National Park Service
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Natural Resource Program Center

Friendship Hill National Historic Site

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/022

THIS PAGE:
Waterfall on Ice Pond Run, Friendship Hill NHP.

ON THE COVER:
Gallatin House, Friendship Hill NHP

NPS Photos

Friendship Hill National Historic Site

Geologic Resource Evaluation Report

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Geologic Resources Division
Natural Resource Program Center
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Executive Summary

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

Friendship Hill, located in southwestern Pennsylvania (fig. 1) was set aside to commemorate the home of Albert Gallatin (fig. 2) and his invaluable contributions to the history of the United States as treasurer during the Jefferson presidency. His estate, established in what was then the frontier, sits atop a high bluff overlooking the Monongahela River (fig. 3). Today this river is a major transportation corridor and joins the Allegheny River in Pittsburgh to form the Ohio River.

In addition to cultural resources such as Gallatin House and its grounds, Friendship Hill National Historic Site preserves land near the junction of three sections in the Appalachian Plateaus physiographic province (fig. 4): Waynesburg Hills, Pittsburgh Low Plateau, and Allegheny Mountain sections (fig. 5). 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 east of Friendship Hill. The Allegheny Mountains separate these two provinces. In the Friendship Hill area, geologic exposures consist primarily of sedimentary rocks of Pennsylvanian through Permian in age. These include sandstones, limestones, claystones, conglomerates, dolomites, and shales that contain fossils, commercially viable coals, and some iron- and sulfide- rich minerals.

Geologic resources serve as the foundation of the entire ecosystem. Geologic processes initiate complex responses that give rise to rock formations, topographic expression, surface and subsurface fluid movement, and soils. These processes create a landscape that can either welcome or discourage human use. At Friendship Hill, human land- use disturbances are clear such as logging and farming on slopes and bluffs. Both surface and underground coal mining has altered the natural topographic expression of the landscape and continues to threaten natural and cultural resources at the national historic site. Mining related hazards include surface subsidence and acid- mine drainage.

The following issues have a high level of management significance at Friendship Hill National Historic Site:

- Acid Mine Drainage. Friendship Hill National Historic Site is located in an area of western Pennsylvania known for extensive coal mining. Abandoned mines pose health, safety, and environmental threats to the area. Foremost among these is acid- mine drainage. The potential for acid- mine drainage and heavy metal contamination that accompanies low pH (~2.7) runoff is a serious resource management concern. Four small tributaries of the Monongahela River within the national historic site have low pH.
- Subsidence and Associated Hazards. Mine workings located beneath historic structures, trails, and other areas are prone to subsidence or collapse and require careful monitoring. Mine openings and airshafts pose hazards associated with both discharge of water and oxygen- depleted air. Deep underground mining and waste piles are associated with the potential for collapse. The NPS Disturbed Lands Restoration Program has been assisting park staff in the reclamation of abandoned mineral lands, including area closures, wetlands construction, waste stabilization, surface mine reclamation, subsidence mitigation, and historic stabilization. The legacy of past coal mining has impacted visitor safety and historic preservation of landscapes and structures and is an ongoing resource management concern.
- Geologic Hazards. The steep terrain along the Monongahela River is prone to several geologic hazards: landslides, slumps, and rockfalls. In particular, slope failures may occur in areas where natural or anthropogenic processes undercut resistant rock units by eroding weaker underlying units. Though not common, seismic activity is possible in western Pennsylvania. Even minor tremors might damage cultural resources, or trigger landslides, mine collapse, and debris flows on steep or water- saturated slopes.
- Water Issues. Fluvial erosion along the Monongahela River may impact the River trail as well as riparian environments and wetlands. Additionally water quality in the park has been affected by industrial development and coal mining near by. Understanding the hydrogeologic system is important for resource management.
- Paleontology. Although fossil resources have not been documented inside the park, potentially fossiliferous formations are present and may contain undiscovered paleontological resources.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Friendship Hill National Historic Site.

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. Scoping meetings are usually held for individual parks and on occasion for an entire Vital Signs Monitoring Network. 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://www2.nature.nps.gov/geology/inventory/).

