legislation creating the First Survey in 1836) and by the general faltering financial condition of the state.

Sheafer continued to work for his father, acquiring much training, knowledge, and experience, until 1848, when he married Harriet Newell Whitcomb (1820–96) of Springfield, Vermont. He then moved to Pottsville with his young bride where he assisted and later succeeded Samuel B. Fisher, a talented surveyor and mining engineer, who is generally remembered for publishing one of the first maps of the Southern and Middle Anthracite fields (Schalck and Henning, 1907; Fisher, 1836). Pottsville became Sheafer’s home and center of business activities for the remainder of his life.

Growing interest by capitalists and businessmen in the development of the anthracite coalfields led to greater opportunities for geological consulting and brought Rogers together with Sheafer and Lesley in 1850 to undertake a major private study and evaluation of several coal lands:

“Most of his [Rogers’s] consulting work was done for companies run by Charles P. and William L. Helfenstein. The latter, a lawyer and former judge of the Court of Common Pleas in Dayton, Ohio, was the moving force behind almost all the development of Pennsylvania’s western middle coalfields from Mount Carmel to Trevorton in the late 1840s and early 1850s. Two major companies were incorporated in 1850 for this development. The first was the Zerbe Run and Shamokin Improvement Company; the second was the Mahanoy and Shamokin Improvement Company. In order to transport the coal, Helfenstein established several railroads to connect the mines with the rest of the region. Rogers was hired by the Helfensteins to report on the relative merits of the coals in the area.

Rogers’s former assistant, Peter Sheafer, was also working as a mining engineer for these companies, and the two were soon joined by Lesley, whom Rogers called for help when he suffered yet another round of poor health in the summer of 1850” (Gerstner, 1994, p. 163).

Working with Rogers and Lesley helped sharpen Sheafer’s skills further on how a detailed (quantitative) geological investigation could and should be conducted, setting a new standard for similar, future work:
“The result of Rogers’s work for the Helfensteins was three published reports in late 1850 and 1851 based on work done mainly in 1850. The working conditions for the preparation of these reports were probably as ideal as Rogers might ever have wished for in his years of surveying. He was given a large group of miners, a corps of geological assistants, and as much time as he wanted, and he claimed that his studies were ‘the most minute, elaborate and systematic hitherto authorized by capitalists in the development of any coal territory in the limits of the United States’ [Rogers, 1850, p. 3].

Together the reports constituted an extensive geological survey of the anthracite areas, taking twelve months and covering some six thousand acres. Lesley later said that some of the first and most important instrumental measurements were done at this time, resulting in a hypsometrical map (one measuring heights with reference to sea level) [i.e., a topographic map with contour lines of equal elevation] of the Shamokin coalfield.” (Gerstner, 1994, p. 163).

Since the cessation of fieldwork by the First Survey in late 1841, various attempts had been made by private individuals and state legislators to revive the Survey and complete the final report, but all to no avail. However, general interest continued to grow for the publication of the final report, particularly because of ongoing rapid exploration and development of Pennsylvania’s coalfields and lack of public information about them. As pointed out by Gerstner (1994, p. 172), “mining developers needed geological information, but there was virtually no place where they could get it unless they commissioned private studies such as Rogers did for the Helfenstein group.” Fortunately, the governor and state legislature showed renewed interest in the successful completion of the Survey by the start of the 1851 legislative session. Spearheading the effort to gain legislative support for a new appropriation was William Parker Foulke, a member of the Philadelphia Academy of Natural Sciences and “an ardent promoter of scientific activity and…concerned with development in the coalfields” (Gerstner, 1994, p. 172). Foulke was a fervent supporter of Rogers and had many well-connected friends, including influential geologists, businessmen, and state legislators. Assisting Foulke in this endeavor was Peter Sheafer:

“Instead of having Rogers speak with legislators about the survey [because of continuing hostility toward him in the legislature], Foulke worked with the legislators primarily through Peter Sheafer, Rogers’s former assistant, who was now a mining engineer working in the Shamokin coalfields. Sheafer had become politically astute in the years since he left the survey, and he was able to act as an aid to Foulke, as a contact with the legislature, and as a lobbyist for the survey. He was willing to work without pay for the sake of getting the final report published and with the hope of getting a job with Rogers should the survey be reopened” (Gerstner, 1994, p. 174).

Foulke and Sheafer spent much of January and February of 1851 lobbying the state legislature and lining up support (as testimonials) from esteemed colleagues and professional societies. Sheafer believed that it was also important to prepare a report that included the testimonials and other pertinent facts for the Joint Committee of the House and Senate looking into a new appropriation for the publication of the Survey results. The report were prepared by Rogers,
Sheafer, and Foulke, and completed in early March. In consultation with committee members, who looked upon a draft of the report favorably, Rogers obtained their approval to have the report printed and distributed. Additional political wrangling and lobbying ensued, but a general appropriations bill authorizing the Survey to receive funding for two more years (to include some additional fieldwork to bring the survey up to date and publication of the final report) finally passed the legislature and was signed into law by the governor in April 1851. (See Gerstner, 1994.)

Staff were hired almost immediately for fieldwork and included Peter Sheafer, who was put in charge of underground mine surveys in the anthracite coalfields, and assisted by his cousin John Sheafer, who was responsible for surface surveys (transit and leveling) to construct the base maps (Lesley, 1876, 1891). In August 1851, Leo Lesquereux, the Carboniferous paleobotanist, joined the First Survey to study the fossil coal plants (Gerstner, 1994), and he, Lesley, and Sheafer quickly became close friends, and all remained so for life.

Meanwhile, field activities were put into jeopardy from the start, as the state treasury ruled that a specific appropriations bill for allocating funds to the Survey was never introduced and passed by the legislature, and therefore treasury had no legal authority to release the money. Rogers had to step in and pay staff salaries at his own expense and was not reimbursed until the following year.

Although Peter Sheafer worked hard to help secure a state appropriation to complete the First Survey and wanted to work for the organization again as well, he nevertheless resigned his commission the following spring (1852). His reasons for doing so remain unclear. Perhaps Sheafer was concerned about his salary and timeliness of payment in light of the treasury decision and knew he could earn considerably more income as a consulting geologist and mining engineer. Yet, having previous experience working for the Survey, money would not have been the motivating factor to do so again. Sheafer and Lesley had become close friends recently—both working with Rogers on private surveys for the Helfensteins and for the newly reorganized First Survey in the Southern and Middle Anthracite coalfields. As Lesley had just severed his longtime friendship with Rogers and left the Survey—owing to various grievances he had with Rogers that included perceived poor leadership, insufficient salary, and failure to properly credit the work of assistants—it may be that Sheafer left as well to express support and solidarity for his friend. (John Sheafer appears to have left around the same time as well.) The Final Report of the First Geological Survey of Pennsylvania was later completed and published in 1858, but Peter Sheafer received little acknowledgment from Rogers for his contributions to anthracite geology—corroborating Lesley’s criticism of Rogers (Rogers, 1858; Lesley, 1876).

**Burgeoning Career and Expanding Interests**

Sheafer returned to his work in private practice in Pottsville as consulting geologist, mining engineer, and surveyor. As his business grew and thrived during the next several decades, he hired additional staff. Eventually, he partnered with his younger brother William, who was trained as a civil and mining engineer (Figure 3). Later on, his three sons joined his company in various capacities.
First and foremost, Sheafer devoted his life to the development of the anthracite coalfields. As an expert in coal geology, he was employed by numerous landowners and coal operators in the Southern and Middle Anthracite fields to examine coal lands and develop mines—particularly in the Beaver Meadows (primarily Luzerne and Schuylkill Counties, Eastern Middle field), Mahanoy (mainly Schuylkill County, Western Middle field), and Schuylkill (Schuylkill County, Southern field) Districts. He became preeminent in his field and one of the most sought-after mining engineers in the anthracite region. Sheafer’s many responsibilities and accomplishments included the siting of the Wadesville Shaft to the west of St. Clair (based on his interpretation of the geology that was subsequently proved correct) and the directing of its construction to the Mammoth coal, and the management of all mines of the Philadelphia and Reading Coal and Iron Company and those of the Girard Estate (Wallace, 1988). In addition to Pennsylvania, Sheafer undertook similar work elsewhere in the United States and Canada, producing hundreds of private reports during his lifetime. Moreover, he evaluated and reported on a number of properties for iron ore and oil and gas. He was also hired to lay out and survey several coal towns, including Ashland, Gilberton, Girardville, Mahanoy City, Mount Carmel, Shenandoah, and others in Schuylkill and adjacent counties (Schalck and Henning, 1907). He was particularly adept at identifying, acquiring, and developing valuable coal lands containing the Mammoth and other thick coals, which became the source of much of his wealth (Lesley, 1891).

He was interested in all aspects of anthracite coal geology and mining and began publishing reports and maps on these subjects in professional and popular publications beginning in the early 1850s (Figure 4). Similarly, he gave lectures and read papers on these matters before several scientific organizations, including the American Association for the Advancement of Sciences, American Philosophical Society, and Pottsville Scientific Association. On account of these activities, he was sometimes called “Professor Sheafer” by individuals and writers alike.

He devoted considerable time to the collection and compilation of mine-production statistics for the anthracite coal trade and released the information in the form of maps and tables. For this, he became a recognized authority. He also created a novel graphical method to portray the
relative changes in coal production over time, which Lesley (1891, p. 40) described as a “statistical coal pagoda” (Figure 5).

Sheafer was very concerned about coal waste throughout the industry—that is, coal left unmined in the ground for various reasons (e.g., amount and kinds of gob, and number and size of coal pillars) in areas considered “worked out” and coal lost after processing through breakers (i.e., by crushing, sizing, and picking) that ended up in culm banks. He repeatedly called attention to this subject and suggested solutions. Late in life in 1890, he was appointed by Governor James A. Beaver as one of the three original commissioners to the legislatively mandated “Coal Waste Commission,” charged with the investigation of coal waste in mining, with emphasis on recommendations to its utilization (Coxe and others, 1893). Sadly, he did not live to see this work completed.

Sheafer also calculated one of the first coal reserve estimates for the combined anthracite fields, noting that only a third of the amount would ever make it to market—the rest contributing to the “total waste” of coal (Sheafer, 1881).

As a mining engineer, he developed an innovative method for filling underground mine voids and reducing mine subsidence by introducing a slurry of coal fines, dirt, and water into abandoned mines through boreholes. Once the grout dewatered and hardened to provide roof support, miners could reenter the old workings in relative safety to rob coal pillars. Furthermore, by stabilizing the voids from collapse and subsidence, coals above the preexisting operations

![Figure 5. Sheafer's graphic presentation of anthracite coal production (total and by district) through time—1820–72 (from Sheafer, 1875, after p.48.)](image-url)
could be mined intact in the future (Lesley, 1891), and damage to the land surface and surface structures was reduced or prevented.

As another interest, Sheafer had a deep appreciation of history. One of his most noteworthy popular publications, prepared for the Historical Society of Pennsylvania, was a map of Pennsylvania as the state appeared around 1775, with particular emphasis on the correct usage and spelling of Indian (Native American) place names (Sheafer, 1873; Sheafer and others, 1875).

Sheafer was the member of several scientific organizations, including the Academy of Natural Sciences of Philadelphia, American Association for the Advancement of Science (honorary), American Institute of Mining Engineers, and American Philosophical Society, and formerly, the Pottsville Scientific Association. Other interests led him to join the Historical Society of Pennsylvania and the American Colonization Society, a philanthropic organization that was dedicated to helping African Americans emigrate to Liberia where they would be free from growing domestic prejudice during the post-Reconstruction Era (this undertaking was a controversial idea at the time, with black and white people both approving and rejecting such an objective).

**Personality and Traits**

Peter Sheafer was intelligent, attentive, shrewd, and eminently practical. Although he could be charming in conversation, he tended to be reserved and quiet in temperament. He was a good listener and enjoyed the company of others. Lesley described him as “a genial and lovable man, a religious man, and...a man of poetical temperament, and a reader of poets” (Lesley, 1891, p. 41), further adding that Sheafer

“was a silent man,...reticent, always smiling and cheery in conversation, but seldom or never allowing even to his enthusiasm more than a momentary flash of expression. He had the confirmed habits of a good listener; and what he himself had to say was said in the fewest words the theme permitted or the occasion demanded. He was intently sympathetic, and loved to hear others talk; his own contributions being chiefly made in the shape of facts. No man better appreciated those whom he loved or respected; and this he owed to his poetic temperament” (Lesley, 1891, p. 42).

Sheafer was a talented geologist and mining engineer and savvy businessman. He enjoyed hard work and could remain well focused. He had a good memory for facts and good ability to analyze them. He developed a clear understanding of the geology of the anthracite coal measures and physical and chemical characteristics (quality) of various coal seams throughout the mining districts, and he put this knowledge to good use. Lesley (1891, p. 40) commented that Sheafer’s
“mind and the training of it was just suited to this work of his life. He had good judgment, inexhaustible liking, and ability for work, a retentive memory, a quick eye for money values, a peaceable disposition, great caution in undertaking, and pertinacity in accomplishing the exploitation of properties. He made himself personally acquainted with everybody and everything that happened or was likely to happen in the anthracite world, and kept himself in constant intercourse with owners, investors, speculators, mining prospectors, engineers, and railroad companies; and, what was key to his fortune, never rode hobbies, or allowed himself to be turned aside into other pursuits...”

He was very devoted to his family and contributed greatly to their well-being. He and his wife Harriet produced five children—Mary Wells Sheafer (1849–68), Emma Louise Sheafer (1852–1919), Arthur Whitcomb Sheafer (1856–1943), William Lesley Sheafer 1859–1913), and Henry Sheafer (1863–1950)—four of whom attained adulthood. Peter Sheafer's three sons all graduated from college, the elder two as geologists and mining engineers and the youngest as an attorney, all of whom worked for him at various times, in addition to engaging in other business interests. Arthur Sheafer, moreover, worked for the Second Geological Survey of Pennsylvania from 1878–82, mostly in coal geology, following in the path of his father.

A man of deep religious faith, Peter Sheafer was an active member of the Methodist Episcopal Church. Yet, “his philanthropy was not bounded by church creed, and he contributed of his means to the support of religious enterprises of whatever name and doctrine” pleased him (Schalck and Henning, 1907, p. 435).

Sheafer was an active member of the Republican Party, though he never ran for elected office. He once held the honorary position of U.S. Assay Commissioner, appointed in 1879, and was a member of the Pennsylvania Electoral College for 1884 (Schalck and Henning, 1907).

He used his political skills to advance causes he felt passionate about, most notably his support for the Pennsylvania Geological Survey. He helped secure a new appropriation for the First Geological of Pennsylvania in 1851 as discussed previously. In the early 1870s, he spent much time lobbying state government for the establishment of the Second Geological Survey of Pennsylvania and appointment of J. Peter Lesley as State Geologist. He achieved success in both endeavors in 1874. Furthermore, Lesley (1891, p. 41) noted that Sheafer “did all that he could to further the interests of the survey at Harrisburg and elsewhere through the following fifteen years of the continuance of the survey.” During the 1880s, the Second Survey focused much of its attention on detailed geologic mapping of the anthracite coalfields (see Dodge, 1988), and Sheafer did everything possible to help the Survey achieve its objectives by providing access to mines and geologic information.

Civic Work and Philanthropy

Sheafer believed strongly in the economic, educational, cultural, and social vitality of his community, and contributed much to its success. He donated time and money to many causes and accepted a number of leadership positions, as several of the following examples show.

In 1854, he helped found the Pottsville Scientific Association, an organization created “to foster [the founders’] own interest in science and for the advancement of scientific research and
education” (Dexter, 1969, p. 29). Although it was only active for eight years, the Association published several worthwhile contributions to science and geology (some of the articles pertained to investigations of the First Survey, as a means of getting information out more quickly). Its large mineral collection was later donated to Lafayette College and its extensive library of scientific literature to the Pottsville Athenaeum (W. W. Munsell and Company, 1881).

With his interest in education, Sheafer was appointed to a committee in 1866 to reorganize and upgrade the standards of the public high school, which opened in its new form two years later. He remained active as a member of the Pottsville Board of Education for some years (Schalck and Henning, 1907).

He joined the Benevolent Association of Pottsville, a charitable organization for the poor and needy, and was particularly active with its Home for Children, both as a manager and as its president from 1877–79. The home was devoted to the care, growth, and education of abused and neglected children between the ages of 4 and 12, “without distinction of creed, race, or color” (W. W. Munsell and Company, 1881, p. 278).

Recognizing the power of communication, Sheafer and a partner acquired the Daily Miners’ Journal and Miners’ Journal Building in 1877, and formed the Miners’ Journal Publishing Company. The Miners’ Journal was a newspaper published daily (except Sundays) that covered all matters pertaining to coal. By the end of the same year, he sold his two-thirds interest in the publishing company (W. W. Munsell and Company, 1881) but appeared to have maintained ownership of the building.

Also in 1877, he helped organize and became the first vice president of the Pottsville Athenaeum, a literary association or society consisting of five activities—a public library, reading room, group for literary entertainment, group for musical entertainment, and debating club. He donated many significant books from his personal collection to the Pottsville Athenaeum and was elected its president in 1885.

Final Years and Legacy

During the 1880s, Sheafer was at the pinnacle of his career and one of the leading and most influential citizens of Pottsville. He was widely respected and admired for his business practices, integrity, and devotion to his community. His family was thriving and growing, with his sons all in successful careers and one, William, married and later father to the elder Sheafer’s first grandchild in 1889.

In addition to the usual array of responsibilities and commitments, Sheafer was also called upon from time to time to provide expert testimony on legal matters involving coal, owing to his knowledge and reputation. Perhaps most notably, he was asked to testify for the plaintiff in the landmark case of the Coxe Brothers and Company versus the Lehigh Valley Railroad Company, held before the Interstate Commerce Commission in 1889. The plaintiff contended that in violation of Commission rules the Lehigh Valley Railroad—the principal carrier of coal in the Eastern Middle Anthracite field where the plaintiff had developed its Drifton Property—charged the Coxe Brothers inflated freight rates for anthracite relative to bituminous coal and other commodities also transported by the railroad (Railway World, 1889). This forced the plaintiff to charge higher wholesale prices for its coal, making it less competitive. Yet, since many railroads
mined and shipped coal from their own properties, it was common practice for them to charge higher transport fees to independent mining operators in order to maintain market share. At the time, profits in the anthracite industry were tied closely to obtaining favorable shipping rates from the railroads. As a secondary matter, the Coxe Brothers asserted that the Lehigh Valley Railroad arbitrarily designated coals as bituminous or anthracite, not classifying them on any scientific basis. The case was watched closely by coal operators and railroad companies alike because of its broad implications and ultimately was ruled in favor of the plaintiff by the Interstate Commerce Commission.

In his testimony for the Coxe Brothers, Sheafer noted in a spirit of compromise that favorable shipping rates for anthracite would actually benefit both parties in terms of profitability, suggesting that, for example,

> “the accumulation of culm, which had heretofore been looked upon as a nuisance in the mining region, when properly screened and made into cakes, was coming into market as a fuel, and were it given favorable rates the one hundred million tons which have accumulated in Pennsylvania in the vicinity of the coal mines could be disposed of at a very handsome profit to the owners of the same as well as afford [additional] paying traffic to the coal-carrying railroads” (Railway World, 1889, p. 150).

By the end of the decade, Sheafer’s health was in decline. At that time, the act creating the Coal Waste Commission, discussed previously, was approved on May 7, 1889. However, the three original commissioners—John A. Price, Chairman, of Scranton; Eckley B. Coxe, of Drifton; and Peter W. Sheafer, of Pottsville—were not appointed by the governor until February 9, 1890. The first meeting of the commission was delayed until May 21, 1890 because of conflicting schedules of the commissioners and distances they had to travel, and because of Sheafer’s “ill health” (Coxe and others, 1893, p. 3). Nevertheless, Sheafer was an active participant and

> “had taken great interest in his part of the work, and, notwithstanding his ill health, had already laid out his plans and gotten together a great deal of very interesting and valuable matter relating to the statistics of the coal trade, to the amount of coal in the culm and dirt banks, and to the size of the latter, at certain collieries, compared with the amount of coal already mined and shipped” (Coxe and others, 1893, p. 3–4).

Early the following year, Sheafer was visiting Atlantic City when his illness greatly worsened, and he was taken for recuperation to The Sanitarium at Browns Mills-in-the-Pines, New Jersey, which specialized in the treatment of tuberculosis. There he died unexpectedly a short time later on March 26, 1891, from “congestion of the lungs” (Engineering and Mining Journal, 1891, p. 409). Sheafer’s death was a tremendous loss to his family, friends, and community, and to the anthracite trade. He was buried in the Charles Baber Cemetery, Pottsville.

Although seldom remembered or appreciated today, Sheafer was in his own time a highly reputable geologist and mining engineer and major land owner and developer of anthracite coal. He contributed much to the understanding of the geology of the Southern and Middle Anthracite coalfields and was a strong supporter of the work of the Pennsylvania Geological Survey throughout the state. He valued coal as the “monarch of the modern industrial world, with its wonderfully diversified interests, and their ever expanding development” (Sheafer, 1881, p. 3),
and made no apologies for the wealth it afforded him. However, he believed in sound scientific and engineering principals in the exploration and exploitation of coal. Sheafer was appalled by some of the prevailing mining practices that led to tremendous loss and waste and devoted considerable time creating awareness of the problem and providing potential solutions. During much of the nineteenth century, he also was a major impetus for the systematic collection and compilation of mine-production data throughout the anthracite fields, which are still of historical value today.

With his death, Sheafer's sons and brother became executors of his estate, which consisted mostly of valuable coal lands. Administration of the estate by the family was headquartered in the Sheafer Building (otherwise known informally as the “Sheafer Mansion”), built in 1893 at 325 South Center Street, Pottsville, on the site of the former Miners' Journal Building, which burned down the year before. The Sheafer heirs continued to be involved in community affairs and philanthropy for years to come.

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CO-GENERATION PLANTS: FROM ENVIRONMENTAL IMPACT TO RESOURCE AVAILABILITY

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Abstract

The Co-generation plants in Northwestern Pennsylvania burn waste coal from the culm banks left over by more than a century of anthracite coal mining. These plants are an illustration of how changes in technology can expand the resource base. In addition to burning coal that is too small for the normal coal furnaces, these plants are burning low-grade carbonaceous material that has only about half the btu content of normal anthracite. By doing so, these plants have expanded the total amount of anthracite coal that can be used economically.

Introduction

The idea of the recovery of waste heat is not new. Ever since people began burning fuels to generate electricity, they've realized that some of the energy was lost in the form of heat. Atomic energy plants, for example, use large cooling towers to dissipate the heat back into the atmosphere. It seems obvious that it would be more thermodynamically efficient if the heat could be captured and put to use. Dual use plants, producing both electricity and heat can create their own challenges. Traditionally in the United States, utility companies have relied on a few very large, centrally located generating stations to provide electricity for regional markets. Heat can't be transported over such a distance. To take full advantage of co-generation smaller plants would have to be built closer to heat consumers.

Pennsylvania Anthracite coal has been mined for domestic and industrial use for nearly two hundred years. Production peaked around World War I, with over on hundred million tons produced annually. Before the coal could be used it had to be cleaned and processed. This involved removing slate and other rock, and either sorting or breaking the coal into regular sizes. Steamboats, locomotives, and home stoves each required a different size of coal. Prior to 1900, most coal 0.875 inches across or smaller was considered a waste product. These coal fines, rock material, and other debris were dumped onto culm piles around the mining site. Even smaller particles washed off during the cleaning process, then collected in settling ponds.

Over time the culm piles grew to be veritable mountains, overshadowing whole communities. They could be dangerous. Often piles had unstable slopes and so could collapse in sudden landslides. The coal fines could catch fire. Erosion gradually washed culm into nearby streams, clogging and polluting them. Sulfur from the coal fines could also leach out and pollute the...
streams. Because the bulk of the mining was done prior to the 1950s, and the introduction of environmental regulation, little can be done to require the removal of or mitigation of culm banks. Often the companies that had created the culm are no longer in existence, and federal programs for restoring abandoned coal lands, while beneficial, have not had the resources to deal with the widespread regional damage found in the Pennsylvania Anthracite fields (Towne, 2012).

**Co-Generation Plants**

Co-generation plants (Figure 1) began to appear in the anthracite coal fields of Northeastern Pennsylvania after the passage of the Public Utility Regulatory Policies Act of 1978 (PURPA). This law was created as a way to respond to the energy crises of the 1970s, and included tax and other incentives to encourage the construction of small, electric power plants burning renewable or waste energy resources (Inners, Edmunds, and Laregina, 1996). These plants were designed to burn waste anthracite and thus provide energy at the same time as providing land reclamation. The Co-generation plants used a new technology, known as fluidized bed combustion chamber, to burn the waste material and generate electricity.

![Figure 1. Photo by D. H. Vice of the McAdoo Co-generation plant](Image)

So far, most of the scholarly research done on anthracite refuse powered co-generation plants has focused on their environmental impact. Burning culm removes surface pollution and limits the possibility of waste-pile runoff polluting nearby streams (Figure 2). Even the ash left over when culm is burned has proven useful in filling surface-mining pits. Different articles have
focused on how specific mine sites have been integrated into the co-generation process (Inners, Lentz and Roskos, 2000), or general environmental impacts. (Inners, Edmunds, Laregina, 1996).

**Resource Availability**

Anthracite co-generation plants are also useful as an example in the long-running debate over resource availability. For the past fifty years scholars have been focused on whether or not we are using mineral resources too quickly, and in danger of leaving nothing for future generations. On one side of this debate are a group we can call Malthusians or “doomsters”. They have created a variety of mathematical models to predict the time when particular resources will be exhausted. The Club of Rome, for example, created a model which predicted the world’s supply of copper would run out between 1993 and 2020, and the supply of gold between 1981 and 2001. However, Arndt and Ganino (2012) show that the same amount or even more resources are known of gold and copper are known now even though Meadows et al. (1972) predicted that society would have exhausted these resources by now (2015).

The doomsters arrived at these predictions of resource depletion by taking the known reserves of each metal and dividing it by the annual amount used (Arndt and Ganino, 2012). In other words, they believed the use of each metal would be constant, and no new discoveries of the copper or gold made. Meadows, et al (1972) made a more mathematically elaborate estimate by assuming an exponential increase in human population, with a steady rate of resource use per
person, and a linear discovery rate of new resources. Finally, M. King Hubbert (1978), focused on America’s natural gas and petroleum resources. He believed production would follow a simple sine curve until each resource was depleted. To create his predictive curve he estimated the total American supply of oil and gas, then, using historic production figures, graphed their increase in use, and assumed the curve would follow a predictable path till exhaustion (Figure 3).

All of these models made several assumptions. One was that once a resource began to be used it would be used to completion. There was no place in any model for consumers to substitute one resource for another. The second was that the total amount of recoverable resources could be estimated. All of the modelers felt comfortable making predictions about future resource use.

On the other side of the resource use debate are the Cornucopians or “boomsters”. They believe we will not run out of resources in the short term, but will instead either be able to substitute new resources for old ones, or use technology to make use of resources that are currently unavailable. McCabe (1998) provided a Cornucopian model that was much more optimistic. This model used the analogy of a pyramid to represent the total amount of any commodity (e.g., copper, gold or oil) on earth with the peak being the highest grade occurrences and the base being the lowest grade occurrences (Figure 4). The cut-off grade (i.e., the level between profitable extraction and operating at a loss) was represented on the pyramid by a level between the peak and the base. This level or cut-off point was determined by a combination of technology and price which could vary the level over time. The Co-generation plants in Northeastern Pennsylvania relate to this debate on whether there will be resources in the future and which model gives the best predictions by demonstrating how a change in technology (i.e., the fluidized bed combustion chamber) can increase the amount of resources that are available to be used.
The Co-generation plants (Fig. 1) represent a change in technology that allows a lower grade material to be utilized to generate electricity (Gonzalez and Vice, 2007). There are thirteen Co-Generation plants in the anthracite region of Northeastern Pennsylvania which burn anthracite waste (Fig. 2) in a fluidized bed furnace and use the heat to make steam (Inners et al., 1996). The steam is used to generate electricity. The fluidized bed combustion chamber can use material with a Btu content per pound as low as 2810 (Inners et al., 1996) while the average fuel content of anthracite coal is 13,000 Btu per pound (Leffel and Eisenberg, 1977). The old technology (i.e., furnaces) could not use the fine anthracite coal and lower grade coal waste and so it was added to the culm piles. Some culm banks contain as much as 25% coal and more carbonaceous shale.

The Doomsters school of thought says that we are using up all of our resources so that future generations will have nothing. The doomsters argue that we as a society will need to drastically change our lifestyles (i.e., go back to a much simpler one that does not use as much resources) in order for some resources to be saved for future generations. They use a model like Hubbert’s curve for all resources (e.g., coal or oil) and a closed market model that says that prices will fall at first as a resource is developed but then will rise as more than fifty percent of the resource is used up (depleted). The doomsters argue that as depletion of resources occurs, society will collapse. The doomsters do not consider the effect of either technology or price on resource availability.

The Boomsters say that we do not need to worry about resource depletion, that technology will find new resources or substitutes when the current resources become scarce. The boomsters also argue that resources can be extended by changes in technology that use less material. The development of substitutes for a resource can also extend resource availability. One example of this substitution is the use of plastic in car bumpers which uses less steel and chrome. The reduction in weight also uses less energy in driving the car. The use of fiber-optics for phone lines replaces copper is another example of substitution. The more efficient use of a resource can extend the life of a resource by using less, for example, cars that get 25 mpg rather than 10 mpg will extend the availability of hydrocarbon resources.
Several examples can be found in the history of the last 50 years where technology has found new resources, has found ways to use smaller amounts of resources, or found substitutes. Although this paper talks about co-generation plants as an example of changes in technology making more resources available by effectively using lower grade material, many other examples can be found. The development of ‘fracking’ technology to extract oil and/or natural gas from black shale like the Marcellus Formation is only the most recent example. This new technology has expanded the available natural gas to the point that it is no longer profitable to import natural gas from overseas. An example of this change in gas availability is the fact that Dominion is converting its Cove Point gas importing facility in Chesapeake Bay to a gas exporting facility (Kendrick, 2015).

**Summary and Conclusions**

The Co-generation plants show how changes in technology can both have a positive impact on the environment, and expand the total available resources. In the case of anthracite coal, this expansion was be utilizing lower grade material that had been discarded as waste. In other resources, the expansion occurred by utilizing lower grade ore.

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COALBED METHANE IN THE ANTHRACITE REGION
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Introduction

Seven counties in southwestern Pennsylvania’s Main Bituminous field were at the height of commercial coalbed methane (CBM) development as a natural gas energy source from 1999 to about 2008 prior to the Marcellus Shale gas boom (Pennsylvania Department of Conservation and Natural Resources, 2008; Figure 1). Exploration has slowed, but production continues today. A recent annual production total was reported at 16 billion cubic feet (Bcf) (0.45 billion cubic meters [Bm3]) (Markowski, 2013) which could supply heat to about 235,000 households for a year.

Figure 1. Map showing the distribution of coals and coal fields in Pennsylvania (Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey, 2000).

On the eastern side of the state are four major anthracite coal fields and one semianthracite coal field. From south to north, the fields are as follows: 1) Southern Anthracite, 2) Western Middle Anthracite, 3) Eastern Middle Anthracite, 4) Northern Anthracite, and 5) Western...
Northern Anthracite (semianthracite) (Figure 1; Adams, 2010). Pockets of methane are known to exist as documented throughout the commonwealth’s early mining history by firedamp (mainly methane) explosions from 1870 to 1880 (Chance, 1883). The Anthracite region remains undeveloped regarding CBM.

**Structural Controls, Tectonic History, and Rank**

Pennsylvania’s highest quality coal beds of the Anthracite region are generally characterized by steeply dipping to nearly vertical, unusually thick and often distorted strata interrupted by folding and faulting. This region is located in a northeast trending, asymmetrical structural depression within the Valley and Ridge Province of eastcentral and northeastern Pennsylvania. The coal fields are situated among complexes of synclines and anticlines broken by multiple reverse, thrust, tear, and bedding-plane faults originating from one or more décollements below the coal-bearing strata (Wood and others, 1986). Each coal field is an intensely folded and faulted synclinorium, with structural trends between N55°E and N85°E. The Southern field exhibits the most deformation, especially to the southeast where tight, overturned folds and a wide variety of faulting exist. Much of the structural deformation occurred during the Alleghanian orogeny about 260 to 325 millions of years ago (Ma) (Hatcher, 2008). The exceptional coal thicknesses of the region were caused by flowage from folding and faulting. Coal is especially thick (some as much as three to four times) in the axes of synclines, and locally increased thicknesses were created by thrust faults which dragged along less competent coal strata and associated deposits at varying distances (Wood and others, 1986) into tight and commonly overturned folds (Eggleston and others, 1999).

Coal rank increases from semianthracite at the western ends of the Southern and Western Middle fields, and the Bernice Basin (Hower and others, 1993) of the Western Northern field to anthracite in the east (Figure 1). Meta-anthracite (defined on page 10) occurs at the eastern ends of the Southern field (Hower and others, 1993) and the Eastern Middle field (Ruppert and others, 2014). This change of rank suggests increasing depth of burial (Levine and Davis, 1983), or increasing structural complexity (Wood and others, 1986). Anthracite is one of nature’s purest forms of carbon due to its high percentage of fixed carbon (92 to 98 percent on a dry mineral matter free basis) (Arndt and others, 1968) and low ash and sulfur values. Average coal quality parameters for anthracite are 13 percent ash, 0.8 percent total sulfur (mainly organic), heating values of 12,800 British thermal units (Btu or Btu/hr) (3.75 kilowatt hours [kWh] or 3,749 joules/sec [J/s]) on an as received basis (Swanson and others, 1976), and a high thermal maturity (percent reflectance [Ro]) value of 5.0 (Hower and others, 1993). Anthracite coal is distinguished from other forms of coal by its brilliant to submetallic luster and conchoidal fracture.

**Depositional History**

Emerging out of the latter stages of Appalachian geosynclinal development (Eggleston and others, 1999) and controlled by plate tectonism (Wood and others, 1986), the anthracite-bearing rocks of eastern Pennsylvania are continental in origin. These strata were formed in broad, interfluvial peat swamps on an alluvial plain (Lyons, 1986) during Pennsylvanian age from 290 to 330 Ma (Berg and others, 1983; Haq and Van Eysinga, 1987; Briggs and Shultz, 1999) after
deposition of fining upward Pottsville sediments. Sedimentary pulses from nearby highlands deposited coarse conglomerates of the Pottsville Formation (Eggleston and others, 1999) at a time of continental impact and subsequent uplift (Wood and others, 1986). Stream sediments periodically entered the swamps to form an extensive braided system. About 50 swamps existed over hundreds to thousands of square miles for hundreds of thousands of years (Wood and others, 1986). Swamps to the north were more short lived and lacked continuity.

Some of the extraordinary coal thicknesses of the Llewellyn Formation strongly suggest that plant growth flourished with no intervention for long time periods in a broad, slowly subsiding and somewhat quiescent swamp environment. This can be compared to a peat accumulation of about 1 ft (0.3 m) per 1,000 years in the Everglades (Altschuler and others, 1983). Application of this data with Ryer and Langer (1980) compression rates resulted in more than 400,000 years of peat and other organic accumulation needed to create a 40 ft (12 m) thick anthracite bed (Wood and others, 1986). Most of the coal beds are much thinner, but these rates imply a long period of deposition. A variety of clastic detritus entered the swamp helping to form a complex heterogeneous rock sequence. A fluctuating coastline to the west and northwest and a highland area to the southeast bounded the basin. Scattered conglomerate, conglomeratic sandstone, and coarse-grained sandstone in the Llewellyn are evidence of periodic highland uplifting (Wood and others, 1969).

**Stratigraphy**

The Anthracite region is contemporaneous with the Pennsylvanian-age Pottsville and Allegheny Formations and the Conemaugh Group of the Main Bituminous field (Figure 1), with most commercial anthracite probably time-equivalent to the Allegheny Formation (Dennison, 1978). The region is also considered to be contemporaneous with the Monongahela Group based on the presence of particular plant fossils in the roof shale of the No. 25 coal bed of the Llewellyn Formation (Eggleston and others 1988, 1996).

After adopting a system used by industry and geologists in the past, names and numbers were used to identify the numerous coals. Where correlations were uncertain, especially to the north, numbers were used (Eggleston and others, 1999). Mining companies were known to use several different names for the same coal bed. Many thin, lenticular beds remain unnamed and unnumbered because of the lack of correlation.

**Pottsville Formation**

Named by Lesley (1876) for a sequence of rocks in a well near Pittsburgh, the Pottsville Formation was defined as a conglomerate overlying Mauch Chunk Red Shale and underlying lower productive coal measure equivalent to the Allegheny Formation. White (1900) changed the location of the type section to Schuylkill Gap, south of the city of Pottsville and recognized four paleobotanical divisions in the stratigraphic sequence.

The Early to Middle Pennsylvanian Pottsville Formation includes all rocks between the underlying Mauch Chunk and overlying Llewellyn Formation mainly ranging in thickness from less than 100 ft (30 m) in the Northern field to about 1,600 ft (488 m) in the southern edges of
the Southern field (Meckel, 1967; Wood and others, 1969). In the synclines of the Southern Anthracite field near Pottsville, however, thicknesses can reach up to 4,900 ft (1,494 m) due to structural thickening (Arnold and others, 1968). According to Wood and others (1986), the Pottsville generally ranges from 50 to 1,500 ft (15 to 457 m) thick.

Three members comprise the Pottsville Formation as follows: Early Pennsylvanian Tumbling Run, late Early Pennsylvanian Schuylkill, and Middle Pennsylvanian Sharp Mountain. The Sharp Mountain Member defines the top of the Pottsville and is overlain by the Buck Mountain (No. 5) coal of the Llewellyn Formation (Wood and others, 1986; Figure 2). The Pottsville is mostly light gray to black in color, except in the olive to greenish gray Tumbling Run Member. The basal Pottsville Formation is dominated by interbedded conglomerate and conglomeratic sandstone; the remainder consists of finer sandstone, siltstone and silt shale, claystone, and coal (Edmunds, 1993). Resistant strata of the Pottsville defines the high ridges around each field.

The Pottsville is one of two coal-bearing units in the Anthracite region. It contains 10 economic coal beds (out of 14 named coals according to Edmunds and others [1999]), in the Southern field (Eggleston and others, 1999), the Western Middle, the Eastern Middle Anthracite fields, and one seam in the Northern Anthracite field. Thickness measurements for a variety of Pottsville coals from Wood and others (1969) result in an average coal thickness of 4.7 ft (1.4 m) and the thickest coal beds can reach up to 10 ft (3 m) (Lyons, 1986).

**Llewellyn Formation**

Wood and others (1962) named the Llewellyn Formation for a town in the Minersville quadrangle of the Southern Anthracite field. Previously, Llewellyn strata were referred to informally as the “coal measures” (Smith, 1895, p. 1920). Stratigraphically equivalent coal beds of the Llewellyn in the Eastern Middle and Northern fields have somewhat different names and numbers than the Llewellyn coals in the Southern and Western Middle fields. Llewellyn coals are thicker and more numerous than Pottsville coals.

The Middle to Late Pennsylvanian Llewellyn Formation contains fine to coarser sediments and thick, persistent coal beds (Eggleston and others, 1999). The Llewellyn is a thicker, coarser grained equivalent of the Allegheny Formation, the Conemaugh Group, and possibly the Monongahela Group. A maximum thickness of about 3,500 ft (1067 m) is preserved in the Southern field near the town of Llewellyn (Eggleston and others, 1999). The Llewellyn is characterized by many lateral variations in rock type which may account for localized, sharp thickness changes from a few to several hundred feet apart between coal bed datum horizons correlated from columnar sections. Thicknesses are more uniform between datums that are of greater distances apart (Wood and others, 1969, 1986). Abrupt, localized variations between datum horizons probably represent syndepositional differential compaction of fine-grained sediments (Wood and others, 1986). Overall uniform thicknesses between datums farther apart reflect deposition of approximately equal volumes of each sediment grain size (Wood and others, 1969). The Llewellyn Formation includes all strata in the Anthracite region above the base of the Buck Mountain No. 5 (Red Ash) coal, underclay, or shale to the present erosional surface, except where covered by alluvium (Wood and others, 1986). Predominantly nonmarine, the Llewellyn
consists of subgraywacke clastics including conglomerate, sandstone, siltstone, shale, and numerous coal beds. The beds are commonly tabular, lenticular, and wedge-shaped. Less resistant than the Pottsville Formation, the Llewellyn lines the synclinal valleys in each field (Eggleston and others, 1999). Some minor nonmarine limestones exist, but in particular, the presence of the fossiliferous Mill Creek limestone points to a brackish marine influence in the Northern field (Eggleston and others, 1999). Fossilized plant material is common throughout the formation.

Wood and others (1969, 1986) identified 40 coal beds that have been mined in the Llewellyn Formation from the Buck Mountain to No. 29. Most of these coals are in the lower part of the formation. Some of the major seams are shown in Figure 2. Many unnamed local coals and splits

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**Figure 2.** Generalized and selected coal seams of the Llewellyn Formation (Pottsville Formation below) in the Southern and Northern Anthracite fields (slightly modified from Milici, 2004 which was modified from Arndt and others, 1968). Numbers to the left of the columns represent average coal thickness. Numbers to the right of the columns are maximum available tested gas content data in ambient cubic feet per ton (cf/t) of coal (Diamond and others, 1986)
occur. The thickest coals like the Mammoth, occur in the lower 1,500 ft (457 m) and maximum natural thicknesses are generally less than 50 to 60 ft (15 to 18 m), except where structural deformation has double folded the coal beds (Edmunds and others, 1999). According to Lyons (1986), the thickness of the Buck Mountain (No. 5) coal can reach 96 ft (29 m), although average Llewellyn coal bed thickness is 2 to 9 ft (0.6 to 2.7 m).

