National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Johnstown Flood National Memorial

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/049

ON THE COVER:
Remnants of the South Fork Dam abutments–
Johnstown Flood National Memorial, Pennsylvania

NPS Photo

Johnstown Flood National Memorial

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/049

Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, Colorado 80225

September 2008

U.S. Department of the Interior
Washington, D.C.

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available online from the Geologic Resource Evaluation Program website (http://www2.nature.nps.gov/geology/inventory/gre_publications) and the Natural Resource Publication Management website (http://www.nature.nps.gov/publications/NRPM/index.cfm) or by sending a request to the address on the back cover.
Please cite this publication as:

Thornberry-Ehrlich, T. 2008. Johnstown Flood National Memorial Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2008/049. National Park Service, Denver, Colorado.

NPS D-67, September 2008

Table of Contents

List of Figures

Executive Summary

This report accompanies the digital geologic map for Johnstown Flood National Memorial in Pennsylvania, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

The story at Johnstown Flood National Memorial is a tragic one. On May 31, 1889, 2,209 people lost their lives in one of the worst disasters in United States history. The memorial is dedicated to this loss. In addition to this cultural resource, the memorial preserves a portion of the Allegheny Mountains section of the Appalachian Plateaus physiographic province. Geologic resources and the natural history of the area are integral parts of the landscape and their interpretation can enhance the visitor's experience.

The rocks in the Appalachian Plateaus province are relatively flat-lying and undeformed in contrast to the rocks of the Valley and Ridge province just to the east of Johnstown. These two provinces are separated by the steep Allegheny Front. In the Johnstown area, surface exposures consist primarily of Devonian through Pennsylvanian age sedimentary rocks. These include sandstones, limestones, clay stones, conglomerates, dolomites, and shales. These rocks contain fossils, coal, iron-rich minerals, and other clues to past environments.

The geologic substrate, as well as surficial processes (geologic, hydrologic, and biologic) determine the features of every landscape. Understanding the geology of central Pennsylvania enhances understanding of the unique relationship between geology, the environment, and the cultural history of the area. Geologic processes give rise to rock formations, mountains, and valleys, escarpments and ridges, dissected plateaus, and soils. The landscape played a prominent role in the history of south-central Pennsylvania, including the development of historic recreational facilities. At Johnstown Flood National Memorial, the South Fork Dam was repaired in 1862 to preserve a recreational paradise for the South Fork Fishing & Hunting Club. Heavy rains and subsequent lake level rise toppled the dam and resulted in catastrophic flooding (fig. 1).

The following issues (described further in the "Geologic Issues" section) have geologic importance and a high level of management significance within the park:

- Geologic Hazards
  The steep terrain that characterizes the Allegheny Front region surrounding the park is prone to landslides, slumps, and rockfalls. In particular, areas containing resistant rock units undercut by erosion of weaker units, or human land use are susceptible to hazardous failure. Friable clays may underlie the abutments of the remnants of the South Fork Dam and could cause damage to the structure if they become water saturated. Though uncommon, seismic activity is possible in central Pennsylvania. Even minor seismic tremors could trigger massive landslides and debris flows on steep or water-saturated slopes.
- Water Issues and Flooding
  Associated with the South Fork of the Little Conemaugh River and various small streams, springs, and seeps at Johnstown Flood National Memorial is the risk of damage and loss of resources due to erosion and the flood activity that is inherent to this river system. Intense seasonal thunderstorms and high runoff have historically caused flooding along these waterways. This flooding threatens human life as well as many of the historical structures and features of the landscape at the park. In order to make informed management decisions it is crucial for park resource managers to understand the park's hydrogeologic system. Increased understanding of surface and subsurface water flow will help more accurately predict environmental changes that occur from hydrologic processes.
- Recreational Demands
  The memorial preserves natural lands for recreational use including the remnants of the South Fork Dam and the meadowlands of the former Lake Conemaugh. Overuse of these areas may lead to contamination from human waste and trash and degradation of the ecosystem such as trampling and removal of vegetation, soil compaction and erosion.
- Acid Mine Drainage
  Johnstown Flood National Memorial is located in south-central Pennsylvania, an area known for coal and iron mining. Abandoned and inactive mines pose health, safety, and environmental problems in the vicinity of the park. Foremost among these is acid mine drainage. The potential for acid mine drainage as well as heavy metal contamination that accompanies low pH runoff is a serious resource management concern. The South Fork of the Little Conemaugh River is devoid of fish due to contamination from upstream mining activities. Alluvial sediments and floodplain deposits are rich in heavy metals precipitated from contaminated runoff.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Johnstown Flood National Memorial.

Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non-geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park-specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www.nature.nps.gov/geology/inventory/).

Geologic Setting

Prior to the failure of the South Fork Dam, Conemaugh Lake provided fishing, hunting, boating, and swimming opportunities for the South Fork Fishing and Hunting Club, an exclusive resort on the lakeshore. On May 31, 1889, at 3:10 a.m., the South Fork Dam failed and 2,209 people lost their lives as torrential floodwaters from Conemaugh Lake destroyed the working class city of Johnstown in south-central Pennsylvania (Bern 1999).

This event is one of the worst natural disasters in United States history and no news was bigger during the last few decades of the nineteenth century. Johnstown Flood National Memorial (designated August 31 1964 during the presidency of John F. Kennedy) commemorates this tragedy and preserves portions (165 acres) of the remains of the South Fork Dam and former Lake Conemaugh. This area is now managed as a wet meadow with approximately seven acres of biodiverse wetlands within the former lakebed.

Johnstown Flood National Memorial is located in south-central Pennsylvania about 16 km (10 miles) northeast of Johnstown. The South Fork of the Little Conemaugh River flows through the park toward its confluence with the Little Conemaugh River and ultimately the Conemaugh River that flows through the city of Johnstown.

The park is located in southwestern Cambria County. Here the mountains range in elevation from 346–734 m (1,135–2,408 ft) above sea level. Historically, the mountains proved a significant obstacle to boat trade of the Pennsylvania Mainline Canal. The memorial is located near the junction of the Appalachian Plateau and the Valley and Ridge physiographic provinces. These provinces are divided into local sections and thus more specifically, the park is within the Allegheny Mountain section (fig. 2). Rolling hills and ridges characterize topography in the park. The ridgetops are composed of resistant Paleozoic sandstones and the valleys are underlain by less resistant units such as carbonates and shales that have preferentially eroded through time.

A general east to west description of several of the different physiographic provinces of the Appalachian Mountains follows.

Piedmont Province

The "Fall Line," or "Fall Zone," marks a transitional zone where the softer, less consolidated sedimentary rocks of the Atlantic Coastal Plain to the east intersect the harder, more resistant metamorphic rock to the west forming an area of ridges, waterfalls, and rapids. Examples of the transition are present in the Potomac Gorge of the Chesapeake and Ohio Canal National Historic Park. The Piedmont physiographic province encompasses the Fall Line westward to the Blue Ridge Mountains. The eastward-sloping Piedmont Plateau formed through a combination of folds, faults, uplifts, and erosion. The resulting eastern landscape of gently rolling hills starting at 60 m (197 ft) in elevation becomes gradually steeper westward toward the western edge of the province and reaches 300 m (984 ft) above sea level. The Piedmont Plateau is composed of hard, crystalline, igneous, and metamorphic rocks such as schist, phyllite, slate, gneiss, and gabbro.

Blue Ridge Province

The Blue Ridge province is located along the eastern edge of the Appalachian Mountains. This province includes the highest elevations in the Appalachian Mountain system, in Great Smoky Mountains National Park in North Carolina and Tennessee. Precambrian and Paleozoic igneous, sedimentary, and metamorphic rocks were uplifted during several orogenic events to form the steep, rugged terrain. Resistant Cambrian quartzite forms most of the high ridges, whereas Precambrian metamorphic rocks underlie the valleys (Nickelsen 1956).

The elongate belt of the Blue Ridge stretches from Georgia to Pennsylvania. Eroding streams have narrowed the northern section of the Blue Ridge Mountains into a thin band of steep ridges that rise to an average height of approximately 1,200 m (3,937 ft).

Valley and Ridge Province

Long, parallel ridges separated by valleys 100–200 m (330–660 ft) below the ridges characterize the landscape of the Valley and Ridge physiographic province (also known as the “Ridge and Valley province”). The valleys formed in areas of more easily eroded shale and carbonate formations and ridges are commonly composed of more resistant sandstones. The province contains strongly folded and faulted sedimentary rocks in central Pennsylvania. The Valley and Ridge province averages 80 km (48 miles) in width. The eastern part of the Valley and Ridge is part of the Great Valley, a rolling lowland formed on folded carbonates and shales. It is connected to the Piedmont province by streams that cut through the Blue Ridge Mountains.

Appalachian Plateaus Province

Compared to the eastern Appalachian physiographic provinces, the Appalachian Plateaus province is relatively undeformed. Instead of the highly folded and inclined strata of the Valley and Ridge province, the rock layers are nearly flat. A steep scarp known as the Allegheny Front bounds the plateau on the east. This escarpment rises abruptly 300–900 m (1,000-3,000 ft) above the adjacent landscape. Maximum elevations along this front are generally greater than those of the ridges in the Valley and Ridge province. In Pennsylvania, elevations range from 530–900 m (1,750–3,000 ft). Deep ravines carved into the nearly horizontal sedimentary rock layers characterize the topography of this province. Local geologic units are typically repetitious sequences of shale, coal, limestone, and sandstone, called cyclothems. Erosion of these units created a rugged, jumbled topographic surface. The northern parts of the province in Pennsylvania and New York display more rounded hills with gentler slopes.