Geologic Setting

Friendship Hill was the home of Swiss emigrant Albert Gallatin, the famous secretary of the Treasury whose legacy extends all the way to the river named in his honor in southwest Montana. He served under Presidents Jefferson and Madison, working to reduce the national debt, purchase the Louisiana Territory, and fund Lewis and Clark's discovery- filled journey. Gallatin's home, commemorating his accomplishments in the late 18th and early 19th centuries, is located in southwestern Pennsylvania, near the border with West Virginia (fig. 1). This estate, located on the frontier at the time of construction, was designated a national historic landmark in 1965, assigned to the National Register of Historic Places in 1966, and redesignated a national historic site by the National Parks and Recreation Act (P.L. 95- 625) on November 10, 1978 (92 STAT. 3509), during the presidency of Jimmy Carter.

Friendship Hill National Historic Site is located on a knoll overlooking the Monongahela River near Point Marion, in western Fayette County, Pennsylvania. It preserves some 675 acres (273 ha) of forested rolling hills broken by steep valleys. Wide river valleys dominate the landscape; whereas local streams such as Georges Creek, Ice Pond Run, Jacobs Creek, and York Run serve as more subtle yet significant drivers of landscape change.

The Monongahela River flows north from its source at the confluence of the West Fork and Tygart rivers near Fairmont, West Virginia. North of Friendship Hill, the river joins the Allegheny River to form the Ohio River. Humans have significantly altered the landscape surrounding Friendship Hill with a series of surface and underground mines along the length of the Monongahela River. Mining activities have effectively leveled preexisting topographic expression.

The rock units at Friendship Hill are generally flat lying and undeformed with surface variations resulting from erosion and downcutting of rivers. This is a typical stratigraphic picture in the Appalachian Plateaus physiographic province. Friendship Hill sits near the junction of three physiographic sub- provinces: Waynesburg Hills, Pittsburgh Low Plateau, and Allegheny Mountain. West of the national historic site are the undulating hills and steep valleys of Monongahela and Dunkard townships, including Durrs

Knob, Rocky Hollow, and Mundell Hollow. East of the site, Hardin, Bartons, and Victor hollows rise steeply towards Chestnut Ridge. Mississippian to Devonian sandstones cap this ridge.

A general east to west description of several of the different physiographic provinces of the Appalachian Mountains follows (fig. 1). The information is relevant to understanding the geologic history and setting of Friendship Hill National Historic Site.

Piedmont Province

The "Fall Line" or "Fall Zone" marks a transitional zone where the softer, less consolidated sedimentary rock of the Atlantic Coastal Plain province to the east intersects the harder, more resilient 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 Historical Park (Maryland, District of Columbia, and West Virginia). The Piedmont physiographic province encompasses the Fall Line westward to the Blue Ridge Mountains. The eastward- sloping Piedmont Plateau of this province formed through a combination of folds, faults, uplifts, and erosion. The resulting landscape of gently rolling hills, starting at 60 m (200 f) in elevation, becomes gradually steeper toward the western edge, reaching 300 m (1,000 ft) above sea level. The Piedmont Plateau is composed of hard, crystalline igneous and metamorphic rocks such as gabbros, schists, phyllites, slates, and gneisses.

Blue Ridge Province

The Blue Ridge province is located along the eastern edge of the Appalachian Mountains. The highest elevations in the Appalachians are near Great Smoky Mountains National Park (Tennessee and North Carolina). Proterozoic and Paleozoic igneous, sedimentary, and metamorphic rocks were uplifted during several orogenic events (i.e., Taconic, Acadian, and Alleghenian) forming steep, rugged terrain. Resistant Cambrian quartzite forms most of the high ridges, whereas Proterozoic metamorphic rocks underlie the valleys (Nickelsen 1956). The elongated belt of Blue Ridge stretches from Georgia to Pennsylvania. Eroding streams have caused the narrowing of the northern section of the Blue Ridge Mountains into a thin band of steep ridges that rise to heights of approximately 1,200 m (3,900 ft). These streams link the adjacent Valley and Range and Piedmont provinces.

Valley and Ridge Province

Long, parallel ridges separated by valleys (100 to 200 m [330 to 660 ft] deep) characterize the landscape of the Valley and Ridge physiographic province. The landforms are strongly representative of the lithology and structure of the deformed bedrock: valleys formed in easily eroded shale and carbonate formations among resistant sandstone ridges.

Averaging 80 km (50 miles) in width, the province contains strongly folded and faulted sedimentary rocks in central Pennsylvania. The eastern portion is part of the Great Valley; this section is rolling lowland formed on folded carbonate rocks and shale.