History of CBM Research

From 1964 through 1979, the former U.S. Bureau of Mines (USBM), now the National Institute for Occupational Safety and Health (NIOSH), conducted methane research because of the urgent need to improve production and safety in deeper and gassier coal mines throughout the country. Congress recognized the need by providing funds and promoting legislation to support this objective. Although new technology reduces the frequency and severity of underground explosions, they still can occur. By understanding and applying basic geological and chemical principles that control methane emissions, methane problems were ameliorated. Ventilation was improved and alternative methods for methane removal were developed. The energy crisis of the 1970s also helped fuel more methane drainage work. After several reorganizations over the years, by 1983 the USBM was responsible for methane control research to improve health and safety standards as well as productivity. In 1995, after 85 years of public service, the USBM closed its doors. By 1997, it was transferred to today's NIOSH which is devoted to the research and prevention of mining injuries, illnesses, and deaths.

A summary of the above methane research can be found in the 1988 U.S. Bureau of Mines Bulletin 687, as in Trevits and others (1988) referenced in this report. Another important compilation by Diamond and others (1986) contains CBM gas desorption (defined on page 10) data from Pennsylvania's anthracite and bituminous coal beds. These results provide reasonable preliminary figures which may aid in the development of a CBM drilling project in the Anthracite region.

This data contains a wide range of gas-in-place (GIP [defined on page 10]) values in the Southern Anthracite field, Schuylkill County, from 6.4 to 28.8 cf/t (0.2 to 0.9 cm$^3$/g) in the Orchard coal to a national high of 691.2 cf/t (21.6 cm$^3$/g) from the Peach Mountain coal at a depth of 685 ft (209 m) (included in Figure 3). The Tunnel coal also had high gas content values from 448.5 to 586 cf/t (14 to 18.3 cm$^3$/g). The average gas content for 11 CBM analyses from six coal beds (including the Orchard, Peach Mountain, and Tunnel coals) in Schuylkill County is 326.8 cf/t (10.2 cm$^3$/g) from 604 to 1,719 ft (184 to 524 m) deep (Diamond and others, 1986).

In the Northern Anthracite field, 19 samples from four Lackawanna County coal beds averaged 32 cf/t (1.0 cm$^3$/g) at 102 to 562 ft (31 to 171 m) deep (Diamond and others, 1986; Figure 3). In comparison, GIP values for the Main Bituminous field range from less than 100 cf/t (3.1 cm$^3$/g) in Armstrong County to about 500 cf/t (15.6 cm$^3$/g) in Indiana County. Hypothetical minimum gas content values for multi-seam commercial development range from 125 to 150 cf/t (3.9 to 4.7 m$^3$/g) (Hunt and Steele, 1991b).
In the 1970s, the USBM drilled two closely spaced boreholes in Reilly Township, near Minersville in Schuylkill County (Figure 4) to assess the methane drainage potential of anthracite coal. The holes ranging in depth from 1,948 to 2,355 ft (594 to 718 m), were drilled into approximately 30° southward dipping strata near the crest of a small anticline (Trevits and others, 1988). After penetrating 20 coal beds in the first well, a desorption test on the Peach Mountain coal exhibited an average gas content of more than 647 cf/t (20.2 cm$^3$/g) (Trevits and others, 1988) at 685 ft (209 m) (Diamond and others, 1986). The hole was retained as an observation well. The second well also reached 20 coalbeds. The Tunnel coal yielded an average gas content of about 480.6 cf/t (15 cm$^3$/g) (Trevits and others, 1988) from 604 to 608 ft (184 to 185 m) (Diamond and others, 1986). Trevits and others (1988) found that although the gas contents were high (greater than 500 cf/t [15.6 cm$^3$/g]) (Figure 3), the low porosity and permeability of the coal impeded the flow regardless of standard perforation and hydraulic stimulation. Other challenges were difficulties drilling through very hard conglomeratic formations, controlling water inflow and caving despite the presence of bottom hole pumps, and retrieval of a jammed core barrel. Perhaps with today's improved technology, results would have been different at these sites.

Figure 3. Gas-in-place data measured under ambient conditions (Diamond and others, 1986) from Milici (2004).
Figure 4. Approximate locations of former USBM CBM test drill holes and/or sampling sites. L1-L3 represent selected gas content samples from two closely spaced drillholes near Minersville for the Peach Mountain, Seven Foot leader, and Tunnel coal beds (Markowski, 2001).
According to a series of laboratory tests from Kim (1977), anthracite coal exhibits more gas storage capacity than the bituminous rank coals. The following results are based on comparisons between anthracite and high-volatile bituminous coal: 1) Adsorption isotherms (defined on page 10) with rank at 0° Centigrade (C) (32° Fahrenheit [F]) in volume versus pressure plots, show that anthracite has more than 50 percent gas storage capacity at a maximum of 60 atm (6,080 kilopascal [kPa]) of pressure than high-volatile bituminous. This indicates that the amount of gas adsorbed by coal increases with higher rank at a given temperature as pressure increases. 2) In volume versus temperature plots with rank at 10 atm (1,013 kPa) of pressure, anthracite contains more than three times the gas storage capacity as high-volatile bituminous at a maximum temperature of about 50° C (122° F). Similarly, the amount of gas adsorbed by coal increases with higher rank at a given pressure as temperature increases. 3) Estimated methane content by desorption versus depth with rank plots demonstrate that anthracite holds almost twice as much methane as high-volatile bituminous at a maximum depth of 700 ft (213 m). Additionally, Lyons and others (2003) discovered that the Mammoth (lower and upper splits), Seven-Foot, and Buck Mountain coal beds as sampled from the Pioneer Tunnel Coal Mine in Ashland, have a high capacity to hold methane under pressure as revealed by adsorption isotherm values from 320 to 850 cf/t (10 to 26.5 cm³/g).

**CBM Potential**

It is difficult to estimate the CBM potential in the Anthracite region because so few projects have been done due to the economics of drilling in a region of complex structure and stratigraphy (Diamond and Levine, 1981; Diamond and others, 1986). A conservative estimate of recoverable natural gas from bituminous and anthracite coal beds by Briggs and Tatlock (1999) totals 2,654 billion cubic feet (Bcf) (75.2 billion cubic meters [Bm³]). This is equivalent to and commonly expressed as 2.7 trillion cubic feet (Tcf) (0.08 trillion cubic meters [Tm³]). Briggs and Tatlock (1999) based a speculative total estimate of CBM from anthracite at 397 Bcf (11 Bm³) or 0.4 Tcf (0.01 Tm³) on a potential recovery at 180 cf/t (5.6 cm³/g) of gas. About 70 percent of the original coal resources remain in the Anthracite region (Lyons and others, 2003). Most of the CBM resources are expected to be in the deeply buried coal beds of Schuylkill County. From the USBM summary data, gas contents for anthracite coal are either anomalously high or low, and due to a poorly developed fracture system, production rates have been found to be low regardless of artificial stimulation. Steeply dipping and deformed coal beds, numerous mines, and unknown quantity and quality of produced water add to the challenge for economic development in the Anthracite region. However, the variety of data presented from these sources indicates very high gas contents in localized areas of great cumulative coal thickness in the Southern Anthracite field. This suggests that further CBM exploration is warranted (Lyons, 1997) in this thermally mature to post mature geologic environment. In fact, several locations in Schuylkill County contain 10 or more coal beds of significant cumulative thickness from 500 to 2,000 ft (152 to 610 m) deep in subhorizontal to gently inclined strata. These areas are outlined in a detailed map and cross sections by Wood (1972). Exploration in this area applying favorable geology with today’s advanced drilling, dewatering, and stimulation techniques, may yield favorable results in an area close to local markets and expanding infrastructure.
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Terms

**Adsorption isotherm**

A laboratory measurement of the gas storage capacity in a coal bed as a function of pressure and constant temperature. This test involves subjecting a representative coal sample to pressure and temperatures simulating in situ stress in a CBM reservoir.

**Desorption**

A process in which adsorbed material (gas) is released from the adsorbent (coal matrix) when hydrostatic pressure is reduced by dewatering unmined coal beds. According to the USBM direct method (Diamond and Levine, 1981), the desorbed gas is the total volume of gas emitted from a coal core sample, determined by measuring the amount of water displaced by the gas in an inverted graduated cylinder. This value is used along with the values for lost gas, residual gas, and sample weight determinations to estimate the total gas content of the sample, commonly measured in cubic feet per ton (cf/t) of coal.

**Gas-in-place (GIP):**

The amount of gas (recoverable and nonrecoverable) in a reservoir at any time, calculated at standard conditions.

**Meta-anthracite**

The rank of coal within the anthracite class of American Society for Testing and Materials (ASTM) Classification D-388 that has a volatile matter content equal to or less than 2 percent (or a fixed carbon equal to or greater than 98 percent) on a dry mineral matter free basis. The coal is nonagglomerating or noncaking (Wood and others, 1983).

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Gosh, Mister, the Boss’ll be awful mad if he finds out you been trespassin’ in his mine!

Reprinted from the 1980 Field Conference of Pennsylvania Geologists Field Trip Guidebook
SUMMARY OF COAL FIRES IN NORTHEASTERN PENNSYLVANIA

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3/2/15

Introduction

The anthracite coal fields of Northeastern Pennsylvania cover an area of 1400 square miles (2253.08 square kilometers) of the Central Appalachian Mountain section of the Valley and Ridge Province of Pennsylvania. Due to erosion, only 439 square miles (706.50 square kilometers) of the area contain coal (Faill and Nickelsen, 1999). The anthracite coal that has not been eroded has been preserved in a series of complex synclinoria, which form four main fields, the Southern, Eastern Middle, Western Middle, and Northern, with several smaller pockets of anthracite and semi-anthracite in outlying areas. The general trend of each field is northeast to southwest, with each field being a complex series of secondary basins (Eggleston, et al., 1999). The coal beds can be thought of as series of nested bowls with only the rims being exposed.

The coal beds occur in the Pottsville and Llewellyn Formations (Pennsylvanian) in Northeastern Pennsylvania and are similar in age to the coals of western Pennsylvania in that they represent deposition in the Pennsylvanian sediments of the Appalachian Basin. The Pottsville and Llewellyn Formations consist predominantly of conglomerate, sandstone, siltstone, claystone, and shale. The Pottsville Formation contains a distinctive conglomerate, which has a framework of large, white quartz pebbles and dark-grayish, sand-rich matrix that has considerable organic matter. Much of the shale and/or claystone in the Llewellyn Formation is medium to dark gray in color.

Both Native Americans and early European settlers were aware of the anthracite deposits in Northeastern Pennsylvania. As long as the local population remained low, and availability of firewood abundant, there was no reason to take up commercial mining. This changed in the 1820s, when slack-water canal systems along the Schuylkill, Delaware, and Lehigh Rivers made it possible to ship anthracite to urban markets like Philadelphia and New York City. Technological innovations like Jesse Fell’s grate, which allowed homeowners to burn anthracite in fireplaces, and new methods of smelting iron with anthracite greatly expanded the market for coal (Lottick, 1992; Aurand, 1971).

The anthracite coal fields of northeastern Pennsylvania were the first in the United States to be widely developed. Along with economic growth came a variety of environmental concerns: acid mine runoff into local streams, waste piles and subsidence from coal removal, and underground mine fires. These last were something new. Although the general literature states that coal fires can start through human activity, spontaneous combustion, or surface fires (Kim
and Chaiken, 1993), with spontaneous combustion being understood as the tendency of a coal bed or stockpile to heat to the point where it starts burning (e.g. Uludag, 2007; Cao et al., 2007; and Nelson and Chen, 2007), generally, the only coals that spontaneously combust (Figure 1) have a low rank and a high sulfur/sulfide mineral content (Cao et al., 2007). The anthracite coal in Pennsylvania has a high rank (92 to 98% fixed carbon) and low sulfur content (0.3 to 1.2%) (Eggleston, et al., 1999). Spontaneous combustion is very unlikely. There is little evidence of surface fires ever igniting anthracite coal. Most of the mine fires in the anthracite region of Pennsylvania have been started by human activity, whether purposeful or accidental, and only started after commercial mining began.

![Figure 1. coal fire that started by spontaneous combustion in Landsburg, King Co., Washington](image)

Photo by Bill Kombol

In the roughly 190 years since people in the anthracite region of Pennsylvania have faced mine fires, the geological problems have remained the same. The sometimes steeply dipping coal deposits have made access to fire sites challenging, while the cracking of the earth's crust during the formation of the Appalachian Mountains has made it difficult to block air flow and smother the fires. At the same time, the way communities respond to fires and who has responsibility for putting them out has changed dramatically. To understand anthracite mine fires and how they impacted local communities, it is necessary to break the fires down into several distinct periods.
The Early Period

From the beginning of commercial mining through roughly the end of World War II underground mine fires were seen as primarily an economic problem. In order to continue production and maintain employment mining companies were given a great deal of leeway in how they would fight or control fires. Much of this was based on the court decision Pennsylvania Coal Company vs. Sanderson. In 1868 Eliza McBrier Sanderson purchased a tract of land in Scranton along Meadow Brook. Her family diverted the stream to provide water for their home and irrigation for an ornamental garden, fountain, and fish pond. Later, when the Pennsylvania Coal Company developed a mine at the head of Meadow Brook, they began pumping acidic mine water into the watershed. The Sandersons sued for damages (Casner, 1999).

The Pennsylvania Supreme Court found for the coal company. They argued that the damage to Meadow Brook was not caused by malice or negligence, but rather was just a natural result of mining coal. The fact that the state allowed the purchase of mineral rights demonstrated that they wanted mining to occur. The necessity of industrial expansion, as sanctioned by the granting of mineral rights, trumped the inconvenience of individual land owners (Casner, 1999). This assumption of the naturalness of damage to the land caused by mining continued. In 1937, when Pennsylvania passed a Clean Streams Law, pollution in the form of coal silt or acid mine run-off was considered exempt (Towne, 2012). Generally, residents of the coal region did not mind giving mining companies such power. Most relied on mining or its associated industries for employment, and, while some owned their own homes, most rented, many from the mining companies themselves. The closing of a mine and loss of jobs was more threatening to families than having to relocate to a new home.

Because mine fires were seen as private rather than public problems the state took little interest, and felt less responsibility for putting them out. As Kim and Chaiken (1993) have noted, prior to 1949 no federal or state agency collected information on coal fires, even on abandoned coal lands. Lack of state involvement has made researching these early fires difficult. Often the only sources of information are local newspapers or the works of non-academic antiquarians. The fires described below illustrate how early mine fires were contained. Some were put out by flooding the mine, others were temporarily contained by the use of one or more barriers. A fuller but not complete list of early fires is provided on Table 1.

Table 1. Early Fires

<table>
<thead>
<tr>
<th>Name and Reference</th>
<th>Field</th>
<th>Cause</th>
<th>Fought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenwood Colliery (Detterline, 1968; Scherer, undated)</td>
<td>Southern</td>
<td>Untended warming fire</td>
<td>Flooded</td>
</tr>
<tr>
<td>Summit Hill (Mazaika, 2007)</td>
<td>Southern</td>
<td>Unknown</td>
<td>Put out by clay barrier</td>
</tr>
</tbody>
</table>
A fire of unknown origin was discovered in the Heckscherville Anchor colliery which was on the northern limb of the Southern Field in 1869 (Blasé, 1997). The colliery was shut down but another operator reopened the mine and worked the third or lower level which was below the fire for several years. The Philadelphia & Reading Coal & Iron Company took over the colliery in 1875 and worked it until 1877 when it was discovered that the fire had reached the lower level. At this point the mine was flooded and abandoned. Attempts were made to reopen the colliery in 1896. No evidence of a coal fire was found when they explored the old workings but Dyer's Creek was turned into the old workings in 1901 as a precaution. No sign of the fire was found in 1906 (Blasé, 1997).

The Laurel Run coal mine fire started in the Northern Field on December 6, 1915, when a careless miner left a lit carbide lamp attached to a mine timber. The owners of the Red Ash Mine had recently fired their night watchman, which allowed the fire to burn undetected over the weekend. When work resumed, the company became aware of the fire and they tried to cut off the air supply by plugging openings with concrete and sand flushed into the immediate area (Randolph, 2002). They believed the fire was under control. In 1921 the fire reappeared, burning beyond the company's containment area (Ashmead, 1922). At that point the company began erecting a series of temporary seals, designed to contain the fire while allowing other sections of the mine to be worked.

<table>
<thead>
<tr>
<th>Location</th>
<th>Field</th>
<th>Period</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heckscherville Anchor Colliery</td>
<td>Southern</td>
<td>Unknown</td>
<td>Flooded mine</td>
</tr>
<tr>
<td>(Blasé, 1997)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cameron Colliery at Shamokin</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Flooded mine</td>
</tr>
<tr>
<td>(Lindemuth, 2008)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laurel Run</td>
<td>Northern</td>
<td>Untended carbide lamp left in mine timber in 1915</td>
<td>Contained until mine abandoned</td>
</tr>
<tr>
<td>(Randolph, 2002; Ashmead, 1922)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peach Mountain</td>
<td>Southern</td>
<td>Unknown</td>
<td>Excavation in 1949</td>
</tr>
<tr>
<td>(Kim and Chaiken, 1993)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A mine fire was found in abandoned workings in the Mammoth Vein near Summit Hill in 1859 (Mazaika, 2007). It was let burn for many years and even became a tourist attraction (Mazaika, 2007). It was finally decided to put out the Summit Hill coal fire about 1910 because of the loss of valuable coal and so a clay barrier was built across the basin which was successful in putting out the fire (Mazaika, 2007).
Middle Period Fires

By the 1950s anthracite coal production was in steep decline. Many mining companies went bankrupt, sometimes transferring their mineral rights to local communities, where a declining tax base left little resources for dealing with the mine fires, or other environmental problems caused by mining. Often communities contributed to the mine fire problem by repurposing abandoned surface mines as municipal garbage dumps, where fires might have easy access to mine workings. Rather than companies fighting mine fires to protect economic opportunity, the government stepped in to protect public health. This was very much in keeping with what was going on in other parts of the United States.

The post-World War II era saw a renewed interest in the environment and using the state to protect natural resources. Anthracite mining communities affected by mine fires were aided by programs like Department of Housing and Urban Development’s for slum clearance, Appalachian Regional Development programs, and Federal Abandoned Mine Lands programs. (Table 2). More fires are known from the middle period because of lists available in US Bureau of Mines publications (e.g., Kim and Chaiken, 1993). Because of the large number of fires, government officials used a rough system of cost-benefit analysis to determine where resources should go. Fires that threatened large communities or major infrastructure projects would receive most of the help.

The fires of Carbondale and Laurel Run are described to show the shift from company to state and federal government responsibility. Other fires are listed in Table 2 by the date of discovery or the date the control action by the government. Many more fires are known from the middle period than from the early and recent periods.

Table 2. Middle Period Fires

<table>
<thead>
<tr>
<th>Fire and Reference</th>
<th>Field</th>
<th>Cause</th>
<th>Fought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kulpmont (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Trench in 1950, Excavation in 1958, Excavation and trench in 1960</td>
</tr>
<tr>
<td>Mt. Carmel (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Seal in 1950,</td>
</tr>
<tr>
<td>Location</td>
<td>Region</td>
<td>Type</td>
<td>Event Description</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Shamokin (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Seal and flush in 1952, Excavation in 1967</td>
</tr>
<tr>
<td>Cedar Avenue in Scranton</td>
<td>Northern</td>
<td>Unknown</td>
<td>First observed and fought in 1953 but was fought again in 1956, 1960, and 1965. The fire was fought using sand-flushing and the construction of isolation trenches.</td>
</tr>
<tr>
<td>Tower City (Kim and Chaiken, 1993)</td>
<td>Southern</td>
<td>Unknown</td>
<td>Flush and excavation in 1954</td>
</tr>
<tr>
<td>Shenandoah (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Inundation in 1960</td>
</tr>
<tr>
<td>Coal Run (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Trench and flush in 1963</td>
</tr>
<tr>
<td>Centralia (Nolter and Vice, 2004; Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Started in trash dump in old stripping pit in 1962</td>
<td>Fought some by US Bur. Mines and Office of Surface Mining with a excavation and flush in 1966, a barrier in 1974, and in 1978, but finally homeowners were bought out and fire was allowed to burn</td>
</tr>
<tr>
<td>Enyon Street (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Flush in 1965</td>
</tr>
<tr>
<td>Hazleton (Kim and Chaiken, 1993)</td>
<td>Eastern Middle</td>
<td>Unknown</td>
<td>Excavation in 1969</td>
</tr>
<tr>
<td>Location</td>
<td>Location</td>
<td>Depth</td>
<td>Notes</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------</td>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Kehley Run (Kim and Chaiken, 1993)</td>
<td>Western Middle</td>
<td>Unknown</td>
<td>Excavation in 1969</td>
</tr>
<tr>
<td>Throop (Dierks et al., 1971)</td>
<td>Northern</td>
<td>Observed in 1966 and was believed to have started in garbage in an old stripping pit that was used as a garbage dump.</td>
<td>Fought by constructing an isolation trench around the area of the mine fire in 1968.</td>
</tr>
<tr>
<td>Warrior Run ((Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Flush and excavation in 1971</td>
</tr>
<tr>
<td>Swoyersville (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Excavation in 1973</td>
</tr>
<tr>
<td>Eddy Creek (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Flush in 1974</td>
</tr>
<tr>
<td>Forestville (Malenka, 1985)</td>
<td>Southern</td>
<td>Started in trash in old stripping pit in 1982</td>
<td>Completely dug out by contractors supervised by the Office of Surface Mining</td>
</tr>
<tr>
<td>Hughestown (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Excavation in 1984</td>
</tr>
<tr>
<td>Sugar Notch (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Excavation in 1984</td>
</tr>
<tr>
<td>Larksville (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Trench and excavation in 1985</td>
</tr>
<tr>
<td>Maffett (Kim and Chaiken, 1993)</td>
<td>Northern</td>
<td>Unknown</td>
<td>Excavation in 1987</td>
</tr>
</tbody>
</table>

A mine fire was discovered on the west side of Carbondale which is in the northern part of the Northern Field in 1946. Carbondale was, after Scranton, the largest community in Lackawanna County. It was one of the first areas to develop mining, shipping coal over a long gravity railroad to the Delaware River. In 1946 it was home to railroad line, and Route 6, a major east-west highway prior to the opening of Interstate 80. The fire may have started as much as five years earlier when the City of Carbondale was using some abandoned strip mining pits as a refuse dump (Munley, 1998). The City of Carbondale and the U. S. Bureau of Mines made a couple of early efforts to control the fire including using water to flush the location of the fire, and pouring approximately 80,000 cubic yards of silt into test boreholes but otherwise did little to
control the fire. However, this changed when an elderly couple died from carbon monoxide poisoning a considerable distance from fire site convinced the city that they had a much larger problem. Starting in 1956, the City of Carbondale applied for and received Federal Urban Renewal funds. Contractors dug a series of trenches up to 100 feet deep and three times as wide and filled these trenches with incombustible earth. The coal that was recovered when these trenches were dug was sold to help defray the cost of the project. When the project was finished in 1972, $2,326,000 had been spent and four million cubic yards removed. Two schools and 450 homes were destroyed (Munley, 1998, pp. 77-81).

Laurel Run’s coal mine fire had been contained since 1914. In 1957, though, active mining ceased. For the most part, people gave little thought to the fire. Then, in September 1962 a resident of South Dickerson Street was forced to abandon her home due to subsidence, and gases from the fire. Laurel Run was next to Wilkes-Barre, the county seat and largest town in Luzerne County. The fire threatened the right of way of Interstate 81, then being constructed. A plan was set in place by the Luzerne County Development Authority and United States Department of Housing and Urban Development. Boreholes were dug to locate the spread of the fire, then 850 residents saw their homes torn down. (Randolph, 2002, pp. 1-6).

The Carbondale and Laurel Run Mine Fire Projects both dealt with serious catastrophes. Many people lost their homes, and communities suffered major disruptions. Like many other mine fire projects of the second period, though, they were viewed as social successes. The community members and local, state, and federal governments came together to work with a common purpose. In part, this was because many men in the community had first-hand experience working in the mines. There had knowledge of the dangers mine fires created, and even had a rough understanding of what areas would be impacted by the fire. People were sorry to lose their homes and neighborhoods, but most knew that had to be the case. The next fire we examine was very different.

**Centralia: The Difference Maker**

Centralia is the best known of all the coal fires in Northeastern Pennsylvania. It started during the middle period of fires, when coal companies were going out of business and abandoning efforts at remediation, and the government, with its system of cost-benefit analysis was coming in. It would ultimately change how fires were fought and perceived by the public.

Centralia is located near the center of one basin in the Western Middle Field (Eggleston et al., 1999). The borough of Centralia had been using an abandoned surface mine as a garbage dump. In May of 1962 they set the dump on fire, and accidently ignited the Buck Mountain coal bed (Nolter and Vice, 2004). The fire began on the nose of an anticline which made it possible for the fire to spread along four different fronts. The dipping and fractured coal beds permitted the propagation of fire deep into the subsurface and contributed to the formation of a self-propagating convection cell (Chaiken et al., 1980). Basically, as air is drawn into the fire through fractures in the surrounding coal and bedrock, hot coal gases escape up the dip of the coal bed, and more air can come in. A 1938 study by McElroy showed that these convection cells can provide fires with a steady enough supply of air to allow them to spread both laterally and down dip in a coal bed (DeKok, 2000).
As soon as the Centralia fire began there were attempts to put it out. These included flushing the mines with water-rock slurry, building fly ash-barriers, and trenching around the fire. The sharply dipping coal beds and highly fractured rock surrounding the coal made fighting the fire difficult and expensive.

The geology of the fire created other problems as well. Because it had started on the nose of an anticline, it was spreading in four directions at once. This made it much more complex than other fires. The fact that two of the fire fronts seemed to be burning away from the town led to a situation where even people with practical experience working in the mines could debate whether or not Centralia was really threatened. Centralia also suffered because while it was in the western field, it was one of the few mining areas that crosses into Columbia County. Officials at the court house had little experience with or understanding of mine fires, particularly the maze of overlapping jurisdictions of state and federal officials. Not knowing how to proceed, Centralia never received enough funding to fight the fire, something made worse by the fact that no major infrastructure or economic assets were at stake. The result was a divided, bickering community, where neighbors turned against neighbors, and everyone realized something had gone wrong. Eventually, Pennsylvania would use its share of Abandoned Mine Lands money and other federal funds to buy out the town’s residents (Kroll-Smith and Couch, 1990; DeKok, 2000).

While Carbondale and Laurel Run had been viewed as successes, Centralia was regarded as a failure. The government was seen as waiting too long to take action, and not caring about the residents. As the fire worsened much of the struggle was played out in the media, causing a public relations disaster.

A recent visit to Centralia by one of the authors (DHV) found indications that the cemetery front of the Centralia coal fire may be largely out. No steam or gases were being emitted and young trees were growing in sites that were previously barren. The latter is taken as an indication of the fire going out because work by Ressler and Markel (2006) found that elevated ground temperatures decreased the number and diversity of trees (Figure 2).

Figure 2. One of the last active areas on the Cemetery Front of the Centralia Fire showing the growth of young trees.
Recent Fires

After the fire at Centralia, and perceived failure of the government's remediation efforts, recent fires have been handled differently. Five recent coal mine and culm bank fires are described in Table 3 to illustrate both community and government reaction from about 2000 to the present. The community response is to bring the federal or state government quickly and the government response is to quickly work to control or extinguish the fire.

<table>
<thead>
<tr>
<th>Fire and Reference</th>
<th>Field</th>
<th>Cause</th>
<th>Fought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mildred (Sullivan Review, 2004)</td>
<td>Western Northern</td>
<td>Uncertain but believed to have started in trash dumped at an old mine</td>
<td>Local fire company put out using water</td>
</tr>
<tr>
<td>Palo Alto (Pottsville Republican-Herald, 2008, 2009)</td>
<td>Southern</td>
<td>Uncertain but believed to be hunter's fire built on a culm bank in December of 2008</td>
<td>Contractors supervised by the Office of Surface Mining quickly constructed a trench around the burning portion of the culm bank</td>
</tr>
<tr>
<td>Dolph or Olyphant</td>
<td>Northern</td>
<td>Unknown origin in 2004 in abandoned underground mine workings</td>
<td>Contractors supervised by the Office of Surface Mining quickly isolated fire with a trench</td>
</tr>
<tr>
<td>Coal Township or Excelsior (Shamokin New-Item, 2006)</td>
<td>Western Middle</td>
<td>Fire (possibly arson) in 2005 in a leaf-based mulch on reclaimed mine lands which caught coal waste on fire</td>
<td>PA Dept. of Environmental Protection ordered the mulch removed and pushed into a nearby stream in 2006. The fire was completely extinguished.</td>
</tr>
<tr>
<td>Simpson</td>
<td>Northern</td>
<td>Unknown origin on a culm bank in 2014</td>
<td>Was extinguished in about 3 months</td>
</tr>
</tbody>
</table>
Palo Alto is located on the southern margin of the Southern Anthracite Field close to the boundary between the Llewellyn and Pottsville Formations. Coal beds in the area are essentially vertical (Levine and Eggleston, 1992). In December, 2008, the community became aware of a coal fire burning just outside their borough limits in East Norwegian Township. The fire had probably started in July, but because the site was isolated, about two hundred yards from any homes or well-travelled roads, it hadn’t been noticed until a local hunter, John Ketner, stumbled across it. Ketner notified the East Norwegian Township supervisors, who, after examining the site, decided “this was way beyond the scope of any municipality”, and contacted the Office of Surface Mining (Pottsville Republican 2008, 2009).

John Mack, Office of Surface Mining project manager, was at the site within two days. After heat guns registered a ground temperature of 178 degrees Fahrenheit, exploratory boreholes were drilled to determine the extent of the fire. Results showed that what was burning was an eight foot long by seventy foot wide teardrop-shaped deposit of buried coal waste. The local water table was only sixty feet below the surface, so there was little chance of the fire spreading downward into lower strata (Pottsville Republican 2009).

Once the extent of the fire was known, Mack said the next step was to “design a trench to isolate the fire.” By spring the trench was in place, with two or three acres effectively isolated (Figure 3). Although Office of Surface Mining Engineer Dave Philbin admitted “there’s a lot of burnable material there”, everyone agreed that the fire had been cut off from spreading, and would not pose a threat to the community of Palo Alto. Later the fire could be entirely dug up and extinguished or left to burn (Pottsville Republican, 2009).

Olyphant lies on the southern limb of the Northern Anthracite Field. In the summer of 2004 an underground mine fire broke out in the abandoned mine workings south of town. Eventually it spread through the mine workings to encompass an area of seven acres. As in the case of other recent fires, the government’s response was swift. A 2000 foot (609.6 meter) long trench up to 130 feet (39.62 meters) deep was dug to isolate the fire. During the digging of the trench, when
temperatures at one area of coal and rocks were warmer than the blasting contractor would tolerate, a sprinkler system was set up to water the affected site until it cooled. This allowed the blasting contractor to set his charges where they were initially scheduled, and prevented the delays that would have accompanied redesigning and extending the trench around the hot area. The entire trenched area was subsequently fenced off.

Excelsior (Figure 4) is in the Western Middle Anthracite Field, just outside Shamokin. Elwood Swank, owner of the Split Vein Coal Company in Paxinos, leased land near Excelsior from Reading Anthracite. He had a permit from Pennsylvania’s Department of Environmental Protection to conduct surface mining on the area, and bring in refuse for reclamation processes. Included in the refuse was a leaf-based mulch approved by the Department. In December 2005 the compost caught fire. Most thought it had been set intentionally by people riding on all-terrain-vehicles. Fumes from the fire drifted toward the city of Shamokin, and soon coal waste on the site had caught fire as well (Shamokin News-Item, 2006).

The Department of Environmental Protection was soon on the site. Swank was ordered to have a backhoe and bulldozer work eight hours a day to remove the burning refuse and push it into a pond. (A nearby stream was already dead from acid mine drainage, so runoffs from the pond could not make things worse.) Workers from Reading Anthracite helped with the clean-up efforts. By January the Department of Environmental Protection’s Tom Rathburn could report that the western end of the refuse pile was extinguished, and they were working towards the eastern end. By summer the fire appeared to be out, but then it restarted. The Department of Environmental Protection again suspected arson, and fire mitigation efforts were delayed until State Police could conduct what turned out to be an inconclusive investigation. Swank was now ordered to remove all of the compost, and again he set to work (Shamokin News-Item, 2006). In 2007 the Department of Environmental Protection realized the fire had burned beneath the refuse into a coal bed. This led to the fire being reclassified as a mine rather than coal refuse fire. Efforts to put the fire out were redoubled. When the authors visited the site in July, 2010 there was no evidence of a continuing fire.

Conclusion

Although coal fires have occurred ever since coal mining started in Northeastern Pennsylvania, not many coal fires are known from the early period, in part because the fires were
considered the responsibility of the mining company and few public records exist, particularly if the coal fires were small. A large number of coal fires are known from the middle period because this was the time period that the US Bureau of Mines and other Federal and state agencies were forced to start fighting these fires because so many of the mining companies had ceased to exist. Only a few mine fires are known from the recent period because of the short time period and more effort has been made to control these fires. In addition more regulation of dumping and more understanding of the dangers of mine fires may have made them less likely.

One reason for the effective handling of these fires might be Centralia itself. The Dolph, Palo Alto and Excelsior mine fires received extensive press coverage, and Centralia seemed to be very much on people’s minds. The comparison flowed both ways. For example, in the case of Palo Alto, nervous citizens, fearful for their community, cited Centralia to encourage action. In the December 31, 2008 issue of The Pottsville Republican Lee Dalton was quoted as saying, "I've heard about Centralia. That's the first thing I think of. It's been burning since June and nobody said anything to us? I have a problem with that." On the other side government officials mentioned Centralia to explain what the Palo Alto fire was not. For example, when State Representative Neal Goodman and Congressman Tim Holden visited the fire, they were quoted as saying, “it’s far enough away from people’s homes that it’s not a danger. It is not a Centralia-type fire.” Palo Alto borough council member Gerald Richter was quoted in the Pottsville Republican on January 7, 2009 saying “This is not another Centralia”. He made similar comments to the paper on January 13 and January 19. Overall, out of the ten articles the Pottsville Republican devoted to the fire between December 20, 2008 and May 5, 2009, seven of them, in one way or another, referenced Centralia (Pottsville Republican, 2008, 2009).

The fire outside Excelsior showed a similar pattern. The Shamokin News-Item on August 11, 2006 asked "Is Excelsior another Centralia in the making? That was just one of the concerns brought up at Thursday’s Coal Township Commissioners meeting by residents worried about a compost pile that continues to burn near Excelsior.” The township commissioners and Department of Environmental Protection had a fiery debate in the paper over who approved of the leaf based mulch Swank had used, and whether the public had had too small of an oversight role. On August 12, 2006 the Shamokin News-item said, “The name Centralia will forever be synonymous with government inaction at all levels. The fire spread while some ignored the problem or when the fire was addressed ineffectively. Surely this area will never allow this to happen again.” Essentially, the memory of the Centralia fire causes communities to respond to coal fires differently than in the past, and the perceived failure of the government (whether rightly or wrongly assigned) in the case of Centralia, encourages the state bureaucracy to respond to fires in a more robust way (Shamokin News-Item 2006).

A second factor which may explain the new ways communities respond to mine fires as compared to what happened in Centralia in the 1960s is the passage of time. In the 1960s most residents of the anthracite coal fields had experience with the mining industry, and were not surprised by its inherent dangers. Today that is no longer the case. When the Palo Alto fire broke out borough councilman Charles Dries was quoted as saying, “The kicker here is there hasn’t been any mining in our town for probably seventy-five years.” (Later callers to the newspaper suggested forty years might be more accurate.) Either way, only the oldest residents of Palo Alto would have had much experience with mine problems. This would have made the fire less
familiar and more alarming. Centralia, though, has achieved something of a cult status as a tourist destination. Everyone has seen it, and knows what a mine fire can do, and reacts accordingly. As the authors conducted research on this and other papers, and have talked to people who live near coal fires, almost everyone has told us to go see Centralia. It has come to epitomize coal fires in a way no other fire has.

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This report presents the results of the GAI study of the Centralia Mine Fire. The work was carried out during the period December 1982 through June 1983.

**Project activities consisted of the following tasks:**

**A. A review of existing data and background information on the fire, including previously attempted control measures.**

Historical perspectives on the fire are presented in Chapter 1 of the report, as are chronologies of fire related events and observed temperature/thermal conditions at Centralia over the twenty years since the fire was discovered.

**B. A review of the geology, mining and hydrology in the Centralia area.**

An examination of the complex interrelationships between mining, geologic structure and current mine pool elevations is presented in Chapter 2. This examination led to the identification of the boundaries that would be expected to prohibit spread of the fire and the resulting region to which the mine fire could conceivably spread if left unimpeded over the long term.

**C. An evaluation of the physical character of the overburden and the identification of thermal effects.**

Physical evidence is presented in Chapter 3 concerning the composition and integrity of the rock strata above and between individual mine workings in relation to ventilation, transmission and potential fire control options, as determined from eight core holes drilled from ground surface to the base of the Buck Mountain Seam in the vicinity of Centralia and Byrnesville. Thermal laboratory tests (differential scanning calorimetry, thermal gravimetric analysis, volatile matter and BTU) conducted on rock cuttings and
rock core provided evidence that certain of the coal seams above and including the Buck Mountain Seam had probably burned or are burning.

D. **A ventilation study of the mine workings in which the fire is actively burning and an analysis of the apparent progression of the fire with time.**

A study of borehole temperature data collected between 1967 and 1983, airborne thermal infrared imagery collected between 1971 and 1982 and sulfur hexafluoride (SF6) tests conducted in 1983 permitted an indication of the centers of activity of the mine fire, how the fire had migrated during the period of observation and the intensity with which the fire has been burning in recent months. The results of the airborne thermal imagery study are presented in Chapter 4. An evaluation of the state of the mine fire based on an analysis of temperature, gas and air flow data is presented in Chapter 5.

E. **A review of proven and experimental methods for containing and extinguishing underground mine fires and the formulation of possible courses of action that might be considered for dealing with the fire.**

Discussions have been conducted with vendors, government specialists and other knowledgeable individuals in the public and private sectors concerning potential fire control methods. A variety of possible courses of action for dealing with the Centralia Mine Fire have been formulated and evaluated in view of geologic, mining and hydrologic conditions associated with the Centralia Mine Fire area. Plans for dealing with the mine fire are discussed in Chapter 6.

**The basic findings of the study are presented below:**

1. The fire-affected area as of mid-1983 occupies approximately 195 acres. This is denoted as the "conditioned temperature area-June, 1983" in Figure 1.

2. The Centralia Mine Fire is not a single, sharply defined entity that is advancing through the coalfield on a broad, uniform front. Instead, the fire is composed of a group of somewhat ill-defined, irregularly shaped zones of combustion adjoined by zones of conditioned coal. At least four high temperature zones currently exist within the study area (Figure 1): the Northwest Zone near and vertically beneath Centralia, the Southwest Zone south of Centralia and northeast of Byrnesville, the South east Zone east of Byrnesville in the vicinity of Big Mine Run and the Northeast Zone east of Centralia and north of Big Mine Run. These zones have been identified in the Buck Mountain Seam.

3. From a near term standpoint, only the Northwest and Southwest Zones appear to impact citizens.

4. The Northwest Zone has been relatively stable in position during the 1982-83 monitoring period. However, over the past twenty years, it has migrated westward toward Centralia and continued movement in that direction can be anticipated. During the 1982-83 monitoring period, the Southwest Zone has moved towards and is now near the village of Byrnesville.

5. Laboratory thermal tests (differential scanning calorimetry, thermal gravimetric analysis, volatile matter and BTU), along with physical indications on rock core samples secured from borings drilled through the base of the Buck Mountain Coal--five on the north flank of the Locust Mountain Anticline and three on the south flank--provide evidence that, at least
locally, the mine fire now or in the past has probably occupied mine workings in the Skidmore, Seven-Foot and Buck Mountain Leader Seams on the north flank of the anticline. Borehole temperature data tend to support this evidence. Over the long term, the fire might conceivably spread to stratigraphically higher coal seams if it has not already; cannot be determined from available information. The recognition that the fire can potentially occupy mine workings in the upper seams warrants consideration in any attempt at containing or extinguishing the mine fire.

6. In seams above the Buck Mountain Coal, the fire could conceivably burn beneath the northern portion of Centralia.

7. A study of the complex interrelationships of geology, mining and hydrology has led to the recognition that over the long term, if left uncontrolled, the fire could conceivably spread over an area of approximately 3,700 acres (Figure 2).

8. The communities of Centralia, Byrnesville and Germantown are situated within the 3,700-acre area.

9. The communities of Ashland, Big Mine Run, Girardville, Connerton, Lost Creek and Raven Run are in near proximity but outside the 3,700-acre area.

In the anthracite region abandoned mine fires are extremely difficult to control because of:

1) multiple-seam mining,
2) steep dip of the coal bearing strata and other complicating geological phenomena,
3) cross-seam rock tunnels and drainage galleries,
4) relatively close spacing between mined seams, and
5) highly fractured rock strata.

All of these factors are present at the Centralia Mine Fire site. In addition, virtually unlimited quantities of air are available to the fire, coming through mine entries, drainage tunnel outlets, strip pits, subsidence-induced fractures in overburden, and very extensive underground mine workings.

The effectiveness of any of the methods employed to control or extinguish mine fires depends on the geology, mining, hydrology and ventilation of the individual mine. To extinguish a fire, the fuel must be removed or the oxygen supply or temperature must be reduced below that which is required to maintain combustion.

The most commonly employed techniques developed to combat mine fires in inactive underground workings include: excavation, inundation, flushing, surface sealing, and barriers (stoppings) constructed in mine workings.

Each of these techniques has been used at one time or another in the anthracite coal fields with varying degrees of success. Excavation and flushing have been unsuccessfully employed in the past to combat the Centralia Mine Fire (Figure 3).

In addition to the commonly employed methods of mine fire control, techniques for combating fires that have been suggested but never implemented, at least in a physical setting comparable to the Centralia Mine Fire, have been categorized as 'experimental. Inclusion of a method in this category does not necessarily preclude its use at Centralia. It does, however,
eliminate the method from consideration at this time as one having a certainty of success at controlling or extinguishing the fire. Test demonstrations could possibly result in one or more of the methods being regarded as proven fire control measures. These include inert gas injection, chemical injection, quenching, burnout control, and incremental flooding/backfilling.