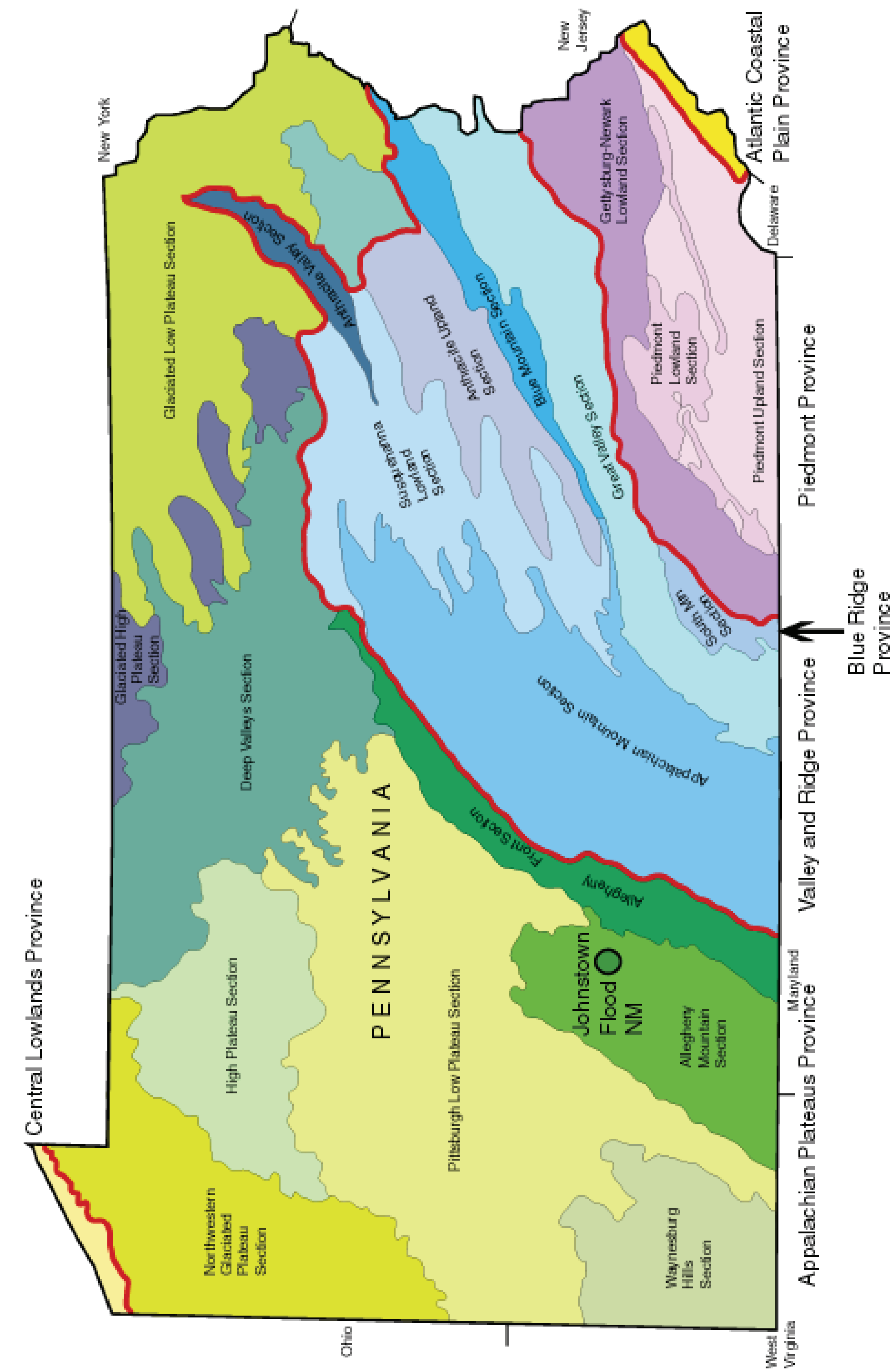


Figure 2. Map of Pennsylvania showing the physiographic setting of Johnstown Flood National Memorial. Red lines indicate boundaries between major physiographic provinces. Northern terminus of Blue Ridge province is located by the black arrow. The location of park is denoted by a green circle. Map information modified from Pennsylvania Geological Survey map 13, 2000). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Johnstown Flood National Memorial on June 22, 2004, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Geologic Hazards

The steep terrain that created a seemingly ideal location for construction of the South Fork Dam is prone to several geologic hazards including landslides, slumps, and rockfalls. Steep slopes along valleys and ravines between ridges and rolling hills are characteristic of the Allegheny Mountains region. Historic features such as the remains of the dam abutments are at risk of damage from slope failures, frost wedging, and seismic activity.

The geologic units in the park are a heterogeneous mix of shale, sandstone, siltstone, limestone, dolomite, conglomerate, and mudstone. Clay-rich units such as shale and mudstone may weaken and deteriorate when saturated with water and are prone to fail when exposed on steep slopes. These types of units may underlie the abutments of the remnants of the South Fork Dam at Johnstown Flood National Memorial. When more resistant rock units such as sandstone and limestone overlie less resistant rock units, preferential erosion may undercut the more resistant units and result in rockfalls. A site investigation could determine if any friable clays are locally present in conjunction with the Ames Limestone (a unit present at the boundary between the clay rich Pennsylvanian age Glenshaw and Casselman Formations). If these units are present together, potential slide hazards exist.

There is limited knowledge regarding moderate or low levels of seismicity and movement along specific faults in the eastern United States (Jacob 1989). Though not common, seismic activity is possible in central Pennsylvania. Some historic earthquakes in the area were caused by blasting at local mines (in 1893 and 1939), additionally a natural ~5 magnitude quake occured in northwest Pennsylvania in 1986 (Scharnberger 1987) Even minor seismic tremors can trigger massive landslides and debris flows on steep and/or water saturated slopes. Assessing vulnerability to seismicly induced geologic hazards may be beneficial for Johnstown Flood National Memorial.

Inventory, Monitoring, and Research Suggestions for Geologic Hazards

- Conduct site investigations of clay rich layers and friable limestones exposed on slopes to determine a vulnerability index to slope failure.
- Inventory the areas along steep slopes of the South Fork of the Little Conemaugh River valley to locate historic landslides.

Water Issues and Flooding

Johnstown Flood National Memorial was designated to memorialize a devastating flood, thus water is an obvious resource management issue at the park. Although Lake Conemaugh and the dam that once held it back are now gone, there is continued risk of damage and loss of resources due to future flooding associated with the South Fork of the Little Conemaugh River and other small streams, springs, and seeps in the vicinity of the park. Floods are most common during spring runoff, and seasonal storm events. Flood events when they occur threaten historic foundations in the river and flood plane.

In addition to the devastating flood of 1889 (fig. 3), the Johnstown area has experienced two other major flood events in 1936 and 1977. The 1977 flood occurred when the hydraulic fill (fill in which the materials are deposited in situ by flowing water) Laurel Run Dam, located on a tributary of the Little Conemaugh River, failed. The dam was constructed in 1915–1918 to supply water to a system of navigational canals for local steel producing operations. In 1960, the dam was purchased by the City of Johnstown to act as a component of the municipal water system. Its malleable clay core failed after 15–30 cm (6–12 inches) of rain fell in 6–8 hours on the night of July 19–20, 1977 (Knight 1989). This event further demonstrates the vulnerability of the system to floods.

An understanding of the hydrogeologic system at the park is crucial for resource managers. Hydrogeologic systems determine groundwater flow, and ultimately the pathways of contaminants and other wastes. The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow. Other contaminant sources include wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. Streams integrate the surface runoff and groundwater flow of their watersheds and provide a cumulative measure of the health of the watershed's hydrologic system. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Inventory, Monitoring, and Research Suggestions for Water Issues and Flooding

- Develop emergency response procedures to implement in case of extreme flood events along park rivers and streams.

- Consult Pennsylvania Geological Survey water reports to obtain further data on the surface and groundwater hydrology in the park.
- Map and quantify groundwater recharge zones.
- Work with the Water Resources Division of the NPS to develop an appropriate water quality monitoring plan.

Recreational Demands

Recreational use at Johnstown Flood National Memorial includes hiking, picnicking, cross-country skiing, bird watching, and photography.

The park receives many visitors, especially during the summer months. In 2007, 126,066 visitors made recreational visits to Johnstown Flood National Memorial. These visitors place increasing demands on the resources of the park. Resource management concerns vary from trail erosion (especially near the remnants of the South Fork Dam), protection of wetlands and water quality, to slope failures.

The park concentrates visitor use along designated trails and at picnic areas. However, visitor use in other areas of the park increases the area of impact and could place delicate ecosystems at risk of contamination from human waste and overuse.

The South Fork of the Little Conemaugh River enhances the natural beauty of the park. Overuse of certain streambanks can lead to contamination from human waste, trash, and increased stream edge erosion.

Inventory, Monitoring, and Research Suggestions for Recreational Demands

- Inventory and monitor human impacts to the wetlands and marsh flora within the former Lake Conemaugh.
- Design and construct interpretive wayside exhibits to encourage responsible use of park resources.

Acid Mine Drainage

Coal and iron mining (siderite in limestones) have long been associated with central Pennsylvania. The Pennsylvanian-age Freeport, Kittanning, and Brookville-Clarion commercially viable coal seams all exist in the vicinity of the park. Extensive underground, mining around the park has resulted in lasting environmental effects ranging from acid mine drainage to potential subsidence and collapse of underground mine workings.

No abandoned mine features have been identified within the boundaries of Johnstown Flood National Memorial. However, nearby mine features in St. Michael and Beaverdale are causing major pollution problems upstream of the park in the South Fork of the Little Conemaugh River. The Pennsylvania Department of Environmental Protection has maps showing mined areas and has documented subsidence associated with mines.

Abandoned and inactive mines pose environmental and health problems for the Johnstown Flood National Memorial area. Foremost among these is acid mine drainage and residual heavy metal contamination of ground water, surface water, and soil. Mine areas upstream from the park produce acid mine drainage. Fluvial sediments (sediments carried by water) can contain metals and other waste materials.

The acidity of coal-mine drainage is caused primarily by the oxidation of the mineral pyrite, which is found in coal, coal overburden, and mine waste piles. The rate of pyrite oxidation depends on the following: reactive surface area of the pyrite, the oxygen concentration and pH of the water, the forms of pyrite, and the presence of iron-oxidizing bacteria (Thiobacillus ferroxidans) (http://energy.er.usgs.gov/health_environment/acid_mine_drainage/index.htm Accessed September 2008).

Acid mine drainage can leach major elements such as aluminum, calcium, and magnesium and trace elements such as copper and zinc from surrounding rocks. Newly-formed acidic, metal-rich waters can then flow into receiving streams. These metals are transported from the vicinity of a mine by ground and surface water as dissolved ions, suspended sediment, or as part of the bedload in a stream (Madison et al. 1998).

Drainage from mines near the upstream communities of Saint Michael and Beaverdale flow through the memorial creating a significant resource management problem. This flow is concentrated in the Little Conemaugh River where high levels of aluminum, sulfates, and iron have contributed to white, orange, and yellow coloring of the riverbed and surrounding floodplains. The water is toxic to fish and other aquatic species as well as riparian vegetation along its banks. Some bacteria, algae, and insects inhabit the polluted waterway. Remediation efforts are underway at the park, but coordination with upstream communities is critical to prevent further contamination and resource damage.

Inventory, Monitoring, and Research Suggestions for Abandoned Mine Drainage

- Determine pathways for the contaminants and work with mine owners, regulatory agencies and others to remediate the acid mine drainage and other problems associated with the upstream mines.
- Monitor biota (e.g., aquatic insects) for heavy metal contamination.
- Incorporate Pennsylvania Department of Environmental Protection maps of mine features into a GIS database.

General Geology, Paleontology, and Miscellaneous Issues

The contrast between the nearly horizontal, undeformed layers of the Appalachian Plateaus province and the folded and faulted Valley and Ridge physiographic provinces has sparked research interest among geologists for many years.

Railroad cuts and other development activities have exposed rock layers for geologic research (Inners 1989). More local research would help resource managers at the park improve understanding of the geology and the relationships among physical factors in the ecosystem.

The rock units in the park area contain vast paleontological resources that record life present during the Devonian through Pennsylvanian periods. These resources present an opportunity for display and interpretation at the park. The park also serves as an excellent outdoor classroom for the history of engineering and natural disasters.