Appalachian Plateaus Province

Compared to the more eastern physiographic provinces, the Appalachian Plateaus province is relatively undeformed. Instead of highly folded and inclined strata like the Valley and Ridge province, the rock layers of this province are nearly flat. A steep scarp, known as the Allegheny Front, bounds the plateaus on the east. This escarpment rises abruptly 300 to 900 m (1,000 to 3,000 ft). Maximum elevations at this front are generally greater than that of the ridges in the Valley and Ridge province. In Pennsylvania, elevations range from 520 to 900 m (1,750 to 3,000 ft).

Deep ravines carved into the horizontal sedimentary rock layers characterize the topography of this province. Geologic units are typically repeated sequences of shale, coal, limestone, and sandstone. Erosion of these units has created a rugged, jumbled topographic surface. In Pennsylvania and New York, the northern reaches of the province, modified by glaciation, display more rounded hills with gentler slopes, and gradually diminish in elevation toward the Great Lakes coastal plain.

The Waynesburg Hills are composed of narrow hilltops separated by steep- sided narrow valleys with relief typically between 180 and 200 m (600 and 1,000 ft). Elevations in this section range from 150 to 500 m (500 to 1,650 ft).

A smooth, undulating topographic expression cut by numerous shallow river valleys characterizes the Pittsburgh Low Plateau. It contains much of the bituminous coal resources of Pennsylvania. Local relief is generally less than 60 m (200 ft) and elevations range from 200 to 520 m (600 to 1,700 ft).

By contrast, the Allegheny Mountain section consists of roughly parallel, broad, rounded ridges separated by broad river valleys. The crests of the ridges in this section are exposed anticlinal cores of very resistant rocks such as Devonian sandstones. Relief in this section reaches greater than 300 m (1,000 ft), and elevations range from the highest point at Mount Davis (979 m [3,213 ft]) to the low point at 236 m (775 ft) (Pennsylvania Geological Survey 2000).

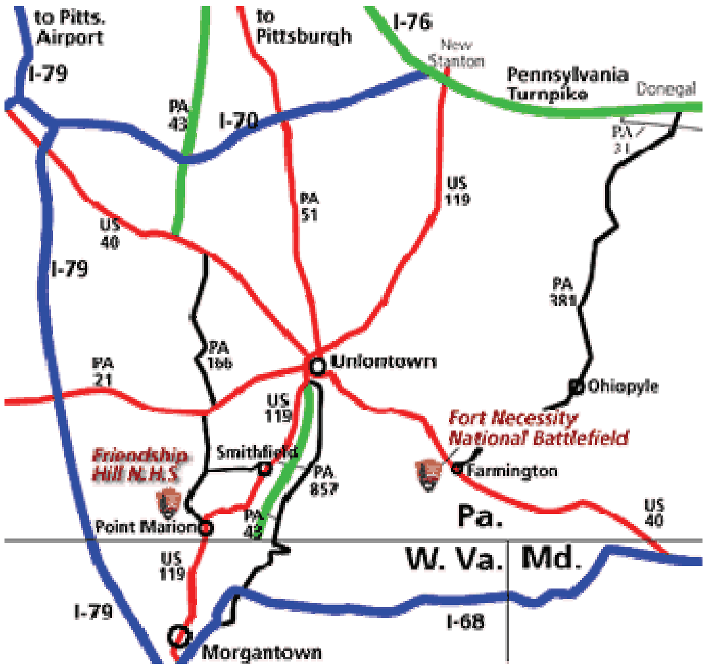

Figure 1. Map showing the location of Friendship Hill National Historic Site, Pennsylvania

Figure 2. Gallatin House. The historic structure sits atop a knoll at Friendship Hill National Historic Site. The main wing (to the left) closely resembles the original structure; several wings attached to the house represent multiple renovations. *Photo*: Ralph Lotshaw http://www.worldisround.com/articles/200796/photo6.html (accessed February 6, 2006).

Figure 3. View of the Monongahela River from Gallatin House. From this vantage point, visitors at Friendship Hill National Historic Site can see the remnants of early engineering structures within the river and the obvious height of the house above the steep slopes leading down to the river's edge. Photo: Ralph Lotshaw http://www.worldisround.com/articles/200796/photo7.html (accessed February 6, 2006).