Several courses of action that might be considered for dealing with the Centralia Mine Fire have been formulated--the nature of the action being dependent upon whether or not it is considered necessary that existing communities be maintained in their present locations and whether or not it is considered necessary to protect the coal resources apart from the communities. socio-economic decisions demanded by these issues are beyond the purview of the present study. However, courses of action that accommodate each of the two issues are examined in the report from a technical and cost perspective.

Several items of significance have been recognized in formulating possible approaches to dealing with the Centralia Mine Fire:

1. The potential costs of implementing the fire control measures necessary to maintain a community in its present location are almost always very great.
2. No single course of action is necessarily appropriate for all locations within the area to which the mine fire might conceivably spread.
3. The potential disruption to a community due to noise, vibrations, dirt, closed streets, etc., resulting from the implementation of the fire control measures could be profound and could continue for a period of several years.
4. The success of the fire control measures is not necessarily assured.

In view of these factors, the relocation of households and businesses in response to local conditions brought about by the fire would appear to be a course of action worthy of consideration.

One method of dealing with the Centralia Mine Fire is to permit the fire to burn unrestrained. The length of time the fire would burn is difficult to assess. It might be for a century or more.

The actual cost of purchasing property to permit relocation of the residents of Byrnesville and Centralia is estimated to be approximately $20 million. Additional costs for the relocation of businesses, churches and other entities could increase the total cost to the neighborhood of $50 million. This figure does not include the value of lost coal reserves, the cost of relocating Route 61 or socio-economic losses to surrounding communities. Rather than permitting the fire to continue unabated if the residents of affected communities are relocated, a possible benefit could be derived by designating the area a mine fire control laboratory, where pilot projects could be conducted to identify technologies for controlling, extinguishing or profitably utilizing underground mine fires.

An attempt to eliminate the fire by excavating (total excavation) would encompass the temperature conditioned coal and the fire, as well as a 100 to 500 foot wide zone surrounding this area to account for potential spread of the fire prior to completion of the excavation. The estimated total yardage to be excavated based on current conditions is 93.4 million cubic yards. High temperature material encountered must be quenched by water spray. The excavated material would be used as backfill. A perimeter excavation would first be made to contain the fire. Excavation would then progress toward the interior. Fifty-three structures in Byrnesville
and Centralia lie within the proposed excavation area and an additional 47 lie within the adjoining safety zone.

Specific courses of action that might be considered if socio-economic considerations indicate that a community be kept in place are presented in Figure 3, with estimated costs. A preferred course of action for each community is presented below. Other courses of action are discussed in section 6.6.2 of Chapter 6.

**Preferred course of action if Byrnesville is to be kept in place:**

1. Byrnesville residents continue to occupy their homes.
2. Bulk fill with cement grout or other suitable noncombustible material all mine workings beneath Byrnesville Buck Mountain, Buck Mountain Leader, and Skidmore Seams. The plan area is approximately 11 acres.
3. Maintain and repair as necessary the existing road access to Byrnesville.

**Comments:**

1. If Isolation Trench “C” (Figures not shown), is constructed to the west of Byrnesville to prevent the southwest migration of the Centralia Mine Fire towards Germantown, it will be necessary to construct a new, temporary access road to Byrnesville and restore Route 61 upon completion of the trenching operation, which would be expected to take several years.
2. Some uncertainty exists as to the thoroughness with which the abandoned mine workings can be bulk filled and the effectiveness of the completed product in diverting the approaching fire, given the relatively broken character of the rock strata above the mine workings.
3. If the Centralia Mine Fire occupies the mine workings directly beneath Byrnesville before action can be implemented, then it may complicate this option.

**Preferred course of action if Centralia is to be kept in place:**

1. Construct Isolation Trench “A” (Figures not shown) to mine pool through mine workings in all seams and north to the Buck Mountain crop line.
2. Permanently relocate homes and buildings situated within the proposed trench limits and adjoining safety zone to appropriate areas west of the trench.

The Centralia Mine Fire has already encroached on Centralia and thirty homes have been moved as of mid-1983. A reasonably safe alignment for Trench “A”, based on technical fire control reasons, would appear to be 200 to 300 (or more) feet west of the fire affected area. However, this alignment places the trench virtually in the heart of Centralia, which negates much of the benefit to be derived from fire control. Placement of the trench closer to the fire to minimize the number of structures that would have to be removed for the trench—a near-fire distance of 100 feet being about the closest that might reasonably be considered (Figure not shown) during trench excavation. It also greatly increases the risk that the fire could pass beneath the trench during construction, even if inert gas techniques or other mitigative measures were employed. In addition, noise, vibration and dirt associated with the construction process could be significant. Furthermore, the estimated cost of Trench “A”, although less than total excavation, is still
significant, and the prospect still exists that an unidentified fire may now reside in the mine workings beneath Centralia to the west of the trench alignment or may occur there in the not too distant future due to spontaneous combustion. Even though the Trench “A” option is considered to be relatively superior to other possible technical options if Centralia is to be kept in place, there are sufficient negative aspects of the plan to warrant consideration of relocation of the community.

Preferred course of action if Germantown is to be kept in place:

Alternate A - If Isolation Trench “C” and Auxiliary Trench “C” (Figures 4 and 5) are constructed west of Byrnesville, then:

1. Germantown residents continue to occupy their homes.
2. Monitor gases and temperatures in all mine workings beneath the town and monitor gases in homes.
3. Evacuate residents and relocate households when and if conditions warrant.

Comment:

The time at which the Centralia Mine Fire might reach Germantown, if at all, cannot be estimated with certainty.

Alternate B - If Isolation Trench “C” and Auxiliary Trench Care constructed west of Byrnesville, then:

4. Germantown is isolated from the Centralia Mine Fire and no further action is required to protect the town. Alternate A is considerably more cost effective than construction of Isolation Trench “C” and Auxiliary Trench “C”, if the sole objective is to maintain Germantown in place. If, however, protection of the coal reserves west of Byrnesville is also an objective (as discussed in section 6.63 of the report), then construction of Isolation Trench “C” and Auxiliary Trench “C” might be justified and Germantown would be protected from the Centralia Mine Fire as a matter of course.

Limiting Potential Spread of the Fire.

If protection of coal reserves is to be a prime consideration in fire control, then isolation trenches excavated to mine pool through mine workings in all seams could potentially be utilized to exclude the Centralia Mine Fire from major sectors of the prospective 3,700-acre natural burnout area. Figure not shown summarizes the dimensions of each trench, its estimated cost and the area protected from potential spread of the fire.

Closure.

In the selection process, it is of pre-eminent importance to appreciate that the potential cost of implementing a fire control measure is generally great, and could well exceed the cost of household relocation. It must also be appreciated that no single course of action is necessarily appropriate for all localities, that disruptions associated with the implementation of fire control measures may well continue for a period of several years and that success of the fire control measures is not necessarily assured. Socio-economic considerations should be part of the selection of appropriate courses of action.
Figure 1. Geological cross-section showing high-temperature and fire-affected areas.
Figure 2. Possible long term spread of fire (red areas)
Figure 3. Map showing location of excavation and flushing techniques unsuccessfully employed at various times to combat the Centralia Mine Fire from date of origin in 1962 to date of GAI report in 1983.
It was supposed to be a meeting on air pollution. Unfortunately, most of the attendees are chain smokers!
THE SCIENCE CONDUCTED ON THE COAL FIRE IN CENTRALIA, PA

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Abstract

For over half a century, the anthracite coal fire at Centralia, PA has affected the surface vegetation, landscape subsidence, soil mineralogy and nutrients, and diversity of vegetation and microbial organisms. It moved along four different fire fronts, and traveled westward along the limbs of the Locust Mountain Anticline. In the past, the fire was known to have a high surface temperature (up to 540° C), it moved at a rate of 20-23 m/yr, and it exhausted high concentrations of CH₄, H₂S, CO, and CO₂. Today, the fire is mostly active along two fire fronts, temperatures reach a high of 60° C, and movement of the fire along these fronts and gas emissions are nearly imperceptible. By all accounts, the fire appears to be diminishing, yet it continues to greatly influence the surface. Steam-induced mass wasting of the landscape has resulted in the development of several new, large sinkholes that align with the burning coal beds. With decreased vent temperatures, succession is occurring as vegetation and organisms recolonize the landscape. There is still much to be learned from the effects of this coal mine fire and the effects of coal mining on the environment. One may develop a better understanding of the fire by integrating the outcomes from multidisciplinary research conducted on the region over the last 50 years.

Introduction

It’s not the biggest, nor is it the oldest, but it is perhaps the most widely known and visited coal fire in the world due to its coverage in the media, books, movies, and it has developed a mythology over the years from stories published on the internet. Centralia, PA, the location of the anthracite mine fire (Figure 1), is no longer a town; it is a destination for those wanting to see an anthracite coal mine fire. Today, however, the fire is not as active as it was in the past, resulting in disappointed visitors unable to find the extreme temperatures and billowing smoke and steam as described in the past (Elick, 2013; 2015).

The fire has changed a great deal since the field trips sponsored by the Pennsylvania Geologic Survey (Inners and Jones, 1990) and the Geological Society of America (Stracher et al, 2006). The rate of fire movement, temperature and location of active of vents, and the concentration of chemicals in the exhaust gases have all decreased (Elick, 2013). Additionally, as temperatures changed, the landscape experienced subsidence, it has been modified by man, and succession is actively taking place in the region. Today, the mine fire at Centralia can be characterized as smoldering, while the landscape heals from it’s past influence (Elick, 2013; 2015).

For decades, the coal fire at Centralia (Figure 1) has been an exceptional outdoor laboratory for science classes and a research site for many different kinds of scientists. Though many, including DeKok (1986 and 2010), Kroll-Smith and Couch (1990), Logue et al., (1991) and Trifonoff (2000), have highlighted the fire impact on Centralians, this paper will discuss scientific
findings that can help us better understand how this particular manmade disaster has altered the environment. This work will highlight some of the research conducted at Centralia over the past 50 years. Many of these multidisciplinary scientific findings are related and can be integrated to better describe the interactions between the subsurface fire and the surface environment.

**Background**

The borough of Centralia was originally known as Bull’s Head (1811), and was named for a tavern in the area (Michalski et al., 1988; Stracher et al., 2006). It was renamed Centreville (Chaiken et al., 1980), after the discovery of anthracite coal in the area, and because it was to become a center of commerce. Another nearby town, however, already used that name, so the area soon became known as Centralia (incorporated in 1866) (Johnson, 2004). Anthracite coal was first mined in Centralia in 1842, and soon after, the town experienced economic prosperity and a population boom with several companies mining the Western Middle Field coal beds (Stracher et al., 2006).

By the 1950s, surface mining largely replaced subsurface mining due to lower labor costs and labor disputes, cleaner alternative fuels, difficulty in mechanization of mines because of complex geology, depletion of more easily accessible coal beds, and oil becoming a popular fuel source (Eggleston et al., 1999; Stracher et al. 2006). Strip mining operations became common in Centralia from the 1950’s to 1962. In 1962, however, 23 mines in Centralia were ordered closed by the state due to the toxic fumes and carbon monoxide infiltrating the active subsurface workings and collieries (Chaiken et al., 1962). These fumes originated from the mine fire burning in Centralia. Following the closing of the mines, subsurface mineral rights were transferred to the borough of Centralia and later to the state (Stracher et al., 2006).
Many of the high points related to the Centralia coal fire history are derived from a more detailed account in DeKok (1986; 2010). The ignition of the fire was prior to the Memorial Day (Decoration Day) events in 1962, when members of the Centralia Borough Council obtained a permit to burn the refuse in an abandoned strip pit near the Odd Fellows Cemetery (Figure 2). The strip pit was 75 feet wide and 50 feet deep from the top to the base; the base was composed of slate (Chaiken et al., 1980). The fire was meant to burn the contents of a dump and rid it of rodents before the festivities, many of which included the nearby cemetery (Stracher et al., 2006; DeKok, 2010). In preparation of the fire, openings into the subsurface of the strip pit were filled with noncombustible materials, a practice necessary to prevent the spread of the fire into the subsurface mine workings.

The fire was lit May 27, 1962. Though the fire department extinguished the fire at the surface, one unsealed opening in the strip pit allowed the fire to continue to burn and spread quickly into the subsurface. Oxygen and air movement in the mines allowed the fire to thrive and move at a rapid pace through the anthracite (Stracher et al., 2006; DeKok, 1986; 2010). From its onset, officials from both the town and state found it difficult to quickly raise the funds necessary to extinguish the fire (DeKok, 2010; Jack Carling, Disaster Programs Director, Pennsylvania Department of Community Affairs, Personal Communication, 2011)); it quickly spread and became non-extinguishable.

From 1962 to 1978, officials tried excavating burning materials, hydraulic flushing of mine voids using water mixed with clay, partial trenching, backfilling, flushing boreholes, they

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**Figure 2.** Geologic map of region around Centralia highlighting the structure and locations of fire fronts (modified from Arndt, 1971). Large black arrows identify the locations of and direction of movement for fire fronts 1 and 2; fire fronts 3 and 4 no longer appear to be active. The yellow star identifies the location of the strip pit/dump and origin of the fire in May 1962.
produced fly-ash barriers, filling the voids in the subsurface with breaker refuse to decrease O2, however all attempts were unsuccessful (Chaiken et al., 1980; GAI Consultants, 1983; Michalski et al., 1988). They drilled over 80 boreholes to monitor the fire, but some of these initial boreholes were uncapped, which may have allowed the subsurface fire to vent like chimneys, drawing down oxygen-rich air from other areas into the subsurface (DeKok, 2010). Additionally, this chimney-like drawdown may have caused the fire to rapidly travel through the subsurface, at a rate faster than anyone anticipated (GAI Consultants, 1983; DeKok, 2010; Neubauer and Elick, 2013).

For the next three decades, the people of Centralia coped with the consequences of the coal fire. Coal fires are known to be destructive, both to the environment and to human health, and the coal fire in Centralia threatened both (Logue et al., 1991; Stracher, 2007). Coal fires can cause carbon monoxide poisoning, chronic bronchitis, stroke, lung cancer, cardiovascular disease, chronic respiratory issues, and chronic obstructive pulmonary disease (Logue et al., 1991; Stracher and Taylor, 2004; DeKok, 2010). They produce greenhouse gases, destroy vegetation and kill organisms, cause subsidence, and waste a valuable resource (PADEP, 2013). Officials were also concerned that the Centralia mine fire could burn through several of the mine workings, it could burn its way to the northern part of Centralia (from the south), it could spread over 3,700 acres, and it could affect multiple communities in that area (Michalski et al., 1980; GAI Consultants, 1983).

Normally, when an economically viable resource ignites, the response is to contain and extinguish it (Kroll-Smith and Couch, 1990). And though many attempts were made to control this fire, it was ultimately established to be cost prohibitive by the state. Officials procured some initial funding to purchase properties from some of the townspeople and move them to nearby locations. This allowed the coal fire to burn until it’s fuel resources ran out or until natural forces caused end to the fire. After spending over 7 million dollars in failed attempts to extinguish the fire, moving several households, and realizing that the cost to end the fire would be over 600 million dollars, in 1983, the federal government offered to purchase the town properties and move the nearly 1200 citizens of Centralia for nearly 43 million dollars (GAI consultants, 1983; DeKok 1986; 2010; PADEP, 2013). By 1992, the state enforced eminent domain and threatened to seize the remaining nine properties from residents who did not accept the original buy-out. After two decades of court battles, in 2012, the state decided to allow the remaining residents to stay in their houses and paid these families a cash settlement of $349,500. They have permission to live in their houses as long as they live, with the state seizing their properties upon their death.

The Geology

Centralia is located at the intersection of PA State Routes 42 and 61 (Figures 1 and 2), in the Western Middle anthracite coalfield, and is underlain by Middle to Upper Pennsylvanian age bedrock (Figures 2 and 3)(Arndt, 1971; Berg et al., 1983). In this part of the Ridge and Valley Province of Pennsylvania, the ridges are composed of the Pottsville Formation and valleys are composed of the Llewellyn Formation (Figure 2). The east-west oriented Centralia Anticline (plunging to the west) and Centralia Thrust Fault are to the north of Centralia, while the Locust Mountain Anticline (plunging to the east) is to the south and the town is situated within the Centralia Syncline (Ardnt, 1971). The bedrock forming the topographically high Locust Mountain Anticline is composed of the Schuylkill and Sharp Members of the Pottsville Formation. The
bedrock forming much of the Centralia Syncline and occurring on the northern and southern limbs of the Locust Anticline is the Llewellyn Formation (Figure 2) (Arndt, 1971).

The Llewellyn Formation is a complex, heterogeneous succession of subgraywacke clastics, ranging from carbonaceous shale to conglomerates and anthracite coal beds (Edmunds et al., 1999). In Centralia, the lowest rock in the Llewellyn Formation, the Buck Mountain coal succession, overlies the Pottsville Formation (Figure 3 A). The coal beds from the Buck Mountain coal succession are on fire, and the fire has burned along both limbs of the Locust Mountain Anticline in a westward direction (Figure 2) (Chaiken et al., 1980; GAI Consultants, 1983). The Buck Mountain coal succession is overlain by the Seven Foot coal (no. 6), the Skidmore Leader (no. 7L) and the Mammoth, which are also from the Llewellyn Formation (Figure 3 A). All other coals in the Llewellyn Formation were removed due to erosion.

The Buck Mountain Coal Succession

The Buck Mountain coal succession, was mapped by Arndt (1971) as the lowest part of the Middle Pennsylvanian Llewellyn Formation in the area of Centralia (Figures 2 and 3 A) (Chaiken et al., 1980; Berg et al., 1983; GAI Consultants, 1983). It is the second most economically important coal-bearing unit in Pennsylvania, next to the Mammoth coal beds (Eggleston et al., 1999). The Buck Mountain succession consists of an interbedded succession of mudstone and siltstone interpreted as paleosols, shale and siltstone representing floodplain deposits, and channel sandstone beds (Figure 3) (Elick, 2013).

There are three splits of coal described in the region around Centralia (Ardnt, 1971), which bear number designations similar to those given by coal companies. The three splits of coal in the Buck Mountain are identified in ascending order as no. 5, no. 5M (middle), and no. 5T (top) (Figures 3 B and C). A borehole core collected near the town (Figure 3 B) and a high-wall exposure from the Blaschak Strip Mine Operation 1.5 km to the west (Figure 3 C) provide the basis for the sedimentological and stratigraphic description of Buck Mountain coal succession. Note that the thickness of rock units in the Buck Mountain coal succession and the number of coal splits may vary at different locations (Haley et al., 1953).

A thin, platy, fossiliferrous, black shale (0.4 m) at the base of the exposure (Figure 3 C) contains abundant coalified plant remains, many encrusted with kaolinite, pyrophyllite and quartz (Figures 3 B, C and 4). Some of the fossil plants found at this location include different species of Neuropteris, Lepidodendron, Alethopteris, Sphenopteris, Sphenophyllum, Sigilaria, and Calamites. Stigmaria were also identified extending from some Lepidodendron tree fossils; some compressed trees are up to 0.45-m wide (Elick, 2015). The no. 5 coal overlies the shale and is 2.0 m thick. Above the coal is a light olive-gray paleosol, which has a blocky soil structure, and contains abundant downward bifurcating root traces (up to 15.0 cm long and 0.8 cm wide). It is overlain by the no. 5M, which is 0.9 m thick. A multistoried, iron-stained lithicwacke sandstone with ripple marks and large cross stratification overlies the middle coal. On top of it are interbedded paleosols and shale deposits (5 m thick) with the no. 5T coal (0.40 m thick). A 3 m thick, cross-stratified, multistoried, lithicwacke sandstone containing small ripple marks, larger mega ripples, and rain drop impressions caps the entire succession. Soil composed of the stony
Figure 3. (A) Stratigraphy of the Middle Pennsylvanian in eastern and central Pennsylvania (modified from Berg et al., 1983). The Buck Mountain coal succession is identified by a black arrow. (B) Measured stratigraphic section from a borehole located near fire front 1 (modified from GAI Consultants, 1983). (C) Photograph and detailed measured section of Buck Mountain coal splits from Blaschak Surface mine (modified from Elick, 2013). A meter stick is located in the lower left side of the photograph for scale.
of mine dump from strip mine operations, cover the landscape influenced by the fire (Parrish, 1965; http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx).

In general, rock from the Llewellyn Formation represents a water-logged environment along a humid alluvial plain that contained coastal marsh peat swamps (Eggleston and Edmunds, 1981; Edmunds et al., 1999). These Pennsylvanian deposits were deformed during the Alleghanian Orogeny (Faiill, 1999), and during maximum burial and tectonic activity, the bedrock experienced low-temperature (250 to 300°C) metamorphic conditions, producing anthracite coal. The kaolinite-pyrophyllite coated plant fossils from the black shale in the Buck Mountain coal succession (Figures 3 B, C and 4), likely formed in this temperature range (Peterson et al., 2011).

The Fire

When the fire first started near the Odd Fellows Cemetery, along the nose of the east plunging Locust Mountain Anticline (Chaiken et al., 1980; GAI Consultants, 1983), it followed the strike of the Buck Mountain coal succession. Though it was thought to have been extinguished, the fire was again discovered in June of 1962. By July, the fire had moved 200 feet into the subsurface, along the strike of the Buck Mountain coal (Chaiken et al.1980; Michalski et al., 1988). It was known to have initially burned along the northern limb of the Locust Mountain Anticline, but by
late 1969, it burned its way to the southern limb, following the strike of the bedrock (Shallenberger, 1993). During this time, a grid of bore holes were drilled in front of the fire to monitor temperature and location and identify and measure gases compositions exhausting from the fire. It was from this grid that early maps of the fire location were produced (Chaiken et al., 1980; GAI Consultants, 1983; Shallenberg, 1990).

The location of the fire has been most accurately identified using thermal infrared imagery (TIR) by Knuth and Stamm (1972), Chaiken et al., (1980); Becker (1982), GAI Consultants (1983) and Elick (2011) with the addition of groundtruthing to identify surface temperatures (Figures 5, 6, and 7). High surface temperatures have been mapped using the location of melted snow

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Figure 5. Top: Aerial Thermal Infrared Image (TIR) of fire fronts at Centralia (circled) from November 10, 2009. Image was taken 853 m above sea level by Stockton Infrared Thermographic Services using a FLIR SC8000 series camera. The dashed line around fire front 3 indicates that it was no longer actively burning at the time the image was collected. (From Elick, 2011). Bottom: map of fire fronts at Centralia shows relationship of TIR image above to labeled street map. Red lines are Buck Mountain coal bed splits 5, 5M, and 5T.
(Nolter and Vice, 2004) and distribution of dead vegetation (Elick, 2012). As it burned, it formed four distinct hot zones that became known as fire fronts (GAI Consultants, 1983; Nolter and Vice, 2004). It moved from the point of origin, in the strip pit adjacent to the Odd Fellows Cemetery, toward the west (Figures 2, 5, 6 and 7). The history of the fire movement across the fire fronts is summarized in Elick (2011) (Figure 6).

Figure 6 Thermal history of the coal fire burning under Centralia, PA. This map integrates direct and indirect observations, borehole data, TIR images, false color infrared, and aerial photographs to show where the fire has been located and how it has moved over time. B. Fire fronts 1, 2, 3, and 4 as identified by Nolter and Voce (2004) Arrows on the fire fronts indicate direction of movement. Fire fronts 3 and 4 have not exhibited movement in any direction. (From Elick, 2011).
With time, the rate of fire propagation fluctuated. Early estimates of fire movement indicated that it moved at a rate of 23 m/yr since 1962 (noted by the PADEP in Nolter and Vice, 2004) however, they showed that it moved 400 m since 1982, at a rate of 20 m/yr. Based on the subsurface location of the fire, identified by GAI Consultants (1983), and the history of TIR data provided by environmental consulting agencies, Elick (2011) suggested that its rate of movement was variable in the past. Recent estimates of fire movement have been less than 2 m/yr, and the westward movement is no longer detectable (Elick, 2013).

Movement of the fire in the subsurface was strongly controlled by oxygen-rich air drawn into the fire (Elick, 2013) (Figure 8). Air flowed into the mines through uncapped boreholes and mine vents, cracks and fractures in the bedrock and ground (vents), and many tiny openings and pores in the soil (Figure 9). Uncapped boreholes and mine vents released gases at the surface, like chimneys, and helped draw air into the subsurface from other openings and locations. Though the installation of mine vents was intended to redirect the toxic gases

Figure 7 (A) Aerial thermal infrared image of fire front 1 showing high temperature vent location from February 2011 (1 am); image was taken by Elick. Semi-circular and linear anomalies occur across the landscape and have been interpreted to identify location of sinkholes and vents parallel to bedrock strike. Image was taken 240m above the surface with an emissivity (E) of 0.95 (dry soil). Coal bed locations from the Buck Mountain coal succession are identified using Bottom (5), Middle (5M) and Top (5T).

(B) Cartoon of a geologic cross section depicting the Buck Mountain coal succession across N-S from 7A. The hot zone is the location of the fire; gases and combustion products rise along the mined out breast to the surface at fire front 1. (A and B are from Elick, 2013).

(C) Recent aerial TIR from May 2015 depicting fire fronts 1 and 2 (white arrows indicate direction of front movement). This image was taken by J. Elick at 4 am using a FLIR P620 series camera at 300 m elevation above the ground surface.
Figure 8. Aerial thermal infrared image of fire front 1 in Centralia (2011) with superimposed subsurface coal map highlighted to show the surface location of the fire (dashed white zone) with the underground spacing of coal pillars (shaded pick) and breasts. The GAI Consultants (1983) high temperature zone is located on the image, in addition the potential location of the fire (based on high temperatures from TIR images). \(O_2\) and \(CO_2\) values are depicted on this image as well, to reveal subsurface airflow and combustion. As air is drawn in from the west, the fire travels toward the west. Aerial TIR image was taken by Stockton Infrared Thermographic Services using a SC8000 series camera. Bedrock in the region of the fire is gently dipping to the north at 20°.
infiltrating houses in the town, within a short period of time, the gases returned to the houses (DeKok, 2010). Neubauer and Elick (2013) suggested that the installation of the open mine vents increased the rate of fire movement. Elick (2013) noted that several large, developing fractures along fire front 1 had been in-filled with debris, resulting in gases being redirected and exhausting new areas. The collapse of the mine roof as a result of steam induced subsidence (Elick, 2013), which produced sinkholes along the strike of the coal beds on fire (Figure 10) may have also acted to block airflow to the fire.

Figure 9. Example of uncapped mine vent in Centralia. The vertical pipe is extremely hot and has a protective cage around it to prevent people from accidentally touching it. These vents were installed to prevent toxic fumes from infiltrating residences in the town, but potentially made the fire burn faster and hotter following installation.

Figure 10. Map depicting alignment of sinkholes (black, yellow and red dashed lines) and coal beds (white lines) from Buck Mountain coal succession along fire front 1. Aerial image from Google, 2012.
Vent temperatures along fire fronts vary across the landscape (Figures 7 A and C) and can change daily (day vs night), seasonally (summer versus winter) and following storms, like northeasters, tropical storms, or hurricanes, that produce abundant precipitation (Elick, 2013). Despite this variation, since 2000, surface temperature readings from active vents along fire front 1, show an overall decline in the temperature of the fire (Figure 11). Stracher et al. (2004) recorded surface temperatures of 540º C, while Nolter and Vice (2004) noted high surface temperatures of 456º C, however for much of the last decade most active vents measure between 40-65º C (Elick, 2103). This suggests the fire may be traveling deeper into the subsurface or it may be diminishing over time.

Though the fire appears to be less active than it was in the past, elevated temperatures along several north-south fractures/vents suggest the fire may be moving to the next overlying coal bed, possibly pre-drying the upper Buck Mountain coal or the Seven Foot coal. GAI Consultants (1983) and Elick (2013) suggested movement of the fire, spreading between beds of gently dipping siliciclastic rocks was a possibility. The fire was originally started and isolated in one bed of coal, the bottom bed (5), but likely spread to the middle coal bed (5M), or top (5T), through this process. Aerial thermal infrared imagery indicated that at least 2, possibly 3 beds in the Buck Mountain coal succession are burning (Figure 7 A) (Elick, 2013).
Today, the fire is located approximately 44 m below the surface, between Park and Second Street (fire front 1), on the north side of Locust Mountain, and nearly a 0.3 km south of the anticline, along old route 61 (fire front 2) (Figures 5-7 and 8). At fire front 1, the high temperature gases escape to the surface along a 20º N dipping slope of mined out rock in the area once known as South Street (Figure 7 B). The dip of bedrock along fire front 2 is 45º S. The fire movement has been to the west along both fronts, following the strike of the Buck Mountain coal succession (Figures 2-7, 8 and 10). It has travelled parallel to the 3 cemeteries that occur along the top of the breached Locust Mountain Anticline (Figures 5, 7 and 8). The north eastern corner of the St. Ignatius Cemetery has been influenced by the heat of the fire-gases, and heat has vented from this location, however, the cemeteries have largely been unaffected by the direct influence of the fire (Elick, 2013).

Integrating Findings from Multidisciplinary Research

The mine fire at Centralia has had both a destructive and constructive and impact on the environment. Research has linked the fire to changes in the landscape, soil nutrient availability, organisms in the soil, and succession. The following descriptions of research finding have been integrated to produce a holistic description of how the fire may be influencing the environment.

Gases, Minerals, and Soil

One of the major hazards of the mine fire has been the toxic gas released from the combustion of coal. The combustion of coal produces gases like CO$_2$, NO$_x$, SO$_2$, CO and CH$_4$ and consumes O$_2$ (Rahman et al., 2000; Stracher et al., 2004; 2006). After the fire ignited, gases moved through the subsurface into nearby homes and produced an acrid fog that covered the valley town (DeKok, 2010). At first, researchers used concentrations of O$_2$, CO$_2$, CO, CH$_4$, and H$_2$S to monitor the fire (GAI Consultants, 1983), by monitoring boreholes, and later by monitoring the homes of town residents (Logue et al., 1990; DeKok, 2010). Between 1963 and 1983, gas concentrations and temperatures across the landscape were monitored from nearly 200 boreholes (PADEP, 2013), mostly placed along fire front 1.

Airflow in the subsurface and the movement of the fire was established using both boreholes and surface vents (GAI Consultants, 1983; Elick, 2013). Updrafts and downdrafts were identified across the landscape (GAI Consultants, 1983), which helped consultants realize that air from outside of the mine was being added to the fire and consumed through combustion. Where O$_2$ values were low (14-15%), the corresponding CO$_2$ values ranged from 3-5%. Conversely, when CO$_2$ values were low, O$_2$ values were high (Elick, 2013) (Figure 8). Though dangerously high levels of methane and carbon monoxide were some of the reasons that resulted in the federal government property buyout in 1986, the concentrations of these gases have been decreasing with time (Elick, 2013). Elevated CO$_2$ levels identified active burning, while high CO values, often occurring after heavy or long-term precipitation events, suggested inactivity of the fire (Elick, 2013).

In addition to the common gases measured by researchers, Stracher et al. (2006), identified nearly forty-five organic and inorganic compounds including toxins such as benzene, toluene, and xylene. Gases exhausting high temperature vents formed minerals that encrusted the soil and debris around the vents. These minerals formed through isochemical or mass-transfer processes.
(Stracher, 2007) including sublimation and gas-liquid-solidification. Stracher and Taylor (2004) and Inners and Jones (1990) described the gas vents as similar to fumaroles, where gases are exhaled from vents, and minerals formed around the vents and in the soil/regolith. Heavy precipitation events dissolve the minerals that form, however they reprecipitate at the surface when steam and gases are exhausted again from the vent.

Minerals like alunogen, copiate, hydrobasaluminite, pyrophyllite, volaite, and native sulfur have been identified using X-ray diffraction (Stracher et al., 2006; 2007; Schroeder et al., 2011) (Table 1). These minerals were found in greatest abundance around the vents. Additionally, Livingood et al., (1999) identified apjohnite and tschermigite precipitated on regolith around the vents. These minerals are rare, mostly found occurring in deposits around volcanic vents and fumaroles, however there have been occurrences of tschermigite in burning coal heaps (Parafiniuk and Ruszewski, 2010). Livingood et al. (1999) suggest that gypsum and pyrite, and other sulfides and sulfates, were in the coal and combusted gases (Table 1). Sulfur has been known to crystallize on the ground (Stracher et al., 2006; Stracher 2007), potentially tainting the local water, and some of it floated away as a gas, polluting the air (Ohlson, 2010).

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alunogen</td>
<td>$\text{Al}_2(\text{SO}_4)(\text{OH})_4 \cdot 7(\text{H}_2\text{O})$</td>
</tr>
<tr>
<td>Copiate</td>
<td>$(\text{Fe, Mg})\text{Fe}_4(\text{SO}_4)_6(\text{OH})_2 \cdot 20\text{H}_2\text{O}$</td>
</tr>
<tr>
<td>Hydrobasaluminite</td>
<td>$\text{AlSO}<em>4(\text{OH})</em>{10} \cdot 12\text{-36H}_2\text{O}$</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>$\text{Al}_2\text{Si}<em>4\text{O}</em>{10}(\text{OH})_2$</td>
</tr>
<tr>
<td>Volaite</td>
<td>$\text{K}_2\text{Fe}^{2+} \text{Fe}^{3+}\text{Al(SO}_4)_12 \cdot 18\text{H}_2\text{O}$</td>
</tr>
<tr>
<td>Native Sulfur</td>
<td>$\text{S}$</td>
</tr>
<tr>
<td>Apjohnite</td>
<td>$(\text{MnAl}_2(\text{SO}_4)_4 \cdot 22(\text{H}_2\text{O})$</td>
</tr>
<tr>
<td>Tschermigite</td>
<td>$(\text{NH}_4)\text{Al(SO}_4)_2 \cdot 12\text{H}_2\text{O}$</td>
</tr>
</tbody>
</table>

(Table 1. Minerals identified using X-ray diffraction (XRD) from coal fire vents in the Centralia coal fire. Other minerals may be present in minor abundance.)
In the region around Centralia, the mine dump soils are generally composed of regolith, often debris from the mining talus (Parrish, 1965) including shale, sandstone and conglomerate, all of which contain abundant quartz, clays, and sulfide minerals. These rocks contribute abundant C, Al, Si, K, Fe, Mg, and S to the soils through the weathering of the quartz, clay, and carbon-rich bedrock. Additionally, minerals in the bedrock like pyrite and other sulfides, kaolinite and pyrophyllite, may also add nutrients to the soil. The coal fire vent minerals contain abundant Al, Fe, NH$_4$, S compounds, and H$_2$O, which are added to the soil around vents (Table 1).

Steam mixing with other gases, like CO$_2$ and sulfur rich minerals in the soil produce acidic conditions, which may enhance weathering. The soils along fire front 1 are mapped as stony loam and mine dump materials and are naturally acidic (Parrish, 1965), having pH values ranging from 3.6 to 5. Burgoes et al. (2000) recorded pH values as low as 2 around active vents, suggesting that the addition of steam and minerals transformed the soil into a highly acidic environment. Martinez and Ressler (2001) investigated the soil to determine if mineral weathering was accelerated by this process and found that heavy metals and nutrients like nitrate, ammonia, and phosphate were added to the soil around vents from the condensed byproducts of combustion. They suggested that if the fire would cease, these nutrients would promote vegetative and microbial communities. Today, where fire temperatures have decreased, there is a coincidental rapid colonization by plants in areas that were once too hot for them to live (Elick, 2012).

In addition to the minerals forming and weathering in the soil, the landscape along fire fronts in Centralia has also been altered by the fire. Elick (2013) identified steam induced subsidence in Centralia from examining the growth of fractures and sinkholes, which developed during 2011 (Figure 10), the wettest year on record in the state of Pennsylvania. Steam was produced from abundant and prolonged precipitation events. This precipitation infiltrated the soil and interacted with hot bedrock. Over long intervals, abundant steam exhausted from vents causing rocks around the vents, like shale to turn to mud and quartz cemented quartz conglomerates to crumble. New sinkholes, some as large as 3 m deep and 23 m wide, formed across the landscape, along the strike of the coal beds in the Buck Mountain succession, where coal fire vents were located. Abundant steam promoted the weakening of bedrock, causing the surface to subside.

**Organisms and Succession**

The fire has had considerable influence on the vegetation covering the landscape in the locations of the fire fronts. As it moved into different regions, the heat from the fire dried out the soil, killing the roots of the trees (Dekok, 1986; Elick, 2012); it may have killed many types of soil organisms as well. Potentially, high concentrations of gases, like CO$_2$ and CO produced by the fire may also have had an effect on the vegetation. Soils with concentrations of CO$_2$ gas from volcanic systems have been known to kill trees (Sorey et al., 1989). This is thought to be accomplished by denying plant roots of O$_2$ and by interfering with nutrient uptake. It is possible that the high concentrations of CO$_2$ in the soil at Centralia may have also had a negative influence on the vegetation. CO$_2$ and other gases moved easily through cracks and fractures as well as pores in the soil (Ressler, Personal Communication, 2005). Acres of trees in Centralia died along the two fire fronts that follow the limbs of the Locust Mountain Anticline (Figure 2 and 7 C) (DeKok, 2010; Elick, 2012).
Shifts in vegetation patterns were observed as the ground temperature changed over time. Aerial photographs, infrared and false colored infrared aerial photographs were examined by Elick (2012), who noticed that the path of the fire could be mapped using the location of dead vegetation, presumably killed by the gases and high temperatures. Ressler and Markel (2006) were among the first to recognize relationships in plant communities with temperature. They attempted to understand the relationship between plant diversity to the stresses of a mine fire, temperatures, and carbon dioxide concentrations. They identified different communities of vegetation, including fire-impacted vegetation: mosses (Leucobryum ssp.) and purslane (Portulaca oleracea), various grasses (Poaceae family), and a mixed grasses and forbs community (such as asteraceae and plantaginaceae). They found that vegetation patterns were mostly temperature dependent, though CO₂ concentration levels also impacted diversity. In addition to causing obvious air pollution, the uncontrolled fire was producing a significant loss of biodiversity in the affected zones as soil temperature and carbon dioxide concentrations rose.

Elevated soil temperatures influenced soil organisms in different ways. Most micro- and macroinvertebrates were negatively impacted, however, despite the heat, certain microbes, known as extremophiles, like Geobacillus thermoevorans (Figure 12) thrived in the warm regions around vents. Extremophiles were first identified in exhaust vents and in the soil around the vents by Burgos et al., (2000). The hot soil and rock served as an environment for thermophilic actinomycetes that produce antimicrobial secondary metabolites (Tammy Tobin, Personal Communication, 2012). Microbes are extremely important in soil environments because they help transform soil materials and add nutrients to the soil. When all other organisms were driven out of the soil due to high temperatures, the thermophilic bacteria thrived. At Centralia, Oberweis (2004) isolated at least two different species of thermophilic bacteria from soil samples. Other bacteria are known from barcoded fragments found in soil samples around active vents, where temperatures increased from 45 to 75.7°C. Despite high temperatures, nitrifying bacteria were found in the soils near vents at temperatures of 60°C (Tobin-Janzin et al., 2005).

When vent and soil temperatures decreased, opportunistic arthropod assemblages began to be found in the soil near vents with elevated temperatures (15 to 50°C) (Stracher et al., 2013). The most abundant and diverse of the mesofauna identified were collected 6 m from vents; these arthropods included Collembola, including endogenic and epigenic groups, thrips, oribatid mites, insect larvae (tentatively Chrysomelidae), and adult beetles (Sphindidae). The presence of such a diverse assemblage suggests a robust food web returning to areas near venting. Larger organisms have also been observed at Centralia over recent years, including many different kinds of birds, snakes, deer and rabbits; they pass through Centralia, and may still not live in the immediate vicinity of the fire fronts or vents. Elick (2012) has noted that ecological succession appears to be occurring as soil and vent temperatures lowered (Figure 10). From 2008 to 2011, grass and weed, tree and animal populations have returned the once barren ground along fire front 1 and new successional stands of sumac, white birch, oak, locust, and maple are flourishing in cooler zones. With lower surface temperatures, succession is taking place in Centralia.
Some have predicted the fire may burn as long as 100 years (Memmi, 2000) or longer consuming hundreds of tons of coal and influencing thousands of acres (GAI Consultants, 1983; Michalski et al., 1988). An enormous amount of coal remains in the subsurface as pillars and structures reserved to hold up the mined out areas or breasts and tunnels. If the fire was to continue to burn, this valuable fuel is readily available in the subsurface. It has been demonstrated that the fire moved from one bed of coal in the Buck Mountain coal succession to multiple beds (GAI Consultants, 1983; Elick, 2013), and it can potentially continue to move to the next higher beds in the Llewellyn Formation.

Several have suggested interesting ways to extinguish the mine fire at Centralia. One group from Texas suggested extinguishing the fire with an expanding nitrogen foam (Morton, 2010; Ohlson, K., 2010). The foam would seal off the fire to oxygen-rich air sources, causing it to go out. The foam also contains microbes that would consume the remaining oxygen in the isolated area. Another suggestion was to pour a huge volume of concrete into the mine to accomplish a similar outcome. Someone else suggested pumping CO₂ produced during hydrofracking or from another industry, into the subsurface to hasten the end of the fire and decrease CO₂ available as a free floating greenhouse gas. Extinguishing a fire requires cooling the coal and isolating it from both heat and oxygen (Ohlson, 2010). At this time the state does not have any plans to extinguish the fire at Centralia (PADEP, 2013).

The fire at Centralia has also been a site exhausting greenhouse gases like CO₂, H₂O(v), and CH₄ (Stracher et al., 2006). Greenhouse gases contribute to global climate change and can affect air quality and contribute to environmentally damaging acid rain. With the coal fire continuing

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**The Future of the Centralia Mine Fire**

Some have predicted the fire may burn as long as 100 years (Memmi, 2000) or longer consuming hundreds of tons of coal and influencing thousands of acres (GAI Consultants, 1983; Michalski et al., 1988). An enormous amount of coal remains in the subsurface as pillars and structures reserved to hold up the mined out areas or breasts and tunnels. If the fire was to continue to burn, this valuable fuel is readily available in the subsurface. It has been demonstrated that the fire moved from one bed of coal in the Buck Mountain coal succession to multiple beds (GAI Consultants, 1983; Elick, 2013), and it can potentially continue to move to the next higher beds in the Llewellyn Formation.