Inventory, Monitoring, and Research Suggestions for General Geology and Miscellaneous Issues

- Promote geomorphologic mapping at the park to better understand landslide hazards.
- Promote land use evolution studies, especially concerning any possible Native American sites, early settlement activities, and trade (transportation) to enhance the park's interpretive materials.
- Promote paleontological research in the park. Refer to the Eastern Rivers and Mountains Network paleontology report by Vince Santucci.
- Promote historical engineering studies related to construction and maintenance of the South Fork Dam. This information can be used to create interpretive materials.

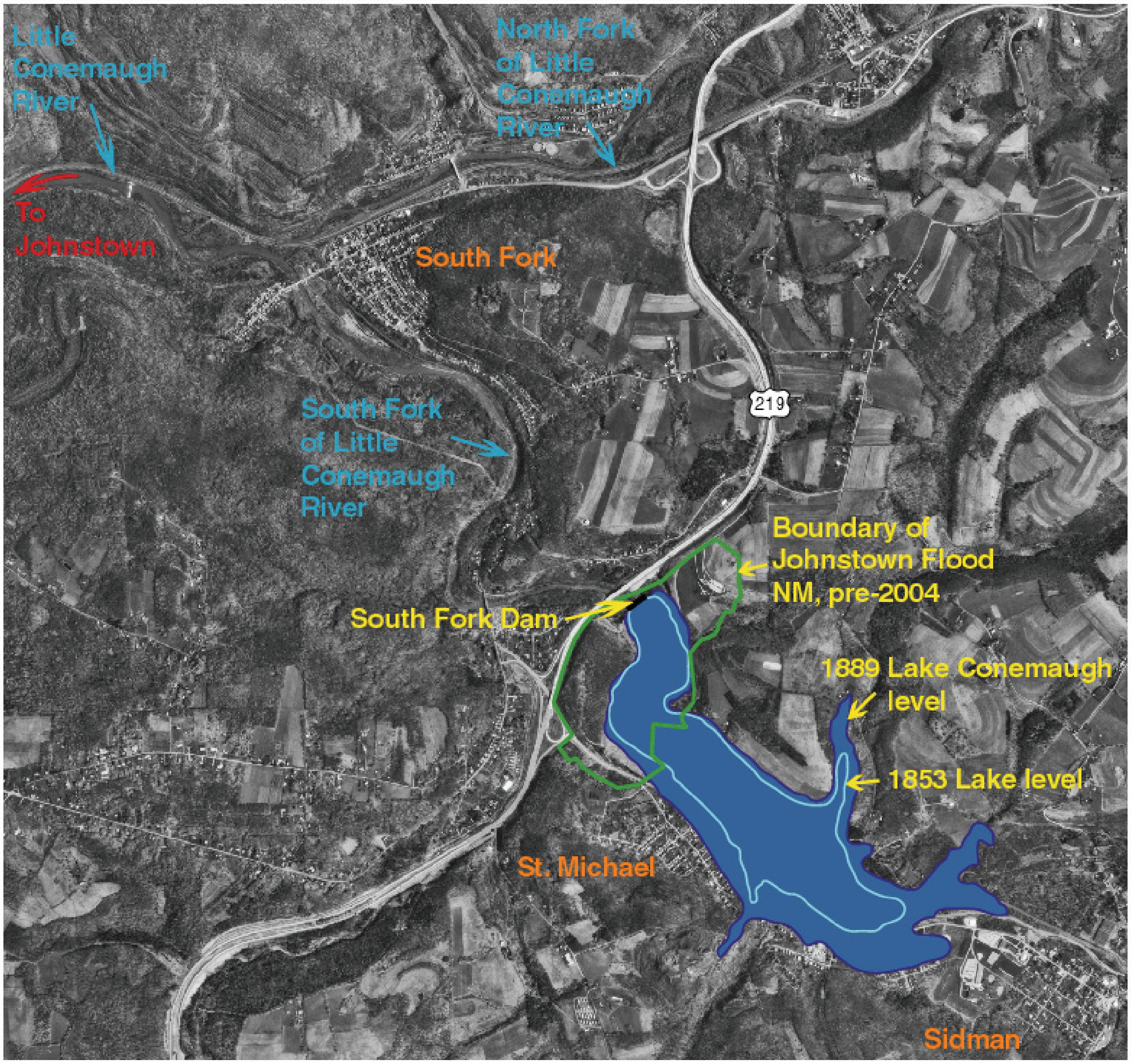


Figure 3. Satellite image of Johnstown Flood National Memorial area courtesy of The Pennsylvania State University. Highstand lake level of 1889 is indicated as well as a regular stand level from 1853. Floodwaters flowed out of the natural topographic basin of Lake Conemaugh, in to the narrow gorge of the South Fork of Little Conemaugh River towards the confluence with the North Fork. The floodwaters surged towards Johnstown after temporarily being redammed behind a viaduct near the oxbow (not on figure). Where the river straightens just before Johnstown, the flow increased in velocity before reaching and devastating the city. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Johnstown Flood National Memorial.

Geology and history connections

On May 31, 1889, following 8 inches of rainfall, the South Fork Dam that contained Lake Conemaugh collapsed, sending a 23 m (76 ft) high wall of 20 million gallons of water rushing (60 km/hr, 40 mph) down a narrow gorge towards a town of 30,000 unsuspecting people and killing 2,209 (fig's 4–6). The dam was constructed in the 1850's, and its lake was the mountain retreat and summer playground for some of the wealthiest men of the Industrial Age including Andrew Carnegie, Robert Pitcairn, Howard Hartley, H.C. Yeager, and Andrew Mellon (Earnest 2002; Issenberg 2004). Two more major floods in 1936 and 1977 inundated Johnstown killing 264 and 85 people, respectively.

The park memorializes the devastating flood of 1889. One of the major purposes of the park is to preserve the historical context of the area; this includes preserving the remains of South Fork Dam and former Lake Conemaugh, historic buildings and the landscape surrounding them (fig.s 7–8). The visible impacts of the flood on the landscape are now softened by erosion and weathering. Maintaining this landscape often means resisting natural geologic changes, which presents several resource management challenges.

Geologic slope processes such as landsliding, slumping, chemical weathering, rockfalls and slope creep are constantly changing the landscape at the park. Runoff erodes sediments and carries them downslope. Erosion over time lowers higher areas and fills in the lower areas changing the historical context of the landscape.

Issues arise between the sometimes-differing objectives of cultural and natural resource management. For example, a proposal to restore an historic building may consist of removing surrounding natural resources or planting exotics plant species. Several areas in the park such as Carriage Road, the South Fork Dam remnants, the caretaker's house, the newly acquired South Fork Fishing & Hunting Club's clubhouse and cottages (Victorian mansions along the former lakeshore) including the Moorehead Cottage are popular historic features for visitors that may require management actions that affect adjacent natural resources (NPS News 2004).

History at Johnstown Flood National Memorial also contains ties to the region's industries. Coal and iron ore mines dotted the landscape as well as regional furnaces to smelt the iron ore. These features stand as testament to the early industrial development of the area. Today they pose environmental and safety hazards within and near the park (see discussion in Geologic Issues section).

Early fields, settlements, and tool quarries of Native Americans predate European settlements. Earliest known evidence of Native American activity dates back to 10,000 years ago from Sheep rock, near Huntingdon, Pennsylvania. The name "Allegheny" stems from the mound building Alligewi or Allegheny Indians from western Pennsylvania (Wells 1973).

Native Americans left artifacts and geomorphological changes to the landscape such as terraced campsites, tool quarries, and other archaeological sites in the Susquehanna River Valley and the Allegheny Mountains (Suciu and Bachman 1992).

South Fork Dam and Lake Conemaugh

> "A dam is the most hazardous of civil engineering structures. Its failure can cause loss of life and property, the value of which may be many times that of the cost of the dam. Moreover, the impact of the failure is felt a great distance beyond the site limits."
> – George F. Sowers, Professor, Georgia Institute of Technology (1977)

When completed in 1853, the 14-year construction of the South Fork Dam was the largest earthfill dam in the world. It measured more than 110 m (70 ft) tall and 275 m (900 ft) across (Katkins 1989; Issenberg 2004). It included a 21 m (70 ft) wide spillway that was cut through sandstone bedrock with cast-iron pipes at the base of the dam to control the water level in the lake (Katkins 1989). It was originally intended to serve as a reservoir for the Pennsylvania Mainline Canal basin in Johnstown, but the lengthy construction rendered the canal obsolete when Pennsylvania Railroad was completed. The railroad company owned the canal and operated it for a number of years. During this time, the original South Fork Dam failed in 1862 but resulted in little flooding (Earnest 2002).

The dam and reservoir changed hands a number of times before they were acquired for $2,000 in a state of disrepair by the South Fork Fishing & Hunting Club. The club began repairs to the dam in 1879 and completed work in 1881. They did not hire qualified engineers to oversee the work and the repairs were substandard.

The culverts, originally installed to control lake level were blocked and water could not flow through them. The eroded embankment from the 1862 flood was repaired by placing an earth and rock berm on the upstream face to raise the dam to a height of 22 m (72 ft). A 3 m (10 ft) wide spillway channel was cut through one abutment 2.5 m (8.2 ft) below the maximum height of the dam. A road was installed across the top of the dam, causing it to sag in the middle. The subsequent lake, Lake Conemaugh, was stocked with fish and served as a resort area for the club between 1881 and 1889 (Katkins 1989; Earnest 2002).

The probability of a major flood in the Johnstown area was high before the construction of the South Fork Dam due to its the unique topographic setting. The valley above the city, where the former Lake Conemaugh was located, is a 4 km (2.5 mi) long bowl-shaped basin that would easily collect runoff (Issenberg 2004). This valley sits atop the narrow gorge of the South Creek of the Little Conemaugh River.

The stream falls steeply below the dam for about 5 km (3 mi). Johnstown sits in a narrow floodplain formed at the junction of Little Conemaugh River and Stoney Creek to form the Conemaugh River (Sowers 1977).

The heavy rains of May 30–31, 1889 carried a considerable amount of debris that jammed at a fish screen installed across the spillway. The dam was toppled by water in its center and failed (Katkins 1989). There is still debate as to whether the 1889 dam failure and resulting flood is solely attributable to the heavy rains or from the lack of basic maintenance of the dam by the South Fork Fishing & Hunting Club. There is some consensus that had the dam been maintained to the original specifications, the disaster would never have occurred (Issenberg 2004).

Figure 4. Historic photograph of the destruction of Johnstown by 1889 flood. The people standing on rooftops were likely sightseers. The event prompted the first major relief effort by the American Red Cross led by Clara Barton. Photograph is courtesy of the Johnstown Flood Museum.

Figure 5. Historic photograph of the destruction of the town of South Fork, Pennsylvania near the confluence of South and North Forks of the Little Conemaugh River. Photograph is courtesy of the Johnstown Flood Museum.

Figure 6. Historic map of Johnstown showing flood damaged areas (shaded). Photograph is courtesy of the Johnstown Flood Museum.

Figure 7. Photograph of remnants of South Fork Dam in the right hand portion of the image. Photograph by Jeffrey Kitsko, 2005.