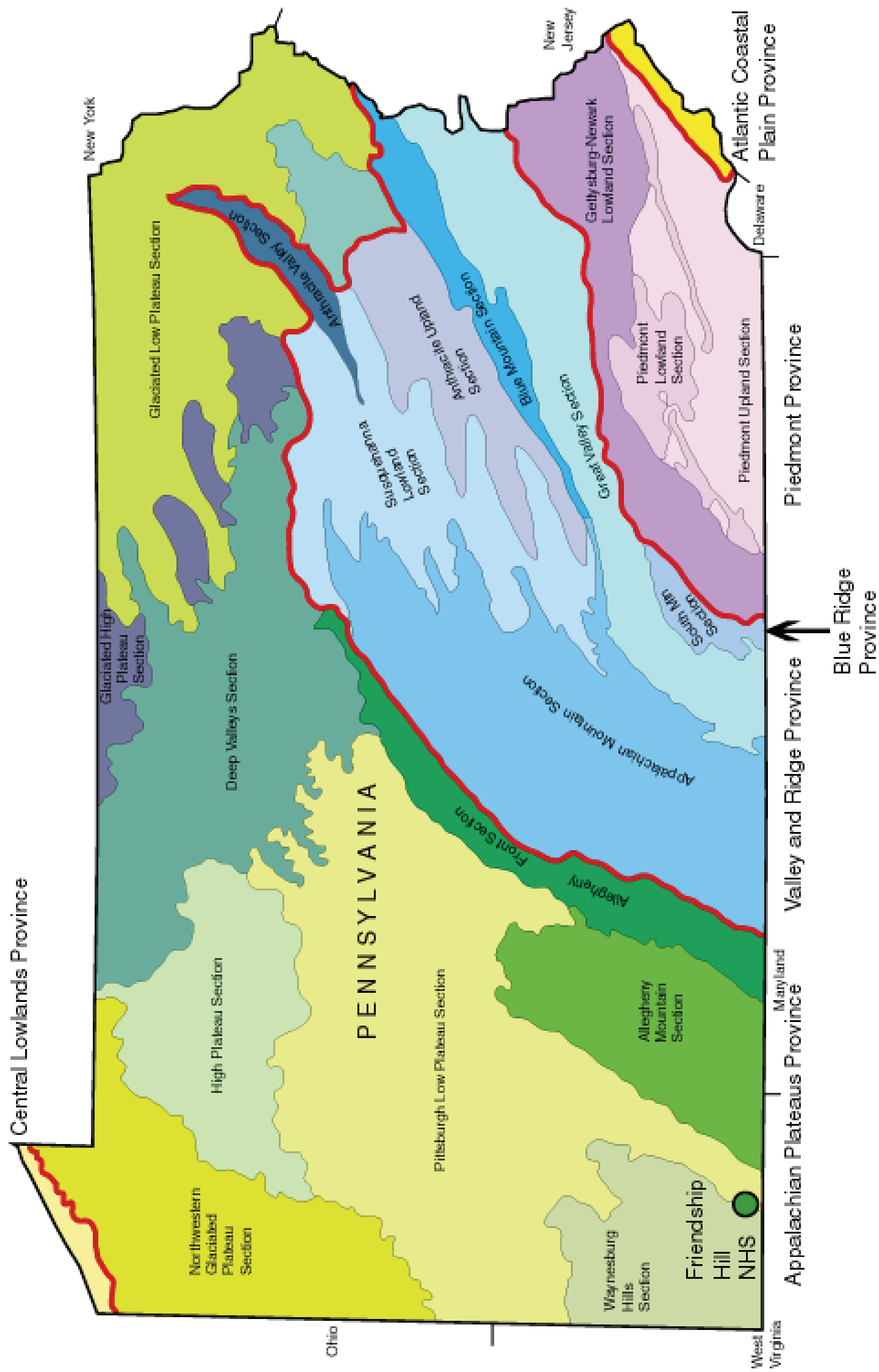

Figure 4. Map of Pennsylvania with Physiographic Provinces. Numerous physiographic sections surround Friendship Hill National Historic Site. Red lines on the figure indicate boundaries between major physiographic provinces. The black arrow indicates the northern terminus of the Blue Ridge province. Note location of national historic site as a green circle. *Source*: Pennsylvania Geological Survey (2000), map 13. *Graphic design*: Trista L. Thornberry-Ehrlich (Colorado State University).