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The fire at Centralia has also been a site exhausting greenhouse gases like CO₂, H₂O(v), and CH₄ (Stracher et al., 2006). Greenhouse gases contribute to global climate change and can affect air quality and contribute to environmentally damaging acid rain. With the coal fire continuing
to burn and with the possible threat of spreading to the next overlying coal bed, the potential future amount of greenhouse gases released could be considerable.

Today, the state continues to monitor some of the boreholes for changes in temperature and gas composition (PADEP, 2013). Due to the political pressures that followed the destruction of the town of Centralia and the environmental degradation and waste of natural resources, the state also now rapidly monitors new coal fires and determines the threat level to surrounding communities. For instance, a coal fire in highly populated Exeter, PA, in Luzerne County, was discovered in 2002, and it was quickly extinguished, while a fire in Carbon County, near Tresckow, which has been burning for years, has not been extinguished as rapidly due to the lower population in the area. Combatting the fire in Tresckow is complicated by the occurrence of a community of Indiana and Northern Long-Eared Bats that have been living in a deep mineshaft. Due to the threatened and endangered species status, these bats are protected by U.S. Fish and Wildlife Service.

Based on the fact that fire front 3 has self-extinguished and fire front 4 is an immobile, low activity venting system (Elick, 2013) (Figures 2 and 5), it is possible that fire fronts 1 and 2 could also eventually self extinguish. The temperature trend for the last 15 years shows a sharp decline in thermal activity (Figure 11). However, it’s also possible that the fire can increase in activity and begin burning coal layers higher in the Llewellyn Formation (Elick, 2013). Some have suggested that the decrease in temperature at the surface is due to the fire moving deeper into the subsurface (Jim Hower, Personal Communication, 2015). For these reasons, the fire will continued to be monitored.

Local educators and geologists will continue to attempt to connect this real world environmental disaster to their coursework (Wisner and Venn, 2011; Elick, 2013). Despite the smoldering appearance of the fire today, there are many other environmental issues related to coal mining one can discover at Centralia. Topics as varied as the history of coal mining in the area and the environmental consequences of mining and the mine fire, greenhouse gas emissions and government intervention in environmental disasters, geology and health, geoscience education and public awareness are discussed in classes visiting Centralia. Additionally, one can discuss Pennsylvanian age depositional environments and preservation, structural geology and tectonics, and the minerals associated with coal and acid mine drainage. Most notably, educators and students can discuss the footprint of man on his environment and the return of nature through succession. The fire at Centralia has provided educators and researchers alike with constructive and destructive elements from which to learn, and it will continue to impact us long after the flames of the fire are no longer burning.

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*\&%$#@ taxonomists keep screwin' up the literature!!!
ICHNOLOGY OF THE UPPER MISSISSIPPIAN MAUCH CHUNK FORMATION
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Introduction

The rapid diversification of terrestrial ecosystems started in the Silurian and continued into the Mississippian (Buatois and Mángano, 2011). Detailed ichnological (trace fossil) collections in the Mississippian Mauch Chunk Formation of eastern Pennsylvania have yielded a number of important vertebrate and invertebrate trace fossils indicating that significant diversity was present during this timeframe. The Mauch Chunk Formation has been divided into three members and recently formally named, from oldest to youngest, Lavelle (lower), Indian Run (middle), and Hometown (upper) members (Wood et al., 1969; Wood 1973; Edmunds et al., 1979; Fillmore et al., 2011b). The Mauch Chunk Formation has produced a few age diagnostic paleofloras (Jennings, 1985) and is considered to be Chesterian (Visean) based on the lateral interfingering facies relationships with biostratigraphically dateable carbonates in western and southwestern Pennsylvania (Fig. 1; Brezinski, 1999), so the middle member Indian Run is approximately 330 Ma (Davydov et al., 2004).

This report summarizes the recent vertebrate and invertebrate ichnological discoveries that have propelled the eastern Pennsylvania Mauch Chunk Formation into the forefront of the evolution of terrestrial discussion based on trace fossils. The Mauch Chunk comprises one of two extensive tetrapod footprint assemblages of Mississippian-age, the other is the Lower Mississippian Horton Bluff Formation in Nova Scotia, Canada and one of the oldest, most diverse invertebrate ichnoassemblages in its timeframe.

History of Mauch Chunk Formation Ichnology

In eastern Pennsylvania, the Mississippian Mauch Chunk Formation is a more than 1-km-thick succession of siliciclastic red beds that yields continental trace fossils.

Isaac Lea (1792-1886) a self-educated, amateur scientist, who, in his lifetime, gained national and international recognition for his contributions to natural science. In 1843, Isaac Lea first reported tetrapod footprints from the Mauch Chunk, naming the tracks Sauropus primaevus (later emended to Palaeosauropus primaevus). These Palaeosauropus vertebrate tracks were shown to leading scientists of the time including Sir Charles Lyell, Joseph Leidy, and Joseph Barrell (Fillmore et al., 2007; 2009). We relocated Lea’s type locality of P. primaevus in Mount Carbon, PA (Fillmore et al., 2007; 2009; 2012).

Vertebrate ichnology

Four kinds of vertebrate ichnofossils are known from the Mauch Chunk Formation: a large structure interpreted as a tetrapod burrow, fish swimming traces we assign to Undichna,
amphibian body resting traces and tetrapod footprints, which are the most common trace fossils (other than Planolites) in the formation. (See Figure 1)

Tetrapod Burrow

The remains of a relatively large burrow were identified from the Hometown Member near Lavelle, PA. (Storm et al., 2010). The burrow is housed in and cross cuts red mudstone and is characterized by two, normally graded, conglomerate to sandstone beds that fill the structure.

The burrow structure is characterized by: 1) a flared opening leading to narrower linear tunnel, 2) the tunnel bends 40° and ends in a large ovate chamber, and 3) flared opening that is higher in elevation than the base of the chamber (Storm et al, 2010). The geometries, angle changes, large termination, width-to-height ratios of the terminal chamber, and graded fill indicate the structure was an open burrow. Associated trackways indicate the burrow was most likely made by an amphibian the size of the trackmaker of Palaeosauropus primaevus. The burrowing behavior was most likely due to the environmental stress related to seasonal droughts as local water sources disappeared, or while nesting and rearing young (Doody et al., 2015).

Undichna

The specimens of Undichna britannica (Higgs, 1988) were collected from outcrops of the Indian Run Member of the Mauch Chunk Formation (Fillmore et al., 2011). Specimens exhibit sets of two intertwined sinusoidal waves. We are not aware of any substantiated reports of fish body fossils from the Mauch Chunk Formation, so the identify the specific Undichna trailmaker is problematic. But the maker of the single furrow must have been created by a fish with an anal fin extending deeper than the caudal fin, or a caudal fin reaching deeper than the anal fin (see Gibert et al., 1999). It is also possible that the single wave traces attributed here to U. unisulca are extramorphological (variation in form based on substrate interaction or preservation) variants of U. brittanica in which the trace of only one wave is preserved.

Amphibian Body Impressions

Another significant previously undocumented specimen is an exceptional case of preservation of body impressions of Mauch Chunk Formation tetrapods that show the outline of most, or all, of a temnospondyl amphibian that provides direct evidence of body shape, texture of the integument, and possible social behavior (Lucas et al., 2010b). The resting trace has a smooth integument, triangular head impression, four robust, heavy limbs with Batrachichnus track impressions, relatively short trunk and long and tapering tail (Lucas et al., 2010b). Three body impressions are present on a single bedding plane representing three individuals who happened to rest (or die) in one place at one time. However, we think it likely that the three body impression preserved together are suggestive of gregarious behavior, and this encourages us to speculate about the possibility that the body impressions may indicate a kind of social behavior known in some extant salamanders (Lucas et al., 2010b).

The unique nature of the traces permits the assigning of a unique ichnogenus and ichnospecies. Lucas et al. (2010b) coined the name Temnocorpichnus isaacleai, translating into the body of a temnospondyl and dedication of the specimen to the memory of Isaac Lea's contribution to Mauch Chunk Formation ichnology.

Tetrapod Footprints

Recently, a tetrapod footprint ichnofauna has been recovered and described from the Indian Run member of the Mauch Chunk Formation (Fillmore et al., 2007; 2009a; 2012; Vrazo et al,
2007; Lucas et al., 2006; 2007; 2010) together with a diverse invertebrate trace fossil assemblage (Fillmore et al., 2010). Five ichnogenera (Batrachichnus, Hylopus, Palaeosauropus, Matthewichnus, and Pseudobradypus) have been recognized (Lucas et al., 2012a; Fillmore et al., 2012). (See Figure 2)

**Batrachichnus salamandroides** (Geinitz, 1861)

*Batrachichnus* is the second most abundant tetrapod ichnotaxon in the Mauch Chunk Formation collections. Pes (foot) lengths and widths are mostly 10-20 mm, with a wide range of extramorphological variation present. Digits are normally short, straight and blunt tipped, but slightly curved digits and pointed digit tips are present. Some specimens have body/tail drags, but most do not. *Batrachichnus* has a stratigraphic range of Mississippian-Triassic (Klein and Lucas, 2010, summary of the Triassic record from the Moenkopi Group in Utah). Trackways of some Cenozoic and extant salamanders (e.g., Peabody, 1959) are also assignable to *Batrachichnus*, indicating convergence in foot structure and locomotory pattern between Paleozoic-Mesozoic temnospondyls and some Cenozoic lissamphibians.

**Characichnos isp.** (Whyte and Romano, 2001)

The specimens assigned to *Characichnos* are long, relatively thin, slightly arcuate or sinuous scratch marks, two to four (usually three) in parallel series. Size is relatively large, with total lengths and widths up to 100 and 60 mm, respectively. Most of the scratch marks are on surfaces with *Palaeosauropus* footprints, and were likely produced by the same trackmaker, a temnospondyl.

**Hylopus hardingi** (Dawson, 1882)

Footprints of a quadrupedal tetrapod in which the manus is tetradactyl and the pes is pentadactyl. The manus and pes are of approximately equal size (especially their widths), generally plantigrade, and may be overstepped. The manus digits are often relatively thin and curved medially, and digit IV is much longer than the rest.

**Matthewichnus** (Haubold, 1970)

*Matthewichnus* is the footprints of a quadruped in which the pes is much larger than the manus. Both manus and pes are plantigrade, the manus is tetradactyl and as wide as long. The pes is pentadactyl and has digits II-IV longer than digit V. The manus imprint is medial to and sometimes overstepped by the pes imprint. Tail/body imprints are sometimes present. Very few Mauch Chunk Formation footprint specimens can be assigned with confidence to *Matthewichnus* because relatively few show clearly associated manus and pes imprints in which a small, tetradactyl manus is substantially smaller than the pentadactyl pes. The trackmaker of *Matthewichnus* is interpreted as a temnospondyl (note the tetradactyl manus), but unlike the temnospondyl trackmakers of *Batrachichnus, Hylopus,* and *Palaeosauropus,* this temnospondyl must have had a much more specialized limb structure and gait.

**Palaeosauropus primaevus** (Lea, 1849)

Key features of *Palaeosauropus,* including tetradactyl manus, pentadactyl pes, wide and blunt tipped digits, manus digit III longest, pes digit IV longest and near overstepping of the manus by the pes (Lucas et al., 2012). Their size also compares well with that of the type material of *Palaeosauropus primaevus*. The trackmaker of *Palaeosauropus* has long been considered a temnospondyl amphibian, either an edopoid or an eryopoid (e.g., Haubold, 1971, 1984) because of the relatively large size and the digital formula of the track—four digits in the manus and five in the pes that matches temnospondyl skeletons.
**Pseudobradypus isp. (Matthew, 1903a)**

*Pseudobradypus* has pes imprints that are plantigrade, antero-posteriorly long and have anteriorly-directed digits. The manus imprints are about half as long as the pes imprints but of approximately the same width. They have forward-directed digits, are immediately anterior to the pes imprints and both manus and pes imprints are symmetrical around a median tail/body drag imprint. *Pseudobradypus* is rare in the Mauch Chunk Formation, with only a few specimens recognized. This track is important because it establishes the oldest record of reptiles (amniotes).

**Tetrapod footprint assemblage**

The tetrapod footprint assemblage of the Mauch Chunk Formation comprises a moderate ichnodiversity of footprints of quadrupedal carnivores (mostly temnospondyl amphibians). The assemblage matches *Batrachichnus* ichnofacies of Hunt and Lucas (2007), which they identified as occurring in Devonian-Middle Triassic tidal flat and alluvial plain paleoenvironments. The Mauch Chunk Formation tetrapod footprints come from an alluvial plan depositional setting, so they are consistent with the range of paleoenvironments envisioned for the *Batrachichnus* ichnofacies.

**Invertebrate Ichnology**

The invertebrate traces are from the Indian Run Member of the Mauch Chunk Formation (Fillmore et al., 2010; 2012) are identified as: *Cruziana problematica, Dipllichnites gouldi, Diplopodichnus, Gordia, Helminthoidichnites tenuis, Kouphichnium isp., Planolites, Rusophyscus, Stialla pilosa, Stiaria intermedia, and Taenidium*. (See Figures 3, 4 and 5)

**Cruziana problematica (Schindewolf, 1928)**

Trails are bilaterally symmetrical, bilobate, curved, with a medial furrow. Additional scratch-mark structures are consistently mm-wide, raised convex serial ridges arranged perpendicular to or slightly oblique to the medial furrow and arranged in a herringbone pattern. In a marine setting, *Cruziana* has been interpreted to be the product of trilobites (Häntzschel, 1975). In nonmarine settings, the trail maker is more problematic and may be notostracan branchiopod crustaceans (Bromley and Asgaard, 1972; Pollard, 1985; Minter et al., 2007), aglaspids (Fischer, 1978), vertebrates (Shone, 1978), or insect or non-insect arthropods (Pollard, 1985; Garvey and Hasiotis, 2008).

**Dipllichnites gouldi (Gevers et al., 1971)**

Straight to slightly curved trackways with two approximately parallel rows of tracks. The trace has been attributed to various types of invertebrates, most notably myriapods (Smith et al., 2003).

**Diplopodichnus biformis (Brady, 1947)**

The traces consist of two unbranched, straight to winding, horizontal parallel convex grooves or concave ridges that occasionally contain slightly impressed and closely spaced round to ellipsoidal tracks that are perpendicular to the trace axis. The morphologic overlap with *Dipllichnites* in the Mauch Chunk Formation specimens indicates that the same trackmaker made both *D. biformis* and *D. gouldi* (Buatois et al., 1998a).
Figure 3. Invertebrate trace fossils. Cruziana – Rusophycus traces, convex hyporelief. (A) Specimen number KU 06.07.06:1. (B) Line drawing highlights the position of some Rusophycus (ovals) and Cruziana (lines). Scale is the same as in A. Note the linkage of some Cruziana and Rusophycus traces. Box show location of inset C. (C) Closeup showing the position of Rusophycus and Cruziana. Note the oblique marks along the trails. All scale bars cm. (D - E) Diplichnites gouldi Type A.
**Gordia** (Emmons, 1844)

Trace consists of overlapping loops and meandering trails. Various organisms have been called upon to generate *Gordia*, including polychaetes (Książkiewicz, 1977), worms or gastropods (Yang, 1984; Geyer and Uchman, 1995) and (more speculatively) the erratic behavior of a flying insect trapped in a thin film of water above the sediment-water interface (Hasiotis, 2002).

**Kouphichnium** (Nopsca, 1923)

Trackways consist of a series of very small (0.8 to 1.3 mm in length) bifid or trifid tracks. *Kouphichnium* has been interpreted to be the product of xiphosurid arthropod walking (Romano and Whyte, 2003) or crawling traces (Bandel, 1967).

**Planolites beverleyensis** (Billings, 1862)

*Planolites* is the most abundant ichnofossil in the Indian Run Member of the Mauch Chunk Formation. Specimens are simple, smooth, cylindrical tubes with a circular to ellipsoidal cross-section, with tube diameters ranging from 1 to more than 10 mm with lengths highly variable.

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![Image of invertebrate trace fossils: Gordia isp. and Diplodopodichnus biformis](image)

**Figure 4.** Invertebrate trace fossils. Gordia isp. and Diplodopodichnus biformis. (A) Collected slab. Specimen number KU 04.30.06:16 (Locality #1), concave epirelief. (B) Line drawing of traces, arrows identify the Diplodopodichnus and Gordia trails, boxes identify locations of insets C and D. (C, D) Closeup of Gordia and Diplodopodichnus, arrows identify portions of the Gordia trails. All scale bars cm.
**Rusophycus carbonarius** (Dawson, 1864)

Trace consists of isolated, symmetrical, bilobate, ovoid, round to rectangular concave epireliefs displaying a medial furrow with transverse striations, and are associated with the *Cruziana*; a few are the terminus of a *Cruziana* trace. *Rusophycus* is the resting trace of an arthropod (Seilacher, 1955; Osgood, 1970).

**Stialla pilosa** (Smith, 1909)

A single specimen is preserved in convex hyporelief and has axial grooves that terminate in a series of radiating scratches, and no axial row of tracks. The arcuate axial grooves occur as either a single groove or as a series of three grooves. The origin of *Stiallia pilosa* is problematic (Buatois et al., 1998b), with various workers interpreting it as resting traces of isopods (Bandel, 1967), locomotion of a myriapod (Buatois et al., 1998b), locomotion of an arthropod skimming the substrate (Walker, 1985), or locomotion followed by resting behavior (Buatois et al., 1998b).

**Stiaria intermedia** (Smith, 1909)

*Stiaria* trackways have either a continuous or a discontinuous medial groove. Apterygote insects are the likely trace makers (see Manton, 1972; Walker, 1985; Minter and Braddy, 2006).

**Taenidium barretti** (Bradshaw, 1981)

In the Indian Run Member of the Mauch Chunk Formation, *Taenidium barretti* and *Planolites beverlyensis* are usually found in association. All *Taenidium* specimens have been recognized from thick beds of sandstone with preserved mudstone drapes. Burrows are sinuous, with a changing diameter along its length, varying in diameter from 50 to 100 mm. Burrow walls are parallel, sharp with respect to the infill, and have smooth to slightly undulating to crenulated wall edges. No lining of the burrow wall is apparent. Various animals have been proposed as the originators of *Taenidium*, including polychaetes (Gevers et al., 1971), amphibians or reptiles (Ridgeway, 1974), and arthropods (Bradshaw, 1981; Keighley and Pickerill, 1997; Morrissey and Braddy, 2004). The presence of menisci and lack of a burrow lining in *T. barretti* indicate active backfilling; each meniscus represents a pause in activity.

The Mauch Chunk Formation invertebrate ichnoassembly consists of backfilled burrows of deposit feeders, both meniscate (*Taenidium*) and non-meniscate (*Planolites*) that typically crosscut bedding; arthropod trackways (*Diplichnites, Diplopodichnus, Kouphichnium, Stialla* and *Stiaria*); striated trails (*Cruziana*) and resting traces (*Rusophycus*); and surface or shallow subsurface grazing trails or burrows (*Gordia*). The Mauch Chunk Formation invertebrate ichnoassembly thus corresponds well to the *Scoyenia* ichnofacies as used by Buatois et al. (1998a) and Buatois and Mángano (2002) in consisting of simple burrows, trackways, striate and bilobate trails and pits and simple meniscate burrows. Furthermore, both the *Diplichnites* and the *Scoyenia* ichnoguilds (*sensu* Buatois et al., 1998a) are well represented by the Mauch Chunk invertebrate trace fossils. This indicates a terrestrial invertebrate fauna dominated by both a mobile epifauna and a shallow, deposit-feeding fauna.
Figure 5. Invertebrate trace fossils. Planolites beverlyensis, Stialla pilosa, Taenidium barretti. (A) Planolites, bedding plane view, slab photograph showing location of enlargement B. Scale in cm. Specimen number KU 04.03.08:2. (B) Enlargement of horizontal cut through burrows. Specimen number KU 03.23.06:40. (C) Slab of oblique cut through Planolites burrows. Specimen number KU 04.24.08:8. Note the contrast between the burrow fill and the host rock. (D) Slab photograph of Planolites, plane view, epirelief. Note the straight to slightly sinuous geometry of the burrows. (E) Photograph of Stialla pilosa. Convex hyporelief. Specimen is KU 05.05.07:8. (F) Line drawing of features in E. (G) Field photograph of rip-rap block containing Taenidium barretti (large burrow) and Planolites beverlyensis (smaller burrows). (H) Taenidium barretti. Note the lateral change in burrow diameter and the diffuse menisci. Specimen number KU 04.24.08:6)
Nevertheless, the Mauch Chunk Formation invertebrate ichnofauna is more diverse than any single Devonian ichnoassemblage from a fluvial setting (cf. Buatois et al., 1998a; Buatois and Mángano, 2007). Most of this higher ichnodiversity is due to a greater diversity of ichnotaxa of arthropod trackways in the Mauch Chunk Formation, so this suggests a greater diversity of terrestrial arthropod tracemakers (or tracemaker behavior) in the Mississippian than in the Devonian. Furthermore, the development of the *Scoyenia* ichnoguild in the Mauch Chunk Formation, in the form of abundant traces of deposit feeders of a shallow to intermediate depth infauna (esp. *Taenidium*), is unusually early, when compared to the Paleozoic record as summarized by Buatois et al. (1998a) and Buatois and Mángano (2007; also see Miller, 1984). Intense bioturbation recognized within the Mauch Chunk indicates that the onset of intense bioturbation developed early than previously thought (Smith et al., 2012). (See Figure 6)

![Figure 6. Intense invertebrate bioturbation throughout a sandstone bed in the Lavelle, PA area.](image)

The Mauch Chunk Formation record now establishes that prolific ichnoassemblages of the *Scoyenia* ichnoguild were present by Mississippian time. Prior to this research, sedimentary indications of high level bioturbation intensity (high ichnofabric) was unknown in nonmarine rocks before the Permian and was not known to be widespread before the Triassic. The Mississippian Mauch Chunk record now pushes back such high intensity bioturbation by at least 30 my, into the Mississippian, and demonstrates a much earlier exploitation of the terrestrial subsurface ecospace than previously known (Smith et al., 2012).
Summary

The Mauch Chunk Formation has produced a significant vertebrate and invertebrate Mississippian trace fossil record. Recently this diversity has been documented to include the following.

Four kinds of vertebrate ichnofossils are known from the Mauch Chunk Formation: 1) a large vertebrate burrow, 2) a tetrapod burrow, fish swimming traces (Undichna), 3) amphibian body resting traces (Temnocorpichnus isaacleai) and 4) tetrapod footprints, including five ichnogenera (Batrachichnus, Hylopus, Palaeosauropus, Matteithwichnus, and Pseudobradypus).

Invertebrate traces are diverse and include: 1) Cruziana problematica, 2) Diplichnites gouldi, 3) Diplopodichnus, Gordia, 4) Helminthoidichnites tenuis, 5) Kouphichnium isp., 6) Planolites, 7) Rusophyscus, 8) Stialla pilosa, 9) Stiaria intermedia, and 10) Taenidium.

Other highlights include: 1) the recognition of the oldest intense bioturbation (Smith et al., 2012), 2) Scoyenia ichnoguild, and 3) Batrachichnus ichnofacies of Hunt and Lucas (2007).

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SEQUENCE OF STRUCTURAL STAGES OF THE ALLEGHANIAN OROGENY IN THE DEVONIAN THROUGH UPPER CARBONIFEROUS SECTION OF THE ANTHRACITE REGION, APPALACHIAN FORELAND, PENNSYLVANIA

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Modified ever so slightly from

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Introduction

The sequence of structural stages (I thru VII) of deformation in this region is best illustrated at the Bear Valley Strip Mine (Figure 1). Generally, the sequence includes Pre-Alleghanian jointing, followed by Alleghanian layer-parallel shortening, overprinted by large-scale folding, and layer-parallel extension.

Figure 1: Index map and location map of Bear Valley Strip Mine. Pennsylvania 225, 125, and 61; U.S. 15, I-80, and I-81 are labeled.
It has been established both by the overprinting of different structural stages at one locality and by the regional distribution of structures associated with the different stages. On the Appalachian Plateau of New York, geologists observe joints formed during Stages I and II and cleavages of Stage III. Here in the Valley and Ridge portion of the Appalachian foreland these stages are overprinted by faults, folds and layer-parallel extension of Stages IV through VII.

Several different relative ages of Alleghanian deformation were suggested by overprinted joints on the Appalachian Plateau, but within this part of the foreland the sequence will be demonstrated by different trends of the structural stages.

**Bear Valley Strip Mine, Shamokin, PA**

The Bear Valley Strip Mine is situated along several faulted second order folds on the south limb of the first order Shamokin synclinorium (Figure 1). The local geologic setting is provided by the map of Arndt and others (1973) while the larger anthracite region is described by Wood and others (1969, 1986), Wood and Bergin (1970). The mine area has been previously described by Nickelsen (1979, 1983).

The Bear Valley Strip Mine offers superb three-dimensional exposures of the structural elements of the northern Valley and Ridge province, and clear views of geometric relationships and sequential overprinting of structures that elucidate the stages and processes of deformation within one orogeny. All of this is visible within a 320,000 ft² (30,000 m²) strip mine area that contains two disharmonically-folded, Pennsylvanian-age cycles of sedimentation exposed in cross section along highwalls and in deformed map view on unique bedding plane surfaces. Deformation mechanisms and the structural sequence of layer-parallel shortening (Stages II, III, IV) overprinted first by large-scale folding (Stage V) and later by layer-parallel extension (Stage VI) can be fully demonstrated at this locality (Figure 2).

The variety of structural elements and deformation mechanisms includes: Stage I joints in coal that are eastern extensions of the pre-Alleghanian Set I joints in coal observed on the Appalachian Plateau by Nickelsen and Hough (1967, Plate 3); hydraulic extensional joints with quartz-fiber fillings in ironstone and sandstone (Stage II); spaced cleavage in shales and silty shales formed by pressure solution, or grain rotation and sliding, or primary crenulation, accompanied by incipient recrystallization (Stage III), wrench (strike-slip) or wedge (thrust) faults with very obvious slickensides and slickenlines (Stage IV); third (size) order flexural slip folds showing disharmony between adjacent structural lithic units (Stage V); and extensional fault "grabens" or extensional joints formed by buckling or release fracturing (Stage VI). Elsewhere in the region Stage VII large scale strike-slip faults with horizontal slickenlines cut all other structures. Finally, it is apparent that ductility contrast between stiff ironstone and sandstone and weaker shale and coal controls the relative structural behavior of rock types.
Station A.

Turn right (west) off the entrance road and walk to the crest of the North anticline at A, a flat-topped box fold (Figure 3). The rocks beneath your feet represent the floor of the coal swamp and have impressions of large lycopsid trees and stigmata (roots). From A, the entire mine is visible, including third order folds, fold disharmonies, many faults, and ironstone concretions. The view of the southwest corner (Figure 4) shows overprinted Stage IV conjugate wrench fault systems (dihedral angle 35°) and a Stage IV thrust. To the east the disharmonic third order folding shown in Figure 5 is visible.

Station B.

Here, 330 ft (100 m) east of A, is an excellent view to the north limb of the Whaleback anticline showing Stage IV thrusts and conjugate wrench faults, the Stage V anticline plunging east, and Stage VI extensional joints and faults (Figure 6). The North anticline on which you are standing has a chevron profile, different from that at Station A, because the kink junction axis is inclined to bedding (Faill, 1973, Fig. 20).

Figure 2: Cartoon depicting the sequence of development of structural stages of the Alleghany orogeny: Stage I. Orthogonal joint sets form in coal; Stage II. Several sets of hydraulic extensional joints form in sandstones and shales; Stage III. Pressure solution and primary crenulation cleavage and small-scale folds form; pressure solution of Stage II joint fillings occurs; Stage IV. Conjugate wrench and wedge faults deform Stage III cleavage; Stage V. Large-scale folding of all previous structures occurs; Stage VI. Extensional joints and faults produce flattening perpendicular to bedding and layer-parallel extension, both parallel and perpendicular to fold hinges. After Nickelsen, 1983.
Station C.

The Stage IV wrench and wedge (thrust) faults of Figure 4 can be studied here. Note that slickenlines on wrench faults are parallel to the fault-bedding intersection, indicating that they formed prior to folding and were later folded to their present attitude during Stage V. Slickenlines on wedge faults bisect the dihedral angle between wrench faults and were formed at the same time. Spaced cleavage (primary crenulation and pressure solution mechanisms) occurs in shales upslope to the southwest of C. Ironstone concretions are the stiffest member of the sedimentary succession, showing only Stage II joints and surface slickenlines that demonstrate how other strata have shortened and flowed around them. The contact between concretions and their enclosing rock are shear planes or boundary zones between different structural lithic units. The sequence of structural stages is established by offset of Stage II joints by Stage III pressure solution cleavage and by drag of Stage III cleavage-bedding intersections against Stage IV wrench faults. All of these structures formed by layer-parallel shortening in horizontal beds prior to folding.

Figure 3: Map showing topography, geology, geologic localities A through I, and figure localities 4, 5, 7, and 8 of the Bear Valley Strip Mine. Location numbers 0, 1, 2, 3, 4, are at 100 ft (30 m) intervals along the crest of the Whaleback anticline.
While walking eastward between Stations C and D, you see Stage II joints in ironstone concretions, ductility contrast between ironstone and sandstone or shale, and a major wrench fault that is the west boundary of the thrust slice of Figure 4.

![Figure 4: Conjugate wrench fault systems and a thrust fault between Stations C and D on the south wall, as viewed from A. Least strain axis IVA is overprinted by IVB. After Nickelsen, 1983.](image)

**Station D.**

The east end of the thrust slice illustrated in Figure 4 can been seen from here. On the Whaleback anticline to the north, wrench faults with intricate slickenline patterns indicate overlap between Stage IV faulting and Stage V folding. Stage VI strike and transverse extensional faults and "grabens" are well exposed.

**Station E.**

The crest of the Whaleback anticline provides the best view of the fold disharmony to the east (Figure 5), Stage II hydraulic joints on the whaleback (at 0 and 1), and the Stage IV wrench and wedge faults and Stage VI strike joints (of release or buckling origin) on the south wall. Note that the Stage VI strike joints are not symmetrical with the acute bisectors and slickenlines of Stage IV wrench and wedge faults, indicating that the structural array formed in response to differently

![Figure 5: North-south section through location 1 of Figure 3.](image)
oriented strains -- Stage IV layer parallel shortening, versus Stage VI extension due to fold buckling.

**Station F.**

The tight hinge of the North syncline is seen here. Upslope in this multilayered sequence of shale and sandstone are excellent bedding-plane slickenlines as well as spaced cleavages in the shales and shaley andstones. Walking to here from Station E along the crest of the whaleback, you pass over pencil cleavage (elongate pieces of rock formed by the interaction of bedding and cleavages breakage along the intersection of those surfaces). It is especially prominent to the southeast of the crest as the whaleback plunges under the surface.

**Station G.**

Vertical bedding on the north limb of the Whaleback anticline is cut by Stage IV thrust faults and Stage VI extensional faults and "grabens" trending both parallel to and perpendicular to the fold hinge (Figure 6, above G). Evidence for the relative age of thrusting and folding is illustrated in Figure 7B and 8. Thrust faults preceded folding because flexural-slip associated with folding has reversed their slip sense, causing a pull back of the tip line of the thrust and exposing the thrust surface as illustrated in Figure 7B. Also, thrust faults and their slickenlines as well as the

![Figure 6: North limb of Whaleback anticline viewed from Station B. Extensional faults (Stage VI) define "grabens" that are both parallel and transverse to the fold hinge. The "grabens" overprint Stage IV wrench and thrust faults. Stations E, G, and H are labeled. After Nickelsen, 1983.](image)

![Figure 7(A): Conjugate wrench faults (Stage IV) viewed on the south wall between Stations C and D cause drag of cleavage-bedding intersections. Gash veins along the left lateral wrench fault cut preexisting Stage III cleavage. (B) Drawing to show how thrust faulting followed by flexural-slip folding has caused pull back of hanging wall to expose a fault surface at Station G. (C) Interpretation of curved slickenlines on a traverse fault at Station H. Folding to 40 north dip preceded wrench faulting. The Whaleback anticline and the fault then evolved together during Stage V folding and Stage VI layer-parallel extension. From Nickelsen, 1983.](image)
acute bisectors of conjugate wrench faults consistently trend counterclockwise of the third order folds that overprint them (Figure 8).

Figure 8: Equal-area projection showing angular relations of structures after they have been rotated with bedding to prefolding attitude. Stage III and IV structures trend counterclockwise of the Stage V fold hinge. From Nickelsen, 1983.

About 60 ft (20 m) west of Station G toward Station H is a triangular fault block (photograph in Nickelsen, 1979, Plate 10A) initially defined by Stage IV conjugate wrench faults but later reacting to Stage VI extensional strains to form a “graben.” Overprinting of slickenlines on the faults bounding the block establishes the sequence. Stage IV slickenlines parallel the bedding-fault intersection, but Stage VI slickenlines are perpendicular to that intersection.

Station H.

Two structural features are of importance here: a fourth order anticline in the trough of the North syncline that displays the evidence for the sequence of structural Stages IV and V, and a fault on the north limb of the Whaleback anticline that remained active from wrench Stage IV through Stage VI. The fourth order anticline illustrated by Nickelsen (1979, Pls. 8A and B) has slickenlines on a left lateral wrench fault (Stage IV) that nearly parallel the bedding-fault intersection and have been folded through 50° during Stage V.

The history of the wrench fault on the north limb is interpreted in Figure 7C. This fault was initiated under compression as a wrench fault, participated in folding (Stage V), and ended movement as an extensional fault, contributing to stretching of the hinge of the Whaleback anticline (Stage VI).
Station I.
From Station E, walk west along the crest of the Whaleback, and turn north along the path. Continue west into a small valley and walk to the area marked Station I on Figure 3, then proceed west for about 125 additional meters. At this locale we can find examples of Carboniferous “tree” trunks and root balls (probably Lepidodendron or Sigillaria) about 10 meters above the valley floor on the northern valley wall. There are also exposed fossilized root balls in the talus along the valley floor.

Figure 9. Lycopsid “Tree” fossils west of the Whaleback. A. Lepidodendron or Sigillaria along north wall of valley, intact fossil is about three feet long. Impression of lower portion of the trunk within shadow. B. Fossilized root system along base of valley found in talus slope along north wall. C. Example Sigillaria from from Pennsylvanian age Joggins formation in Nova Scotia. Note hammer for scale.

Photo by Michael C. Rygel.
References


IN MEMORIAM

RICHARD P. NICKELSEN AND RODGER T. FAILL

Richard P. “Nick” Nickelsen (right) and Rodger Faill (left) contemplating Appalachian structures in 1997.

Photograph from Pennsylvania Geological Survey files.
IN MEMORIAM – RICHARD P NICKELSEN
Gary M. Fleeger, Pennsylvania Geological Survey

Of all of the outstanding geological work completed by Dick Nickelsen (Figure 1), Professor Emeritus at Bucknell University, in his 60+ year career, he is probably best known for his work at Bear Valley strip mine and the Whaleback near Shamokin, PA (refer to previous article and STOP #5 in the Roadlog). It was the subject of a detailed article published in the American Journal of Science in 1979, culminating his 17-year-long, complete structural analysis of the site. In that study, he was able to define, based on cross-cutting relationships and orientation analysis, the sequence of 6 structural stages during the Alleghany Orogeny from pre-folding jointing to fold-related extension resulting in grabens (Nickelsen, 1979). He also documented clockwise stress axis orientation changes during the orogeny. Nick passed away in Lewisburg at age 89 on November 23, 2014.

Nick studied under the tutelage of the world-famous Ernst Cloos at Johns Hopkins, where he mapped the Blue Ridge near Harper’s Ferry, WV (Nickelsen, 1956). After graduation, he taught at Penn State, but decided that he preferred a smaller school where there was more emphasis on teaching. In 1959, he went to Bucknell, where he started the geology department. Nick was my structural geology professor, and also my senior thesis advisor at Bucknell in the mid-1970s.

Nick was a regular attendee of the annual Field Conference of Pennsylvania Geologists. From the at least 1955 (when he was a leader) through 2007, he attended many Field Conferences. I accompanied Nick and another Bucknell student on my first Field Conference in 1975, where we actually camped out on boulder colluvium in a cemetery, to avoid detection and eviction during the night.

Nick led his first Field Conference in 1955 while at Penn State. He and Gene Williams led a one-day trip on the structure and stratigraphy of Pennsylvanian units near Philipsburg and Clearfield, PA (Nickelsen and Williams, 1955). Nick demonstrated the jointing and faulting in that area in a number of strip mines. His work on the jointing became part of his more extensive work on joints on the plateau (Nickelsen and Hough, 1967).

Nick later turned his attention to the Ridge and Valley. He and Rodger Faill co-led the 1973 Field Conference looking at Ridge and Valley structures (Faill and Nickelsen, 1973; Figure 2). They showed that folds were of various orders (sizes), frequently disharmonic, and largely kink folds. Penetrative deformation was much more extensive and significant to deformation than previously thought.

This year is the second visit to Bear Valley by the Field Conference (see STOP #5, Day 1 Roadlog). A few years after his AJS publication on Bear Valley, Nick led the 1983 Field Conference to demonstrate his work to the geologic public. Co-led with Ed Cotter, Professor Emeritus at
Bucknell (Nickelsen and Cotter, 1983), it holds the record for the largest attendance on a Field Conference trip, with 278 participants. Bear Valley continues to be an incredible teaching laboratory, and is visited by geologists from around the world, still learning from Nick's work. In addition to the highlight of Bear Valley, other stops expanded upon the structures seen in 1973, especially penetrative deformation.

During his later years teaching at Bucknell, he studied folded thrusts and duplexes in the Kishacoquillas Valley region of the Ridge and Valley. He first recognized that the sequence of structures rotated counterclockwise on the SW limb of the Pennsylvania salient, opposite what he saw in the NE limb, such as here at Bear Valley. He led a PA Survey staff trip there in October, 1988. Much of that work was used as a basis for the Field Conference of PA Geologists in 2007, led by Tom McElroy and Don Hoskins, who were then mapping in the Kishacoquillas Valley area. Nick was the guest speaker at that year's banquet, which, after 52 years, was the last Field Conference that he attended.

After Nick’s retirement from Bucknell in 1992, he continued to map and research the structural geology of the McConnellsburg area, looking at the sequence of deformation and the counterclockwise rotation of the structure. He compared the Tuscarora Fault to the Antes-Coburn detachment that he identified in his Kishacoquillas Valley work. He led the 1996 Field Conference to show the results his McConnellsburg work (Nickelsen, 1996).

Nick was very concerned with the preservation and enhancement of significant geological sites. Several times, he was involved with preservation attempts at Bear Valley, which continue today, but was concerned about any restriction of access that might occur as a result.

Nick was one who rarely turned down an opportunity to take people in the field. He led numerous field trips for various groups, including industry groups and non-geologists. The Pennsylvania Survey staff benefitted from a few Nick-led trips, the last being, appropriately, to Bear Valley in 2007 (Figure 1) at age 82.

References


IN MEMORIAM – RODGER T. FAILL

As a member of the Field Conference of Pennsylvania Geologists, Rodger was the principal leader for several of the annual Field Conference trips, where he was a mentor to students and fellow colleagues alike with his explanations and field demonstrations of his interpretations. Rodger led (Figure 1) or contributed to six Field Conferences between 1973 and 2008. As was to be expected because of his extensive geological knowledge across the state, he contributed to Field Conferences in the Allegheny Plateau, Ridge and Valley, Mesozoic basin, and Piedmont Upland.

Rodger’s family recalls that, while sitting in a class taught by Professor John Imbrie of Columbia University, he decided to become a geologist. Rodger had graduated with a bachelor’s degree from Princeton University in 1958, and then matriculated at Columbia University’s Lamont-Doherty Earth Observatory, where he earned the following degrees in geology: B.S. (1962), M.S. (1963), and Ph.D. (1966).

Rodger found employment in September 1965 with the Pennsylvania Geological Survey and provided Pennsylvania with 42 years of exemplary public service. In 1992, Rodger became Chief of the Eastern Mapping Section (in the Geologic Mapping Division), where he supervised two to three geologists working largely in the Ridge and Valley and Piedmont provinces, a position he held until his retirement in 2007.

Notable among his many reports published by the bureau was Atlas 136, Geology and Mineral Resources of the Millerstown Quadrangle. While doing field work for this quadrangle, he first encountered a style of folds that did not fit the commonly accepted concentric model for describing folds in the Ridge and Valley. Recognizing that the model was faulty and needed to be replaced, Rodger submitted two manuscripts that were published by the Geological Society of America in 1969 and 1973, in which he described and explained an accurate fold model of kink bands at all scales (Figure 2).

Rodger authored or coauthored two chapters in the Geology of Pennsylvania, published in 1999. Rodger was senior author, with Dick Nickelsen of Bucknell University, of the chapter on the structural geology and tectonics of the Appalachian Mountain section of the Ridge and Valley province. He was the sole author of the chapter on the geologic history of the Paleozoic Era. Better authors for those 2 chapters could not have been found.

Two of Rodger’s last Pennsylvania Geological Survey publications were the Earthquake Catalog and Epicenter Map of Pennsylvania and Folds of Pennsylvania—GIS Data and Map. Both
were extensive compilations of data from various sources and were representative of Rodger’s interest in structural geology and tectonics.

Six weeks before his death on December 10, 2014, Rodger was preparing a new geological manuscript. It dealt with the deeply hidden causes for the anticlinal structures that form most of the topographic ridges of Pennsylvania’s Appalachian Mountains. Some of Rodger’s last geological words, dated Wednesday, October 1, 2014, were in a handwritten paper entitled Reverse Sequence Outline, and were as follows: “Changes in the anticlinal wave length were minimal from Plateau to V&R [Valley and Ridge] and occurred from basal decoll [décollement] in the Cambrian. Supra salt structures on anticlinal crests were a consequence of salt tectonics, building atop underlying low amplitude anticlines …”

Rodger had many interests and well served his community. Enjoying classical music, Rodger was host for the early morning FM radio (the former WMSP) broadcast “Sleepers Awake” from Harrisburg’s Market Square Presbyterian Church. He also supported his residence community by serving as the chairman of their Shade Tree Commission and as Judge of Elections. He was also, for a time, involved with the Harrisburg Community Theater.