Figure 8. Photograph of the lakebed of former Lake Conemaugh, now managed as a wetland – meadow system. Photograph by Jeffrey Kitsko, 2005.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Johnstown Flood National Memorial. The accompanying table is highly generalized and is provided for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Johnstown Flood National Memorial informed the "Geologic History," "Geologic Features and Processes," and "Geologic Issues" sections of this report. Geologic maps are essentially two-dimensional representations of complex three-dimensional relationships. The various colors on geologic maps represent rocks and unconsolidated deposits. Bold lines that cross and separate the color patterns mark structural features such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mine features, wells, and cave openings.

Incorporation of geologic data into a geographic information system (GIS) increases the utility of geologic maps and clarifies spatial relationships to other natural resources and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make correlations between geology and biology; for instance, geologic maps have served as tools for locating threatened and endangered plant species.

Although geologic maps do not show where future earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps will not show where the next landslide, rockfall, or volcanic eruption will occur, but mapped deposits show areas that have been susceptible to such geologic hazards. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by various geomorphic features that are shown on geologic maps: alluvial terraces may preserve artifacts, and inhabited alcoves may occur at the contact between two rock units.

The features and properties of the geologic units in the following table correspond to the accompanying digital geologic data. Map units are listed from youngest to oldest. Please refer to the geologic time scale (fig. 9) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use. The following are source data for the GRE digital geologic map:

Whitfield, T.G. and others. 2001. *Digital Bedrock Geology of Pennsylvania, Johnstown and Tyrone 30' x 60' quadrangles, Pennsylvania*. Scale 1:250,000. PAGS 30'x60' Digital Quadrangle maps. Middletown Pennsylvania: Pennsylvania Geological Survey.

McElroy, T.A. 1998. *Groundwater resources of Cambria County, Pennsylvania*. Scale 1:50,000. Water Resource Report W 67. Middletown Pennsylvania: Pennsylvania Geological Survey.

Using ESRI ArcGIS software, the Geologic Resource Evaluation team created a digital geologic map from this source. GRE digital geologic-GIS map products include data in ESRI shapefile and coverage GIS formats, FGDC metadata, a Windows HelpFile that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map with appropriate symbology.

GRE digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/).

Johnstown Flood Geologic Map Unit Notes

Johnstown Flood National Memorial sits near the boundary between the Valley and Ridge and Appalachian Plateau physiographic provinces. The oldest rocks in the park area are the Cambrian Waynesboro, Pleasant Hill, Warrior, and Gatesburg Formations. These units are deformed sedimentary rocks consisting of dolomite, limestone, sandstone, and shale. The limestone and dolomite units locally contain fossil algae called stromatolites from early Cambrian seas (Berg et al. 1980; Whitfield et al. 2001).

Ordovician units such as the Nittany, Stonehenge/Larke, Bellefonte, Axemann, Coburn through Loysburg, Reedsville, Bald Eagle, and Juniata Formations were deposited atop the Cambrian units. Cherty dolomites, shales, and fossiliferous limestones dominate the lower units. Siltstones, sandstones and conglomerates (in the Bald Eagle Formation) become more abundant upwards in the Ordovician stratigraphic sequence.

Following the Taconic orogeny, Silurian units such as the Tuscarora Formation, Clinton Group, Bloomsburg, Mifflintown, and Wills Creek Formations record the gradual return to tectonic quiescence and intense erosion of the newly formed Taconic highlands. Sediments changed from largely terrigenous sandstones to muds, and eventually to marine carbonate units with occasional storm layers as sea level rose and the mountains were deeply eroded (Cotter 1983).

The Keyser and Tonoloway Formations contain fossiliferous limestones and mudcracked shales recording the transition between the Silurian and Devonian Periods. Marine deposition continued throughout the Devonian comprising the calcareous shales, siltstones, chert, and fossiliferous limestones of the Onondaga and Old Port Formations, the Hamilton Group, Braillier and Harrell Formations.

Sandstone and mudstone become more prevalent in the Scherr, Foreknobs, and Catskill Formations, whereas the argillaceous sandstone and shale with local conglomerates of the Rockwell, and Shenango through Oswayo Formations record the transition from the Devonian to Mississippian Periods (Berg et al. 1980; Whitfield et al. 2001).

Within the park and immediate surrounding area, map units from the Mississippian and Pennsylvanian Periods are present and include the Pocono Formation, Burgoon Sandstone, Loyalhanna, and Mauch Chunk Formations, the Pottsville and Allegheny Groups, and the Glenshaw and Casselman Formations. These units contain abundant sandstone and siltstone, some conglomerate layers, shale, and limestone. These units are also fossiliferous containing remains of vast marshy peat swamps and wetlands. They contain significant amounts of coal including the commercially valuable Freeport, Kittanning, and Brookeville-Clarion coals (Whitfield et al. 2001).

Mesozoic and all but the most recent Cenozoic rock units are missing from the landscape surrounding Johnstown Flood National Memorial due to regional erosion or non-deposition. Recent, Quaternary age alluvium deposits line local river and stream valleys. These consist of unconsolidated clay, silt, sand, gravel, and occasional boulder deposits (McElroy 1998).

The following pages present a tabular view of the stratigraphic column and an itemized list of features for each map unit. Map units are listed from youngest to oldest; please refer to the geologic time scale (see fig. 9) for the age associated with each time period. This table includes properties of each map unit such as map symbol, name, description, resistance to erosion, suitability for development, hazards, potential paleontologic resources, cultural and mineral resources, potential karst issues, potential for recreational use, and global significance.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Johnstown Flood National Memorial, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

Johnstown Flood National Memorial sits along the zone between the Valley and Ridge and Appalachian Plateau physiographic provinces in central Pennsylvania known as the Allegheny Front section. The park contains features intimately tied with the long geologic history of the Appalachian Mountains and the evolution of the eastern coast of the North American continent. A regional perspective is presented here to connect the landscape and geology of the park to its surroundings.

The recorded history of the Appalachian Mountains begins in the Proterozoic (fig. 9). During the Grenville orogeny (mid-Proterozoic), a supercontinent formed that consisted of most of the continental crust in existence at that time. This included the crust of North America and Africa. The sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism are apparent in the metamorphic granite and gneiss in the core of the modern Blue Ridge Mountains to the south and east of Johnstown Flood National Memorial (Harris et al. 1997).

These rocks formed over a period of approximately 100 million years and are more than a billion years old, making them among the oldest rocks in this region. They were later uplifted and thus exposed to erosion for hundreds of millions of years. Their leveled surface forms a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001).

The late Proterozoic, roughly 800–600 million years ago, brought extensional rifting to the area. The crustal extension created fissures through which massive volumes of basaltic magma were extruded (fig. 10A). The volcanism lasted tens of millions of years and alternated between flood basalt flows and ash falls. The volcanic rocks covered the granitic/gneissic basement in central Pennsylvania.

Continued crustal extension caused the supercontinent to break up, and a basin formed that eventually became the Iapetus Ocean. This basin subsided, and sediments that would eventually form the rock units of the Appalachian Mountains were deposited (fig. 10B). Some of the sediments were deposited as alluvial fans, large submarine landslides, and turbidity flows, which today preserve their depositional features.

These late Proterozoic sediments are exposed throughout eastern Pennsylvania. There is a good exposure of these rocks on South Mountain some 100 km (60 mi) southeast of the site (Chilhowee Group: Loudoun Formation, Weverton Formation, Harpers Formation, and Antietam Formation) (Southworth et al. 2001).

Extensive sand, silt, and mud deposited in near-shore, deltaic, barrier island, and tidal-flat areas were associated with the shallow marine setting along the eastern continental margin of the Iapetus sea (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). In addition, widespread carbonate sediments, sand, and mud, such as the Cambrian Waynesboro, Pleasant Hill, and Gatesburg Formations in the Johnstown area, were deposited on top of the Chilhowee Group. They represent part of a grand platform that thickened to the east and that persisted during the Cambrian and Ordovician Periods (545–480 million years ago) (Means 1995). Ordovician units such as the Nittany, Bellefonte, Reedsville, and Juniata Formations recorded the transition from a carbonate platform to a more near-shore terrestrial deposition associated with the beginning of the Taconic orogeny.

Igneous plutons intruded the sedimentary rocks along the eastern edge of the continent intermittently (540, 470, and 360 million years ago). During several episodes of mountain building and continental collision (described below), the entire sedimentary section, intrusive rocks, and basalt were deformed and metamorphosed into schist, gneiss, marble, slate, and migmatite (Southworth et al. 2000).

Taconic Orogeny

From Early Cambrian through Early Ordovician time, orogenic activity along the eastern margin of the continent began again. The Taconic orogeny (~440–420 million years ago in the central Appalachians) was associated with a volcanic arc–continent convergence. Oceanic crust and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of the North American continent. The Taconic orogeny resulted in the closing of the ocean, subduction of oceanic crust, creation of volcanic arcs, and uplift of continental crust (Means 1995). Initial metamorphism of the basalt of the Catoctin Formation into metabasalt and metarhyolite, as well as the Chilhowee Group rocks into quartzite and phyllite, occurred during this orogenic event.

The crust bowed downwards in response to the overriding plate that was thrust westward onto the continental margin of North America, creating a deep basin that filled with mud and sand eroded from the highlands to the east (fig. 10C) (Harris et al. 1997). This so-called Appalachian basin was centered on what is now West Virginia. These in-filling sediments covered the

Cambrian carbonate platform and are today represented by the Ordovician (505–440 million years ago) units (Southworth et al. 2001).

The oceanic sediments of the shrinking Iapetus sea were thrust westward along the Pleasant Grove fault during the Late Ordovician onto other deep-water sediments of the western Piedmont. Sand, mud, silt, and carbonate sediment of the Tuscarora Formation, Clinton Group, Bloomsburg Formation, and other Silurian rocks were then deposited in a shallow marine to deltaic environment of the Appalachian basin. These rocks, now metamorphosed, underlie the Valley and Ridge physiographic province (Fisher 1976).

Shallow marine to fluvial sedimentation continued intermittently for a period of about 200 million years during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods. This resulted in a thick sedimentary section. The source of these sediments was the highlands to the east that were rising during the Taconian orogeny (Ordovician) and the Acadian orogeny (Devonian). The Keyser and Tonoloway Formations contain widespread limestone and shale that reflect the transition from the Silurian to the Devonian periods.

Acadian Orogeny

The Acadian orogeny (≈360 million years ago) continued the mountain building of the Taconic orogeny as the African continent drifted towards North America (Harris et al. 1997). The Acadian event involved collision of landmasses, mountain building, and regional metamorphism similar to the preceding Taconic orogeny (Means 1995). This event was focused north of present-day central Pennsylvania.

The Acadian event caused further uplift of Taconic highlands in central Pennsylvania. Erosion of these highlands provided more sediments, leading to the basin-wide deposition of the Onondaga, Catskill, Foreknobs, and Old Port Formations, the Hamilton Group, and other Devonian units.

The tectonic quiescence between the Acadian and Alleghanian orogenic events (see below) led to the deposition of the vast marsh and wetland deposits of the Mississippian and Pennsylvanian periods. Burial and compression of these deposits created the vast coal-bearing units of the Mississippian Burgoon Sandstone, the Pennsylvanian Casselman and Glenshaw Formations, and the Allegheny and Pottsville Groups (Berg et al. 1980; Whitfield et al. 2001).