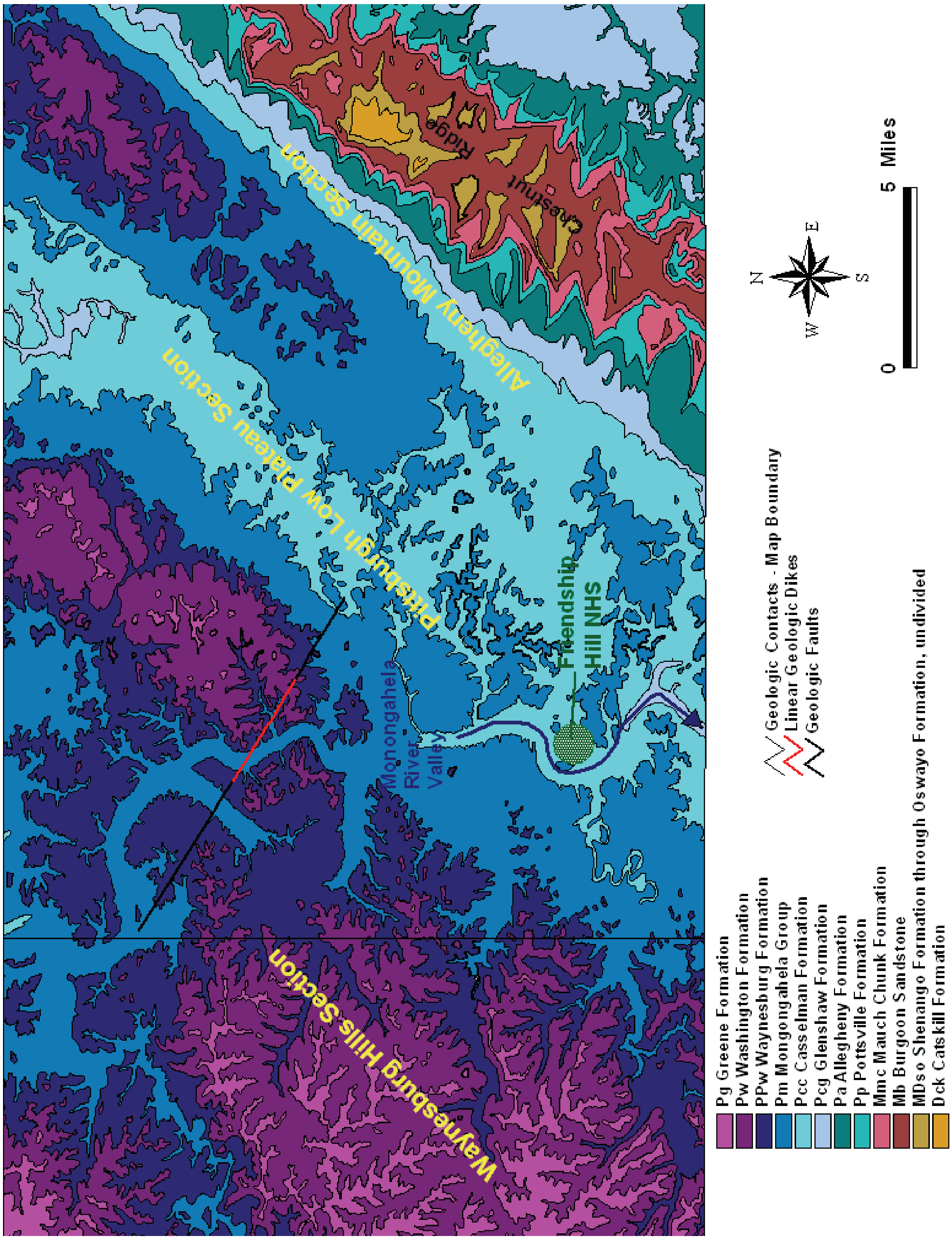

Figure 5. Generalized Geologic Map of Friendship Hill National Historic Site. The physiographic sections surrounding the national historic site are labeled. Note location of site as a green circle. *Source*: Pennsylvania Geological Survey, digital geologic map data. *Graphic design*: Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Issues

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

In this section, issues are listed in relative order of resource management significance, with the most critical identified first. Potential action items (i.e., inventory, monitoring, and research needs) are presented at the end of each subsection.