We shall sorely miss his collegiality and his ability to see geology as it is when examined as deeply and carefully as he did. He set a standard for all to follow who seek to interpret the complex geology of the Appalachians.

– Excerpted from Pennsylvania Geology, Vol. 44, No.4

Winter 2014
### Day 1 Road Log route map with STOP locations

#### MILES

<table>
<thead>
<tr>
<th>Int.</th>
<th>Cum.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>Leave parking lot of MainStay Suites. Just to north of entrance to Inn is a prominent, north-dipping ledge of massive Pottsville (Sharp Mountain) conglomerate.</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>Stop sign. Turn right on SR 1009.</td>
</tr>
<tr>
<td>0.2</td>
<td>0.3</td>
<td>Stop sign. Turn left on PA 54 West.</td>
</tr>
<tr>
<td>0.4</td>
<td>0.7</td>
<td>Cut in north-dipping Llewellyn Formation to left.</td>
</tr>
<tr>
<td>0.7</td>
<td>1.4</td>
<td>Enter Mahanoy City. Founded in 1859 and incorporated as a borough in 1863, Mahanoy City was “home” to numerous anthracite collieries for more than 100 years, beginning in the mid-19th century. Among them were the North Mahanoy, Hill’s, Vulcan, Buck Mountain, New Boston, Tunnel Ridge, and St. Nicholas collieries.</td>
</tr>
</tbody>
</table>
4th traffic light on Centre Street at intersection with Main Street. To right is the old, soon to be demolished (or already taken down) Kaier Brewery Building. Charles D. Kaier opened the brewery in 1880, with the present building being erected three years later. By 1912, the brewery was producing 100,000 barrels of beer per year. It reputedly operated illegally all through Prohibition, pumping off beer through a pipe to a nearby barn. The Kaier Brewery closed in 1968.

Farther back along this road to the northeast is the old Springdale Shaft in Bowman’s Patch, where one of the last wheeled-headframes in the Anthracite region is still standing. Opened by the Lentz Lilly Corp. on land leased from the Delano Land Co. in about 1867, the mine was abandoned in 1897 and began to fill with water. To protect adjacent mines, the Philadelphia and Reading Coal and Iron Co. began pumping operations, keeping the mine intermittently active into the 1940’s. The machinery in the adjacent Engine House is beautifully intact.

Headframe of the Springdale Shaft at Bowman’s Patch

Traffic light at Catawissa Street. To left is the Molly Maguire Historical Park, completed in 2010 and featuring a statue by sculptor Zenos Frudakis of a hooded man bound hand and foot with ropes and standing on a gallows (but sans rope around his neck). The park also contains a plaque listing the names of all those who died violently during the Molly Maguire era—the 20 “Mollies” who where hung (some rightly, some wrongly), their victims (mostly coal company personnel), and those killed in retaliation by vigilantes and coal-company operatives.

PHMC Historical Marker to the right reads:

<table>
<thead>
<tr>
<th>VICTOR SCHERTZINGER (1888-1941)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Violin prodigy who performed with John Philip Sousa and later became a film director and composer. He pioneered the use of original music for films, and his film “One Night of Love” won best musical score and sound recording Oscars in 1934. He composed the pop standard “Tangerine.” Among many films he directed were two of the Hope and Crosby “Road movies. He was awarded a star on the Hollywood Walk of Fame. His childhood home was here.</em></td>
</tr>
</tbody>
</table>

Leave Mahanoy City.
On top of Broad Mountain off in the distance to the left is the John B. Rich Memorial Power Station (COGEN). Starting-up commercially in mid-1988, the plant has a net-power output of about 80 megawatts (MW) using processed culm that has a heat value of 7762 BTU/lb. As of 1996, the Rich COGEN plant was consuming about 425,000 tons of culm per year. Processed steam from the plant is being used by the Mahanoy State Correctional Institution (SCI) on Morea Road just to the east of the plant.

Blaschak’s St. Nicholas Breaker to right. Constructed in 1955 to process anthracite from a deep mine that the Blaschak Coal Corp. acquired at St. Nicholas, just down the road, in 1945, the breaker has been upgraded in 1967 and 2002 to handle coal mined at numerous strip mines. In 2010 Blaschak acquired mining rights to the Lattimer Basin north of Hazleton. Company coal sales reached a peak in 2014, topping out at 374,000 tons.

Old St. Nicholas Breaker of Reading Anthracite Co. (if still standing) to right. The breaker was constructed in 1930 and began operating in 1932, being acclaimed as the largest and most productive anthracite breaker in the world. It closed down in 1963, standing idle for many years as a monument to the declining anthracite industry and a prime candidate for preservation as an industrial heritage site. But alas, Reading Anthracite began officially tearing it down in January 2015 to get at the coal beneath it.

PA 54 bears off to right here. Continue ahead on SR 4030.

Enter Wiggan’s Patch. Built in the 1860’s and named after George Wiggan, co-owner of the Bear Run Colliery, it at was here in the early morning of 10 December 1875 that a party of 30 vigilantes raided the house of Charles McAllister, an alleged “Molly Maguire.” McAllister himself escaped, but the thugs shot dead his pregnant wife, pistol whipped his mother-in-law, and shot and killed Charles O’Donnell, a boarder, one of three men who tried to escape. This brutality, never matched by the “Mollies” themselves, was perpetrated in retaliation for the murders of Thomas Sanger and William Uren, mine boss and miner, respectively, at Raven Run on September 1, 1875. No one was ever tried for the “Wiggans Patch Massacre.” Reportedly, the house in which the murders took place is still standing.
To left is “red dog” ash from the John B. Rich COGEN plant and numerous railroad tank cars. The assemblage of tank cars here is reputedly related to Saudi Arabia’s recent dumping of the price of oil—not a great deal of foreign oil is being transported at the present time.

0.4 4.7 Remnant of patch town of Boston Run.

0.4 5.1 Gilberton Coal Co. operation mainly to left—breaker, washing plant, culm, coal, etc. The company—an affiliate of Reading Anthracite—operates the Rich COGEN plant.

0.7 5.8 To right, at end of Gilberton operation, is a the sloping highwall of an old strip mine.

0.2 6.0 Enter Gilberton, named for John Gilbert, a 19th century coal-mine operator.

0.5 6.5 After passing under bridge on PA 924, turn right on ramp to PA 924 (Frackville).

0.2 6.7 Cut in Llewellyn Formation to left.

0.1 6.8 Stop sign. Merge with PA 924 South.

0.6 7.4 To left is the beginning of a long cut in north-dipping Pottsville sandstone, conglomerate, etc. The north end of the cut in the Sharp Mountain Member is the site of serious, recurrent rockslides from the mid-1960’s into the 1980’s—not surprising caused by undercutting steeply inclined bedding planes.

0.6 8.0 PHMC Historical Marker to right reads:

**MAHANOY PLANE**

*Critical to the Pennsylvania anthracite industry, this inclined plane railroad transported coal from the Mahanoy Valley up the Broad Mountain to Frackville. Opened in 1862 as part of the Reading Railroad system, improvements in the early 20th century increased its size and capacity, making it an engineering marvel able to meet national demands. After hoisting hundreds of millions of tons of coal, it closed in 1932. Partial ruins remain nearby.*

0.1 8.1 Enter Frackville. First settled in the 1830s and ‘40s, Frackville was incorporated in 1876 with the merger of the villages of Frackville and Mountain City. It was founded by Daniel Frack, who had opened the first tavern in St. Clair, the Cross Keys, in 1829 to serve workers on the Danville & Pottsville Railroad. (He moved to found Frackville a few years later.)

0.3 8.4 At second traffic light in Frackville (end of PA 924), turn right on PA 61 North (West Oak Street).

1.0 9.4 Frackville Waste Water Facility to left.

1.4 10.8 Cut in Mauch Chunk Formation to right.

2.5 13.3 Village of Fountain Springs.

0.5 13.8 Stop sign. Turn right, keeping on PA 61.

0.2 14.0 St. Catherine Medical Center to left. This was the former Ashland State Hospital, founded in 1879 and completed in 1882 as the State Hospital for
the Injured Persons of the Anthracite Coal Region. Originally built to treat only coal miners, it evolved over the years as a general hospital for everyone in the region. The current building was completed in 1967 and the name changed in 2006. The hospital closed in April 2012 after 130 years of operation.

0.4 14.4 Long cut in Mauch Chunk Formation on right.
0.2 14.6 Cut in Pottsville Formation on right.
0.3 14.9 Cross railroad and enter borough of Ashland, named after the plantation of Henry Clay in Kentucky.
0.1 15.0 Cross Mahanoy Creek.
0.1 15.1 To left is steeply north-dipping outcrop of Llewellyn sandstone exhibiting channel cut-outs, prominent joints, and spheroidal weathering. The metal plaque honors Dr. J. L. Hoffman, a physician and civic-minded citizen who contributed to the construction of the Ashland Reservoir and the erection of the Mothers’ Memorial.

ASHLAND BOYS’ ASSOCIATION
Widespread job loss in Pennsylvania’s anthracite region in the late 19th century led many Ashland “boys” to seek employment elsewhere. Strong attachment to the miners’ former hometown prompted formation of the A.B.A. c. 1900. Until 1976, the A.B.A. held Labor Day homecoming celebrations and during the Great Depression raised funds for the WPA-built Mothers’ Memorial. It symbolizes abiding affection for family and community felt here and in the industrial US.

0.1 15.2 Traffic light at intersection with PA 54. Turn left on Centre Street, keeping on PA 61 (also PA 54). Directly ahead on the hillside is the famous Mothers’ Memorial (Whistler’s Mother Statue) as well as the Ashland War Memorial. The PHMC Historical Marker for the statue reads:

0.3 15.5 Traffic light in downtown Ashland. Ahead is a steep climb uphill on Centre Street.
0.7 16.2 S. 20th Street on left leads to Pioneer Tunnel Coal Mine Tour. (Thursday Preconference Field Trip).
0.1 16.3 Traffic light. Turn right on PA 61 (North Memorial Blvd.) Note that PA 54 continues straight ahead. TRICKY SPOT!
0.2 16.5 Enter Conyngham Township, Columbia County.
0.7 17.2 Bear right on rerouted PA 61.
0.2 17.4 Religious monument on left. This area was the former site of the village of Byrnesville, abandoned in the 1980s and ‘90s due to the Centralia Mine Fire. The village had been established in 1856, many of the early settlers coming from County Mayo in Ireland. Most of the men found employment at the nearby Locust Run Colliery. In its heyday, Byrnesville was home to more than 60 families.

0.7 18.1 Enter Centralia, formerly a borough, now largely abandoned because of a 53-year mine fire that is still burning. To the left is site of St. Ignatius Roman Catholic Church (demolished in the fall of 1997) and the St.
Ignatius Cemetery. The soil bank to the left blocks the former route of PA 61, abandoned in 1994 because of subsidences over the burning underground mine. Sometime before St. Ignatius was torn down, the author Bill Bryson passed through Centralia on his “trek” along the Appalachian Trail. In *A Walk in the Woods* (1998) he described a short walk along old PA 61:

> I walked to the front of the church. A heavy metal crash barrier stood across the old road and a new highway curved off down a hillside away from the town. I stepped around the barrier and walked down old Highway 61. Clumps of weedy grass poked through the surface here and there, but it still looked like a serviceable road. All around on both sides for a considerable distance the land smoked broodingly, like the aftermath of a forest fire. About fifty yards along, a jagged crack appeared down the center of the highway and quickly grew into a severe gash several inches across, emitting still more smoke. In places, the road on one side of the gash had subsided a foot or more, or slumped into a shallow, bowl-shaped depression. From time to time I peered into the crack but couldn’t gauge anything of its depth for the swirling smoke, which approved to be disagreeably acrid and sulphurous when the breeze pushed it over me.

Centralia was founded as “Centerville” in the mid-1840s by Alexander Rea, a mining engineer for the Locust Mountain Coal and Iron Company. (The name was changed in 1865). The Mine Run Railroad was built in 1854, and the first mines opened in 1856. Centralia was incorporated as a borough in 1866, and two years later, on 17 October, Alexander Rea was murdered by the Molly Maguires along the road to Mine Run just to the east.

Continue down the hill on former Locust Avenue (PA 61).

- **0.1 18.2** Turn left into parking area.
- **0.1 18.3** Turn left into partially paved area.

### STOP 1. Centralia Mine Fire

**40.800078 N, -76.334113 W**

Leave STOP 1, turning left on PA 61.

- **0.2 18.5** Stop sign. Turn left on former Centre Street, staying on PA 61. This was the center of Centralia.
- **0.2 18.7** Several of the few remaining houses in Centralia are on the left.
- **0.3 19.0** “Conyngham Township” sign on right marks the former limits of Centralia boro going west toward Mount Carmel.
- **0.3 19.3** Waste piles and strippings to right.
- **0.3 19.6** Entrance to stripping on right.
- **0.5 20.1** Turn right on paved road into stripping area.

### STOP 2. Site 1 of Logan Surface Mine of Blaschak Coal Corporation. SMP #19950101

**40.802778 N, -76.358611 W**
STOP 3. Site 2 of Logan Surface Mine of Blaschak Coal Corporation
40.802778 N, -76.358611 W

Leave STOP 3. Return to entrance to strip-mine area and turn right on PA 61.

1.3 21.4
Enter Northumberland County, Mount Carmel Township.

0.5 21.9
Enter borough of Mount Carmel. The first permanent settler here was Lawrence Lamberson, a Revolutionary War veteran who surveyed the area in 1793 and became the first permanent settler in about 1800. Albert Bradford, an early sawmill operator, is said to have named the village after the holy mountain in Palestine because of its elevation and beautiful situation in the mountains. The Green Ridge Improvement Company opened the first coal mine and built the first breaker in the immediate area in 1854. Rapid development followed. Mount Carmel was incorporated as a borough in 1862. For a time in the 1970s and ‘80s it was feared that the Centralia Mine Fire would burn westward down the valley and threaten Mount Carmel. Such is no longer believed to be the case.

0.4 22.3
Traffic light. Turn right, staying on PA 61.

0.3 22.6
Turn left on West Avenue, staying on PA 61.

0.2 22.8
PHMC Historical Marker to right reads:

GEN. JAMES M. GAVIN (1907-1990)

0.2 23.0
Stop sign. Turn right, staying on PA 61.

0.1 23.1
Cross Shamokin Creek.

0.2 23.3
Enter village of Atlas.

0.8 24.1
Traffic light intersection with PA 54. Continue ahead on PA 61.

0.8 24.2
Enter village of Strong. Just to the right here are greenhouses heated by steam from the Foster Wheeler Mount Carmel COGEN Plant on the ridge to the north (see mile 55.8).

0.9 25.1
Enter borough of Kulpmont, incorporated in 1915.

0.6 25.7
Traffic light in Kulpmont.

0.8 26.5
Old textile factory to right.

0.6 27.1
South-dipping ledges of Llewellyn sandstone to right.

0.7 27.8
Traffic light in front of The Plaza at Coal Township.

0.2 28.0
Enter Ranshaw Township.

0.4 28.4
Sandstone outcrops to right.

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2015 – 80th Annual Field Conference of Pennsylvania Geologists – Road Log Day 1

0.2    28.6  Cut along road to right opposite Weis Market exhibits an excellent upright chevron fold (syncline) in the Llewellyn Formation (not visible from highway).

0.3    28.9  Llewellyn rock-cut along turnaround to right.

1.0    29.9  Enter city of Shamokin. Its name taken from the 18th century Amerindian village of “Shamokin” near Fort Augusta at the forks of the Susquehanna (now the city of Sunbury). Shamokin was incorporated as a borough in 1864 and as a city in 1949. It is bordered on the north by the world’s largest man-made mountain, the Glen Burn-Cameron Colliery culm bank. The city once boasted numerous collieries—including the Cameron-Glen Burn (see STOP 4) and Luke Fidler on the north, the Henry Clay on the east and south, the Burnside on the south, and the Bear Valley on the south and west.

0.2    30.1  Traffic light. Bear left, staying on PA 61.

0.4    30.5  Trinity Evangelical Lutheran Church to right.

0.2    30.7  Traffic light. Turn left on PA 125 (Market Street).

0.1    30.8  Cross Shamokin Creek at start of boulevard, then turn right on Arch Street.

0.2    31.0  Turn right into parking area.

STOP 4 and LUNCH. Claude E. Kehler Park: History and fate of the Glen Burn Colliery

40.788889 N, -76.562500 W

End of LUNCH. Turn left on Arch Street and return to Market Street (PA 125).

0.2    31.2  Turn right on Market Street.

0.5    31.7  Bear right, staying on PA 125.

0.7    32.4  To left is the Sterling Mine from which issues a steady flow of “yellow boy” (acid-mine drainage). Continue straight ahead onto Bear Valley Patch Road. (PA 125 bends off to left.)

Sterling Mine at intersection of PA 125 and Bear Valley Road. The slope mine here was opened in 1934. The “yellow boy” feeds into Carbon Run just to the north (which flows past STOP 4) then into Shamokin Creek.

0.1    32.5  Enter Bear Valley 1st Patch.

0.2    32.7  Recycling Center to right (on Venn Access). Enter Bear Valley 2nd Patch.
0.4  33.1  “NO MAINTENANCE BEYOND THIS POINT. ENTER AT YOUR OWN RISK.”
Road degenerates greatly beyond here. Many large potholes!

0.8  33.9  Stop at end of asphalt “paving” just before start of very rocky incline.
Disembark. Buses turn around.

STOP 5. Bear Valley Strip Mine:
“The Whaleback”

40.763137 N, -76.593375 W

End of STOP 5. Walk back to buses and return to PA 125.

1.5  35.4  Stop sign. Continue straight ahead, now on PA 125.

0.7  36.1  Stop sign. Continue on PA 125 (Market Street).

0.4  36.5  Traffic light at Lincoln Avenue.

0.1  36.6  Traffic light. Turn right on PA 61 (Sunbury Street) and continue back east.

0.5  37.1  Traffic light. Bear right, staying on PA 61.

0.9  38.0  To left at traffic light is a cut (old stripping?) exposing a 5 ft+–thick coalbed, dipping steeply south.

4.7  42.7  To left are greenhouses of the Foster-Wheeler Mount Carmel COGEN Plant at Natalie.

0.5  43.2  Traffic light. Turn left on PA 54.

0.8  44.0  Visible through trees to left is the Foster-Wheeler Mount Carmel COGEN Plant (see mile 55.8).

0.3  44.3  Enter village of Natalie.

0.7  45.0  Cut in Pottsville Formation to left at crest of Big Mountain.

0.4  45.4  Sandstone ledges to left are in the Mauch Chunk Formation.

0.3  45.7  Ahead to right is Brush Valley between Big and Little Mountains, carved by South Branch Roaring Creek out of the Mauch Chunk Formation.

0.9  46.6  To left is AQUA Pennsylvania, a water and wastewater utility company serving 8 states.

0.3  46.9  Enter Bear Gap in Little Mountain and pass deep cut in the Pocono Formation to left.

0.2  47.1  Enter Ralpho Township.

1.2  48.3  Good view of Trimmers Rock “upland” ahead.

0.2  48.5  All Saints’ Cemetery to right.

0.5  49.0  Turn right on Quarry Road.

0.7  49.7  Red metal gate—continue straight ahead on gravel road.

0.2  49.9  Offices of Bear Gap Quarry. Disembark.
STOP 6. Bear Gap Quarry
40.858867 N, -76.517310 W

Leave STOP 6, returning to PA 54.

<table>
<thead>
<tr>
<th>Mile</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Distance</th>
<th>Description</th>
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</thead>
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<tr>
<td>0.9</td>
<td>50.8</td>
<td></td>
<td>0.9</td>
<td>STOP sign. Turn left on PA 54, returning back to PA 61.</td>
</tr>
<tr>
<td>0.4</td>
<td>51.2</td>
<td></td>
<td>0.4</td>
<td>Good view of Bear Gap in Little Mountain, with Big Mountain behind.</td>
</tr>
<tr>
<td>0.5</td>
<td>51.7</td>
<td></td>
<td>0.5</td>
<td>Another good view of Bear Gap.</td>
</tr>
<tr>
<td>1.1</td>
<td>52.8</td>
<td></td>
<td>1.1</td>
<td>Pocono sandstone to right.</td>
</tr>
<tr>
<td>0.5</td>
<td>53.3</td>
<td></td>
<td>0.5</td>
<td>Cross Brush Valley again.</td>
</tr>
<tr>
<td>0.5</td>
<td>53.8</td>
<td></td>
<td>0.5</td>
<td>Enter Mt. Carmel Township.</td>
</tr>
<tr>
<td>0.5</td>
<td>54.3</td>
<td></td>
<td>0.5</td>
<td>Mauch Chunk ledges to right.</td>
</tr>
<tr>
<td>0.4</td>
<td>54.7</td>
<td></td>
<td>0.4</td>
<td>Pottsville ledges to right at crest of Big Mountain.</td>
</tr>
<tr>
<td>0.3</td>
<td>55.0</td>
<td></td>
<td>0.3</td>
<td>Enter village of Natalie.</td>
</tr>
<tr>
<td>0.8</td>
<td>55.8</td>
<td></td>
<td>0.8</td>
<td>Good view of Foster-Wheeler Mount Carmel COGEN Plant to right. Started up in February 1990, the plant has a net power output of 40 MW by the burning of “culm” that has a heat value of 3250 BTU/lb. At that time, it consumed about 840,000 tons/yr of this coal waste. Process steam is used to heat greenhouses located between the plant and PA 61 (see mile 24.2).</td>
</tr>
<tr>
<td>0.9</td>
<td>56.7</td>
<td></td>
<td>0.9</td>
<td>Strip mine to left in distance.</td>
</tr>
<tr>
<td>0.4</td>
<td>57.1</td>
<td></td>
<td>0.4</td>
<td>Traffic light. Turn left on PA 61. Continue on PA 61 through Mt. Carmel and Centralia to Ashland, Frackville, and Pottsville.</td>
</tr>
<tr>
<td>7.6</td>
<td>64.7</td>
<td></td>
<td>7.6</td>
<td>Stop sign entering Ashland. Turn left, staying on PA 61 (Market Street).</td>
</tr>
<tr>
<td>0.1</td>
<td>64.8</td>
<td></td>
<td>0.1</td>
<td>Scenic view east from Market Street in Ashland.</td>
</tr>
<tr>
<td>1.0</td>
<td>65.8</td>
<td></td>
<td>1.0</td>
<td>Traffic light. Turn right, staying on PA 61.</td>
</tr>
<tr>
<td>6.7</td>
<td>72.5</td>
<td></td>
<td>6.7</td>
<td>Traffic light in Frackville. Turn right, staying on PA 61.</td>
</tr>
<tr>
<td>0.1</td>
<td>72.6</td>
<td></td>
<td>0.1</td>
<td>Holy Ascension Orthodox Church to left.</td>
</tr>
</tbody>
</table>

View east down Market Street in Ashland. “Nose” of Bear Ridge in the distance (mile 64.8)
<table>
<thead>
<tr>
<th>Mileage</th>
<th>Distance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>72.9</td>
<td>Dutch Kitchen Diner to left.</td>
</tr>
<tr>
<td>0.4</td>
<td>73.3</td>
<td>Bear right onto ramp for I-81 North.</td>
</tr>
<tr>
<td>0.4</td>
<td>73.7</td>
<td>Merge with I-81 North.</td>
</tr>
<tr>
<td>0.9</td>
<td>74.6</td>
<td>Frackville State Correctional Institution (SCI) Penitentiary to right.</td>
</tr>
<tr>
<td>0.6</td>
<td>75.2</td>
<td>John B. Rich COGEN plant on top of Broad Mountain to left.</td>
</tr>
<tr>
<td>0.4</td>
<td>75.6</td>
<td>To right are gas pipes from Wheelabrator-Frackville COGEN Plant to Frackville SCI.</td>
</tr>
<tr>
<td>0.6</td>
<td>76.2</td>
<td>Ahead to left is the Wheelabrator-Frackville COGEN Plant (see Day-2 roadlog, mile 4.2).</td>
</tr>
<tr>
<td>0.2</td>
<td>76.4</td>
<td>Deep cuts in Llewellyn Formation on both sides of road.</td>
</tr>
<tr>
<td>3.1</td>
<td>79.5</td>
<td>Cut in north-dipping Pottsville conglomerate.</td>
</tr>
<tr>
<td>1.5</td>
<td>81.0</td>
<td>Bear right onto exit ramp to PA 924 North (Mahanoy City).</td>
</tr>
<tr>
<td>0.3</td>
<td>81.3</td>
<td>Merge with PA 924.</td>
</tr>
<tr>
<td>0.2</td>
<td>81.5</td>
<td>Turn left onto SR 1008.</td>
</tr>
<tr>
<td>0.1</td>
<td>81.6</td>
<td>Turn left into MainStay Suites.</td>
</tr>
<tr>
<td>0.1</td>
<td>81.7</td>
<td>Parking lot of MainStay Suites.</td>
</tr>
</tbody>
</table>

End of Day 1 Field Trip!
REFERENCES


Dempsey, T., [no date], Schuylkill County Patch Towns: [Schuylkill County Historical Society].


STOP #1: CENTRALIA COAL MINE FIRE

Stop Leader – Jennifer Elick, Susquehanna University

SITE 1 Origin of Coal Mine Fire

Approaching Centralia from the south (Ashland), take PA-61 N to the St. Ignatius Cemetery (Figure 1-1). Turn left onto an unmarked road (across from the St Ignatius Cemetery) known as Second Street. Drive approximately 1000 ft on Second Street and park beyond the Odd Fellows Cemetery. From here you can see old mine vents. Walk east along an ATV path, to a wider road, (~ 1/8 of a mile). This location is adjacent to the dump where the Centralia coal fire was ignited on May 27, 1962 (Figure 1-2).

Figure 1-1. Map directions to Centralia with major PA highways (top) and sites in Stop 1(bottom). Site 1 is the origin of the coal fire, the location of the dump and a site for collecting Pennsylvanian plant fossils. Site 2 is Fire front 2, located along Graffiti Highway (Old PA 61). Site 3 is Fire Front 1, located alongside the St. Ignatius Cemetery.
Caution should be used at this exposure due to the steep slope. The rock exposed along the nose of the anticline is interbedded carbonaceous black shale, with iron-stained quartz sandstone and dark gray shaly siltstone from the Buck Mountain coal succession (Llewellyn Formation) (Arndt, 1971) (Figure 1-3). Note the variance of strike (N37°E to N60°E) and dip (28 to 45° SE) due to the folding. These rocks are interpreted to represent a water-logged environment along a humid alluvial plain that contained coastal marsh peat swamps (Edmunds et al., 1999).

Figure 1-3. A). Stratigraphy of the Middle Pennsylvanian in eastern and central Pennsylvania (modified from Berg et al., 1983) The Buck Mountain coal succession is identified by a black arrow. B). Photograph and detailed measured section of Buck Mountain coal splits from Blaschak Surface mine (modified from Elick, 2013).
Here Pennsylvanian age plant fossils from the black shale near the base of the Buck Mountain coal succession are abundant. The shale contains abundant carbonized and coalified plant fossils, many of which are kaolinite and pyrophyllite coated or iron-stained. Some of the fossil plants found at this location include different species of Neuropteris, Lepidodendron, Alethopteris, Sphenopteris, Sphenophyllum, Sigillaria, and Calamites. Stigmaria were also identified extending from some Lepidodendron tree fossils. A cone from either a Lycopod (Lepidodendron, Sigillaria) or possibly Horsetail (Calamites) that came from St. Clair, Pennsylvania was also found. There are many unidentified plant fragments. Compressed, large tree trunks, up to 0.45-m, are located at the base of the hill. An exposure of quartz sandstone is discontinuous, iron-stained, and micaceous and undulates across the exposure. It contains ripples, and plant fragments. The shaly siltstone did not appear to contain as many plant fossils as the friable shale.

Many of the fossils at this location are coated by pyrophyllite and kaolinite, and likely formed under low-temperature metamorphic conditions, (approximately 275° C). They are similar to those described by Peterson et al. (2011), who studied alteration of fern fossils from the shale in the Buck Mountain coal succession in St. Clair, PA. The ferns died and were buried in a low-energy, low-oxygen environment, like a swamp, and the sediments eventually lithified into rock. During maximum burial, the unit was heated to between 250 and 300° C, allowing pyrophyllite to replace an early forming mineral phase, such as pyrite (Peterson et al., 2011) and also increasing the coal rank to anthracite (Figure1- 4).

The mine vents located near the Odd Fellows Cemetery were drilled down to the subsurface workings in order to draft the gases out of the town. For a short while, the vents provided some relief (DeKok, 2010). However, they likely accelerated the fire movement in the long-term by creating an updraft that circulated oxygen-rich air to the fire from other locations (Neubauer and Elick, 2013).

**SITE 2 Fire Front 2 along Old PA 61**

From South Street, return to PA Route 61 S and turn right. Drive 200 ft, and pull off the road to the right where “Old Route 61” is located (Figure 1-1). This particular stretch of PA-61, is also known as the “Graffiti Highway,” and was closed to traffic in 1992 due to the fire. We will examine features at this stop that are within a 1500-ft walk down the road. Park in front of the St Ignatius Cemetery, along PA-61, and walk past and down the blocked road. Heat from the coal fire was released along vents from fire front 2 and under the road. The big crack in the road and vents in the trench delineate the path of the fire along the southern limb of the Locust Mountain Anticline (Figures 1-1, 1-2, and 1- 5).
SITE 2A, Big Crack on “Graffiti Highway”  

A large crack, nearly 76-m long and 1.2- to 1.5-m wide, extends through the middle of Old PA-61 S (Figure 1-5). As the fire moved through the area, it caused the road to contort and buckle. After repairing the road several times between 1987 and 1992, this stretch of the road was closed to traffic (DeKok, 2010). The crack in the road is longer and wider than it was in 2006, suggesting renewed activity by the fire, however, crown vetch grows throughout the crack and the temperature in this location is not elevated. The highway endured stretching and subsidence from the heat, which produced large extensional features like en-echelon fractures and deformational structures that resemble normal faults (Figure 1-5).

SITE 2B, Excavation Trench on Hill  

A short hike up the hill, along a footpath, north of the big crack in old PA-61, leads to one of the excavation trenches dug out as a means of extinguishing the fire. The trench exposes black shale and siltstone (N70°E; 40°SE). This is also the location of additional exhaust vents from fire front 2. The high temperatures from the fire burned off the organics in the shale, and the shale is now a bright reddish-orange color where gases were exhausted.

SITE 3 Fire front 1  

From the Odd Fellows Cemetery, return to PA-61 N. Drive approximately 200 ft N and turn left onto South Street (Figures 1-1 and 1-2). Though many visitors drive across this landscape, it is recommend here that you park at the base of South Street, on the sandstone, and walk westward, along fire front 1. This area (Figure 1-6) contains numerous sinkholes, fractures, and exhaust vents and care should be taken while walking.
SITE 3A, PA DEP Borehole

The orange-painted PADEP borehole (X-2) helps mark fire front 1. It is located at the intersection of Peach and South Streets (both are unmarked), west of the parking area. Borehole X-2 is one of 46 sealed holes that the PADEP continue to monitor on a monthly basis for temperature/depth. In July of 2011, the temperature of this particular borehole at a depth of 23 m depth was 137° C. Though this is high relative to the current surface exhaust vent temperatures of today, it is low in comparison to some record borehole temperatures in the past. The highest temperature recorded at a borehole in 2011 was 206° C; this borehole was located on Park Street, just east of PA-61 (PADEP, 2013). In the 1970’s and 1980’s, many boreholes commonly reached temperatures > 530° C (GAI Consultants, 1983). During this time interval, one particular borehole reached 732° C at depth, with corresponding surface exhaust vent temperatures of 482° C (PADEP, 2013).

SITE 3B, Sinkholes

Continue walking westward, following South Street, up the hill, to the Ss. Peter and Paul Cemetery. The road leading to the cemetery exhibits 2 m of subsidence (Figure 1-7). This sunken road is part of a large sinkhole that formed as smaller sinkholes coalesced (Elick, 2013). The sinkholes began to form following heavy precipitation events in 2011 (the wettest year on record in central PA), when over 185 cm of precipitation fell in central PA, nearly twice the average for the state (Elick, 2013). The precipitation interacted with the hot rock from the fire, causing shale to turn to mud and quartz-cemented sandstone and conglomerate to crumble and fall apart. Steam interacting with the bedrock helped cause the surface bedrock to collapse, producing sinkholes that follow the bedrock orientation. In all, nine new sinkholes formed in 2011, along the strike of 5, 5M, and 5T coal beds of the Buck Mountain coal succession. The large sinkhole at the top of the hill is 23 m wide and 26 m long and up to it 2 m deep (Elick, 2013).

SITE 3C, North-south oriented heat exchange

Approximately 300-ft north of the NE corner of the Ss. Peter and Paul Cemetery is a location where several N-S oriented fractures are venting heat from fire front 1 (Figure 1-8). Because the coal fire is known to have moved through the Buck Mountain coal succession (from 5 to 5M to 5T) (Elick, 2013), it therefore has potential to migrate to the next overlying coal bed, the Seven Foot coal (No. 6) (Figure 1-3).

Anthracite coal begins combustion at approximately 500° C under normal surface conditions (Schweinfurth, 2009). Under adiabatic conditions, the minimum temperature at which coal can combust may be lower (Kim, 2007). Coal fires can therefore migrate into successive coals by preheating the adjacent coals, commonly along a structural cracks or collapse features in the bedrock (Cao et al., 2007). In the recent past, borehole X-2 has reached temperatures in the range necessary to initiate combustion of adjacent coals in this manner. Elick (2013) measured fracture orientations, and identified a north-south oriented fracture set associated with the Appalachian Orogeny (Faill, 1999) and subsurface mining. Additionally, fractures from mine subsidence may influence the spread of the fire. Currently, north-south oriented vents are monitored to determine if the fire will migrate to the adjacent coal beds, such as the Seven Foot coal (No. 6).
SITE 3D, Succession  

Continue walking west along the dirt road for another 100 ft, towards a Y in the road (Figure 1-6). Turn west and follow the road to the right-hand fork for another 150 ft. The road then turns nearly 90° to the north. We will stop here to examine a large sinkhole, nearly 15-m wide and 3-m deep. To the left, on the other side of the road, is a field of birch trees. Between 2000 and 2007, heat and gases from the mine fire escaped from vents into the field, killing all of the large trees. By 2007, the surface temperatures began to decrease, and vegetation returned. Birch, a common successional tree in the coal regions and colonizer following environmental disruption, has thrived in this area and in other places where the ground temperatures have lowered. When soil temperatures and gas compositions returned to normal levels by 2012, it was concluded that the westward progression of the fire had ceased (Elick, 2013).

The decline in temperatures throughout Centralia (Figure 1-9), indicates that the fire is currently diminishing. Martinez and Ressler (2001) predicted that coal fire gases would introduce nutrients to the soil, like ammonia, nitrate, and phosphate, which would aid in the regrowth of vegetation once the fire temperatures subsided. Today, birch, oak, and sumac trees are rapidly colonizing the once hot landscape.

REFERENCES

STOPS # 2 & 3: BLASCHAK OPERATIONS  
BETWEEN CENTRALIA AND MOUNT CARMEL

Structural geology of the Logan Main Mining Pit and the Logan West Pit

Stop Leader – Robin Koeberle

These STOPs in Logan Main Mining Pit (#2) and the Logan West Pit (#3) provide visual evidence of thrust faulting prior to major folding in the central portion of the Western Middle Anthracite field.

Geology

The Pennsylvania Anthracite region is divided into four fields: Northern, Eastern Middle, Western Middle, and Southern. The Logan pits of Blasck Coal Company are located in the central part of the Western Middle field in the Mount Carmel and Ashland 7½-minute quadrangles. The geologic map of Figure 2-1 (Arndt, 1971a and b) shows the complex structure affecting the two rock units comprising bedrock of the mined area: the Llewellyn Formation and the underlying Pottsville Formation, ubiquitous in all four Anthracite fields.

Mount Carmel Quadrangle  
Ashland Quadrangle

Figure 2-1. USGS Geologic Quadrangles showing the location of STOPs 2 and 3 (Arndt Wood, 1971a and b)

The dominant Llewellyn Formation is Middle to Late Pennsylvanian in age (Wood et al., 1962) and extends from the bottom rock of the Buck Mountain (No. 5) vein up to the present erosion surface. Prior to 1962, the Llewellyn was informally called the “Coal Measures,” then assigned to the Allegheny and Conemaugh Formations and to the informal unit known as the “post-Pottsville.” The Llewellyn is comprised of siltstone, shales, sandstones, conglomerates, and coal. The underlying Pottsville is largely conglomerate and sandstone, with a few coalbeds that
are only locally mineable in the Western Middle field. Figure 2-2 is a composite stratigraphic section from Arndt (1971a and b).

![Composite stratigraphic section from Arndt, 1971a and b](image)

The Llewellyn Formation in all four Anthracite fields is contorted into complexly folded and faulted synclinoria. These structural features formed during the various phases of the Appalachian Orogeny. Superimposed upon these complex fold systems are a multitude of low-angle thrust, high-angle reverse, underthrust, tear, and bedding-plane faults. Throughout the Anthracite region, advancing surface mining operations encounter visual geologic evidence of the chronological development of these various structures. This can supply a wealth of detailed information, giving actual “survey” data to the understanding of the geologic structures present in the area. Unfortunately, this visual evidence is lost and sometimes never recorded as operations advance or are backfilled. Locations like the Bear Valley “Whaleback” (STOP 5 of this Field Conference) are examples of structures that help us understand the complexity of this region. Numerous authors have discussed the sequences from detailed field investigations. Gordon Wood of the U.S.G.S. noted that few natural outcrops of the Llewellyn Formation exist. Most detailed information is supplied by underground mine maps and surface mine excavations, all centered on the coal veins; relatively little is known of the strata between these veins.

A detailed Lithotectonic Map of the Appalachian Orogen in Canada and the United States (Hibbard et al., 2006) combines much of the research on the salients and recesses associated with this Orogeny. Figure 2-3 shows these salients and recesses in the Appalachian-Ouachita orogenic belt as published somewhat earlier by Thomas (1983).
Figure 2-3. Structural geologic map of recesses and salients along the Appalachian-Ouachita orogenic belt during the late Paleozoic, showing basement faults and arches of the North American craton (Thomas, 1983). Appalachian external basement massifs: B = Berkshire; BR = Blue Ridge; C-S = Corbin-Salem Church; G = Green Mountain; LR = Long Range; RP = Reading Prong. Intracratonic basement faults: A-W-A = Arbuckle-Wichita-Amarillo; S-RC = Shawneetown-Rough Creek

Mine History

Three underground mines operated in this area and are generally named the Logan Colliery, Sayre Colliery, and Morris Ridge Colliery. Names and operators of these collieries have changed many times, and a book could be written on this aspect alone. Numerous other operators have mined on the properties—from underground independent miners to various surface mining operators. Mine maps for these various can be obtained from various sources and utilized for mine planning and development.

The Logan Colliery is located in the Centralia syncline between the boroughs of Mount Carmel and Centralia. To the north are the Morris Ridge and Sayre Collieries in the Coal Ridge syncline, which is between Mount Carmel and the village of Aristes. The Centralia anticline is the general dividing line between these three mine complexes.

STOP OVERVIEWS

STOP 2. Logan Mine Mining Pit

You will be viewing the bottom rock of the Buck Mountain vein on the north limb of the Centralia syncline. To the west is the Centralia fault, which cuts the Buck Mountain vein, causing an overturned fold and a repeat of the Buck Mountain vein (Figure 2-4, closeup in Figure 2-5). The Centralia fault runs east to west on the north limb of the Centralia syncline and extends past the village of Delano far to the east. It causes an overturned fold on the Buck Mountain vein. On the Mount Carmel quadrangle, the Centralia fault is shown to branch off and arc around in the Coal Ridge syncline (Arndt, 1971b)—whereas in actuality the fault there is a thrust fault separate from the Centralia fault. This is discussed later in The Missing Evidence.
The Centralia fault is well defined and was originally described in the underground mine mapping as a “roll.” Later mine operators searched for the “Bubble” as they extended their underground operations. Figures 4 and 5 show how well defined the fault is once it is exposed in open pits and strippings. As we go 2000 feet farther west of this location, the fault disappears to a point where the bottom rock of the Buck Mountain vein is just beginning to overturn and fracture (Figure 2-6).
STOP 3. Logan West Pit

Here we see an asymmetrical fold in the Seven-Foot (No. 6) vein (Figure 3-7). To the south, but no longer visible, was a trailing imbricate fan with the beginning of the Centralia fault (Figure 3-8). The southern portion of the fold is cause by compression folding that took place in the later stages of the orogeny in the area.

Figure 2-6. Overturned Buck Mountain vein top rock and the Centralia fault. Looking west.

Figure 3-7. Here we see an asymmetrical fold caused by compression. Looking east.
The Missing Evidence

The Morris Ridge Colliery, located directly north of the Logan Colliery, is an active mining operation of Mallard Contracting. Here the Coal Ridge syncline is a tight fold, forming a chevron fold to the east (Figure 3-9) and broadening into two synclines as it progresses to the west.
Looking at the mining cross sections it is evident that a number of thin-skinned thrusts occurred, one of which duplicated the Mammoth vein. This thrust is evident from the Morris Ridge Colliery westward and is, in essence, a klippe. On the U.S.G.S. Quadrangle Map the fault is assumed to be part of the Centralia fault (Arndt, 1971a), but is in reality a separate thrust fault that occurred prior to the major folding event. It is important to not that these thrusts are all dipping to the north and can be traced visually across the syncline to outcrop at the surface. This event is seen in the uppermost strata. The main questions are how far the map trace of this thrust extends to the west, and does this overthrust of the Mammoth vein tie into the overthrust that occurred to the south?

In the Centralia syncline, mining indicated that there was only one Mammoth vein. The Centralia fault begins just to the west, where the bottom rock of the Buck Mountain vein began to offset at the top of an anticline. To the north of this offset are three trailing imbricate thrusts. The Centralia fault came in at a later date than the flat decollement thrusts in the Mammoth vein, due to the fact that the Buck Mountain underlap had made a more complete syncline being cut off on its southern limb.