Alleghanian Orogeny

During the Late Paleozoic and following the Acadian orogeny, the proto-Atlantic Iapetus Ocean was closed as the North American continent collided with the African continent. This formed a supercontinent named Pangaea and the Appalachian mountain belt we see today. This mountain-building episode is called the Alleghanian orogeny (≈325–265 million years ago), the last major orogeny that affected the Appalachians (fig. 10D) (Means 1995). The rocks were deformed during as many as seven phases of folding and faulting, producing the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge–South Mountain anticlinorium, and the numerous folds of the Valley and Ridge province in the Johnstown Flood National Memorial area (Nickelsen 1983; Southworth et al. 2001). Many of the faults and folds associated with the Alleghanian orogeny are exposed today around the Johnstown Flood National Memorial.

During this orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were transported along the North Mountain fault as a massive block (Blue Ridge–Piedmont thrust sheet) westward onto younger rocks of the Valley and Ridge. The amount of crustal shortening was very large: estimates of 20–50 percent shortening would amount to 125–350 km (80–220 mi) (Harris et al. 1997).

Deformed rocks in the eastern Piedmont were also folded and faulted, and existing thrust faults were reactivated as both strike-slip and thrust faults during the Alleghanian orogeny (Southworth et al. 2001). Paleoelevations of the Alleghenian Mountains are estimated at approximately 6,000 m (20,000 ft), analogous to the modern-day Himalaya Range in Asia. These mountains have been beveled by erosion to elevations less than 734 m (2,408 ft) above sea level in the Johnstown Flood National Memorial area (Means 1995).

Triassic Extension to the Present

Following the Alleghanian orogeny, during the late Triassic (230–200 million years ago), a period of rifting began as the deformed rocks of the joined continents began to break apart. The supercontinent Pangaea was segmented into roughly the same continents that persist today. This episode of rifting initiated the formation of the current Atlantic Ocean and caused many block-fault basins to develop with accompanying volcanism (fig. 10E) (Harris et al. 1997; Southworth et al. 2001).

The Newark Basin system, to the east of Johnstown Flood National Memorial, is a large part of this tectonic setting. Large streams carried debris shed from the uplifted Blue Ridge and Piedmont provinces depositing them in alluvial fans. These were deposited as non-marine mud and sand in fault-created troughs such as the Frederick Valley in central Maryland and the Culpeper basin in the western Piedmont of central Virginia. Many of these rifted areas became lacustrine basins and were filled with thick silt and sand deposits.

Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroded Alleghenian mountains. These were deposited eastward at the base of the mountains as alluvial fans and became part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The amount of material that was deposited has been inferred from the now-exposed metamorphic rocks in the Blue Ridge province to have been immense. Many of the rocks exposed at the surface must have been at least 20 km (≈10 mi) below the surface prior to regional uplift and erosion. The erosion continues to create the present landscape, the Susquehanna, Juniata, and Delaware rivers and their tributaries eroding sediments and depositing alluvial terraces along the rivers (fig. 10F).

The North American plate has continued to drift toward the west since the breakup of Pangaea and the uplift of the Appalachian Mountains. The isostatic adjustments that uplifted the continent after the Alleghanian orogeny continued at a lesser rate throughout the Cenozoic Period (Harris et al. 1997).

The landscape and geomorphology of the greater Allegheny Front area are the result of erosion and deposition along the rivers from about the mid-Cenozoic Period to the present, or at least the last 5 million years. The distribution of floodplain alluvium and ancient river terraces reflect the historical development of the local drainage systems. It seems the rivers have cut downward through very old, resistant rocks, overprinting their early drainageways (Southworth et al. 2001). The steep ridges and ravines present at Johnstown Flood National Memorial attest to this downward cutting and overprinting.

Glaciers from the Pleistocene Ice Ages never reached central Pennsylvania. The southern terminus was at 365–610 m (1,200–2,000 ft) in elevation in northwestern and northeastern Pennsylvania. In the northern part of Pennsylvania, upland surfaces have been glaciated to rounded ridges and sand- and gravel-filled valleys (Davies 2005). However, the colder climates of the Ice Ages played a role in the formation of the landscape at Johnstown Flood National Memorial.

The Allegheny Mountains developed periglacial conditions that included discontinuous permafrost, tundra-like vegetation, and many freeze-thaw cycles due to its proximity to the glacial environment as well as its high elevation. These freeze-and-thaw cycles led to the ice wedging of thousands of boulders and small rocks from the mountains. Water would melt during the day and seep into cracks, freeze at night, expand, and force the rocks apart. Downslope movement of these rocks created talus piles, and larger, water-saturated rock masses slid over the partially frozen layer below in a process known as solifluction (Means 1995). Frost wedging continues in the area today (fig. 11).

The Ice Age climate may have affected the morphology of the river valleys as well. The periglacial conditions at high altitudes intensified weathering and other erosional processes (Harris et al. 1997). The landforms and deposits are probably late Tertiary to Quaternary, when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to drain into the ancestral river channels, enhancing downcutting and erosion by waterways such as Blair Gap Run (Means 1995). The several water gaps through the resistant ridges throughout the Valley and Ridge province are examples of these incised waterways.

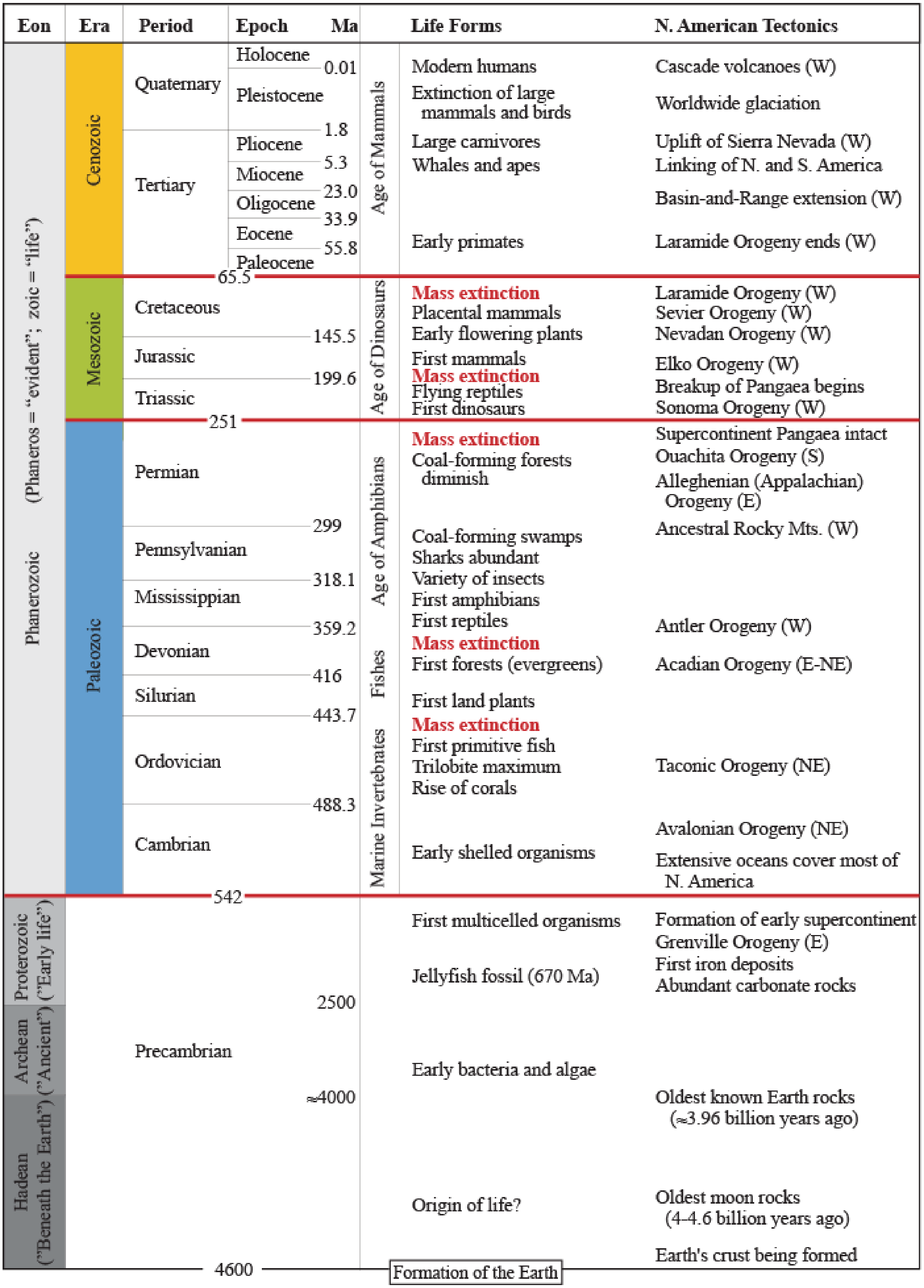
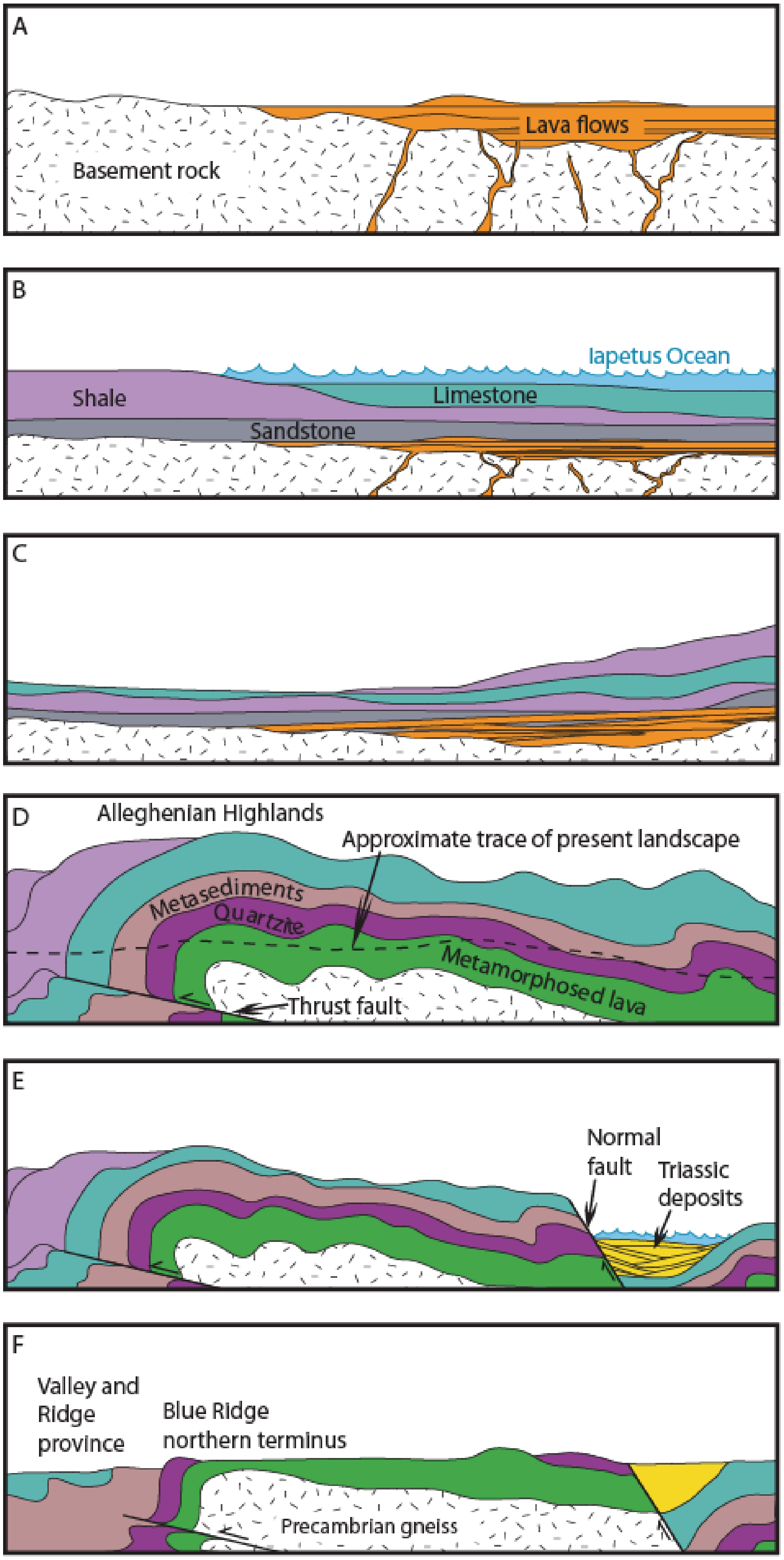