Coal Mining and Abandoned Mine Drainage

Coal and iron mining (siderite in limestones) have long been associated with central Pennsylvania. One sixth of all abandoned coal mine areas in the United States are located in the 12 southwestern counties of the state (Bogovich 1992). The Freeport, Kittanning, and Brookville- Clarion commercially viable coal seams, associated with the Pennsylvanian Allegheny Group, occur near the national historic site. The Pittsburgh Coal seam, at the base of the Monongahela Group, contains some of the largest underground coal mines in North America and underlies Friendship Hill National Historic Site. Investigators estimate that 50%–60% of the coal reserves have been extracted (Donovan and Leavitt 2002); however, these coal beds are also a potential source of coalbed methane (Markowski 2001). According to U.S. Geological Survey Open- File Report 95- 631, there are 239 acres of surface minable coal and 710 acres of underground minable coal at Friendship Hill National Historic Site, all in private ownership.

According to briefing statements issued by the Geologic Resources Division of the National Park Service in 2006, regarding the management of coal resource development within and adjacent to units of the National Park Service, federally- owned coal in parks may not be leased for mining. This is in accordance with the Mineral Leasing Act of 1920 and the Mineral Leasing Act for Acquired Lands of 1947. Additionally, the Surface Mining Control and Reclamation Act of 1977 controls surface coal mining and reclamation activities on both federal and non-federal lands. Surface coal mining includes activities conducted on the land surface in connection with a surface coal mine or surface operations and impacts associated with an underground mine. Section 522(e) of this Act contains provisions that protect "publicly owned parks" from adverse impacts of surface coal mining on lands within the boundaries of parks, unless there are "valid existing rights." The Geologic Resources Division is providing policy and technical support to parks involved with external minerals issues.

Extensive underground and surface mining in the area of the national historic site has resulted in lasting impacts on the landscape, including areas of altered topography mappable at a scale of 1:24,000. Negative impacts of coal mining include acid- mine drainage, subsidence, and collapse.

At Friendship Hill National Historic Site, surrounding mining activities cause major pollution of waterways, including the Monongahela River and Ice Pond Run. Maps of the area show mine features and document past mine subsidence events (Pennsylvania Department of Environmental Protection 2007, http://www.depweb.state.pa.us/southwestro/site/ accessed January 14, 2008)

Abandoned and inactive mines pose safety, environmental, and health problems to the Friendship Hill area. Foremost among these is acid- mine (and residual heavy metal) contamination of groundwater, surface water, and soils. Contaminated water and soil resources exceed the baseline concentrations of metals that existed prior to mining activities (Moore and Woessner 2000). In addition, fluvial sediments, remnant in river channels, can contain metals and mill waste materials.

Acid- mine drainage occurs when sulfides (e.g. pyrite – FeS_2) react with water and lower the pH by producing sulfuric acid (H_2SO_4), sulfate (SO_4^{2-}), and reduced ferrous iron (Fe^{2+}). This reaction is self- sustaining in the presence of Thiobacillus bacteria, which generate energy by using oxygen from the atmosphere to oxidize ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) which in turn reacts with more iron sulfide to produce more ferrous iron for the bacteria and sulfuric acid. The cycle continues until the iron sulfide supply is exhausted. This acidity increases the solubility of some potentially harmful metals. Groundwater and surface water disperse these metals from a mine source area as dissolved ions, suspended sediment, or as part of the fluvial bedload (Madison et al. 1998).

At least six components dictate the formation and severity of acid- mine drainage conditions (Trexler et al. 1975):

1. Availability of sulfides (including pyrite)
2. Presence of oxygen and iron- oxidizing bacteria
3. Water in the atmosphere
4. Availability of other metals and minerals (calcite neutralizes acidity)
5. Availability of water to transport dissolved components
6. Mine and waste area characteristics

All of these components are present at Friendship Hill National Historic Site and have produced onsite acid mine drainage. Mine workings such as those below the Gallatin House are commonly flooded with acidic groundwater. A flooded mine area beneath the Gallatin House has a pH of 2.7. If water levels rise, acidic floods from these underground mines could result in large-scale environmental impacts (Donovan and Leavitt 2002). The acidic water dissolves other minerals commonly present in geologic units in central Pennsylvania, including other sulfides and aluminosilicate minerals.

Metals such as manganese, aluminum, arsenic, zinc, cobalt, nickel, and iron as well as sulfides can be present in the drainage water (Kairies 2000). When cation concentrations are high enough and pH drops to low levels, minerals containing these dissolved metals begin to precipitate ferric hydroxide ($Fe[OH]_3$) and other insoluble minerals such as goethite, quartz, illite, kaolinite, and sulfates (Madison et al. 1998; Kairies 2000). Precipitates cloud surface water, coat rocks, form iron mounds around springs and seeps, and settle in floodplains and streambeds.