Figures 3-10 through 3-15 well illustrate the complex structural framework of the Coal Ridge syncline—its folds, thrusts, imbricate thrusts, folded thrusts, and overthrusts.

Figure 3-10. Coal Ridge synclinal axis at loader, and a Marion 7400 dragline mining the southern syncline. Thrust faults are evident at the top of the photo, with an imbricate thrust visible. Looking west.
Figure 3-11. Folded thrust sheet with imbricate thrust

Figure 3-12. North-dipping limb of the Mammoth vein, showing the Mammoth-vein bottom rock, upper right, over the Mammoth vein. Looking west.
Figure 3-13. Coal Ridge syncline, showing detail of the compression folding on the north-dipping limb of the Mammoth vein. Looking west.

Figure 3-14. Overthrust on the Holmes veins located on the north limb of the Coal Ridge syncline. Looking west.
REFERENCES FOR STOPS 2 AND 3


STOP #4 AND LUNCH: CLAUDE E. KEHLER PARK, SHAMOKIN
History and fate of the Lower Gap-Cameron-Glen Burn Colliery

Stop Leaders – Jon D. Inners and Michael Korb

Claude E. Kehler Park in Shamokin provides a good view of the gap cut though Big Mountain by Shamokin Creek, a tributary of the trunk Susquehanna River whose mouth is at the south edge of Sunbury, 13 miles to the west-northwest. Big Mountain is the bounding Pottsville ridge on the north side of the Western Middle Anthracite field, extending about 20 miles from west of Trevorton to northeast of Centralia (Figure 4-1). For more than 100 years, the gap was the site of one of the largest collieries in the Anthracite fields—the classic Cameron-Glen Burn Colliery, the final breaker of which was immortalized on many postcards from the mid-20th century (Figure 4-2).

Figure 4-1. Location map for STOP 4 and Lunch—Claude E. Kehler Park, Shamokin

Figure 4-2. A postcard view of the Glen Burn breaker, probably from the 50's or 60's. The breaker was dismantled in 2000.
Mining and Geology

The Cameron-Glen Burn Colliery was situated at the extreme north edge of Shamokin. The Glen Burn mine lay entirely west of the gap, its western boundary about 3 miles distant, and the Cameron mine straddled the gap, extending 1.3 miles to the east. The combined mines were bounded on the east by the Hickory Swamp mine, on the south by the Luke Fidler, Neilson, Stirling, and Bear Valley mines, and on the west by the Bear Valley mine. Only the western part of the Cameron mine underlies a significant area of the city of Shamokin.

The roughly east-west axis of the Western Middle synclinorium is about a mile south of the mines. Folds in the northern part of the coal field are subsidiary folds on the north limb of the synclinorium, being doubly-plunging, parallel to subparallel folds, some broken by thrust faults trending subparallel to the folds. They trend N75°E and are mostly less than 1000 feet wide. Few persist more than a mile or two along strike before merging or overlapping an adjacent fold. The major structures affecting the Cameron-Glen Burn mines are the Hickory Swamp basin ("basin" being the miners’ term for a coal-bearing syncline) and the Luke Fidler anticline, the Cameron basin, the Edgewood anticline, and the Glen Burn basin (proceeding east to west). Bounding the mines to the southwest of the gap is the south-dipping Furnace Run fault, which reaches the surface about 3000 feet south of the crest of Big Mountain.

The Llewellyn Formation at Shamokin has a maximum thickness of about 1900 feet and contains 18 persistent coal beds (i.e., beds that can be traced throughout a basin and can be correlated between adjacent basins). Eleven seams were mined at the Cameron-Glen Burn mines—Primrose (No. 11), Rough (No. 10½), Holmes (No. 10), Four-Foot (No. 9½), Mammoth Top Split (No. 9), Mammoth Middle Split (No. 8½), Mammoth Bottom Split (No. 8), Skidmore (No. 7), Skidmore Leader (No. 7L), Seven-Foot (No. 6), and Buck Mountain (No. 5). These coals were mined from to depths of more than 1000 feet east of the gap and 1200 feet west of the gap. The thickest of these beds were in the Mammoth Coal Zone—a maximum of 15.0 feet (av. 7.8) in the Top Split, 10.7 feet (av. 7.3) in the Middle Split, and 12.4 feet (av. 6.7) in the Bottom Split. The Seven-Foot—mined extensively in the Cameron—had a maximum thickness of 10.4 feet (av. 6.0). Coal beds younger than the Orchard (No. 12) underlie the city of Shamokin, where little mining was done.

History

Mining began at the future site of the Glen Burn Colliery in the Big Mountain gap of Shamokin Creek in 1836, the coal probably being cleaned and sized by hand-operated shakers. The first breaker was built in 1857 by W. L. Dewart at his “Lower Gap Colliery.” It was renamed the Cameron Colliery in 1864. In 1871 a new large “double type” breaker was built to replace the original structure. As demand increased, the need for a still larger cleaning plant prompted erection of a new facility in 1888. This breaker was built in January of that year, but burned down that October. It was quickly replaced the next year.

In 1894 a “jig house,” containing more sophisticated cleaning and sizing equipment and sizing equipment to process some smaller sizes of coal, was added to the breaker. Fifteen years later electric lighting was installed in the breaker, an update greatly inspired by the frequent visits to the area of Thomas Edison. Prior to that time the breaker was illuminated by oil lamps, which certainly contributed to the fire danger. The final breaker on the site, an all-steel breaker considered at the time the most modern processing plant in the Anthracite region, was built in 1939 by the Stevens Coal Company. That same year the Susquehanna Colliery Co., based in Wilkes-Barre, took over operation of the Cameron and renamed it the Glen Burn Colliery in 1940. Susquehanna operated the mine and breaker until it was acquired by Kerris and Helfrick in the late 1960’s.
The number of workers employed at the Cameron/Glen Burn Colliery peaked in 1899 at more than 1500 men and boys. Production at the Cameron Colliery was impressive in the 1880’s: 175,000 tons in 1881, 164,000 tons in 1882, 220,094 tons in 1884, 245,436 tons in 1885, and 193,931 tons in 1886. (Compare with that of the Pine Forest Colliery at STOP 10.) But the highest production occurred between 1934 and 1948, peaking at 627,158 tons in 1942. Daily production in that year averaged more than 2400 tons. Though mining ceased in 1970, Kerris and Helfrick continued to operate the breaker—processing up to 500 tons of coal per hour from other mines into the 1980’s. Unfortunately the breaker was not equipped to handle the coal finer than Buckwheat #4 (i.e., through 3/32 to over 3/64 inch). A strike stopped production in 1986, and the breaker ceased operation the next year for an indefinite period. Then in 1990 it shut down permanently. The Glen Burn breaker was dismantled in 2000—and a classic landmark at the northern entrance to “The Region” along PA 61 was no more.

Over the 134-year life of the various named colliers in the gap, about 30,000,000 tons of coal was removed from the Glen Burn and Cameron mines beneath the north side of Shamokin. Recorded accidents claimed the lives of 217 workers during the colliery’s years of operation. The worst was on 27 May 1911, when five men died in an explosion. Nearby mines also had their share of disasters. At the smaller Luke Fidler mine just to the southeast, five men died in a fire on 8 October 1894 and seven were killed in an explosion on 25 November 1902. A fire at the Neilson mine just to the south of the gap claimed ten lives on 1 April 1893.

Interestingly, the mine workings west of the gap were designated a fallout shelter in the 1950’s and ’60’s. Hundreds of tins of crackers and water barrels, as well as much toilet paper and medicine, were still evident in 1997 when “explorers” entered deep into the west drift.

**The Glen Burn Mine Fire**

The immense tree-covered culm bank, extending about 1.5 miles down the southern slope of Big Mountain west of the gap, is evidence of the mine’s production over more than a century and a quarter of time. It is the largest in the entire Anthracite region and claimed locally to be the “world’s largest man-made mountain”—though it seems unclear whether Guinness recognizes it as such. Both an underground mine fire and an above-ground culm bank fire plagued the colliery for many years starting in the middle years of the past century; only the underground fire is still burning (Figure 4-3).

The combined underground-culm bank extended eastward into adjoining problem areas and burned for more than 50 years. The once-burning refuse bank is situated over the outcrop of at least 13 coal seams. During periods of air inversion, the smoke from this area caused breathing difficulties in Shamokin. There was also the problem of the large areas of the refuse bank sliding and subsiding. At its maximum extent above ground fire covered an area of nearly 500 acres.
The Glen Burn Mine Fire is actually the combination of at least 5 separate fires. Two were extensive surface fires (New Bank and Old Bank at numerous locations, now extinguished), and three are deep mine fires (Cameron, Luke Fidler, and Hickory Swamp). Active burning of the fire in December 2011 was confirmed by surface venting that started a forest fire extinguished by the Coal Township Fire Department. The large fire zone is on uninhabited Big Mountain (Figure 4-4). The steeply dipping coal veins cause flushing materials to wash down-dip into the underground mine pools, making it necessary to “rubblize” in order to place flushing materials. Surface sealing and clearing may prevent future forest fires. The fire has been classified as “High Cost, Moderate Benefit, Low Worth” by PA DEP Bureau of Mining Reclamation. Estimated reclamation cost is $15,000,000+.

REFERENCES


Koeberle, R., Blaschak Coal Co., personnel communication, June 2015.


STOP #5: ALLEGHANIAN DEFORMATION AT THE BEAR VALLEY STRIP MINE

Stop Leader – Stephen Whisner
Bloomsburg University

Adapted from:
Field Trip Guidebook T166: Day 3
28th International Geological Congress
by
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Lewisburg, PA  17837

Summary

The Bear Valley strip mine, home of the Whaleback, lies at the west end of Pennsylvania's middle anthracite coal field in the Appalachian Valley and Ridge. Mining of Pennsylvanian coals has exposed beautiful, complex structures, making this one of the preeminent locations in eastern North America in which to view deformation in three dimensions. Nickelsen (1979, 1983) decrypted the overprinted structures to parse out six stages of deformation: extension jointing in coals followed by Alleghanian deformation that includes extension jointing in sandstones and ironstones, formation of spaced cleavage and small folds, faulting, larger-scale folding, and extension. In addition to providing evidence of progressive deformation, this is a superb locale for examining disharmonic folding, in which layer thickness and competency contrasts control deformation.

Introduction

The Bear Valley Strip Mine is situated along several faulted second order folds on the south limb of the first order Shamokin synclinorium (Figure 5-1). The mine area has been previously described by Nickelsen (1979, 1983) from whose work most of this stop description is derived (see Memoriam, this Guidebook).

The mine offers superb three-dimensional exposures of the structural elements of the northern Valley and Ridge province, and clear views of geometric relationships and sequential overprinting of structures that elucidate the stages and processes of deformation during the

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*** PLEASE BE CAUTIOUS AS YOU MOVE AROUND THE SITE ***

– smooth slopes, precipitous drops, narrow paths, and wet leaves make for treacherous footing –
Alleghanian orogeny. All of the stages displayed are Pennsylvanian or younger but no Mesozoic deformation is thought to have occurred here.

All of this is visible within a 320,000 ft² (30,000 m²) strip mine area that contains two disharmonically-folded, Pennsylvanian-age cycles of sedimentation exposed in cross section along highwalls and on unique bedding plane surfaces. Deformation mechanisms and the structural sequence of layer-parallel shortening (Stages II, III, IV) overprinted first by large-scale folding (Stage V) and later by layer-parallel extension (Stage VI) can be fully demonstrated at this locality (Figure 5-2).

The variety of structural elements and deformation mechanisms includes: Stage I joints in coal that are eastern extensions of the pre-Alleghanian Set I joints in coal observed on the Appalachian Plateau by Nickelsen and Hough (1967, Plate 3); hydraulic extensional joints with quartz-fiber fillings in ironstone and sandstone (Stage II); spaced cleavage in shales and silty shales formed by pressure solution, or grain rotation and sliding, or primary crenulation, accompanied by incipient recrystallization (Stage III), wrench (strike-slip) or wedge (thrust) faults with very obvious slickensides and slickenlines (Stage IV); third (size) order flexural slip folds showing disharmony between adjacent structural lithic units (Stage V); and extensional fault “grabens” or extensional joints formed by buckling or release fracturing (Stage VI). Elsewhere in the region Stage VII large scale strike-slip faults with horizontal slickenlines cut all other structures. Finally, it is apparent that ductility contrast between stiff ironstone and sandstone and weaker shale and coal controls the relative structural behavior of rock types.
Figure 5-2. Cartoon depicting the sequence of development of structural stages of the Alleghany orogeny: Stage I. Orthogonal joint sets form in coal; Stage II. Several sets of hydraulic extensional joints form in sandstones and shales; Stage III. Pressure solution and primary crenulation cleavage and small-scale folds form; pressure solution of Stage II joint fillings occurs; Stage IV. Conjugate wrench and wedge faults deform Stage III cleavage; Stage V. Large-scale folding of all previous structures occurs; Stage VI. Extensional joints and faults produce flattening perpendicular to bedding and layer-parallel extension, both parallel and perpendicular to fold hinges. After Nickelsen, 1983.

Station 1

Turn left (east) off the entrance path and walk to the crest of the north anticline at Station 1 (Figure 5-3). The rocks beneath your feet represent the floor of the coal swamp and have impressions of large lycopsid trees and stigmaria (roots). From 1, the entire mine is visible, including third order folds, fold disharmonies, many faults, and ironstone concretions. The view of the southwest corner (Figure 5-4) shows overprinted Stage IV conjugate wrench fault systems (dihedral angle 35°) and a Stage IV thrust. To the east the disharmonic third order folding shown in Figure 5-5 is visible. Looking south is an excellent view to the north limb of the Whaleback anticline showing Stage IV thrusts and conjugate wrench faults, the Stage V anticline plunging east, and Stage VI extensional joints and faults (Figure 5-6). The north anticline on which you are standing has a chevron profile because the kink junction axis is inclined to bedding (Faill and Nickelsen, 1973, Fig. 20).
Figure 5-3. Map showing topography, geology and station localities 1 to 7, of the Bear Valley strip mine. After Nickelsen, 1983

Figure 5-4. Conjugate wrench fault systems and a thrust fault between Stations 2 and 3 on the south wall, as viewed from Station 1. (Figures 5-4, 5-5 after Nickelsen, 1983)

Figure 5-5. Diagram of Bear Valley strip mine structures as viewed from west end of the Whaleback. Bottom of sketch shows structure of sandstone bed viewed north-south through Station 1 of Figure 3. Top section shows east wall structures as visible from crest of Whaleback.

Figure 5-6. North limb of Whaleback anticline viewed from Station 1. Extensional faults (Stage VI) define “grabens” that are both parallel to and transverse to the fold hinge. The “grabens” overprint Stage IV wrench and thrust faults. Station 5 is labeled.
Station 2

The Stage IV wrench and wedge (thrust) faults of Figure 5-4 can be studied here. Note that slickenlines on wrench faults are parallel to the fault-bedding intersection, indicating that they formed prior to folding and were later folded to their present attitude during Stage V. Slickenlines on wedge faults bisect the dihedral angle between wrench faults and were formed at the same time. Spaced cleavage (primary crenulation and pressure solution mechanisms) occurs in shales upslope to the southwest. Ironstone concretions are the stiffest member of the sedimentary succession (McAleer, 2004) showing only Stage II joints and surface slickenlines that demonstrate how other strata have shortened and flowed around them. The contact between concretions and their enclosing rock are shear planes or boundary zones between different structural lithic units. The sequence of structural stages is established by offset of Stage II joints by Stage III pressure solution cleavage and by drag of Stage III cleavage-bedding intersections against Stage IV wrench faults. All of these structures formed by layer-parallel shortening in horizontal beds prior to folding.

While walking eastward between Stations 2 and 3, you can see Stage II joints in ironstone concretions, ductility contrast between ironstone and sandstone or shale, and a major wrench fault that is the west boundary of the thrust slice of Figure 5-4.

Station 3

The east end of the thrust slice illustrated in Figure 5-4 can been seen from here. On the Whaleback anticline to the north, wrench faults with intricate slickenline patterns indicate overlap between Stage IV faulting and Stage V folding. Stage VI strike and transverse extensional faults and "grabens" are also well exposed.

Station 4

Here, looking at the hinge of the Whaleback, you can observe extensional features such as filled veins and jointing surfaces, especially along the upper layers of the sandstone.

Station 5

The crest of the Whaleback anticline provides the best view of the fold disharmony to the east (Fig. 5-5). Stage II hydraulic joints on the whaleback and the Stage IV wrench and wedge faults and Stage VI strike joints (of release or buckling origin) on the south wall. Note that the Stage VI strike joints are not symmetrical with the acute bisectors and slickenlines of Stage IV wrench and wedge faults, indicating that the structural array formed in response to differently oriented strains - Stage IV layer parallel shortening, versus Stage VI extension due to fold buckling.

Station 6  *(Optional – please watch your step if you wish to visit Station 6.)*

Walking along the crest of the Whaleback from Station 5 towards Station 5-6, you pass over abundant pencil cleavage, (elongate pieces of rock formed by breakage along the intersection of bedding and cleavage surfaces). Pencil cleavage is especially prominent to the southeast of the crest as the Whaleback plunges under the surface to the east. Station 6 provides a close-up view of disharmonic folding along the eastern wall where one can see clearly the concentric folding in the sandstones versus the faulted and more kink-shaped folds in shales and coals (Fig. 5-5).

Station 7

From Station 5, walk west along the crest of the Whaleback, and turn north along the path. Continue west into a small valley and walk to the area marked Station 7 on Figure 5-3, then proceed west for about 125 additional meters. At this locale we can find examples of Carboniferous "tree" trunks and root balls (probably *Lepidodendron* or *Sigillaria*) about 10
meters above the valley floor on the northern valley wall. There are also exposed fossilized root balls in the talus along the valley floor (Figure 5-7).

Figure 5-7. Oblique view of tree trunk at Station 7.

References


STOP # 6: BEAR GAP QUARRY

Stop Leader – Aaron Bierly, Pennsylvania Geological Survey

Introduction

Stop six is located in Ralpho Township, Northumberland County approximately 1.8 miles south east of Elysburg. The Bear Gap quarry has been open since 1968 and was purchased by the current owners, Corson Quarries, Inc., in 2006 (B. Corson, personal communication). The strata being quarried is the Devonian-aged, Trimmers Rock Formation which is crushed for aggregate. The area of the quarry was mapped by H. A. Arndt, G. H. Wood, Jr., and R. F. Schryver in 1973 though the quarry itself was apparently not investigated. Figure 6-1 shows the location of Bear Gap Quarry.

Structure

The Bear Gap quarry is located on the southern limb of the Selinsgrove Anticlinorium. Beds commonly strike from 053 to 082 with dips ranging from 23 to 53 degrees southeast. Small local folds are present and a previously unmapped anticline/syncline pair can be observed in the northwestern and northeastern corners of the quarry as seen in Figures 6-2 A and B.

Two major fracture patterns are well established in the Trimmers Rock. The first is a joint or cleavage that nearly parallels bedding strike, but dips 40 to 70 degrees to the northwest. This fractures is often well exposed in weathered road cuts and stream banks and commonly spaced from 1 to 12 inches apart. The second fracture is a joint running sub perpendicular to perpendicular to the prior fracture and commonly dips between 70 to 90 degrees.

Figure 6-3 is a geologic map of the area surrounding Bear Gap Quarry. LIDAR illustrates the valley formed by the more easily eroded shales of the underlying Mahantango Formation on the South Selinsgrove anticline to the north of the quarry.
Figure 6-3. Geologic map using LIDAR image to highlight topography, showing Bear Gap Quarry and surrounding area.
Stratigraphy and Depositional Environment

The Trimmers Rock Formation in the immediate proximity of the quarry is dominantly a medium gray to light-olive gray siltstone to very-fine grained sandstone with subordinate interbeds of shale (Figure 6-4). Sedimentary features observed include laminations, cross laminations, and soft sediment deformation structures (Figure 6-5). The formation is approximately 2,120 feet thick.

This formation formed in a marine environment which is supported by the presence of fossil invertebrates (Figure 6-6) including brachiopods, crinoids, bivalves, bryozoans, and sponges (rare). The source of sediment was derived by deltaic and shore line currents (Harper 1999). Repetitious cycles of shale and siltstone were observed in the basal third of the formation and are interpreted by the author to be turbidites; possibly suggesting, at least locally, that the basal Trimmers Rock formation was deposited on the steeper slopes of a deltaic ramp. An excellent exposure of these turbidite deposits can be seen approximately 2.5 miles east-northeast along Pineswamp Road near the intersection of Keller School Road (Figure 6-7).

The upper contact of the Trimmer Rock Formation quickly grades into the Irish Valley Member of the Catskill Formation and occurs where the marine setting gives way to terrestrial environments. This change in environment is often mapped at the first occurrence of red beds but fossilized rootlets and plant debris may give hint in the changing of the formations. Periodically, marine zones reoccur within the Irish Valley Member. The Trimmers Rock Formation tends to be more resistant to erosion compared to the adjacent formations creating a more hilly terrain with deeply incised headwater ravines and hollows.

The lower contact with the Brailler Formation (also marine in origin) is transitional and is defined by a change in lithology from a dominantly siltstone and very fine grained sandstones sequence (Trimmers Rock Formation) downward to a dominantly dark gray to olive gray shale with thin sandstone interbeds (Brailler Formation). Lack of extensive exposures and the gradational nature of these two formation likely led to these formations being mapped together as one undivided unit in the 1971 and 1973 USGS geologic maps of the Mount Carmel Quadrangle and South Half of the Shamokin Quadrangle.
Figure 6-5 (left) - An exposure along Pineswamp Road bearing soft-sediment deformation features. Note Shale squeezing up between siltstone bed above rock hammer (arrow).

Figure 6-6 (below) - Marine fossils found in the Trimmers Rock Formation near the Bear Gap Quarry. Photo is in grayscale with brightness and saturation of the photo altered to bring out details. Left is a fossilized sponge, center contains a bryozoan and brachiopod, to right is a crinoid. Scale bar is in centimeters.

References


Figure 6-7. repetition of alternating shale and siltstone deposition in this exposure along Pineswamp Road are interpreted as delta ramp turbidites.
BONUS STOP: CENTRALIA MINE FIRE DRAINAGE TUNNEL

Stop Leader – Jennifer Elick, Susquehanna University

Location

Take PA-61 N to the intersection of PA-61 and PA-42 and turn right on to Big Mine Run Road. Follow this road for 1.5 miles and pull off to the right. Along the road is an ~100-ft-long footpath through the woods, which leads to the Centralia mine drainage tunnel (Fig. 1).

Figure 1. Map directions to Centralia mine fire drainage tunnel. Bonus Stop is located at the bottom right hand corner of the map. Centralia Mine Fire Stop #1 sites are shown as reference.

Centralia Mine Fire Drainage Tunnel

The tunnel was constructed to drain standing water from the mine so that the coal could be mined without pumping large quantities of water to the surface (PADEP, 2013). The tunnel discharges ~2300 gal/min on average (3.3 million gal/d) (PADEP, 2013). The groundwater emanating from the mine system is green in color, with a pH of 3.7–3.8 (Fear et al., 2010) and low dissolved oxygen content. The rim of the ponded area and shallow areas are orange and coated with iron oxide. The water draining the mine has a very high iron and sulfur content and is considered toxic to many forms of aquatic life (PADEP, 2013). The iron and sulfur are products of pyrite oxidation.

This stop serves as a reminder that many mine-related environmental issues still affect the region of Centralia, as well as other towns and cities in the anthracite coalfields. The coal fire is an important chapter in the mining history of Centralia, along with acid-mine drainage and polluted streams, coal tailings and culm heaps, forest removal and environmental displacement, and mined-out strip pits filled with garbage. It is a reminder of the adverse legacy of coal mining on the environment.

References

Pennsylvany?  Yep!  It used ta be right over thar!  'Course, thet were ‘fore the price o’ coal went up!

Reprinted from the 1980 Field Conference of Pennsylvania Geologists Field Trip Guidebook
DAY 2 ROADLOG

Day 2 Road Log route map with STOP locations

MILES

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<td>Leave parking lot of MainStay Suites.</td>
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<td>Stop sign. Turn right on SR 1008.</td>
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<td>Turn right onto ramp to I-81 South.</td>
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<td>Merge with I-81 South.</td>
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<td>3.9</td>
<td>4.2</td>
<td>Excellent view of COGEN plants to right, John B. Rich Memorial Power Station on top of the distant ridge and Wheelabrator Frackville just off the Interstate. Wheelabrator Frackville went on line in May 1989. It has a net power output of about 42 MW and consumes about 550,000 tons/year of culm having a heat value of about 3500 BTU/lb. The Frackville State SCI uses the process steam.</td>
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<td>0.4</td>
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<td>Cut in Pottsville Formation.</td>
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1.6  6.4  Frackville SCI to left.
0.7  7.1  Bear right onto ramp for PA 61 South (St. Clair).
0.5  7.6  Merge with PA 61 South at south end of Frackville.
0.3  7.9  Schuylkill Mall overpass.
0.4  8.3  Enter Broad Mountain gap.
0.3  8.6  Deep cut in Pottsville conglomerate.
0.5  9.1  Deep cut in Mauch Chunk to right.
0.2  9.3  Enter New Castle Township.
0.1  9.4  First of several cuts in south-dipping Mauch Chunk to right.
0.6 10.0  Cut in Mauch Chunk sandstone to right.
0.2 10.2  Cut in Mauch Chunk behind fence.
0.3 10.5  Cut in Pottsville conglomerate to right.
0.4 10.9  Dark Water.

Just to right is a shaft of the old Repplier Colliery north of the Mine Hill anticline. Opposite the shaft on the other side of Dark Water Road is the Repplier Water Level Tunnel (see Wood, 1972).

**Shaft of the old Repplier Colliery at the intersection of PA 61 and Dark Water Road, mile (10.9)**

0.7  11.6  Traffic light at Coal Creek Commerce Center (STOP 11 to left).
0.6  12.2  Traffic light—Hancock Street, St. Clair, to left, Wade Street to right.
0.4  12.6  Traffic light at Russell Street.
0.2 12.8 Traffic Light at Ann Street. Cut in south-dipping Llewellyn sandstone to right.

0.2 13.1 Long cut in Llewellyn Formation to right, with anticlinal kink fold at north end and south-dipping strata in southern part, where a folded and sheared coalbed crops out at the top.

0.3 13.4 Cut in south-dipping Llewellyn Formation to right exposes black shale and rusty-weathered sandstone at the north end, a 20-foot-thick black shale and coal interval in the middle, and thick-bedded, well-jointed, coarse-grained sandstone and conglomerate at the top.

0.1 13.5 Traffic light at Mall Drive and Tunnel Road.

0.1 13.6 Long “canyon” cut in south-dipping Llewellyn Formation. At the north end is a sheared coal bed, with mostly rusty weathered sandstone and a few thick, recessed intervals of black shale in the south part.

0.4 14.0 Traffic light at Pottsville Diner. Just beyond on the left is a cut in Llewellyn sandstone with a well-defined kink fold at the north end.

0.5 14.5 Long cut in south-dipping Llewellyn Formation at curve to left. The strata exposed are in the vicinity of the Peach Mountain (No. 18), Tunnel (No. 19), and Rabbit Hole (No. 20) coalbeds (Wood, 1972).

0.1 14.6 Grand view of Pottsville ahead. Note Yuengling Brewery; Sharp Mountain on horizon with Second Mountain visible through Schuylkill River gap.

Pottsville was established as a village in Norwegian Township in 1819 and incorporated as a borough on 19 February 1828. It became the county seat in 1851, replacing Orwigsburg. As the 19th century progressed Pottsville became an ever more significant iron-producing, anthracite-mining, and railroad hub—the most important town in the Southern
Anthracite field. In the early 1870’s the Philadelphia and Reading Coal and Iron Company (predecessor of Reading Anthracite) established its headquarters on Centre Street (later moved to Mahantongo Street), and later in that decade several Molly Maguire trials and executions took place in the old courthouse and still-extant stone prison in the northern part of town. It was chartered as a third-class city on 22 March 1911.

It is immortalized in American literature as the “Gibbsville” of novelist and short-story writer John O’Hara (1905-1970).

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<td>Traffic light at Norwegian Street.</td>
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<td>0.2</td>
<td>On Bunker Hill to the right is a magnificent, but somewhat neglected, statue-monument honoring statesman Henry Clay (1777-1852), erected in the early 1850’s by the powers-that-be of Schuylkill County in recognition of Clay’s support of a high tariff on iron and iron products—a significant spur to the accelerating anthracite-iron industry of the time.</td>
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<td>0.1</td>
<td>Traffic light at PA 209 intersection. Enter construction zone. Continue straight ahead.</td>
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Traffic light in construction zone. Directly ahead to left is the upper part of the reference section of the Pottsville Formation and the north end of STOP 7.

Long cut in Mauch Chunk Formation to left (part of STOP 7).

Turn left onto Reservoir Road.

Turn right into Tumbling Run Water Treatment Facility. Proceed to parking area, probably just to right of entrance. The dam here is the lower of two dams on Tumbling Run, a west-flowing tributary of the Schuylkill River that flows in the Mauch Chunk valley between Second Mountain (Pocono Formation) and Sharp Mountain (Pottsville Formation). The dams were originally built in the 1830’s to supply the Schuylkill Canal. From 1890 to 1914 the lake above the upper dam was the site of the Tumbling Run Amusement Park, the entertainment centerpiece of the Pottsville area. The park boasted a hotel, theater, dance pavilion, amusement hall, roller coaster, carousel, and skating rink—as well as dozens of boathouses along the shores of the lake. The characters in John O’Hara’s *Ten North Frederick* (1955) and *The Lockwood Concern* (1965) spent many a pleasant day there.

During the 19th and early 20th centuries, ice was harvested from the two Tumbling Run lakes.

**STOP 7. Pottsville and Mauch Chunk Formation in PA 61-cut through Sharp Mountain on PA 61**

Leave STOP 7, turning left on Reservoir Road and proceeding back to PA 61.

Stop sign. Turn right on PA 61. (Not allowed during construction)

Traffic light at US 209 (Mauch Chunk Street).

Ledges to right are Llewellyn Formation.

Deep cuts to right behind buildings mark the site of a major railroad coal-loading facility dating back to the 19th century.

Cut in south-dipping Llewellyn Formation at curve on right.

Cut in kink-folded Llewellyn Formation on right, just before Pottsville Diner (on left).

Enter Norwegian Township.

“Canyon” in south-dipping Llewellyn Formation.

Directly ahead is the steep south slope of synclinal Broad Mountain, with anticlinal Mine Hill just in front of it.

Traffic light at Ann Street. Enter borough of Saint Clair, the downtown area being to the right. St. Clair was named for St. Clair Nichols, who co-owned the land and assisted in laying out the town in the early 1830s. (More on St. Clair at STOPS 10 and 11.)
PHMC Historical Marker to right reads:

JOHN SINEY (1831-1880)
Pioneering labor organizer and leader of the Workingmen’s Benevolent Association (WBA) of Schuylkill County, a union of anthracite mineworkers. Formed nearby in 1868, WBA had 20,000 members in 22 districts; secured state mine safety laws and the first labor contract in the industry. Siney was president of the Miners’ National Association and was active in the Greenback labor Party.

Traffic light. Turn left on Wade Street.
Enter Arnots Addition (part of St. Clair borough).
Enter New Castle Township and village of Wadesville.
St. Boniface and St. Mary’s Cemeteries to left. John Siney is buried in the latter.

Old stripping to right in distance.
Stop sign. Turn right on West Wade Street.
Old cemetery to left. Graves here date back nearly to 1800. Nearly all of the 19th century monument stones are marble and deeply weathered. Quite a few are inscribed in German, including one slate stone that is still quite legible. The few 20th century markers are granite.

Road to right (just before large abandoned house) leads into the upper south wall of the “Mammoth” Wadesville stripping. Continue ahead.
Another stripping access road to right.
Y-intersection; continue on road to right, East Darkwater Road.
1.2 22.5 Turn right into entrance to Pottsville Materials. Proceed back to Wadesville strip mine overlook.

**STOP 8. Wadesville strip mine of Reading Anthracite Company**  
40.718576 N, -76.210149 W

**STOP 9. Pottsville Materials Company quarry**  
40.724997 N, -76.218456 W

0.3 22.8 Exit taking left on Darkwater Road. Take second left onto haul road into Wadesville pit. Visit pit (weather permitting) that was discussed at Stop 8 and viewed from above at Stops 8 & 9  
Exit Wadesville pit. Turn left.

0.4 23.2 Y-intersection; stay left to stop sign, then continue straight on West Wade Road.

0.6 23.8 Turn left (blind intersection near transformer) onto E. Wade Road and continue on to PA 61.

0.6 24.4 Enter Wadesville.

0.2 24.6 Enter St. Clair.

0.3 24.9 Traffic light. Go straight on Hancock Street and enter “downtown” St. Clair.

0.2 25.1 Cross Mill Creek, then turn right on Nicholas Street.

0.1 25.2 To right, in the former St. John’s Lutheran church, is the home of the St. Clair Community and Historical Society.

0.1 25.3 Stop sign. Turn left on Lawton Street.

0.4 25.7 Enter parking lot.

**STOP 10 and LUNCH. St. Clair Fish and Game:**  
Mining history, geology, and paleontology of the Pine Forest Shaft and Ravensdale Tunnel  
40.720833 N, -76.179167 W

End of LUNCH. Leave STOP 10, exit parking lot.

1.0 26.7 Return to PA 61 by same route on Lawton, Nicholas, and Hancock Streets. Turn right, north on PA 61.

0.5 27.2 Traffic light. Turn right on Terry Rich Road into Coal Creek Commerce Center. Continue ahead 0.1 mile, then turn left and proceed east along highwall past Home Depot 0.4 mi to “end” of paved road to parking area.
STOP 11. Coal Creek Commerce Center:
(A) Mammoth (No. 8) coalbed seatrock
(B) Lower Llewellyn/Pottsville stratigraphy
& St. Clair mining history
40.729876 N, -76.190776 W

0.5 27.4 End of STOP 11. Return to PA 61, turning left at traffic light back onto PA 61. Proceed south on PA 61.
0.6 28.0 Traffic light. Turn left on W. Hancock Street in St. Clair.
0.2 28.2 Cross Mill Creek.
0.4 28.6 Enter East Norwegian Township. We are now on what the locals call the “Burma Road.”
0.4 29.0 Large reclaimed strippings on both sides of road.
0.4 29.4 Enter Blythe Township.
1.3 30.7 “Shooting Gallery” on right.
0.1 30.8 Turn right into parking area. Walk back a half mile through woods to old strippings.

STOP 12. St. Clair plant fossil site
(Reading Anthracite Company)
40.738439 N, -76.141556 W

End of STOP 12. Return to “Burma Road”; continue northeast.
1.0 31.8 Abandoned stripping to right.
0.2 32.0 Another abandoned stripping to right.
1.6 33.6 Enter Ryan Township.
1.7 35.3 Mountain Valley Golf Course.
0.4 35.7 Enter Mahanoy Township.
0.1 35.8 Enter Ryan Township, cemetery to right.
0.3 36.1 Pass under I-81.
0.2 36.3 Coal operation to left.
0.5 36.8 Stop sign. Ahead is the German Protestant Cemetery. Turn right on Morea Road.
0.1 36.9 Far off to left is a large active stripping.
0.3 37.2 FABCON to right.
0.5 37.7 Turn right into MainStay Suites.
0.1 37.8 Parking lot of MainStay Suites.

End of Day 2 Field Trip! Have a safe trip home!

References

Dempsey, T., [no date], Schuylkill County Patch Towns: [Schuylkill County Historical Society].


FISSILITY - (fí-síl'-i-tí, n., L. fissilis, past participle of findere, to split) A characteristic of shales that proves the theory that clay mineralogists are flaky.
STOP #7: UPPER MISSISSIPPIAN TO MIDDLE PENNSYLVANIAN STRATIGRAPHIC SECTION, POTTSVILLE, PENNSYLVANIA

Stop Leaders — Rudy Slingerland, The Pennsylvania State University, Edward Simpson, Kutztown University

Introduction

The rocks at this site are exposed along a road cut on the eastern side of Pennsylvania 61, 0.3 to 0.5 mi (0.4 to 0.8 km) south of Pottsville, Pennsylvania (Figure 7-1), on the southern margin of the Southern Anthracite field where the Schuylkill River has cut a deep gap in Sharp Mountain. The outcrop exposes a 2,000-ft (600+-m)-thick section of upper Carboniferous molasse, representing the northwestward in-flux of clastic detritus into the Appalachian foreland basin from an orogenic source terrane formerly situated along the present Atlantic Coastal Plain. Subsequent to their deposition, these sediments were deeply buried, metamorphosed, technically deformed in the Alleghanian Orogeny, uplifted, and largely eroded. The Southern Anthracite field now preserves the thickest, coarsest-grained, most proximal to the source, and most stratigraphically continuous occurrence of upper Carboniferous molasse in the central Appalachians.

Of particular interest here is an alternation of facies that reflects a gradual but progressive evolution of depositional environments from a semi-arid alluvial plain (Mauch Chunk Formation), to a semi-humid alluvial plain (Pottsville Formation), to a humid alluvial plain dominated by peat swamps (Llewellyn Formation). This transition, documented by dramatic changes in sedimentary facies, facies sequences, and maximum clast sizes, clearly reflects incipient Alleghanian tectonism and regional (perhaps even world-wide) climatic changes occurring near the end of the Mississippian. Early investigators (e.g., Meckel, 1967) emphasized tectonics as the origin of the facies changes. Later Levine and Slingerland (1987) argued that the transition arises mainly from a change to more humid climatic conditions in the Pennsylvanian.
that produced larger sediment yields and stream discharges. At this stop we will reconsider these two hypotheses.

**Stratigraphic And Geomorphic Overview**

Molasse sediments of the Anthracite region are stratigraphically subdivided on the basis of grain size and predominant coloration (Wood and others, 1969). The fine-grained, red Mauch Chunk Formation (Middle to Upper Mississippian) intertongues with and is replaced by the coarse-grained, gray Pottsville Formation (Lower to Middle Pennsylvanian), which in turn gives way to the finer-grained, gray to black, coal-rich Llewellyn Formation (Middle Pennsylvanian), representing the youngest extant molasse in the region. The former presence of many miles (kilometers) of overlying rocks is implied by the high coal rank and compaction of the Llewellyn sediments (Paxton, 1983; Levine, 1986).

The Mauch Chunk Formation is informally subdivided into three members (Wood and others, 1969). The middle member represents the ‘type’ Mauch Chunk red bed lithofacies. The lower and upper members represent the zones of intertonguing with the underlying Pocono Formation and the overlying Pottsville Formation, respectively. The upper contact of the Mauch Chunk is defined as the top of the uppermost Mauch Chunk-type red bed (Figure 7-2).

The Pottsville Formation is formally subdivided into three members (Wood and others, 1956), each representing a crudely fining-upward megacycle. Of the three, the Tumbling Run and the Sharp Mountain members are the coarser-grained, while the intervening Schuylkill Member is finer-grained and contains a greater proportion of coal. The lower contacts of the Schuylkill and Sharp Mountain members are defined at the base of major conglomeratic units. The base of the Schuylkill Member is by no means obvious at the outcrop, but the “Great White Egg” quartz pebble conglomerate at the base of the Sharp Mountain Member is very distinctive. The contact between the Pottsville and Llewellyn Formations is placed at the base of the lowermost thick, stratigraphically persistent coal horizon, the Buck Mountain (#5), which has been correlated over large areas of the Anthracite fields (Wood and others, 1963).

Chronostratigraphic age designations in the Anthracite region, based upon the 13 upper Paleozoic floral zones defined by Read and Mamay (1964; also see Edmunds and others, 1979, Fig. 11), indicate the Pottsville section is conformable, extending from Zone 3 in the upper Mauch Chunk Formation (Chesterian Series) to Zone 10 in the lower Llewellyn Formation (Des Moinesian/Missourian Series), a duration of approximately 20 million years. The Mauch Chunk/Pottsville contact, occurring between Zones 3 and 4, corresponds roughly to the Mississippian/Pennsylvanian systemic boundary. In areas of the central Appalachians other than the Southern and Middle Anthracite fields, Zones 4, 5, and 6 are absent, suggesting the presence of a significant disconformity between the youngest Mississippian and oldest Pennsylvanian strata (see discussion in Edmunds and others, 1979).

The strata exposed at the site are slightly overturned and comprise part of the southern limb of the Minersville Synclinorium, forming the southern margin of the Southern Anthracite field. They attained their present attitude during the late Paleozoic Alleghanian Orogeny when northwest-directed tectonic forces produced a progression of deformational phases that migrated northwestward across the foreland basin. At the Pottsville site all structural phases are superposed (Wood and Bergin, 1970; Nickelsen, 1979).

The structure and stratigraphy of the upper Paleozoic molasse sequence are revealed geomorphically by the relative resistance to erosion of the near-vertical component units. The Pocono sandstone, subjacent to the Mauch Chunk Formation, upholds Second Mountain, the major ridge visible to the south of the Pottsville section. The Mauch Chunk Formation underlies
the valley between Second and Sharp mountains. The distinctive double ridge of Sharp Mountain is formed by the Tumbling Run and Sharp Mountain members of the Pottsville Formation. The Schuylkill River, which excavated the gap in Sharp Mountain, flows southeasterly across the Valley and Ridge Province on its course to the Chesapeake Bay, opposite to the streams that originally deposited the Pottsville sediments.

Figure 7-2. Stratigraphic column of Pottsville section
Sedimentology of the Pottsville Section — Facies States and Composition

Sedimentary bed forms, sediment composition, facies sequences, and paleobotany reveal a significant alteration in paleo-climatic conditions across the Pottsville section, ranging from generally semi-arid, poorly vegetated conditions at the base to perennially humid, lush conditions at the top. Ten general facies have been defined at this site and are described in Table 1. Transition matrix analysis reveals two repeating motifs, one characteristic of the Mauch Chunk and one of the Pottsville. When compared to facies sequences from modern environments of deposition, the Mauch Chunk sequence is similar to that of Bijou Creek, Colorado, a sandy, braided, ephemeral stream subject to catastrophic floods (Miall, 1977). Facies S3 and S4 probably comprised sand flats or shallow channel deposits; S5i and S2t comprised waning flow deposits or overbank deposits more removed from the active channel. M1 represents intrachannel, slack water deposits and M2 represents overbank soils.