Figure 9. Geologic time scale; adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years.



800-600 Ma—Following the Grenville orogeny and erosion, crustal extension leads to volcanism, producing flood basalt and ash flows.

650-450 Ma—Iapetus Ocean continues to widen and the basin subsides; deposits of sand, silt, and clay, shed from the nearby highlands, and marine limestone fill the basin atop the flood basalt.

450-350 Ma—Inland-sea deposition continues as the Taconic and Acadian highlands rise to the east, providing more sediment.

325-265 Ma—Alleghenian orogeny leads to metamorphism of the rocks, which are fractured, folded, and overturned to form high mountains over the present landscape.

225-200 Ma—Following continental collision, the extensional environment creates fault-bounded basins along the eroding front of the mountain ranges, which provide sediment to the basins.

Present—Erosion bevels the mountains to the present topographic surface, deposition continues toward the eastern coast. and resistant rocks form local ridges.

Figure 10. Evolution of the landscape in the area of Johnstown Flood National Memorial area from the Precambrian through the present. Graphic adapted from Means (1995). Ma, millions of years (mega-annum). Drawings not to scale.

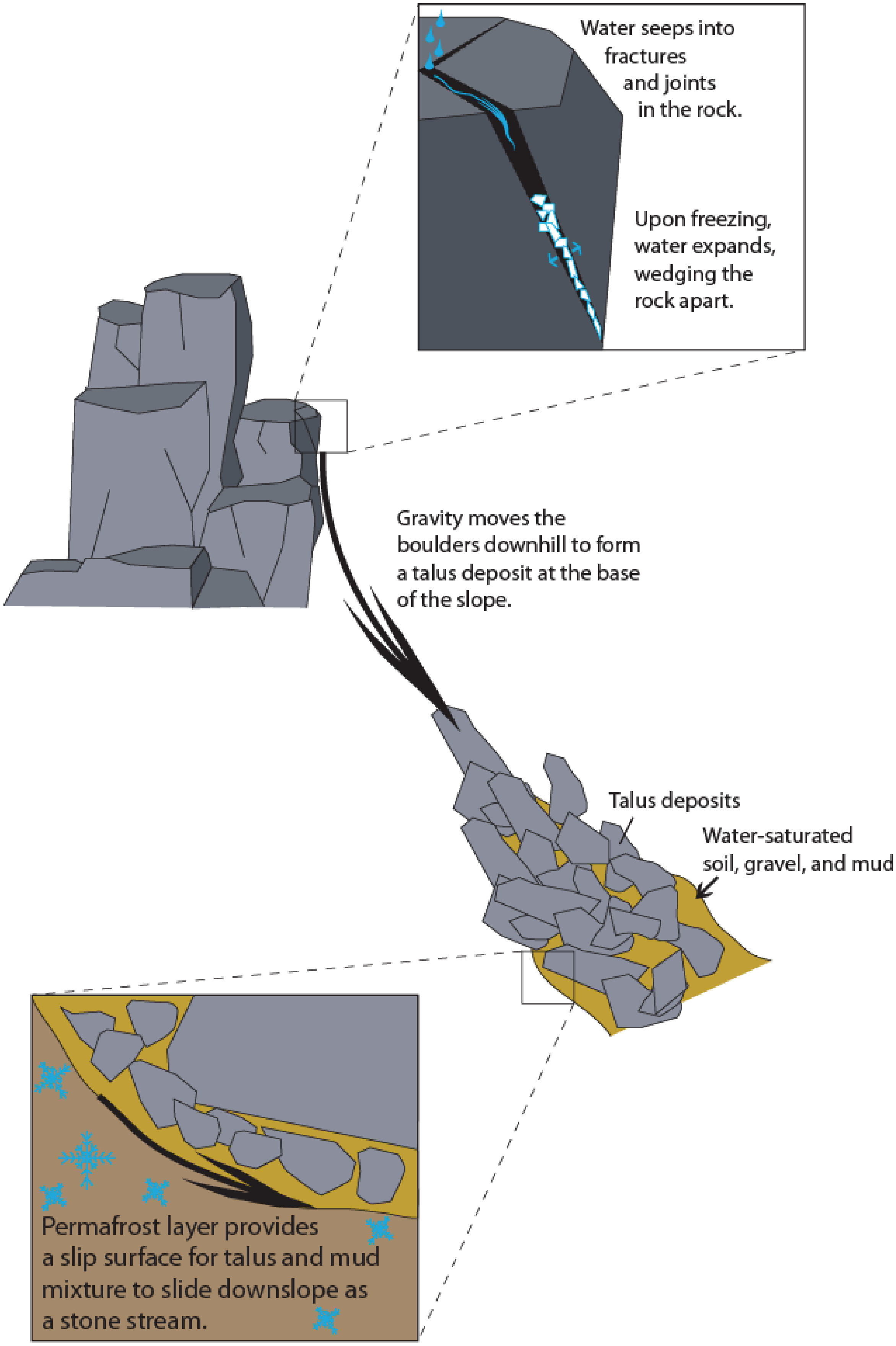


Figure 11. Diagram showing frost wedge weathering and subsequent formation of talus piles in a typical outcrop in the Allegheny Mountains. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

active margin. A continental margin where significant volcanic and earthquake activity occurs; commonly a convergent plate margin.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a high-gradient stream flows out of a mountain front into an area of lesser gradient, such as a valley.

alluvium. Stream-deposited sediment that is generally rounded, sorted, and stratified.

angular unconformity. An unconformity where the strata above and below are oriented differently; generally caused by structural deformation and erosion prior to deposition of the upper bed.

anticlinorium. A composite anticlinal structure of regional extent composed of lesser folds.

aquifer. Rock or sediment that are sufficiently porous, permeable, and saturated to be useful as a source of water.

ash (volcanic). Fine pyroclastic material ejected from a volcano (also see "tuff").

asthenosphere. Weak layer in the upper mantle below the lithosphere where seismic waves are attenuated.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.

basin (structural). A doubly-plunging syncline in which rocks dip inward from all sides (also see "dome").

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.

bedding. Depositional layering or stratification of sediments.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

block (fault). A crustal unit bounded by faults, either completely or in part.

braided stream. A stream, clogged with sediment that forms multiple channels that divide and rejoin.

calcareous. A rock or sediment containing calcium carbonate.

carbonaceous. A rock or sediment with considerable carbon, especially organics, hydrocarbons, or coal.

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical sediment. A sediment precipitated directly from solution (also called "nonclastic").

chemical weathering. The dissolution or chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances.

clastic. Rock or sediment made of fragments or pre-existing rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (>1/256 mm).

cleavage (rock). The tendency of rock to break along parallel planes that correspond to the alignment of platy minerals.

concordant. Strata with contacts parallel to the attitude of adjacent strata.

conglomerate. A coarse-grained sedimentary rock with clasts larger than 2 mm in a fine-grained matrix.

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25–60 km (16–37 mi) and a density of approximately 2.7 grams per cubic centimeter.

continental drift. The concept that continents have shifted in position over Earth (see and use "plate tectonics").

continental rise. Gently sloping region from the foot of the continental slope to the abyssal plain.

continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths of less than 200 m (656 ft).

continental shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone only gentle warping compared to the intense deformation of bordering crust

continental slope. The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

convergent boundary. A plate boundary where two tectonic plates are moving together (i.e., a zone of subduction or obduction).

craton. The relatively old and geologically stable interior of a continent (also see "continental shield").

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions.

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in an oriented vertical plane.

crust. The outermost compositional shell of Earth, 10–40 km (6–25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

crystalline. Describes the structure of a regular, orderly, repeating geometric arrangement of atoms

debris flow. A rapid and often sudden flow or slide of rock and soil material involving a wide range of types and sizes.

deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

delta. A sediment wedge deposited at a stream's mouth where it flows into a lake or sea.

dike. A tabular, discordant igneous intrusion.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

disconformity. An unconformity at which the bedding of the strata above and below are parallel.

discordant. Having contacts that cut across or are set an angle to the orientation of adjacent rocks.

divergent boundary. A tectonic plate boundary where the plates are moving apart (e.g., a spreading ridge or continental rift zone).

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

eustatic. Relates to simultaneous worldwide rise or fall of sea level in Earth's oceans.

evaporite. Chemically precipitated mineral(s) formed by the evaporation of solute-rich water under restricted conditions.

exfoliation. The breakup, spalling, peeling, flaking, etc., of layers or concentric sheets from an exposed rock mass due to differential stresses resulting from thermal changes or pressure unloading.

extrusion. The emission of relatively viscous lava onto the Earth's surface; also, the rock so formed.

extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.

facies (metamorphic). The pressure-temperature regime that results in a particular, distinctive metamorphic mineralogy (i.e., a suite of index minerals).