More than 90, 718 metric tons (100,000 tons) of iron is discharged from coal mines in the United States each year as a result of the weathering of pyrite and other sulfide minerals (Kairies 2000). This iron- rich sludge is becoming increasingly interesting as a potential salvageable resource.

Remediation of mine- affected areas in southwestern Pennsylvania is a cooperative effort among the National Park Service, U.S. Geological Survey, U.S. Department of Agriculture, Pennsylvania Department of Environmental Protection, and Pennsylvania Environmental Council. At Friendship Hill National Historic Site, wetlands consisting of a series of lanes and drained ponds along streams, including Ice Pond Run, have been shown to remediate the effects of acid- mine drainage. Wetlands naturally remediate contaminated water by slow filtering through organic sediments and by microbial sulfate reduction (Klusman et al. 1993). The performance of constructed wetlands is limited by the rate at which alkalinity is generated within the substrate via mineral (usually calcite) dissolution or microbial processes. This passive system can significantly improve the water quality at moderately acidic sites; however, the acidity of mine drainage at Friendship Hill is too low for significantly raising pH using this system (Hedin et al. 1994).

The Ice Pond Run drainage has higher acid and metal concentrations than 90% of acid- mine drainages in Pennsylvania (Hammarstrom et al. 2003). Friendship Hill National Historic Site is one of the first sites to employ a low- cost, acid- mine drainage treatment that uses limestone neutralization. Limestone is the least expensive material available to raise the pH of acid mine drainage (Reeder 2000). However, this low- cost method is hampered by coatings of gypsum (hydrous calcium sulfate), Fe- Al hydroxysulfate, and Fe(III) oxyhydroxide precipitated on the limestone grains, preventing contact between the acidic water and neutralizing limestone. An innovation developed at the U.S. Geological Survey, Leetown Science Center, adds carbon dioxide (CO_2) to the acid- mine drainage to increase the dissolution rate of the limestone. Water also pulses through the system enhancing grain- to- grain abrasion and reducing any armoring coatings that develop as pH is increased (Hammarstrom et al. 2003). This new method holds promise for the remediation of low pH–high metal, acid-mine drainage. Heavy metal precipitates (metal hydroxides) settle out of the system into tanks and the treated water is pumped back to stream headquarters (Hammarstrom et al. 2003).

Inventory, Monitoring, and Research Needs for Coal Mining and Abandoned Mine Drainage

- Monitor biota (e.g., aquatic insects) for heavy metal contamination.
- Incorporate Pennsylvania Department of Environmental Protection maps of mine features in a GIS layer.
- Promote studies to reconstruct the hydrogeology of mined areas beneath Friendship Hill to identify areas in need of remediation.
- Continue to promote acid- mine drainage remediation experimental efforts, such as that occurring at Ice Pond Run.
- Promote studies to predict the location of discharge of flooded abandoned mines in the Friendship Hill area (e.g., Vandivort et al. 2001).
- Generate maps showing groundwater contamination through time, using monitoring, well data, groundwater flow modeling and GIS.
- Investigate the use of ozone to remediate dissolved manganese and other metals from coal mine drainage (U.S. Patent No. 6,485,696 B1, Nov. 26, 2002) at Friendship Hill. Toby Creek Treatment Plant in Elk County, Pennsylvania, uses this technique (Tewalt et al. 2004).
- Investigate pumping at the net mine inflow rate (recharge) to maintain low groundwater levels locally, particularly beneath Gallatin House (Donovan et al. 2000).

Mine Shaft Subsidence and Associated Hazards

Mine openings and airshafts pose hazards associated with discharge of water and low (<19%) free oxygen air (Bogovich 1992). Deep shaft mining and waste piles are associated with collapse, and mine openings and related structures pose safety hazards (Madison et al. 1998). The NPS Disturbed Lands Restoration Program has been assisting park staff in treating abandoned mineral lands including area closures, wetlands construction, waste stabilization, strip mine reclamation, subsidence mitigation, and historic stabilization (National Park Service 2001). The program staff inventoried three mine sites and 16 hazardous openings. Due to the pervasive mine features located within and beneath the national historic site, visitor safety and the preservation of historic landscapes and structures are ongoing resource management concerns. Park staff closely monitors subsidence areas.