The Pottsville sequence is similar to that produced by the Donjek River, Yukon Territory, a gravel-sand mixed bedload, perennial braided stream (Miall, 1977). Facies G2, S1, and S3 formed in the lower parts of the active channels by longitudinal braid bar migration. Facies S2t and S5t formed in the upper parts of active channels or minor channels and on the tops of braid bars. Facies S5i and M1 formed on bar tops, abandoned channels, and overbank areas, and facies C was deposited in inter-channel swamps. The channels forming the Pottsville Formation were deeper with greater cross-sectional areas, and lower width/depth ratios than those forming the Mauch Chunk Formation. In consequence, maximum clast size is greater as is the thickness of cross-bed sets.

Sandstone petrology, organic matter content, clay mineralogy, and features of the paleosols (Table 1) all show a progressive trend to more highly leaching, less oxidizing (i.e., more humid) conditions higher in the section. Sandstones are compositionally mature throughout the section but become even more mature up section. The Tumbling Run Member of the Pottsville Formation contains the highest variety and proportion of non-quartzose fragments while the Sharp Mountain Member contains the highest proportion of vein quartz (Meckel, 1967). Preservation of organic matter in the upper part of the section implies conditions of low Eh, maintained by continuous saturation by stagnant or slowly moving water. Clay minerals are enriched in alumina and depleted in iron higher in the section indicating a greater degree of chemical and biological leaching.

Paleosols occurring throughout the section are particularly useful in revealing paleo-environmental conditions. Most paleosols of the Pottsville and Llewellyn Formations formed as underclays beneath peat swamps and, therefore, must have been water-saturated during most of their development. In contrast, paleosols of the Mauch Chunk Formation, classified as vertisols by Holbrook (1970), exhibit a variety of features indicating episodic wetting/drying cycles (Table 1).

Caliche, occurring as thin, bed-parallel laminae or in nodular layers less than 3 ft (1 m) in thickness is common in the middle member of the Mauch Chunk (Figure 7-2) and occurs occasionally in the upper member. Caliche forms in seasonally arid conditions when surface evaporation produces supersaturation of dissolved salts, especially calcium carbonate and silica. The laminar caliche is interpreted to have formed at the sediment surface in shallow ponds during evaporative cycles (Holbrook, 1970). A surface or near-surface origin is indicated for the nodular caliche as well (Holbrook, 1970) based on: (1) sedimentary laminations that pass from the surrounding sediment into the concretions, (2) nodules occurring as intraformational clasts in conglomerates, (3) the presence of carbonate as nodules in the shales but not as cement in the adjacent sandstones, and (4) ball and pillow structures occurring between the nodules and the underlying (but not the overlying) sediments.
**TABLE 1 - FACIES STATES, SEQUENCES, COMPOSITION, AND FEATURES OF POTTsville SECTION.**

<table>
<thead>
<tr>
<th>CODE:</th>
<th>$G_1$</th>
<th>$G_{STP}$</th>
<th>$S_1$</th>
<th>$S_{STP}$</th>
<th>$S_3$</th>
<th>$S_4$</th>
<th>$S_{SF21}$</th>
<th>$M_1$</th>
<th>$M_2$</th>
<th>$C$</th>
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<tbody>
<tr>
<td>SYMBOL:</td>
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<td><img src="image2" alt="Image" />.</td>
<td><img src="image3" alt="Image" />.</td>
<td><img src="image4" alt="Image" />.</td>
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<td><img src="image9" alt="Image" />.</td>
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</tr>
<tr>
<td>INTERNAL BED FORMS:</td>
<td>Subangular, interbed. Coarse sand &amp; pebbly sand.</td>
<td>Lenticular medium bed.</td>
<td>Medium to very thick, irregular beds.</td>
<td>Matrix supported, conglomerate (Note 1).</td>
<td>Low angle, laterally extensive, wedge sets.</td>
<td>Lenticular medium bed.</td>
<td>Domethic - thick, tabular or wedge sets.</td>
<td>Tabular or wedge sets.</td>
<td>Lenticular medium bed.</td>
<td>Lenticular medium bed.</td>
</tr>
<tr>
<td>COMPOSITION MAUCH CHUNK TYPE:</td>
<td>(No specific data)</td>
<td>Maturity</td>
<td>Monosized quartz</td>
<td>Fedlagin</td>
<td>Rock fragments plus minor.</td>
<td>90% of M.</td>
<td>C. Shales are red beds (organ.) - rich in carbonates, calcium &amp; iron.</td>
<td>80% illite &amp; 20% chlorite.</td>
<td>60% illite &amp; 20% chlorite.</td>
<td>None.</td>
</tr>
<tr>
<td>PV. - LLEWELLYN - TYPE:</td>
<td>Vale (?).</td>
<td>Maturity</td>
<td>Fedlagin</td>
<td>Rock fragments plus minor.</td>
<td>90% of M.</td>
<td>C. Shales are red beds (organ.) - rich in carbonates, calcium &amp; iron.</td>
<td>80% illite &amp; 20% chlorite.</td>
<td>60% illite &amp; 20% chlorite.</td>
<td>None.</td>
<td></td>
</tr>
<tr>
<td>TYPICAL BASE:</td>
<td>Undersized sand.</td>
<td>Undersized sand.</td>
<td>Undersized sand.</td>
<td>Undersized sand.</td>
<td>Gradational from $S_1$ or above from $M_1$.</td>
<td>Gradational from $S_4$ or above from $M_1$.</td>
<td>Gradational from $S_2$ or above from $M_1$.</td>
<td>Gradational from $S_3$ or above from $M_1$.</td>
<td>Gradational from $M_1$.</td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
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<td>Undersized sand.</td>
<td>Undersized sand.</td>
<td>Undersized sand.</td>
<td>Gradational from $S_1$ or above from $M_1$.</td>
<td>Gradational from $S_4$ or above from $M_1$.</td>
<td>Gradational from $S_2$ or above from $M_1$.</td>
<td>Gradational from $S_3$ or above from $M_1$.</td>
<td>Gradational from $M_1$.</td>
<td></td>
</tr>
<tr>
<td>OTHER SYMBOLS:</td>
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<td><img src="image13" alt="Image" />.</td>
<td><img src="image14" alt="Image" />.</td>
<td><img src="image15" alt="Image" />.</td>
<td><img src="image16" alt="Image" />.</td>
<td><img src="image17" alt="Image" />.</td>
<td><img src="image18" alt="Image" />.</td>
<td><img src="image19" alt="Image" />.</td>
<td></td>
</tr>
</tbody>
</table>

(Compositional information from Meckel, 1967; Wood et al., 1969; Hoibrock, 1970; Hosten et al., 1970)
The composition of the organic matter and clay minerals has been strongly influenced by diagenetic conditions during burial. The coal has been elevated to anthracite rank. Expandable layer clays are not present and illite is of the highly ordered 2-M form, representing “anchizone” alteration. Pyrophyllite is an anchizone alteration product of kaolinite that forms only in Fe-depleted rocks (cf., Hosterman and others, 1970, Table 1). Ammonium illite is thought to form at high coal rank in organic matter-rich sediments by nitrogen released during late stages of coalification (Paxton, 1983). These transformations imply temperatures of ca. 225-275°C and 4 to 6 mi (6 to 9 km) of burial.

**Tectonic and Climatic Significance of the Pottsville Section**

During deposition of the Pottsville section the depositional margin of the basin lay in the vicinity of Philadelphia as indicated by paleocurrent directions and regional trends in maximum grain size (Pelletier, 1958; Meckel, 1967; Wood and others, 1969). Northeast-flowing streams carried sediments toward the basin axis, which trended northeast-southwest across western Pennsylvania. Time equivalent upper Carboniferous rocks are alluvial in eastern Pennsylvania and deltaic and shallow marine to the west (Edmunds and others, 1979). The Mauch Chunk Formation documents a relatively quiescent interval represented variously by fine-grained sedimentation and soil development in the east, an erosional disconformity toward the west, and shallow marine carbonate sedimentation along the basin axis. The influx of coarse clastics in the Pottsville interval has traditionally been ascribed to tectonic uplift in the source (e.g., Meckel, 1967), but while this might be partly true, it is neither a necessary nor sufficient explanation. It also is inconsistent with the flexural modeling of Beaumont et al. (1987; 1988) who used thicknesses of Appalachian basin fill at various times to back-calculate the magnitudes and locations of the necessary crustal loads. During the Early Pennsylvanian the loads were far south in Virginia and of modest thickness (Figure 7-3A); it was not until the Permian that the crust east of Pennsylvania was loaded (Figure 7-3B).

Figure 7-3. A) Lower Pennsylvanian isopach map (contours in feet). Model prediction at time of deposition showing the load thicknesses (km) necessary to produce the model subsidence in the Appalachian and Arkoma basins. Dash and dot patterns denote observed and restored shale, and fine and coarse sandstones. Light and dark shading represent coastal plain and coal swamp environments. Large arrows show the inferred major sediment dispersal directions. Fine arrows show the migration of the peripheral bulge during the advance of the overthrust loads in the Ouachita orogen;

B) Permian isopach map (contours in feet). Model prediction at time of deposition showing the load thicknesses (km) necessary to produce the model subsidence in the Appalachian and Arkoma basins. Shading represents regions deformed by thrusting in which the extra thickness of sediment may, in part, be occupied by older sediments that were shortened and thickened during thrusting.
The simplest explanation for the Mauch Chunk to Pottsville facies progression is a change to more humid climatic conditions in the Pennsylvanian that produced larger sediment yields and stream discharges. This climate change arose as eastern North America drifted northward from under the southern descending limb of the Hadley cell to under the equator.

The interpreted tectonic and paleoenvironmental setting during Mauch Chunk deposition would have resembled in many respects the current alluvial plain extending from the Zagros Mountains to the Persian Gulf where arid conditions produce little clastic influx from the technically active mountain belt. The adjacent foreland basin axis—lying parallel to the mountain belt—receives primarily carbonate sedimentation. Were a future global climatic change to transform the Middle East into a humid region, the margins of the Persian Gulf could perhaps evolve into a broad peat-forming environment such as existed in the Appalachian basin during Pottsville and Llewellyn times.

References


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**HARPER’S GEOLOGICAL DICTIONARY**

**AMPHIBOLE - A tree with a constantly bifurcating trunk.**
STOP # 8: WADESVILLE ANTHRACITE SURFACE MINE – READING ANTHRACITE COMPANY

Stop Leaders – Daniel Koury and Nathan Houtz, Pennsylvania Department of Environmental Protection

Reading Anthracite Company is one of the oldest and largest mining companies in the Pennsylvania Anthracite Region. The company was founded in 1871 as The Philadelphia and Reading Coal and Iron Company by its parent company, The Philadelphia and Reading Railroad. The Company was formed in order to purchase coal lands in the Southern and Western Middle Anthracite fields and therefore insure revenue to the railroad. Although the company was originally formed to lease coal lands, as operators on these lands fell on hard times and were forced into bankruptcy, the company took over these operations and became a mining company.

Wadesville was originally developed by numerous collieries that worked in and around the area prior to 1828. The Wadesville shaft was formerly known as the Hickory shaft; which was dug beginning in 1864. In 1871 the mine was found to be on fire and water was turned into the mine from Mill Creek to drown it. The property was sold at sheriff sale in September 1876 to the Philadelphia and Reading Coal and Iron Company. On May 9th, 1877, an explosion of gas occurred, which resulted in the death of six men. After this, old workings again caught on fire and the mine was again flooded in 1878. The deep mine operation at the Wadesville Colliery was discontinued in 1930, and with the cessation of pumping, the water pool within the mine increased to such a high level that the overflow discharged into Mill Creek at Saint Clair from an abandoned Saint Clair Colliery shaft. In 1949, the Philadelphia and Reading Company, now Reading Anthracite Company, began a surface mine at Wadesville and they installed deep well pumps in the Wadesville Shaft to allow access to lower coal reserves. The Wadesville Shaft is approximately 700 feet deep.

Over the years Reading Anthracite Company has developed the large surface mine at Wadesville which encompasses nearly 400 acres and is over 500 feet deep. The operation is one of Reading’s largest, producing approximately 200,000 tons of coal per year. A 7800 Marion 35 cubic yard (cu yd) Walking Dragline removes the coal and a PC 4000 Kamatsu 29 cu yd Hydrologic Shovel removes the overburden. A Komatsu 18 cu yd Loader loads the coal into 150 ton Caterpillar trucks for transport to the New St. Nicholas coal breaker via a network of haulage roads. The excavation lies within a shallow syncline and is concentrated on splits of the Mammoth coal bed (Nos. 8 and 9) with a total thickness in excess of 40 feet (Figure 8-1). Three other coal beds are encountered and mined in pursuit of the Mammoth bed including the Four Foot (No. 9.5), Holmes (No. 10) and the Primrose (No. 11).

Figure 8-1. Drill location for the stratigraphic column
The Wadesville pit covers approximately 135 acres (Figures 8-2–8-7). In order to mine the Wadesville pit the minepool must be pumped. Exelon Generating, a nuclear power company, recognized that the minepool can be utilized as a reservoir. They pump up to 14.4 MGD at the Wadesville Shaft at certain times of the year to augment water from the Schuylkill River, to satisfy flow or temperature conditions of the river at the Limerick Generating Station 70 miles downstream.

![Figure 8-2. View looking West. Shows the proximity to the town of Arnotts Addition. Photo taken in 1999](image)

![Figure 8-3. View looking West/Southwest overview. Photo taken in 1999](image)

![Figure 8-4. View looking South. There has been substantial development since 1999. The large block of material in the mine against the south wall has been removed in recent years. Photo taken in 1999](image)

![Figure 8-5. View looking Southeast. Photo taken in 1999](image)

![Figure 8-6. Original photo of the Wadesville drill shown in closeup in Figure 8-1. View of the South wall near the southeast corner of the pit. Photo taken in 2002](image)

![Figure 8-7. View looking Southeast, as in Figure 8-5, above, 16 years later. Recent photo taken in 2015.](image)
STOP #9: POTTSVILLE MATERIALS
Stop Leader – Susan K. Brown, H&K Group

Introduction

Pottsville Materials (Entrance Latitude = N40° 43' 29.99', Longitude = W 76° 13' 06.44'”), owned by Pottsville Materials LLC, is a 179-acre area permitted by the Pennsylvania Department of Environmental Protection (PADEP) as a Large Noncoal Surface Mining Permit which produces construction aggregate and hot-mix asphalt (Figure 9-1). Prior to the initial permit date of October 14, 2009, the noncoal permitted area was part of the surrounding, larger Coal Mining Permit known as the Wadesville Mine, operated by Reading Anthracite Company. Through a partnership between The H&K Group and Reading Anthracite, the 179-acre site was carved out of the coal permit to form the non-coal permit in order to mine and process construction aggregates.

Figure 9-1. Panoramic view of Pottsville Materials quarry looking east

Geology

Pottsville Materials is located in the Anthracite Upland Section (previously part of the Appalachian Mountain Section) of the Ridge and Valley Physiographic Province of Pennsylvania. The dominant topography of the Anthracite Upland Section is that of low, linear to rounded hills formed by fluvial and glacial erosion acting upon the geologic structure that is characterized by narrow folds with steep limbs and numerous faults (Sevon, 2000).

More specifically, the site is situated on the Mine Hill Anticline, with the anticlinal axis trending northeast-southwest at approximately N 60-65°E. The site is underlain by the Pennsylvanian Period Llewellyn Formation (see Figures 9-7 & 9-8 at the end of Geology section), comprised of sandstone, conglomeratic sandstone, quartz pebble conglomerate, siltstone, shale, and numerous coal seams, and The Pottsville Formation, which is comprised of three members. The uppermost Sharp Mountain member, which consists of alternating beds of coarse-grained sandstone, conglomerate, minor siltstone and shale, and occasional thin coal seams, is found at the surface at the eastern most end of the permit area. The Sharp Member dips to the west beneath the Llewellyn Formation. Within the surface mining permit boundary, the main coal seams outcropping at the surface include the Buck Mountain (Coal No. 5), the Seven Foot (Coal No. 6) and the Skidmore (Coal Nos. 7 and 7L). The Buck Mountain seam marks the boundary between the Llewellyn and Pottsville Formations and outcrops at the far eastern end of the site where it dips to the southwest, reaching it's greatest depth at the western site boundary. The geology, along with the Permit boundary, surrounding roads, etc., is shown on Figure 9-2.
In 2006, The H&K Group's Engineering & Environmental Services Division drilled and logged three core holes, C-1, C-2 and C-3, along the axis of the Mine Hill Anticline to depths ranging from 300 to 400 feet below ground surface in order to map the geology and to collect samples for aggregate quality testing. The locations of the cores collected, logged, and photographed by an H&K geologist are shown on Figures 9-2 and 9-3.

Figure 9-2. Pottsville Materials overview. Shows the location of the site and core holes relative to surrounding features

Figure 9-3. Map showing existing and proposed features within production area overlaid on aerial image (Google Earth)
Core profiles, depicting the subsurface stratigraphy as logged from the cores and correlation of the coal beds, are depicted on Figure 9-4. Historic mine maps and cross sections provided by Reading Anthracite, and a USGS cross section (Wood, 1972), shown as Figure 9-5, supplemented the core hole data to build detailed cross sections (Figure 9-6) for the mining permit application.

![Figure 9-4](image.png)

**Figure 9-4.** Core hole profiles developed by The H&K Group during the exploring and permitting phase of Pottsville Materials.

Based upon the results of the coring, it was estimated that the Llewellyn Formation extends to a maximum depth of approximately 110 feet below ground surface (bgs) within the permit area. The Sharp Mountain member of the Pottsville Formation is located beneath the Llewellyn Formation. It is expected that the Pottsville Formation (and the Buck Mountain coal which larks the contact) will be encountered throughout the quarry as mining progresses, however at varying depths due to the dip of the beds. Two prominent coal beds have been encountered during quarry
excavation, one of which is exposed clearly in the southern highwall along the access ramp to the lower level of the pit (Figure 9-7). This coal seam extended across the pit along the surface of the upper bench, which has dictated the development of benches in a convex upward fashion (discussed further below). Geologic analysis of the site indicates that the coals encountered in the quarry are unnamed coal beds located between the Seven Foot and the Buck Mountain.

![Figure 9-5](image-url)  
*Figure 9-5. USGS Cross Section F–F’, looking west. Location of cross section labeled on Figures 9-2 and 9-3. Stratigraphy depicted on the section (Wood, 1972) referenced to identify coal beds encountered in cores and in the pit.*

![Figure 9-6](image-url)  
*Figure 9-6. Cross Section USGS F – USGS F’. Cross section along same line developed for the USGS (Wood 1972) above in Figure 9-5, but showing quarry-specific details and re-interpretation of geology based on drilling and highwall exposures.*
Historically, the site has been affected by coal mining both at the surface and underground. A site reconnaissance will reveal surface depressions where outcropping coal was removed. Surface coal extraction by coal mining entities has occurred to the north and south of the ridge on which Pottsville Materials quarry sits because thick coal beds are found at shallower depths at these locations. In the Wadesville pit to the south, the Mammoth Vein is still being mined with a dragline today. With three splits numbered 8, 8 ½, and 9 having a cumulative average coal thickness of nearly 35 feet, the Mammoth is one of the thickest anthracite coal beds in the region.

The thickest coal-producing seam within the permit area is the Buck Mountain seam (No. 5). It is reported that the Buck Mountain bed thickness ranges from 1.0 to 17.3 feet, and the coal thickness ranges from 0 to 12.2 feet (Wood, 1972). Core holes drilled in December 2006 encountered mine workings in the form of voids associated with the Buck Mountain coal seam. The voids encountered at locations C-1 and C-2 measured 3 and 6 feet, respectively. Fragments of wooden support beams were also retrieved in the core sample. Due to mine subsidence, the measured thickness of the void is likely smaller than the original working. Published data, mine maps from Reading Anthracite Company's abandoned underground mine map archives, and the PADEP Pottsville Mining Office/Deep Mine Safety indicate that the Buck Mountain has been heavily mined by anthracite underground miners. Portions of the Skidmore and the Seven Foot have also been mined.

Figure 9-7. Identification of prominent coal seam in the southern highwall along the access ramp to the lower level.

Figure 9-8. Fossil from Llewellyn Formation at Pottsville Materials. Believed to be Lepidodendron, also known as scale tree, it is one of the most common plant fossils found in Pennsylvanian age rocks.

Figure 9-9. Well-formed quartz crystals found in sandstone of the Llewellyn Formation at Pottsville Materials.
Production – Aggregate

Pottsville Materials consists of an aggregate processing plant and a hot-mix asphalt plant. The processing plant crushes approximately 375 to 400 tons of Pottsville Formation conglomerate and sandstone per hour, and averages 425,000 tons per year. Production begins at the quarry face with drilling and blasting to produce shot rock (large boulders), which are then loaded in rock trucks with excavators and front-end loaders, for transport to the primary hopper/jaw. Through a series of conveyors and screens, different aggregate products are produced at the primary such as 2A modified, ballast, and rip-rap. Some of the stone is then conveyed to the surge pile and onto the secondary cone crusher, producing additional aggregate products including #8’s (½-inch minus), screenings, and NY #2’s. Again, a third, or tertiary, cone crusher produces #57 stone (1½-inch minus), a portion of which is run through a coarse material wash screw. A wash screw cleans the stone of fine silt and clay, producing clean #57 aggregate, also referred to as “plant material”, which is typically used in concrete and asphalt production. Seven aggregate products produced at Pottsville Materials are approved for use in state roadways through an on-going series of testing by the Pennsylvania Department of Transportation (PADOT). Currently, the majority of the products are used in the construction of roadways, either as subgrade/subbase, or in the asphalt mixes produced at the on-site asphalt plant. Products such as #57’s and #8’s are sold for use in concrete at customer’s concrete plants. Sand is also produced which may be used in concrete, asphalt, or, when tested and approved, as septic sand. Figures 9-8 and 9-9 on the opposite page are examples of rock found in the quarry.

Quality control is an important factor in aggregate production. Although the coal bed itself is relatively thin, and separation and recovery of this seam is not economically significant, the coal and its associated shale beds would contaminate aggregate products. For example, greater than 3% “deleterious shale” would prohibit a product from being PADOT approval. For this reason, mining along this seam in a convex upward fashion allows for easier segregation of the coal and shale from the sandstone and conglomerate.

Production – Hot Mix Asphalt

The hot-mix asphalt plant at Pottsville Materials is a stationary Astec Industries 400 ton per hour counter flow double barrel (a drum within a drum) drum mix plant equipped with three 300 ton capacity heated storage silos capable of producing up to 395,000 tons annually. On average, Pottsville produces 100,000 tons of asphalt. The hot mix asphalt process consists of introducing various aggregates from the quarry, including #7, #8, #57 stone, and B-3 sand, into the inner drum via five electronically metered cold feed bins through a conveyor system. The aggregate is dried and heated within the inner drum to approximately 300-350 degrees by means of a natural gas fired burner. The burner is also capable of firing No.2 fuel oil or recycled fuel oil as an alternative. Once the aggregate is thoroughly heated and dried within the inner drum aggregate is transferred to the outer drum at which point Recycled Asphalt Product (RAP; pavement that has been removed from road surfaces with a milling machine when preparing to re-pave a road), mineral filler (dust) and asphalt cement (AC) are added to the mix. Up to 25% of the total mix can be recycled asphalt products. RAP is processed on-site with a portable crusher and/or screen to specific sizes and gradations.

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Google Earth, New Castle, PA area. Imagery Date 9/12/2012; Downloaded 8/19/2015.

STOP #10 AND LUNCH: PINE FOREST SHAFT, ST. CLAIR
PINE FOREST WORKINGS, RAVENSDALE TUNNEL, AND MARINE FOSSILS IN THE LLEWELLYN FORMATION

Stop Leaders – Jon D. Inners, Clifford H. Dodge, and Robert J. Scherr

Introduction

The grounds of St. Clair Fish and Game Club occupy part of the site of the former Pine Forest Colliery. The earlier deep mines and the later surface operations were off to the east and north, respectively, of the picnic pavilion where we will have lunch (see STOP 11 for location map). The latter are reclaimed and no long evident, whereas the Pine Forest Shaft and the drainage tunnel connected to the shaft are accessible and will be visited. About 2,500 ft east of the Club is the former location of the Ravensdale Tunnel—long removed by strip mining—where invertebrate fossils were reportedly found in 1857 (Figure 10-1).

Geology

The Pine Forest Shaft is located on the south-dipping north limb of the complexly faulted Pine Forest syncline between the surface trace of the Holmes (No. 10) coalbed to the north and the Primrose (No. 11) coalbed to the south; it is 550 ft south of the South Branch Mine Hill fault and 600 ft north of the Arnot fault (Wood, 1972, 1973) (Figure 10-1). As noted below, the shaft, sunk in 1864–66, penetrated the Mammoth coal zone at a depth of 362 ft. It encountered the 4 ft 4 in.-thick Holmes at 80 ft and the 7 ft 3 in.-thick “Seven-Foot” (now called the Lower Four-Foot) at 305 ft (Pennsylvania Geological Survey, 1889), and penetrated the south-dipping South Branch Mine Hill fault between the “Seven-Foot” and the top of the Mammoth zone (Figure 10-2).

![Figure 10-1. Detailed map of structure and coalbeds in the vicinity of the Pine Forest Shaft (modified from Wood, 1972). Bold letter “X” marks location of entrance to former Ravensdale Tunnel.](image-url)
Figure 10-2. Columnar section of shaft at the Pine Forest Colliery from surface to base of “Seven-Foot” coal (right) and overlapping tunnel section from “Seven-Foot” coal to base of Skidmore coal (left). (modified from Second Geological Survey of Pennsylvania, 1889).
History of mining at the Pine Forest Slope and Shaft (slightly modified from Wallace, 1988)

In 1845, Benjamin Haywood and George W. Snyder sank the Pine Forest Slope in partnership with Benjamin Milnes, an experienced English miner who had come to the United States about 18 years earlier. The slope ran down along the eastern boundary of the St. Clair Tract, leaving a pillar of untouched coal along the property line and opening out gangways on the Mammoth and Seven-Foot veins that extended east for over a mile. Two nearby mine patches, Crow Hollow and Ravensdale, served the colliery established at Pine Forest.

All the machinery for the colliery—engines, pumps, and breaker—was constructed at Snyder and Haywood’s machine shop and foundry in Pottsville, originally established by Snyder in 1835. By 1850, the colliery was employing 60 hands and producing about 15,000 gross tons per year; but after Haywood moved to California in 1850 to take advantage of the “gold rush” and Milnes left the firm in 1853 to take over the Hickory Colliery, Snyder took charge. He sank a second slope in 1857, and production increased rapidly to over 100,000 gross tons annually from three lifts below water level. By 1860, however, the operators needed to reach lower levels, and a vertical shaft was proposed. The sinking of the still extant, but long-flooded Pine Forest Shaft began late in 1864. Progress was delayed by water, and the work was not completed until November 1866 (Figure 10-3). This 12- by 20-ft shaft struck the Mammoth vein at 362 ft and a 43-ft tunnel south intercepted the Four-Foot (called the Seven-Foot at the time) and another tunnel, 270 ft north, reached the Skidmore.

![Pine Forest Shaft Colliery, 1866 (Wallace, 1988, p. 113)](image)

In 1863, Snyder installed a steam fan to aid ventilation, probably the first in the vicinity. The aggregate steam power at the older Pine Forest Slope was 250 horses; at the new shaft it was over 500. As the first state mine inspector, John Eltringham, put it in 1869, “the machinery and
engines, and the appurtenances of the colliery, cannot be excelled in the county” (Eltringham, 1870, p. 68–69). And again in 1870, “none but competent persons are in charge of engines and machinery” (McAndrew, 1871, p. 126). The breaker stood adjacent to the shaft, so that the cars ran up 80 ft to the top of the breaker and automatically unloaded the coal without leaving the cage; the cage was thoughtfully provided with a cover some time later to protect those riding in it.

Nevertheless, despite the mechanical sophistication displayed at the new mine, the Pine Forest Shaft Colliery turned out to be a failure. Tonnage figures in the mine inspectors’ annual reports tell the story. Completed in 1866, the colliery suspended operations in 1884 and was finally abandoned in 1890. During its 24 years of existence, it was in condition to ship coal for only 12 years, and during even those 12 years, it produced only 626,112 gross tons, for an average annual production of 52,342 gross tons—merely half of what the old slope did back in the 1850s, and far below its estimated capacity of 150,000 gross tons per year. Statistics from the 1880s, by which time the colliery was under operation by the Philadelphia & Reading Coal & Iron Company (P&RC&I Co.), highlight the sad production story (Ashburner, 1883, 1885; Hill, 1887):

<table>
<thead>
<tr>
<th>YEAR</th>
<th>GROSS TONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1881</td>
<td>41,549</td>
</tr>
<tr>
<td>1882</td>
<td>42,486</td>
</tr>
<tr>
<td>1883</td>
<td>60,024</td>
</tr>
<tr>
<td>1884</td>
<td>31,090</td>
</tr>
<tr>
<td>1885</td>
<td>6,025</td>
</tr>
<tr>
<td>1886</td>
<td>0</td>
</tr>
</tbody>
</table>

The problem with the Pine Forest Shaft was its ventilation, which was ill-designed when the shaft first opened in 1866. It prevented effective production until 1872, when Snyder sold the colliery to the P&RC&I Co. and a professional operator took over the lease. Snyder chose as the inside boss an Irish immigrant, Thomas Maguire, who had worked for Snyder ever since the sinking of the shaft began. Maguire was a practical miner but illiterate and, as his son put it later in his autobiography, “did not want to be a boss, but they simply made him be one” (Patterson, 1914, p. 314). The elder Maguire depended on his son, then in his twenties, to keep the colliery account books and to maintain records of the inside air volume and velocity. Bad engineering resulted in a poor ventilation system that ran the downcast air from the foot of the shaft through the entire mine before returning to the surface at a fan located close to the breaker. Mine inspector Eltringham (1870, p. 69) observed that “there is a considerable quantity of gas evolved in the face of the gangway and breast, so that it is necessary and expedient to use no lamps but the Davy safety-lamps,” and he was forced to issue detailed instructions on the use of lamps and other precautions for fire safety. Next year (1870), even after the upcast air shaft and fan were moved to a point 1,000 yds distant from the breaker, the condition was little better, as “the accumulation of carburetted hydrogen [methane] gas in the mine at present is considerable, and none but the most careful miners should be permitted to work in certain districts with or without safety lamps” (McAndrew, 1871, p. 126). At times, all production had to be halted because of rockfalls in the gangways that block the flow of air, and fires and explosions that closed down the mine for extended periods in the 1870s.
In 1872, William Kendrick took charge of the Pine Forest on behalf of the P&RC&I Co., but Thomas Maguire continued as inside boss until his death in 1877. Maguire’s son John took his place for a time, before moving on in the employment of the company as superintendent, district superintendent, and finally division superintendent. But, despite the superior experience of Kendrick and better technical education of the younger Maguire, the mine never lived up to its promise, and in 1890 was left to fill up with water.

In 1961, when Reading Anthracite took over the P&RC&I Co., the renamed firm began employment of a Marion 7800 dragline (220-ft boom and 35-yd bucket) at the Pine Forest stripping just north of the old shaft. The shaft was converted to a pumping station draining water from the aquifer through which the open pit mine descended. The outlet of the drainage tunnel is about 200 ft south of the shaft entrance. (Figures 10.4–10.9). The big dragline is still operating at Wadesville (STOP 8).

Figure 10-5. Pump at the Pine Forest Shaft, October 1971
Figure 10-6. Entrance to Pine Forest Shaft, November 2014
Figure 10-7. Looking down the Pine Forest Shaft. View to the water level about 15 ft below land surface, November 2014
Figure 10-8. Marion 7800 dragline at the Pine Forest surface stripping operation, May 1972

Figure 10-4. Outlet of the drainage tunnel at the Pine Forest Shaft, November 2014

Figure 10-4. Outlet of the drainage tunnel at the Pine Forest Shaft, November 2014
Ravensdale Tunnel

Located north of Ravensdale Hollow about 1 mi east of St. Clair, the former Ravensdale Tunnel is particularly noteworthy as the discovery site of the first-known “marine” invertebrate fossils from the coal measures in the Southern Anthracite coalfield. The fossils were found in the summer of 1857 by William B. Rogers, Jr., geological assistant of the First Geological Survey of Pennsylvania (1836–58) and nephew of the state geologist, who “discovered the casts of two or three (an Avicula? and a Tellinomya?) in coal-slate [inside] near the mouth of the Ravensdale tunnel” (Rogers, 1858, p. 833). Although the reported mollusk genera are now invalid, they correspond most likely to non-specific (at least) pectinid and nuculid bivalves, respectively, which are recognized as marine to restricted marine in origin. The description of the discovery site and cross section through the tunnel are sufficiently detailed to constrain the stratigraphic interval from which the fossils were collected as between (older to younger) the Orchard (No. 12) and Diamond (No. 14) coalbeds, which are separated by a vertical distance of about 200 ft (Figure 10-10).

The Little Diamond (L. Diam.) coal on the cross section is now recognized as the Diamond (Woods, 1972). Unfortunately, the fossil specimens that the younger Rogers collected are not known to have survived, but attempts are underway to verify this. Based on the present correlation scheme of coals throughout the several anthracite coalfields (despite acknowledged uncertainties) (see Eggleston and others, 1999, p. 460, and p. 461, Figure 36–2), it would appear that the marine fossils at Ravensdale represent one of the Glenshaw Formation (Conemaugh Group) marine zones of western Pennsylvania, though stratigraphically lower (older) than the Mill Creek limestone of Ashburner (1886) of the Northern Anthracite field, which is the probable equivalent of the Ames marine zone of western Pennsylvania (Chow 1951).
The former Ravensdale Tunnel operated in the mid-nineteenth century as a horizontal mine
entry (access point) into the south-dipping anthracite-coal measures (Pennsylvanian lower
Llewellyn Formation), between (older to younger) the Primrose (No. 11) and Little Orchard (No.
13) coalbeds. The tunnel trended northward into the hillside for a distance of about 555 ft, as of
the late 1850s. It was subsequently removed by surface mining in the twentieth century and
therefore is lost to science for further investigation. Nevertheless, plans are ongoing to search
for invertebrate fossils elsewhere near St. Clair and Pottsville in the same stratigraphic interval
as encountered at the former Ravensdale Tunnel. Even today, known occurrences of marine
invertebrate fossils (i.e., marine zones), or any fossil faunae for that matter, in the Southern
Anthracite coalfield are extremely rare—perhaps because they are absent or poorly preserved,
or more likely (?), because they have never been systematically searched for in the black shales
where they most probably occur but may be difficult to discern without careful examination.
Recognition of marine zones here could lead to improved stratigraphic correlations with the
bituminous coalfields of Pennsylvania, where the sequence of marine zones is well established,
and to a better understanding of the stratigraphy and depositional history of the anthracite
coalfields as a whole.

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HARPER’S GEOLOGICAL DICTIONARY

FIRE DAMP – A coal mining oxymoron.
STOP # 11:
COAL CREEK COMMERCE CENTER, ST. CLAIR
MAMMOTH (NO. 8) COALBED SEATROCK, LOWER LLEWELLYN/
POTTsville STRATIGRAPHY, AND ST. CLAIR MINING HISTORY

STOP Leaders—Jon D. Inners, Robert J. Scherr, and Leonard J. Lentz

Figure 11-1. Location map of STOPS 10 (Lunch) and 11 (Pottsville 7 ½ quadrangle, 1995)

Figure 11-2. Lidar image of St. Clair area. Arrow points to Coal Creek Commerce Center.
Geology and Physiography

The borough of St. Clair is situated in the northern part of the complexly folded and faulted Minersville Synclinorium and is entirely underlain by the coal-bearing Middle to Late Pennsylvanian-age Llewellyn Formation. To the north and northeast the Mine Hill anticline—a west-plunging spur of the Broad Mountain anticlinorium—elevates the Early to Middle Pennsylvanian-age Pottsville Formation, as well as lower coal beds of the Llewellyn Formation (here non-productive) and separates the productive St. Clair-Wadesville tract from a narrow productive band extending from Dark Water on Mill Creek westward to New Castle and Coal Castle (the Heckscherville syncline). The most important Llewellyn coal beds mined in the St. Clair area are (in descending order) the Diamond (No. 14, Orchard (No.12), Primrose (No. 11), Holmes (No. 10), Mammoth Top, Middle, and Bottom Splits (Nos. 9, 8 1/2, and 8), Skidmore (No. 7), and Buck Mountain (No. 8). Just south of St. Clair, the coals incline precipitously south into the basin, soon reaching uneconomical depths—a fact recognized as early as 1838 by H. D. Rogers of the First Pennsylvania Geological Survey (1836–58), but hotly contested for several decades by contemporary Pottsville boosters, such as Eli Bowen, Benjamin B. Bannon, and Samuel H. Daddow. (See Figures 11-1 through 11-4)
The Coal Creek Commerce Center is situated at the north edge of the complexly folded and faulted Minersville synclinorium, which in the vicinity of Pottsville and St. Clair constitutes the entirety of the Southern Anthracite field, here about 5 miles wide (Wood, 1972, 1973). The entire synclinorium is underlain by the Upper Pennsylvanian Llewellyn Formation. Exposed for about a quarter mile along the north edge of the Commerce Center is the steeply dipping seatrock of the Mammoth Bottom Split (No. 8) coalbed (Walking Tour, 1). About 400 feet north of the highwall along the old railroad grade (behind Dunkin’ Donuts) is a water-level drift in the Buck Mountain (No. 5) coalbed (3a). Between the highwall and the drift is a partial stratigraphic section of the rocks between the drift and the highwall (2). Along the south side of the Commerce Center, exposures just south and southeast of Tractor Supply Co. exhibit gently folded beds in the lower Llewellyn Formation near the crest of the South Wolf Creek anticline. A coalbed exposed at the base of the cut directly south of Tractor Supply Co. exposes the Skidmore (No 7 coalbed ?) and an east-dipping, cross-cut thrust fault (Figures 11-5 and 11-6).

Figure 11-5. Gently folded beds in the lower Llewellyn Formation near the crest of the South Wolf Creek Anticline of Wood (1972), behind Tractor Supply Co. at the south end of the Coal Creek Commerce Center. A coalbed exposed at the base of the cut is probably the Skidmore (No.7).

Figure 11-6. East-dipping thrust fault at the west end of the folded beds behind Tractor Supply Co.
To the north of the Commerce Center is the unfaulted Mine Hill anticline, which plunges westward toward Mill Creek and the Pottsville Aggregates quarry (STOP 9). Mine Hill is underlain by the Pottsville Formation, the rock forming the core of the fold and underlying the high, central ridge being the Tumbling Run Member. The Schuylkill Member crops out and defines the anticline along the old railroad grade on the east side of Mill Creek (Walking Tour, 3c).

**Mining in St. Clair**


Anthracite was discovered in St. Clair in 1824. Outcrops of coal attracted some of the early miners. Many veins subsequently important in the Southern, Western Middle, and Eastern Middle fields were discovered and named in and around St. Clair, e.g. the Primrose, Holmes, Mammoth, Orchard, Seven-foot, and Skidmore. Lines of outcrop of the Primrose vein, named for the primroses that grew around the area, surfaced south of St. Clair. Several mine patches settled close by. Some of these were Mill Creek, Scalpington, East Mines, and Centreville. The vein was struck at 122 feet in 1830 and was about three feet thick.

To the north of St. Clair, the Mammoth vein outcropped at Mine Hill. Isaac Beck accidentally discovered this vein while washing his hands in Mill Creek in 1830. It was hit at 438 feet and was 22 feet thick. The Holmes vein was hit at 194½ feet and was 4½. John Holmes was an Irishman who emigrated from Dublin around 1841. This vein is the next vein below the Primrose. Pinkerton and Company named the Orchard vein after Samuel Arnout’s Apple Orchard where the vein was opened in 1850. John Pinkerton and Company also discovered the Skidmore and Buck Mountain veins while tunneling north through the Mammoth vein. These veins were the thinnest significant veins that ran under, generally being only ten to fourteen inches thick. The Seven-Foot vein was struck at 402 feet and was 8½ inches thick.

St. Clair was considered one of the principal coal towns of the Southern Anthracite field (Figure 11-7). Most of the land was owned by two large extended families from Philadelphia. They were the Carey Group and the Wetherill Group. Both families were interested in making money for their heirs and squeezed every penny from the operators, wanting their royalties paid promptly and in full. Over the years the groups would sell the land while retaining the mineral rights. Both groups sold their estates to the Philadelphia and Reading Coal and Iron Company in 1872. In the early mines, the miners paid a heavy price due to the greed of the owners and operators. Many of the operators ignored best mining practices and took shortcuts on such things as ventilation and timbering. This led to explosions, cave-ins, fires, and floods that killed and crippled many of the men who entered these mines. For years the owners rationalized the problems and disasters effecting the mines as caused by “the Careless Miner” and heedlessly kept producing anthracite to fuel the Industrial Revolution—and at the same time fatten their pockets.
Collieries

*Parvin's Colliery*, opened by owner and operator Frank Nichols in 1825 on the Primrose vein, was the first colliery in St. Clair. This slope was located on Parvin's Hill, north of Wade Road on the west side of Mill Creek. Nicholas continued operation until 1829. Potts and Patterson worked the mine from 1829 to 1836. Joseph Lawton was in charge for the next ten years until 1846, when Frank Parvin and Company resumed operations. This slope slanted south from the outcrop and produced about 30,000 tons of coal per year. A fire damp explosion occurred in 1859 causing the mine to be flooded. Parvin and Company sold the mine to Andrew Russell, but after a few years the mine was abandoned in the early 1860’s.
The second colliery was the Rainbow Colliery, named for the color of the coal taken from this mine. This unusual color was due to its gaseous composition. The Rainbow colliery was located east of St. Clair at Crow Hollow. Ulrich and Schrader operated this colliery from 1826 to 1836. For the next four decades the mine continued to operate under a succession of owners until Maurice and Rothermell abandoned it in 1868.