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

fault. A subplanar break in rock along which relative movement occurs between the two sides.

formation. Fundamental rock-stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, fault)

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

geology. The study of Earth including its origin, history, physical processes, components, and morphology.

igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes or rocks—igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

isostasy. The process by which the crust "floats" at an elevation compatible with the density and thickness of the crustal rocks relative to underlying mantle.

isostatic adjustment. The shift of the lithosphere of the Earth to maintain equilibrium among units of varying mass and density; excess mass above is balanced by a deficit of density below, and vice versa.

joint. A semi-planar break in rock without relative movement of rocks on either side of the fracture surface.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lamination. The finest stratification or bedding as seen in shale and siltstone (syn: lamina or laminae) or the formation of laminae.

landslide. Any process or landform resulting from rapid mass movement under relatively dry conditions.

lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.

levees. Raised ridges lining the banks of a stream; may be natural or artificial.

limbs. The two sides of a structural fold on either side of its hingeline.

lineament. Any relatively straight surface feature that can be identified via observation, mapping, or remote sensing, commonly representing tectonic features.

lithification. The conversion of sediment into solid rock.

lithology. The description of a rock or rock unit, especially the texture, composition, and structure of sedimentary rocks.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50–100 km (31–62 mi) thick, that encompasses the crust and uppermost mantle.

loess. Silt-sized sediment deposited by wind, generally of glacial origin.

mafic. A rock, magma, or mineral rich in magnesium and iron.

magma. Molten rock generated within the Earth that is the parent of igneous rocks.

mantle. The zone of Earth's interior between crust and core.

matrix. The fine-grained interstitial material between coarse grains in porphyritic igneous rocks and poorly sorted clastic sediments or rocks.

meanders. Sinuous lateral curves or bends in a stream channel.

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

member. A lithostratigraphic unit with definable contacts that subdivides a formation.

metamorphic. Pertaining to the process of metamorphism or to its results.

metamorphism. Literally, "change in form." Metamorphism occurs in rocks through mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

mid-ocean ridge. The continuous, generally submarine, seismic, median mountain range that marks the divergent tectonic margin(s) in the world's oceans.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during subaerial dehydration.

nonconformity. An erosional surface preserved in strata in which crystalline igneous or metamorphic rocks underlie sedimentary rocks.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–mi) thick and generally of basaltic composition.

orogeny. A mountain-building event, particularly a well-recognized event in the geological past (e.g., the Laramide orogeny).

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

overbank deposits. Alluvium deposited outside a stream channel during flooding.

paleogeography. The study, description, and reconstruction of the physical geography from past geologic periods.

paleontology. The study of the life and chronology of Earth's geologic past based on the phylogeny of fossil organisms.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic Periods (also see "Laurasia" and "Gondwana").

parent (rock). The original rock from which a metamorphic rock or soil was formed.

passive margin. A tectonically quiet continental margin indicated by little volcanic or seismic activity.

pebble. Generally, small, rounded rock particles from 4 to 64 mm in diameter.

permeability. A measure of the ease or rate that fluids move through rocks or sediments.

plateau. A broad, flat-topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.

pluton. A body of intrusive igneous rock.

plutonic. Describes igneous rock intruded and crystallized at some depth in the Earth.

porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.

Principal of Original Horizontality. The concept that sediments are originally deposited in horizontal layers and that deviations from the horizontal indicate post-depositional deformation.

Principle of Superposition. The concept that sediments are deposited in layers, one atop another, i.e., the rocks on the bottom are oldest with the overlying rocks progressively younger toward the top.

progradation. The seaward building of land area due to sedimentary deposition.

provenance. A place of origin. The area from which the constituent materials of a sedimentary rock were derived.

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

radiometric age. An age in years determined from radioisotopes and their decay products.

recharge. Infiltration processes that replenish ground water.

red beds. Sedimentary strata composed largely of sandstone, siltstone, and shale that are predominantly red due to the presence of ferric oxide (hematite) coating individual grains.

regression. A long-term seaward retreat of the shoreline or relative fall of sea level.

relative dating. Determining the chronological placement of rocks, events, fossils, etc. from geological evidence.

reverse fault. A contractional, high-angle (>45°), dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").

rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

ripple marks. The undulating, subparallel, usually small-scale ridge pattern formed on sediment by the flow of wind or water.

rock. A solid, cohesive aggregate of one or more minerals or mineraloids.

roundness. The relative amount of curvature of the "corners" of a sediment grain, especially with respect to the maximum radius of curvature of the particle.

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

scarp. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement.

seafloor spreading. The process by which tectonic plates diverge and new lithosphere is created at oceanic ridges.

sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a major sea level transgression-regression sediment package.

shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256–1/16 mm).

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

slickenside. A smoothly polished and commonly striated surface representing deformation of a fault plane.

slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).

slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and commonly overlying the parent rock from which it formed.

spring. A site where water flows out at the surface due to the water table intersecting the ground surface.

strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, age, etc. of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow and confined within a channel.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

subsidence. The gradual sinking or depression of part of Earth's surface.

suture. The linear zone where two continental landmasses become joined due to obduction.

syncline. A fold of which the core contains the stratigraphically younger rocks; it is generally concave upward.

synclinorium. A composite synclinal structure of regional extent composed of lesser folds.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

tectonics. The geological study of the broad structural architecture and deformational processes of the lithosphere and aesthenosphere (also see "structural geology").

terraces (stream). Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

terrane. A region or group of rocks with similar geology, age, or structural style.

terrestrial. Relating to Earth or Earth's dry land.

theory. A hypothesis that has been rigorously tested against further observations or experiments to become a generally accepted tenet of science.

thrust fault. A contractional, dip-slip fault with a shallowly dipping fault surface ($<45^{o}$) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

trace (fault). The exposed intersection of a fault with Earth's surface.

trace fossils. Sedimentary structures, such as tracks, trails, burrows, etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

transgression. Landward migration of the sea due to a relative rise in sea level.

trend. The direction or azimuth of elongation of a linear geological feature.

type locality. The geographic location where a stratigraphic unit is well displayed, is formally defined as a typical section, and derives its name.

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

volcanic. Related to volcanoes; describes igneous rock crystallized at or near Earth's surface (e.g., lava).

water table. The upper surface of the saturated (phreatic) zone.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

References

This section lists references cited in this report, as well as a general bibliography that may be of use to resource managers. A more complete geologic bibliography is available from the National Park Service Geologic Resources Division.

Alterman, I.B. 1972. Structure and tectonic history of the Taconic allochthon and surrounding autochthon, east-central Pennsylvania. 34 (6), Columbia University, Palisades, NY: Doctoral Dissertation.

Becker, T.; Thomas, W.A.; Samson, S.D.; and Gehrels, G.E. 2003. Characterization of the late Paleozoic Alleghanian Orogen by detrital zircons from the synorogenic clastic wedge. *Abstracts with Programs–Geological Society of America*, 35 (6): 389.

Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers. 1980. *Geologic map of Pennsylvania*. Pennsylvania Geological Survey, 4th ser., Map 1, 1:250,000 scale, from source maps (PAGS Map 61) mapped at 1:62,500 scale.

Bern, Louise. 1999. Flooding; the Great Johnstown flood. In *The geology of Pennsylvania*, ed. Shultz, Charles H., 758-761. Harrisburg – Pittsburgh, PA: Geological Survey of Pennsylvania and Pittsburgh Geological Society.

Cotter, E. 1983. Silurian depositional history. In Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge. Guidebook for the Annual Field Conference of Pennsylvania Geologists, ld. Nickelsen, R.P.; and Cotter, E. 48: 3-28

Cotter, E.; and Driese, S.G. 1998. Incised-valley fills and other evidence of sea-level fluctuations affecting deposition of the Catskill Formation (Upper Devonian), Appalachian foreland basin, Pennsylvania. *Journal of Sedimentary Research* 68 (2): 347-361.

Coyle, P.R.; and Anderson, T.H. 2002. Structural and stratigraphic controls on the distribution of siliceous iron ore, Allegheny Plateau, west central Pennsylvania. *Abstracts with Programs–Geological Society of America* 34(6): 133.

Cressler, W.L.; Scheckler, S.E.; Basinger, J.F.; and Lindsay-Postnikoff, D. 2002. Wetlands paleoecology of the Middle and Late Devonian. *Abstracts with Programs–Geological Society of America* 34 (6): 210.

Davies, W.E. 2005. Physiography. http://www.cagenweb.com/quarries/articles_and_books/min_res_appalachian_region/physiography.html (accessed November 4, 2005).

Duffy, D.F., and Whittecar, G.R. 1991. Geomorphic development of segmented alluvial fans in the Shenandoah Valley, Stuarts Draft, Virginia. *Abstracts with Programs–Geological Society of America* 23 (1): 24.

Earnest, J. 2002. The Dam and Lake. http://www.nps.gov/jofl/thedam.htm (accessed November 29, 2005).

Erney, B.M.; Schneider, J.; VanDyne, A.; and Schiappa, T. 2003 Use of stratigraphic analysis to reconstruct the Pennsylvanian depositional history of western Pennsylvania. *Abstracts with Programs–Geological Society of America* 35 (3): 92.

Evans, M.A. 2000. Characterizing the deformation associated with cross-strike tear faults in south central Pennsylvania. *Abstracts with Programs–Geological Society of America* 32 (1): 16.

Fisher, G.W. 1976. The geologic evolution of the northeastern Piedmont of the Appalachians. *Abstracts with Programs–Geological Society of America* 8 (2): 172-173.

Harris, A.G., Tuttle, E., and Tuttle, S.D. 1997. *Geology of National Parks*. Kendall/Hunt Publishing Company.

Hower, J.C.; Levine, J.R.; Skehan, J.W.; Daniels, E.J.; Davis, A.; Gray, R.J.; and Altaner, S.P. 1992. Appalachian anthracites. *Annual Meeting of the Society for Organic Petrology. Abstracts and Program*s 9: 118-120.

Inners, J.D. 1989. Historical geography, stratigraphy, and economic geology of the Horseshoe Curve area, west-central Pennsylvania. *Abstracts with Programs–Geological Society of America* 21 (2): 25.

Issenberg, A. 2004. After the Flood. *Special to the Washington Post* 11-17-2004: C02, http://www.washingtonpost.com/wp-dyn/articles/A55686-2004Nov16.html (accessed December 1, 2005).

Jacob, K.H. 1989. Earthquake Hazards in the Eastern U.S.; Research topics and hazards mitigation strategies. *Abstracts with Programs–Geological Society of America* 21 (2): 25.

Kaktins, U. 1989. Stop #10; Johnstown Flood National Memorial. In *Geology in the Laural Highlands of southwestern Pennsylvania*, ed. Harper, John A., 224-227. Harrisburg, PA: Field Conference of Pennsylvania Geologists.

Kauffman, M.E,; and Frey, E.P. 1979. Antietam sandstone ridges; exhumed barrier islands or fault-bounded blocks? *Abstracts with Programs–Geological Society of America* 11 (1): 18.

Knight, F. James. 1989. Stop #5; Laurel Run Dam and the Johnstown flood of 1977. In *Geology in the Laural Highlands of southwestern Pennsylvania*, ed. Harper, John A., 211-213. Harrisburg, PA: Field Conference of Pennsylvania Geologists.

Kochel, R.C.; Eaton, L.S.; and Howard, A.D. 1996. Catastrophic debris flows in the Northern and Central Appalachians; considerations of their role in the evolution of Piedmont geomorphology. *Abstracts with Programs–Geological Society of America* 28 (7): 299.

Laughrey, C.D.; Billman, D.A.; and Canich, M.R. 1999. Geology of the Council Run gas field, north central Pennsylvania; implications for energy resource development in the Eastern Plateaus Province of the central Appalachian Basin. *AAPG Bulletin* 83 (8): 1369.

Madison, J.P.; Lonn, J.D.; Marvin, R.K.; Metesh, J.J.; and Wintergerst, R. 1998. Abandoned-inactive mines program, Deer Lodge National Forest; Volume IV, Upper Clark Fork River drainage. *MBMG Open-File Report*.

McElroy, T.A. 1998. Groundwater resources of Cambria County, Pennsylvania, *Pennsylvania Geological Survey, Water Resource Report* W 67, 1:50,000 scale

Means, J. 1995. Maryland's Catoctin Mountain parks; an interpretive guide to Catoctin Mountain Park and Cunningham Falls State Park. Blacksburg, VA: McDonald & Woodward Publishing Company.

Miller, J.D.; and Kent, D.V. 1986. Synfolding and prefolding magnetizations in the Upper Devonian Catskill Formation of eastern Pennsylvania; implications for the tectonic history of Acadia. *Journal of Geophysical Research* 91 (B12): 12,791-12,803.

Moore, J.N., and Woessner, W.W. 2000. Geologic, Soil Water and Groundwater Report – 2000, Grant-Kohrs Ranch National Historic Site. U.S. National Park Service, Department of the Interior.

Nickelsen, R.P. 1983. Aspects of Alleghanian deformation. In Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge. Guidebook for the Annual Field Conference of Pennsylvania Geologists, ld. Nickelsen, R.P.; and Cotter, E. 48: 29-39.

Potter, N., Jr. 1985. Colluvial and alluvial gravels, carbonate weathering, and the preservation of a Cenozoic erosional history in the Great Valley, Southcentral Pennsylvania. *Abstracts with Programs–Geological Society of America* 17 (1): 59.

Prave, A.R.; and Duke, W.L. 1991. Sedimentology and sequence stratigraphic framework of the Middle Devonian Mahantango Formation in central Pennsylvania. In *Geologic evolution of the Eastern United States; field trip guidebook NE-SE GSA 1991. Guidebook Virginia Museum of Natural History,* ed. Schultz, A.; and Compton-Gooding, E. 2: 207-228.

Sasowsky, I.D.; Kempthorne, R.A.; Crowell, B.; Walko, S.M.; Larock, E.J.; and Harbert, W. 2000. Clastic sediments in a long-term karst trap, Valley and Ridge, central Pennsylvania. *Abstracts with Programs–Geological Society of America* 32 (7): 27.

Scharnberger, C.K. 1987. Some questionable events in the earthquake history of south-central Pennsylvania. *Seismological Research Letters* 58 (4): 104.

Schwab, F.L. 1970. Origin of the Antietam Formation (late Precambrian?, lower Cambrian), central Virginia. *Journal of Sedimentary Petrology* 40 (1): 354-366.

Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge. 1983. In *Guidebook for the Annual Field Conference of Pennsylvania Geologists,* ld. Nickelsen, R.P.; Cotter, E. 48.

Simpson, E.L. 1991. An exhumed Lower Cambrian tidal-flat; the Antietam Formation, central Virginia, U.S.A. In *Clastic tidal sedimentology*. *Memoir–Canadian Society of Petroleum Geologists,* eds. Smith, D G.;, Zaitlin, B.A.; Reinson, G.E.; and Rahmani, R.A. 16: 123-133.

Southworth, S.; Brezinski, D.K.; Orndorff, R.C.; Chirico, P.G.; and Lagueux, K.M. 2001. Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia. *A, Geologic map and GIS files (disc 1); B, Geologic report and figures (disc 2). U. S. Geological Survey, Open-File Report: OF 01-0188*.

Sowers, G. F. 1977. Earth dam failures. In *Lectures of the Seminar; Failures of large dams, reasons and remedial measures*, ed. Rouve, G.; Strack, B.; Idel, K. H.; Beckmann, J.; Hager, M.; Boucek, B.; Sowers, G. F.; Gilg, B., 178-226. Aachen, Federal Republic of Germany: Inst. Found. Eng., Soil Mech., Rock Mech., Water Ways Constr.

Stoher, P. 1992. A review of the fossil evidence for the existence of land plants from Silurian rocks of Pennsylvania. *Abstracts with Programs–Geological Society of America* 24 (3): 79.

Suciu, D.L.; Bachman, D.C.; and Owens, R.W. 1992. Pathway to history; the cultural geology of the U.S. 11/15 corridor in central Pennsylvania from prehistoric occupation to the 21st century. *Abstracts with Programs–Geological Society of America* 24 (3): 79.

Trexler, B.D.Jr., Ralston, D.A., Reece, D.A., and Williams, R.E. 1975. *Sources and causes of acid mine drainage*. Idaho Bureau of Mines and Geology, Pamphlet 165

Wells, R.B. 1973. Historical sketch; Juniata and Susquehanna rivers . Structure and Silurian and Devonian stratigraphy of the Valley and Ridge Province in central Pennsylvania. In *38th Annual Field Conference of Pennsylvania Geologists,* ed. Faill, R.T.: 51-52.

Whitfield, T.G. and others. 2001. *Digital Bedrock Geology of Pennsylvania, Johnstown and Tyrone 30' x 60' quadrangles, Pennsylvania*. Pennsylvania Geological Survey, PAGS 30'x60' Digital Quadrangle maps, 1:250,000 scale.

Whittecar, G. R.; and Duffy, D.F. 2000. Geomorphology and stratigraphy of late Cenozoic alluvial fans, Augusta County, Virginia, U.S.A. In *Regolith in the Central and Southern Appalachians. Southeastern Geology*, eds. Clark, G.M.; Mills, H.H.; and Kite, J.S. 39 (3-4): 259-279.

Appendix A: Geologic Map Graphic

The following page is a preview or snapshot of the geologic map for Johnstown Flood National Memorial. For a poster-size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Johnstown Flood National Memorial. The scoping meeting was on June 22, 2004; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

A geologic resources evaluation workshop was held for Allegheny Portage Railroad National Historic Site (ALPO) and Johnstown Flood National Memorial (JOFL) on June 22, 2004 to view and discuss the parks' geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), NPS ALPO and JOFL units, as well as local geologic experts were present for the workshop.

Geologic Mapping

Existing Geologic Maps and Publications

After the bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for ALPO and JOFL.

The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverage's were developed based on scales (*1:24,000*, *1:100,000*, etc.) available for the specific parks. Numerous geologic maps at varying scales and vintages cover the area. Index maps were distributed to each workshop participant during the scoping session.

It was decided to use Pennsylvania Map 61 for Blair County with focus on the Cresson, Hollidaysburg, and Frankstown quadrangles. Map 61 is presented at 1:62,500 scale but was originally mapped at 1:24,000. This covers main unit of ALPO

No water report has ever been done for Blair County since 1945 folio on Holidaysburg and Huntington.

Use the Pennsylvania map W-67 for Cambria County; this covers Staple Bend Unit and JOFL; some of ALPO main will be included as part of this map at 1:50,000 scale

Additionally for coal information discussion focused on map m-96 by the Pennsylvania Geological Survey (PA GS) for only areas containing coal. The GRE would need interpretation from PA GS before digitizing.

Small scale digital map of Pennsylvania exists and is available from PA GS website

Other Topics of Discussion

A discussion of geologic resource management issues followed the mapping discussion touching upon the following features and/or processes:

- Aeolian: NA
- Fluvial (surface water) Processes: ALPO (Staple Bend Unit) runs down Little Conemaugh River; ALPO main unit is eastern slope of Blair Gap Run;
    - JOFL is South fork of Little Conemaugh; obviously theme is in park name; foundations in river may be threatened
- Groundwater: NA; but can reference the PA GS water reports as well
- Hazards: Landslides, slumps, rockfalls prevalent in western PA
    - Clays that disintegrate when they become water saturated may be underlying JOFL dam abutments; should conduct a site investigation if Ames Limestone is present
    - Occasional earthquakes but not of significant magnitude; largest in PA was ~5M in northwest PA
    - Roof fall in Staple Bend tunnel
    - Floods
    - No CO3 sinkholes
- Paleontology: See Vince Santucci's report on ERMN paleontology.
- Mineral Extraction: See disturbed lands but coal and Fe known to have been mined
- Caves / karst: Carbonate beds often too thin to form karst thus a non-issue
- Glacial: NA
- Coastal/Marine: NA
- Geologic interpretation: Allegheny Front was reason for AL Portage and Staple Bend tunnel
    - Coal mine remediation
    - Mahoning sandstone quarry is big part of park's story
    - JOFL topography is essential to park's story
- Unique geologic features: Allegheny Front
    - Staple Bend tunnel was first blasted through solid rock in U.S.; took 3 years
    - Oxbows at Little Conemaugh viaduct
- Geothermal: NA

- Disturbed Lands–mining subsidence: Coal Mining subsidence at ALPO and JOFL; ALPO Staple Bend Unit and Main unit have acid mine drainage issues; JOFL has acid mine drainage initiating external to the park; PA Department of Environmental Protection has maps showing mined areas and they document mine subsidence events; should be GIS layer.
    - The maps are quad-based. They are a regulatory agency; PA GS is a research agency.
    - Mine shafts are an issue at ALPO main unit; Staple Bend unit they appear to be collapsed but haven't been investigated to date; should submit TA request to GRD for Burghardt or Cloues assistance
    - Only mined lands need reclaimed in both parks
    - Fe-mining of siderite in limestones supplanted local steel industry; effects unknown

Monitoring Issues

Monitor for landslides along steep hillsides of Allegheny Front.

Meeting attendees and contact information

Connors Tim NPS, Geologic Resources Division (303) 969-2093 e-mail: tim_connors@nps.gov

Harper John Pennsylvania Geological Survey (412) 442-4230 e-mail: jharper@state.pa.us

Heise Bruce NPS, Geologic Resources Division (303) 969-2017 e-mail: Bruce_Heise@nps.gov

Inners John Pennsylvania Geological Survey (717) 702-2034 e-mail: jinners@state.pa.us

Marshall Matt ERMN (814) 863-0134 e-mail: matt_marshall@nps.gov

Penrod Kathy NPS ALPO & JOFL (814) 886-6128 e-mail: kathy_penrod@nps.gov

Piekielek Nate ERMN (814) 863-2320 e-mail: nathan_piekielek@nps.gov

Santucci Vince NPS, Geologic Resources Division (307) 877-4455 e-mail: Vincent_Santucci@nps.gov

Johnstown Flood National Memorial

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/049
NPS D-67, September 2008

National Park Service

Director • Mary A. Bomar

Natural Resource Stewardship and Science

Associate Director • Bert Frost

Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross-cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

Geologic Resources Division

Chief • Dave Steensen
Planning Evaluation and Permits Branch Chief • Carol McCoy

Credits

Author • Trista Thornberry-Ehrlich
Review • Lisa Norby and Carol McCoy
Digital Map Production • Stephanie O'Meara and Trista Thornberry-Ehrlich
Map Layout Design • Melanie Ransmeier

National Park Service
U.S. Department of the Interior

Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, CO 80225

http://www.nature.nps.gov/geology/inventory/
(303) 969-2090