The Eagle Colliery was located in the north end of St. Clair. It was constructed by Frank Hass in 1826 and operated until 1832. William and Thomas Johns began operations on Wetherill Lands in 1846. It then became known as Johns’ Eagle Colliery (Figure 11-8). The first breaker was built in 1849 and continued in operation until it was replaced with a much larger one in 1857. This colliery had several fires. The first was in 1878; the big breaker burned on Decoration (Memorial) Day, allegedly by an arsonist. Within a few years, both the engine house and blacksmith shops were destroyed by fire. In fact, the breaker burned at least twice in 28 years. In 1872, when the Philadelphia and Reading Coal and Iron (P&RC&I) Company purchased the mineral rights, they renewed their lease and the Johns family continued operations until 1882. The P&RC&I Co. operated the mine from 1882 until the late 1880’s or early ’90’s, after which the St. Clair Coal Company leased it.

The Hickory Colliery was located across Mill Creek from the Eagle Colliery and was operated by Beck and Woodside from 1828 to 1835 (Figure 11-9). John Pinkerton ran it from 1835 to 1844. He dug a tunnel north to an earlier drift making an air hole, and then continued west for about half a mile. This mine at its peak produced 10,000 tons per year. Benjamin and William Milnes purchased the mine from Pinkerton, sinking a new slope and continuing westward. By 1860 the mine was so large that it presented problems with ventilation. Also having problems with rotting timbers and cave-ins in the old workings, they sank a new slope—but in 1864 sold the operation to the Mammoth Vein Consolidated Coal Company. The company leased the land from the Wetherills, paying a royalty of 26 cents per ton. P. W. Shaefer (see Dodge, this Guidebook) was the directing engineer, and, in his opinion, the only way to save the colliery was to sink a vertical slope on the Mammoth at Wadesville. This was
necessary because the timbers had been stolen from the Old Hickory workings. The colliery was abandoned in 1874.

West, Hudson, and Pinkerton opened the **Pinkerton Tunnel Colliery**, located in the north end of town, in 1830. They operated it until 1841, after which John Pinkerton and Whitfield took over the operation from 1841 to 1853.

In 1845 Snyder and Haywood sank the **Pine Forest Slope**. This colliery was to the east of St. Clair, where the patch of Crow Hollow grew up around it (see STOP 10). The colliery produced 15,000 tons per year and employed sixty men by 1850. After Haywood moved to California in 1857, Snyder sank a second slope and increased the tonnage to 100,000 tons. The operators needed to reach lower levels by 1860 and followed McGinness and Carey’s example by sinking a vertical shaft in November 1866. As with many other collieries in the area, the ventilation presented a problem. After continually being plagued by gas, Snyder sold the colliery to the P&RC&I Co. in 1872. This brought about the use of the first Davy safety lamps. William Kendrick took charge for the “Coal and Iron,” but despite his experience, the mine did not prosper and was abandoned in 1890. During its 24 years of operation, the shaft mine was productive for only 12 years and produced only 628,112 tons—far below the estimated capacity of 150,000 per year.

The **St. Clair Slope and Shaft** was built by Enoch McGinness in 1853 and 1854 to exploit the Mammoth vein. The slope was sunk first and then the vertical shaft—located at the end of Carroll Street beyond the railroad tracks, reaching several hundred feet to make lower coal accessible. This was of great importance, as it proved the 40-ft-thick white ash vein [Mammoth seam?] was at an easy accessible depth throughout the Broad Mountain range. His friends honored McGinness, for they believed he had opened a coalfield that would take generations to exhaust. The breaker was built in 1854 directly over the shaft. Pottsville inventor George Martz designed the hoisting system powered by a 40-horsepower engine designed by McGinness. This colliery mined underneath the entire town of St. Clair north of Lawton Street by the 1870’s. The initial design of the mine, ventilation, bad workmanship, and flooding in the tunnel when it rained contributed to low and intermittent production. McGinness himself predicted 1,000 tons per day would be produced. However, the average tons per year was about 50,000. McGinness sold the mine to Kirk and Baum in July 1855. In August 1856 the breaker, along with most of the other buildings, burned and collapsed into the shaft. (A similar disaster at Avondale in the Northern Field in September 1869 killed 110 miners and led to first state-wide mine safety law and the prohibition of breakers being built over mine openings.) In 1860, Kirk and Baum gave up their lease. E. L. Hart worked the mine from 1862 to 1864. The St. Clair Coal Company of Boston took over the lease in July 1865. The breaker was again destroyed by fires, and by 1868 the mine was flooded and abandoned. A group of local operators started to refurbish and enlarge the shaft, but Carey gave up and sold the mine to the P&RC&I. Under the supervision of William Kendrick, the P&RC&I recognized the many problems of the mine and closed it in 1874.

The **Hooker Colliery** was located to east of Morris Street above Lawton Street. The Mount Hope Coal Company began operations in the early 1870’s on the site known as the Jackson Colliery. They continued their operations until shortly after World War I.

A group of New York businessmen led by William H. Taylor and members of the Patterson family leased the former **Herbine Colliery** (originally the Eagle Colliery [see above]) in 1895, renaming it the **St. Clair Coal Company**, Inc. (Figure 11-10). Mr. W. T. Smythe of Mahantongo Street in Pottsville came several years later and became general manager and superintendent. Coal was mined in several slopes near the colliery, which was located northeast of town. Slopes were also located on the Burma Road (SR 1006) and in Silver Creek. A drift was put in directly
across from the breaker on the sight of the former Hickory Colliery. The veins encountered in the mine ranged from several inches thick to the 80-foot Mammoth vein.

The first fire that occurred under this ownership was on 4 August 1903. The machine shop was destroyed, causing $5,000 in damage. The shop was rebuilt and the colliery remained in operation. On St. Patrick’s Day, 1911, a great fire destroyed the old wooden breaker. It was estimated at the time that $100,000 in damage was incurred. Reconstruction was started immediately, and a new breaker was erected. This was to be the fifth breaker on the site. At the time 1,050 men worked at the breaker, and they averaged $45.00 a month in pay. Harold M. Smythe, son of W. T. Smythe, took control of the St. Clair Coal Co., in 1933. He was president of the company until his death in 1956. He was well respected in the region, both by employees and contemporaries. He also served on the Anthracite Institute as a member of the board of directors in the 1940’s.

1938 came and with it one of the worst disasters in St. Clair history. On 27 April, at approximately 7:30 in the morning, an explosion occurred 300 feet below the surface in the Buck Mountain No. 9 tunnel of the St. Clair Coal Co. Men working nearby sounded the alarm, and the rescue and subsequent recovery began. The entrance to No. 9 was blown shut, compelling the mine rescue team to carry the injured and dead through gangways a mile long to an emergency slope off the Mammoth vein. It was said that pillars under the gangway had crumbled and released gas from old workings, causing the explosion. Eight men were killed and eleven injured in this terrible disaster.

The St. Clair Coal Co. employed 500 men with an annual payroll of $600,000 in 1938. The previous year 635,138 tons of coal were mined. An addition was added to the breaker in 1943. Wilmot Engineering Company of Hazleton constructed a new Hydrator plant. This increased plant feed capacity to 6,000 tons per 7-hour shift.

On 14 February 1948, two contract miners were killed on No. 30 slope near No. 10 tunnel north of Burma Road on the east side of St. Clair. They were caught under a heavy fall of top rock while working near a chute. Ironically, Nicholas Panko, age 53, survived the 1938 disaster only to be killed in this mishap. The St. Clair Coal Co. colliery was idled by a long strike lasting several months in 1949. The strike began over a firing of a contract miner for disciplinary reasons. Then all United Mine Workers of America (UMWA) miners east of the Mississippi went on strike. St. Clair miners returned to work on 30 September of that year.

When 1955 came it brought an end to an historic era. On 1 November the No. 30 and No. 40 slopes were closed. This was the first time in St. Clair’s history that no deep mining was done.
Two hundred inside and 30 outside employees lost their jobs. The pump in the Pine Forest Shaft was kept running in hope of deep mining returning, but this never happened. The breaker and a strip-mining operation remained working. The colliery remained open for two years, with Mrs. Harold Smythe becoming president in 1956. On 12 September 1957 the P&RC&I denied renewal of the lease held by the St. Clair Coal Co. colliery. Pleas were heard from local clergy, businessmen, town officials and UMWA officials, but it was all to no avail. On 15 October 1957, the St. Clair Coal Co. closed its doors. Two hundred men lost their jobs. In 1956, the last full year of operation, 360,589 tons of coal were mined and processed at the breaker.

An independent operator reopened the No. 30 slope in 1968. An underground monorail, the first of its kind, was used to haul coal to the surface. This venture lasted only several years. Reading Anthracite (successor to the P&RC&I Co.) operated the Pine Forest stripping east of town until 1987 and continues to operate the Wadesville stripping. In 1999 Reading Anthracite leased the St. Clair Coal Co. tract between the borough and Mine Hill to Wal-Mart, with Coal Creek Commerce Center erected soon afterward.

**Walking Tour of Significant Sites**

1. **Highwall of Mammoth Bottom Split (No. 8) coalbed.**

   The ~1/4-mile long highwall at the north edge of Commerce Center exposes the seatrock of the Mammoth Bottom Split (No. 8) coalbed, one of the major veins exploited in the old underground workings and in the later strippings here (Figure 11-11). On average, bedding strikes N65°E and dips 60°SE into the St. Clair syncline of Wood (1972, 1973). This is the same seatrock horizon that is so splendidly exposed on the south side of the Bear Valley stripping and over The Whaleback (STOP 5, this Guidebook). *Stigmaria* (lycopod roots) are abundant, and a few broken unidentified trunks are also evident (Figure 11-12). Unlike in the No. 8 seatrock exposed at Bear Valley, however, only a few weathered siderite concretions occur at the Commerce Center.

![Figure 11-11. Steeply inclined highwall exposing the seatrock of the Mammoth Bottom Split (No. 8) at 1. On top of Mine Hill in the background are old culm banks of the St. Clair Coal Co. Colliery.](image-url)
The No. 8 seatrock exposed here is a silty, dark gray claystone. The *Stigmaria* are the in-place roots of the lycopods *Sigillaria* and *Lepidodendron*. (See Wnuk, 1988, for a discussion of the origin of seat-earth floras in the Anthracite fields.)

![Figure 11-12. Stigmaria in the seatrock of the Mammoth Bottom Split (No. 8) coalbed at 1](image)

**2. Dunkin’ Donuts stratigraphic section.**

The construction cut at Dunkin’ Donuts at the north end of the Commerce Center exposes 210 feet of rock section below the Mammoth Bottom Split (No. 8) coalbed, including four “coal” horizons—two of which probably represent the Seven-Foot (No. 6) and the Skidmore (No. 7) (Figure 11-13 and measured Lower Llewellyn section in Table 1).

About 60 percent of the rock exposed is sandstone, conglomeratic sandstone, and conglomerate. Bedding in the lower beds is generally relatively planar bedded, with abundant carbonized plant fossils in a massive, 20-foot thick bed near the base (unit 4). The upper 60 feet (units 25-31), below the 12-foot-thick Mammoth seatrock (unit 32), are conglomeratic and commonly current bedded. The 5-foot-thick Seven-Foot coalbed (unit 6) near the base would appear to be minable. The Skidmore (unit 11) is relatively thick, but shaly and bony. The other two horizons (units 14 and 23) are thin and bony. Attitude of bedding here is approximately N60°E/25°SE.

![Figure 11-13. Lower beds of stratigraphic section exposed at 2. The coal bed in the Middle is probably the Seven-Foot (No. 6, unit 6 of measured section).](image)
TABLE 1
LOWER LLEWELLYN SECTION AT DUNKIN’ DONUTS — COAL CREEK COMMERCE CENTER, ST. CLAIR, PA

<table>
<thead>
<tr>
<th></th>
<th>Description and Details</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.</td>
<td>Mammoth Bottom Split (No. 8) coalbed (concealed)</td>
<td></td>
</tr>
<tr>
<td>32.</td>
<td>Claystone, silty, dk gy, rootworked, especially in upper 5', Stigmaria common</td>
<td>12.0'</td>
</tr>
<tr>
<td>31.</td>
<td>Sandstone, fine to md grained, lt ol gy, rusty weathered</td>
<td>5.0'</td>
</tr>
<tr>
<td>30.</td>
<td>Qtz conglomerate, thick bedded, md dk gy to lt ol gy, rusty weathered</td>
<td>3.0'</td>
</tr>
<tr>
<td>29.</td>
<td>Qtz conglomerate, massive, md gy to md dk gy; pebbles to ½”, mostly &gt;1/4 in</td>
<td>4.0'</td>
</tr>
<tr>
<td>28.</td>
<td>Sandstone, md to thk bedded, coarse grained, md gy to md dk gy, rusty weathered, w/ hands of fine-pebbly qtz conglomerate to 6” thick</td>
<td>30.0'</td>
</tr>
<tr>
<td>27.</td>
<td>Qtz conglomerate, massive, rusty weathered; sharp contact at top</td>
<td>2.0'</td>
</tr>
<tr>
<td>26.</td>
<td>Sandstone, thick bedded, fine to md grained, md gy, poorly exposed at top</td>
<td>13.0'</td>
</tr>
<tr>
<td>25.</td>
<td>Qtz conglomerate, thk bedded, rusty weathered; pebbles to ½” mostly &gt;1/4”</td>
<td>3.0'</td>
</tr>
<tr>
<td>24.</td>
<td>Shale, fissile, dk gy, rusty weathered</td>
<td>2.5'</td>
</tr>
<tr>
<td>23.</td>
<td>Bony coal, blk</td>
<td>1.0'</td>
</tr>
<tr>
<td>22.</td>
<td>Concealed interval</td>
<td>5.0'</td>
</tr>
<tr>
<td>21.</td>
<td>Sandstone, md bedded, fine to coarse grained, md dk gy, ol gy weathered, w/ some thin, fine pebbly beds; shaly at base, but poorly exposed</td>
<td>4.0'</td>
</tr>
<tr>
<td>20.</td>
<td>Concealed, rubbly interval</td>
<td>12.0'</td>
</tr>
<tr>
<td>19.</td>
<td>Sandstone, md bedded, current bedded, rusty weathered</td>
<td>10.0'</td>
</tr>
<tr>
<td>18.</td>
<td>Concealed interval</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Sandstone, md bedded (2”-6”), current bedded, fine grained, md dk gy, rusty weathered</td>
<td>0.5'</td>
</tr>
<tr>
<td>16.</td>
<td>Concealed interval</td>
<td>6.0'</td>
</tr>
<tr>
<td>15.</td>
<td>Shale, fissile to platy, dk gy, rusty weathered; lower 0.5’ hard and non-fissile</td>
<td>5.0'</td>
</tr>
<tr>
<td>14.</td>
<td>Bony coal, blk</td>
<td>0.5'</td>
</tr>
<tr>
<td>13.</td>
<td>Clay shale, fissile to splintery, md dk gy to gy blk; poorly exposed</td>
<td>4.0'</td>
</tr>
<tr>
<td>12.</td>
<td>Claystone, hard, dk gy, rootworked; poorly exposed</td>
<td>8.0'</td>
</tr>
<tr>
<td>11.</td>
<td>Shale and bony coal, blk, rootworked w/ plant fossils (pyrophyllite?); poorly exposed Horizon of Skidmore (No. 7) coalbed (?)</td>
<td>9.0'</td>
</tr>
<tr>
<td>10.</td>
<td>Sandstone, thk bedded to massive, fine grained, md gy to md dk gy, rusty weathered</td>
<td>5.0'</td>
</tr>
<tr>
<td>9.</td>
<td>Sandstone, thin to md bedded, fine grained, micaceous, md gy, ol gy and rusty weathered</td>
<td>3.5'</td>
</tr>
<tr>
<td>8.</td>
<td>Sandstone, thick bedded, md to coarse grained, lithic, md dk gy to dk gy, rusty weathered, rubbly; bd partings mostly ½” to 1”; probable channel</td>
<td>17.0'</td>
</tr>
<tr>
<td>7.</td>
<td>Shaly coal, dk gy to blk; upper part of underlying coalbed</td>
<td>1.2'</td>
</tr>
<tr>
<td>6.</td>
<td>Coal, thk bedded, blk; sheared at 2’ intervals (shear planes at N30°W/47°SW) Seven-Foot (No. 6) coalbed (?)</td>
<td>5.0'</td>
</tr>
<tr>
<td>5.</td>
<td>Claystone, gy blk, rootworked; seatrock of No. 7 coalbed</td>
<td>1.7’</td>
</tr>
<tr>
<td>4.</td>
<td>Sandstone, massive, coarse grained, micaceous, lithic, md gy, rusty weathered; some intervals between in middle part w/ relatively even partings spaced 1-2” apart; carbonized plant fossils common</td>
<td>20.0’</td>
</tr>
<tr>
<td>3.</td>
<td>Sandstone, md bedded, coarse grained, micaceous, lithic, md gy</td>
<td>5.0’</td>
</tr>
<tr>
<td>2.</td>
<td>Concealed interval</td>
<td>100.0+</td>
</tr>
<tr>
<td>1.</td>
<td>Buck Mountain (No. 5) coalbed (concealed at mine drift)</td>
<td></td>
</tr>
</tbody>
</table>
For comparison to stratigraphic section in Table 1, Matthew Snyder (Penn State Schuylkill) and D.H. Vice (Penn State Hazleton) have described an exposure of the Llewellyn section at the Sheetz Plaza on the west end of Pottsville (~5 mi SW of STOP #11) in terms of depositional environment (July, 2015):

Rocks in the Llewellyn Fm. have been exposed in the Sheetz Plaza on the West End of Pottsville during the excavation of the area for a gas station and strip mall (Vice and Snyder, 2004). This rock cut exposes a stratigraphic sequence of about 230 feet of Llewellyn sediments are exposed (see figure at right). This sequence is very different from that in the Tremont area. The lower 170 feet consist of sandstone channels alternating with mudstones and/or siltstones which appear to represent proximal floodplain deposits. The upper 60 feet of these Llewellyn sediments are shales and mudstones that appear to represent distal floodplain and/or backswamp deposits. Plant impressions have been found in the upper part of these deposits. R. J. Cuffey (2003, per. comm.) suggested that one of these impressions was a badly degraded Calamites sp.

Edmunds et al. (1999) suggests that it has been difficult to develop an understanding of the variation in the lithology of the Llewellyn Formation because of the complex interaction between climate, sea level, and tectonics. It is hoped that this outcrop can help provide a better picture of the stratigraphy of the Llewellyn Formation. The Sheetz Plaza outcrop of the Llewellyn Formation fits illustrates the variable nature of the Llewellyn Formation as described by Sevon et al. (1982) and also the abrupt change in the depositional environment from that of a braided stream in the Pottsville Formation to that of a typical, clay-rich, meandering, fluvial environment.

References for Snyder & Vice:


3. Along the old Railroad Grade north of Dunkin’ Donuts

(Note that permission to pass beyond the gate must be obtained from the Schuylkill County Municipal Authority, 221 S. Centre Street, Pottsville, PA, 570-622-8240)

North of the Llewellyn section at Dunkin’ Donuts the old Reading Railroad grade extends north through the Mill Creek gap in Mine Hill and Broad Mountain. Built in the 1860’s to ultimately connect with the Mahanoy Plane just northwest of Frackville, the Reading here became as important a transport route for anthracite as any in “The Region”— being one of the main reasons for the construction of the great St. Clair Railroad Yards that were completed south of the borough in 1913. We will walk north along the trail here to Darkwater (time permitting), observing several interesting features along the way.

a. Water-level drift on the Buck Mountain coalbed

Just beyond the gate on the right is a drift of the St. Clair Coal Co. on the Buck Mountain (No. 5) coalbed, probably dating from the early 1900’s. The company’s No. 1 Slope on the Buck is uphill and some distance east along the slope of Mine Hill (Figures 11-14 A, B & C).


**b. Concrete engine-house ruins**

High on the hillside west of the old railroad grade, about 275 feet north of the Buck Mountain drift, are the ruins of the concrete engine house for No. 1 slope of the St. Clair Coal Co. (Figure 11-15), constructed about 1900. This was about the time that concrete came into wide use in the Anthracite fields—highlighted by the building of the community of “Concrete City” at Nanticoke, Luzerne County, by the Delaware, Lackawanna, and Western Coal Company in 1911. The engine house operated until the closing of the mine in the 1950’s.

![Figure 11-15. Ruins of the concrete engine house for the No. 1 slope of the St. Clair Coal Co. at 3b.](image)

**c. Pottsville conglomerate crags define the axial trace of the Mine Hill anticline**

Farther up the trail, two prominent crags of gray conglomerate and sandstone, mapped as Schuylkill Member (Wood, 1973), define the west-plunging axis of the Mine Hill anticline. The southern crag dips about 21° south, and the northern one dips about 40° north. Between the two crags the slope is covered with large conglomerate boulders, and other ledges are visible higher on the slope, though mostly hidden in the trees.

**d. Darkwater**

At the north end of the traverse is a pump house of the Schuylkill County Water Authority. Prior to re-construction of PA 61 in the 1940’s, the patch town of Darkwater was located in this vicinity. It was here in the late 1880’s that the Pennsylvania Railroad built a high trestle (viaduct) that bridged the Mill Creek gorge (Figure 11-16), towering over the Reading track—wooden ties of which can still be seen along the old grade near the SCWA treatment plant. On the other side of the creek, just northwest of the intersection of Darkwater Road and PA 61, is a shaft of the old Repplier Colliery, now a pumping station and drainage pit (see Day-2 Roadlog, mile 10.9). Originally started as a drift mine far off to the west near the patch town of New Castle in about 1840, the Repplier (Figure 11-17) operated on and off into the 1950’s—one of the last large deep mines to shut down.

![Figure 11-16. The Pennsylvania Railroad trestle across the Mill Creek gorge at Darkwater (3d).](image)
Figure 11-17. Repplier Colliery northwest of Darkwater in the 1800’s. After the final closing of the colliery in the 1950’s, the entire area was strip-mined (see Day-2 Roadlog, mile 10.9).

References


HARPERS GEOLOGICAL DICTIONARY

PERIODIC TABLE - A convertible wooden bench.
STOP #12: PINE FOREST SHAFT, ST. CLAIR


THE SITE IS PRIVATE PROPERTY AND CAN ONLY BE ACCESSED WITH PERMISSION FROM READING ANTHRACITE COAL COMPANY

The site is located 0.34 mile east-southeast of Burma Road (SR 1006) or 0.5 mile west of the intersection of Tucker Hill Road (SR 527) and Silver Creek Road (SR 166) approximately 2.87 miles northeast of St. Clair. Coordinates 40.73843889, -76.14155556 (Figure 12-1).

There is a small pull off area on the east side of Burma Road approximately 0.2 mile northeast of the “shooting range” also on the east side of the road (note: the shooting range contains the same fossils found at the main site but collecting is discouraged here for obvious reasons). Access to the property is by following an unimproved road east off of Burma Road to the clearing. Outcrops are found along strike of the pit from the west edge eastward for about 120 feet. Elevation of the site is approximately 1383 feet.

![Location map for Stop 12. Pottsville, 7.5-minute quadrangle; north is up.](image)

**Introduction**

Stop 12 has been included with several field trips within the Anthracite region primarily due to the unique occurrence of the St. Clair flora (e.g., Sevon and others, 1982; Inners, 1988; Levine and Eggleston, 1992; Pfefferkorn and others, 2006). The most thorough discussion comes from
Sevon and others (1982) where Inners and Smith (p. 16-22), discuss the regional stratigraphic and geologic setting as well as the mineralogical occurrence of the white pyrophyllite coating on the fossil flora. Much of the general background material for this stop is taken from their entry.

**Stratigraphy and Geology**

The site is representative of fossil plants associated with the Buck Mountain (No. 5) coal seam, the regional stratigraphic marker between the Llewellyn and underlying Pottsville Formations, Late Middle Pennsylvanian (Figure 12-2).

The fossil-bearing zones are the “roof rock” of a thin, un-mined lower split of the Buck Mountain coal seam and the “seat rock” of the main coal bed, which has been stripped away over a wide area. The contact between the Llewellyn Formation and the Sharp Mountain Member of the Pottsville Formation likely occurs only a few feet below the lower coal split (Sevon and others, 1982).

The site exposes a portion of the eastern limb of the South Mine Hill anticline. This anticline plunges toward the southwest and extends northeastward to the St. Clair-Mahoney City Road. The exposed shale and siltstone strikes approximately N80° E and with dips 12-15° to the southeast (Wood, 1973). The light gray conglomerate and conglomeratic sandstone boulders that are found in the woods to the north and in the “claimed” area of the mine to the east are derived from the Sharp Mountain Member in the core of the South Mine Hill anticline.

Roughly 300 feet south, a splay from the Wolf Creek branch of the South Mine Hill fault separates the Buck Mountain from the Skidmore (No. 7) and Mammoth Bottom Split (No. 8) coals. Approximately 0.3 mile to the east and northeast the two latter coals, as well as the Mammoth Middle Split (No. 8.5) and Top Split (No. 9), are part of an intricate maze of thrust faults and folds (Sevon and others, 1982).

A geologic map of the St. Clair area is shown in Figure 12-3.
Figure 12-3. Geologic map of the St. Clair fossil site. Adapted from Wood (1973).

Paleontology

Fossil plants indicate two different environments. Some, like the seed plants (conifers and Cordaites) indicated an upland environment. The uplands had more erosion than deposition so plant fossils from this environment are rarer in the fossil record. In contrast, the second environment was the mud swamps, an area frequently flooded bringing with it silts and muds, burying the plants and plant debris. The Sphenopsids (such as Calamites) and pteridosperms (e.g., Alethopteris, Nueropteris) formed in this environment. This stop is an example of a mud swamp.

During global warming events and fluctuation of sea level, these environments would have been more ephemeral, shifting positions locally through larger-scale changes globally. Such fluctuations would have prevailed throughout the early Carboniferous into the Permian from episodic polar glacial periods (Gestaldo and others, 1997) and Alleghanian tectonic activity. The wet mud swamp of pteridosperms and Sphenosids is replaced by the drier peat swamp of the Lepidodendron.

It was once believed that these plants reflected the majority of plant life in diversity. Today, most paleobotanists think the coal measure plants are anachronistic – they represent primitive plants that have held on in their swampy realm because the climatic conditions were relatively more stable. With the rapidly changing environment in the uplands, flora was abundant, but the uplands did not produce many fossils (Phillips and Rose, 2001).

Our location is geologically unique. The fossiliferous rocks are both “seat” rocks and roof shales, depending upon how you look at the stratigraphic profile. Roof shale floras have been a major source of data for understanding Carboniferous vegetation. Gastaldo and others (1995) propose three levels at which preservation of plant parts can be viewed: 1) early taphonomic processes and earliest diagenesis can destroy or preserve plant parts in a given clastic depositional setting; 2) those plant parts that are preserved can be autochthonous, parautochthonous, or allochthonous in relationship to their original place of growth; 3) with respect to a peat layer (coal bed), the overlying clastic material can be deposited in a continuous transition, after a short temporal break (discontinuity), or after a significant hiatus of time.
In general, there are two broad groups associated with roof-shale floras. First, there are those that represent the final vegetation of the forest that formed the underlying peat (autochtonous or parautochthonous). Secondly, there are those from lowland habitats that were deposited in the same site after the cessation of peat formation. The former is a geologically instantaneous picture of the forest that has undergone either catastrophic burial, or death from edaphic stress (bad soil) followed by slow burial. Through clastic deposition, the final peat-swamp forest may be gradually replaced by clastic swamps resulting in a succession of autochthonous clastic-swamp accumulations in the shale above the coal bed (Gastaldo and others (1995).

At the site....

David White (1900) collected fossil plants from the Pottsville Formation in the Southern Anthracite field at 41 localities and from the roof of the coal forming the dividing line between the Pottsville formation and the overlying "Productive Coal Measures." His Group 5 includes flora from the Buck Mountain coal (correlative Twin coal) at the "Pottsville Gap." He described the flora in the roof of the Buck Mountain coal as a "typical Coal Measures flora" very distinct from the floras typical of the Pottsville formation; although a few of its species do manage to creep into the upper parts of the overlying Llewellyn Formation. He bases the stratigraphic position as being slightly later than that of the basal beds of the "Lower Coal Measures" in the Northern Anthracite field or of the Allegheny series in the northern bituminous basins.

Various regional studies make reference to the Buck Mountain flora in a stratigraphic context, linking the coal horizon to the Lower Kittanning of western Pennsylvania in what appears to be a case of following White’s and Oleksyshyn’s (1982) paleobotanical summaries (Read, 1954; Wood and others (1956), Eggleston and others (1988), Wagner and Lyons (1997), Sevon and others (1982), Read and Mamay (1964); Edmunds, 1996).

More than 80 fossil plant species, as well as several arthropods, have been identified from the St. Clair fossil site. Table 12-1 lists the more common and diagnostic genera and species, with photos of the two most prevalent at the site shown in Plate 12-1 below:

Plate 12-1. Images of the two most common plant fossils at St. Clair, Stop 12.
The plant species are assigned to genera that include large stems and trunks (*Lepidodendron, Sigillaria* and *Calamites*); roots (*Stigmaria*), cones (*Macrostachya*); seeds (*Rhasbdocarpus* and *Trigonocarpus*); and leaves (*Asterophyllites, Annularia, Sphenophyllum, Pecopteris, Sphenopteris, Eusphenopteris, Mariopteris, Alethopteris* and *Neuropteris*). These are all typical members of the Middle Pennsylvanian coal swamp floras (Sevon, 1982; Phillips and Rose, 2001). Arthropod remains include wings of cockroaches (*Blatteria*), "ancestral" crickets (*Caloneurodea*) and "ancestral" dragonflies (*Protodonata*). Occasional specimens of legs and pleural segments of the long-bodied fresh-water trilobitomorph *Arthropleura* have also been reported (Sevon, 1982).

Table 12-1. List of fossil flora identified from the St. Clair fossil site (from Phillips and Rose, 2001).

<table>
<thead>
<tr>
<th>Division: Lycopsida</th>
<th>Division: Pteridophyta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class: Lycopsida</td>
<td>Class: Pteropsida</td>
</tr>
<tr>
<td>Order: Lepidodendrales</td>
<td>Order: Filicales</td>
</tr>
<tr>
<td><em>Lepidodendron lanceolatum</em></td>
<td><em>Pecopteris arborescens</em></td>
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<tr>
<td><em>Lepidostrobophyllum ovatifolium</em></td>
<td><em>Pecopteris crytea</em></td>
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<tr>
<td><em>Sigillaria cf. elongate</em></td>
<td><em>Pecopteris hemitelioides</em></td>
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<td><em>Stigmaria ficoides</em></td>
<td><em>Pecopteris miltoni</em></td>
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<td></td>
<td><em>Pecopteris unita</em></td>
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<tr>
<th>Division: Arthropoda</th>
<th>Division: Pteridospermophyta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class: Sphenopsida</td>
<td>Subdivision: Gymnospermae</td>
</tr>
<tr>
<td>Order: Calamitales</td>
<td>Order: Pteridospermales</td>
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<tr>
<td><em>Asterophyllites equisetiformis</em></td>
<td><em>Sphenopteris missouriensis</em></td>
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<td><em>Asterophyllites longifolius</em></td>
<td><em>Sphenopteris macilenta</em></td>
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<td><em>Sphenopteris spiniformis</em></td>
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<td><em>Annularia stellata</em></td>
<td><em>Eusphenopteris nummularia</em></td>
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<tr>
<td></td>
<td><em>forma nummularia</em></td>
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<td><em>Mariopteris cf. inflata</em></td>
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<td></td>
<td><em>Mariopteris cf. lobata</em></td>
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<tr>
<td></td>
<td><em>Diplotheca cheathasmi</em></td>
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<td><em>Alethopteris decurrens</em></td>
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<td><em>Alethopteris friedelli</em></td>
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<td><strong>Alethopteris serili</strong></td>
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<td><em>Neuropteris macrophylla</em></td>
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<td></td>
<td><em>Neuropteris oblique</em></td>
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<td></td>
<td><strong>Neuropteris ovata, forma typical</strong></td>
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<tr>
<td></td>
<td><em>Neuropteris ovata, forma flexuosa</em></td>
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<tr>
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<td><strong>Neuropteris scheuchzeri</strong></td>
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<tr>
<td></td>
<td><em>Neuropteris tenuifolia</em></td>
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<tr>
<td></td>
<td><em>Odobopteris subcuneata</em></td>
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Discussion

Along with the Mazon Creek flora in Illinois, the St. Clair site has become a standard for collections worldwide of Pennsylvanian-age plant fossils. With its coating of the clay mineral pyrophyllite, the whitened fossils stand out in marked contrast with the dark-gray shaly background, providing an added aesthetic appeal to fossil specimens.

The first reported occurrence of pyrophyllite-coated flora is from Genth (1879). He analyzed specimens collected by Mr. Eli S. Reinhold finding “the purest specimens having a white to yellowish-white color, and a lustre between silky and pearly…the fibrous particles showing a somewhat laminated structure.” He adds that the pyrophyllite bed (of the Buck Mountain) “is usually found in horizontal seams, parallel with the coal beds…it has not been found in any of the other beds of the same mine, and only this mine has furnished it…although the bed in which it occurs is worked in other mines.”

However, in the opening paragraph, Genth begins, “One of the most interesting varieties of pyrophyllite is that from the coal slates of the “North Mahanoy Colliery” (old Silliman Colliery) near Mahanoy City, Schuylkill County, Pa.” Research of the North Mahanoy Colliery places it just north of Mahanoy City along Mahanoy Creek (Thompson, 1899), approximately 5 miles NNE of Stop 12.

And with the final nail, Genth (1879) states, “This occurrence of pyrophyllite in coal slates and as the petrifying material of coal plants is exceedingly interesting, and I believe it to be the first time that it has thus been observed.” Apparently, it seems that the white pyrophyllite coating of the Buck Mountain flora had its “roots” outside of Mahanoy City courtesy of the North Mahanoy Colliery, Mr. Eli Reinhold, and Frederick Genth. The North Mahanoy Colliery by the way, mined the Buck Mountain coal (Abandoned Mine Research, Inc., 2013).

A review of the early fossil plant descriptions by Lesquereux (1858, 1880, and 1884) and White (1900) describe plant fossil sites just to the south of Stop 12 (approximately 0.5 miles) near New Philadelphia and Silver Creek but they are not in reference to the Buck Mountain coal horizon. White’s (1900) collection of flora from the Buck Mountain horizon at the “Pottsville Gap” does not make any reference to the unique mineral preservation.

In Wood (1860) 30 new species were described; one locality being St. Clair. Specimen Solenoula nobis is listed as being from the Milnes Mine, St. Clair, but its position is with the Mammoth seam not Buck Mountain (p. 238).

The site at stop 12 was being mined during 1938 as determined by aerial imagery from that period (Figure 12-4) so it may be that the locality for what is now known as the St. Clair site, simply had not been exploited by White (or other researchers) prior to that time (David White died in 1935).

Darrah (1969), in tracking down plant fossil localities obtained from David White's collections, states that he (Darrah) collected specimens associated with the Buck Mountain from a locality “… at the east end of the old strippings 2.5 miles east of St. Clair.” With a bit of inference, this just about matches the Stop 12 location, however, this is somewhat speculative as “east” is relative and there had been other seams mined in the vicinity. Unpublished records coming from amateur fossil enthusiasts, recall having visited and collected at the St. Clair site proper during the 1950’s (Joe Dague, pers. comm.).
Time and Time Again

Darrah (1969) referred the Buck Mountain coal bed (No. 5 of Wood et al, 1962) to the Westphalian D based on work by Oleksyshyn (1982), but he goes on to point out that due to the reported presence of *Sphenoptilum oblongifolium* (from Oleksyshyn), would make it basal Stephanian (Cantabrian); also the presence of *Alethopteris grandinoides* var. *subrzeileri* also tends to suggest basal Cantabrian, whereas *Pecopteris monyi* and *Pecopteris nyranensis* would confirm either Westphalian D or lower Cantabrian. Ultimately, the Buck Mountain flora of Oleksyshyn (1982) contains elements of both Westphalian D and the overlying lower Stephanian. Oleksyshyn also compares the Buck Mountain with the Lower Kittanning horizon of western Pennsylvania.

A Bit on Pyrophyllite

Pyrophyllite is a hydrous aluminum silicate; chemically bearing a close resemblance to other clay minerals such as dickite and kaolinite.

Hosterman and others (1970) identified pyrophyllite in 24 of 76 samples taken from the underclays of various coals throughout the anthracite region. They found pyrophyllite to more prevalent in the Southern and the two Middle Fields than in the Northern Field and that the distribution of samples indicated that the pyrophyllite is concentrated in the upper part of the Pottsville and lower part of the Llewellyn.

Analyses of the pyrophyllite coating by Myer and others (1977) concluded that the growth of the pyrophyllite was controlled by the leaf structure; the entire leaf is generally preserved as pyrophyllite, the cuticle, and veins are occasionally preserved as graphite. Myer and others (1977) also suggest that the plant remains were first replaced by pyrite, which was then later
replaced by pyrophyllite at higher temperatures and pressure. Woody structures such as the veins which resisted replacement by the initial low temperature phase were converted to graphite at that time.

Genth (1879) also made some interesting observations regarding the relationship between pyrite and pyrophyllite. He describes the occurrence in large cracks seeming to have crystallized “...from above and below...and that the two seams (of pyrophyllite)...are mostly separated by a thin layer of pyrite in minute crystalline masses, which leaves the impressions of their crystals upon the pyrophyllite...” - meaning that the pyrite came after the pyrophyllite. He goes on to state, however, that “…the fibrous pyrophyllite, as well as the pyrite, are coated with a very thin layer, not thicker than the finest tissue paper, of a scaly variety of pyrophyllite of an almost silver-white color” - inferring that the pyrophyllite came after the pyrite. It sounds as if the pyrophyllite/pyrite interaction went back and forth. This is corroborative with Myers and others (1977), at least in part, where they suggest the plant remains may have initially been replaced with pyrite then later by the pyrophyllite.

The pyrophyllitic coating has been observed at other localities in the anthracite fields. It has been observed in abandoned surface mines just southeast of Eckley Miner’s Village near Hazleton and in an abandoned mine just north of Ashland (Kochanov and Inners, pers. observ.).

Analyses of selected coals and shale from the anthracite region by Daniels and Altaner (1990) interpreted the minerals to be formed in several stages of hydrothermal alteration, as evidenced by the presence of higher temperature clay minerals in the series soudite-tosudite-rectorite. Figure 5 shows the range of occurrence for some selected clay minerals and their temperatures. Pyrophyllite and tosudite would begin forming in the 200 °C range and higher (Ruiz-Cruz, 2007); kaolinite and dickite at lower temperatures. The transition of kaolin mineral to pyrophyllite approximately marks the transition from diagenesis to metamorphism (Ruiz-Cruz, 2007).

In a study of mineral matter content of anthracite coals, Spackman and Moses (1961,p. 10) also correlated pyrophyllite with the Buck Mountain and Seven Foot seams (the Seven Foot is the next seam lying stratigraphically above the Buck Mountain).

The bracketing of pyrophyllite at this particular stratigraphic level bears some parallels to the occurrence of another uncommon mineral, tosudite.

The presence of the clay mineral tosudite (Smith, 1982; Smith and Barnes, 1988) found within the basal Pottsville of the Eastern Middle Anthracite Field as well as interstitially within the Pottsville Sharp Mountain conglomerates and basal Llewellyn in the Northern Anthracite Field (Kochanov, 2012) adds another coincidental occurrence of a unique mineral species during this time-stratigraphic interval. Note its range of occurrence in Figure 12-5.

Harrison and others (2004) concluded that through field observations, illite-crystallinity studies and fluid-inclusion analysis indicate that coal-bearing Pottsville and Llewellyn Formations and the underlying Pottchunk Fault acted as a regional aquifer for the migration of hot fluids during the Alleghanian Orogeny. The presence of quartz veins, tosudite and pyrophyllite in the strata, among other indicators, suggest the migration of fluids though the sandstones and abundant fractures that developed in response to the Alleghanian Orogeny. The fluids achieved a minimum temperature of 270 °C at a depth of ~3.1-8.5 km. Anthracitization was likely the result of stratigraphically controlled hot fluid through the coal-bearing horizons at shallow depths equal to or less than 5 km.

One can presume a regional temperature gradient during the Alleghanian orogeny contributing towards the formation of specific clay minerals such as dickite and kaolinite. Amplification of temperatures by localized folding and faulting may have altered allochthonous
clays that were deposited in the St. Clair swamps (and elsewhere) to pyrophyllite, emplacing them specifically along the Sharp Mountain/Lower Llewellyn timeline.

An interesting aside comes from western Pennsylvania in the form of euhedral zircons and biotite crystals from the Pine Creek marine horizon (Lower Stephanian), which suggest ash fallout from volcanic activity (Harper, 2000). It is plausible that the volcanic fallout, concurrent with tectonic activity, was widespread in distribution, suggesting that these minerals could also be found along similar timelines within the anthracite fields and perhaps introducing a unique “clayseed” along the Pottsville/Llewellyn timeline.

<table>
<thead>
<tr>
<th>Modified from Ruiz-Cruz, 2007</th>
<th>TEMP C°</th>
<th>DEPTH km</th>
<th>CLAY MINERALS</th>
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<tr>
<td>SEDIMENTATION AND BURIAL</td>
<td>20</td>
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</tr>
<tr>
<td>DIAGENESIS</td>
<td>100</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>METAMORPHISM</td>
<td>200</td>
<td>10-30</td>
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</tr>
<tr>
<td>PARTIAL MELTING</td>
<td>650</td>
<td>35-40</td>
<td>KM, D, MC, T, P</td>
</tr>
<tr>
<td>COMPLETE MELTING</td>
<td>800-1200</td>
<td>50-100</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 12-5. Temperature of formation and burial depths for selected clays. Kaolinite mineral (KM), tosudite (T), muscovite/chlorite (MC), pyrophyllite (P), dickite (D). Modified from Ruiz-Cruz (2007).*

Localized structural complexes of multiple folds and faulting at the St Clair site may have helped focus various mineral end members through hydrothermal alteration of detrital clays derived from eroded Pennsylvanian highland (paleosols) that were then deposited into the St. Clair swamps. Subsequent alteration of clays as a result of hydrothermal fluids following permeable, interstitial pore spaces, faults and joint pathways help to define areas of the unique clay mineralogy prevalent in the anthracite region.

**References**


Rose-Anna Behr gardening in the Pennsylvanian.
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