Inventory, Monitoring, and Research Needs for Mine Shaft Subsidence and Associated Hazards

- Contact the NPS Disturbed Lands Restoration Program on a regular basis for current updates in information.
- Incorporate inventories of mine features in a GIS layer.
- Monitor discharge of low- oxygen air from any mine-related feature at Friendship Hill.

Geologic Hazards

The steep terrain of valleys and ravines between ridges and hills, which defines the Allegheny Mountain region, is prone to several geologic hazards including landslides, slumps, and rockfalls. Friendship Hill National Historic Site sits on a bluff above the Monongahela River. The geologic units underlying the slopes at Friendship Hill contain a heterogeneous mix of shale, sandstone, siltstone, limestone, dolomite, conglomerate, and mudstone. Clay- rich units (e.g., shale and mudstone) may disintegrate when they become water saturated and are prone to fail when exposed on a slope. When more resistant rock units such as sandstone and limestone are located above weaker units, undercutting occurs from preferential erosion, causing rockfall hazards. As the river erodes the base of the bluff at the national historic site, the potential for mass movement increases, which may threaten cultural resources.

A unique and potentially hazardous stratigraphic setting exists in the Friendship Hill area. Between the clay- rich Pennsylvanian Glenshaw and Casselman formations is the resistant Ames Limestone. During high precipitation events, clays retain water in their structure weakening the crystalline bonds, resulting in slope failure. The undercut limestone layer may also collapse resulting in landslides and rockfalls. A site investigation by a slope-stability expert could determine if these clays as well as the Ames Limestone are present on the slopes at Friendship Hill and their susceptibility to movement.

Though not common, seismic activity is possible in south- central Pennsylvania. Some historic earthquakes in the area have been attributed to blasting at local coal mines (e.g., in 1893 and 1939), but natural seismicity is also known. A magnitude 5.2 (on the Richter scale) quake occurred in northwestern Pennsylvania in 1998 (Scharnberger 1987; http://earthquake.usgs.gov/). Even minor seismic tremors might trigger landslides and debris flows on steep or water- saturated slopes. An assessment of the vulnerability to seismically induced geologic hazards at Friendship Hill National Historic Site would be a useful data set for resource management.

Inventory, Monitoring, and Research Needs for Geologic Hazards

- Conduct site investigations of clay- rich layers and friable limestones exposed on slopes to determine a vulnerability index to slope failure.
- Monitor for landslides and rockfall along steep slopes of the bluff at Friendship Hill.
- Promote seismic monitoring in southern Pennsylvania.

Water Issues

The geomorphic imprint of the Monongahela River and its tributaries dominate the landscape at Friendship Hill. The meandering nature of this river and human use of this waterway is a significant interpretive story. The Monongahela joins the Allegheny River in Pittsburgh to form the Ohio River, one of the most important water corridors in the United States. The park structures are located on a high bluff above the 500- year floodplain and are, therefore, relatively safe from flooding. However, fluvial erosion at the river's edge threatens resources such as the River trail, riparian environments, and wetlands. Flooding as recent as July 2002 damaged areas adjacent to the river in the national historic site (National Park Service 2005).

Surface water at Friendship Hill National Historic Site flows in four small- scale streams: Ice Pond Run, Dublin Run, Rhododendron Run, and South Run. All are tributaries of the Monongahela River (National Park Service 2005). Average annual runoff into these streams ranges from 63 to 102 cm (25 to 40 in) per year. The estimate of average recharge is 20 to 38 cm (8 to 15 in) per year, whereas annual average precipitation in the area is 107 cm (42 in) (Pennsylvania Environment Council 2006).

Water quality has suffered from the pervasive industrial development and natural resource extraction throughout the Monongahela watershed. The meanders of the river near Friendship Hill are capturing sediments that may contain contaminants from nearby mines (Pennsylvania Environment Council 2006). Cooperative efforts are underway by entities including Rivers of Steel, county governments, the city of Pittsburgh, the Pennsylvania Environmental Council, the National Park Service, and the U.S. Geological Survey, are underway to remediate the watershed of both point and non- point sources of pollution (Pennsylvania Environment Council 2006).

Understanding the hydrogeologic system, complicated by underground mine features, is crucial for resource management at Friendship Hill. To predict hydrologic response to inputs such as contaminants, acid- mine drainage, and other wastes, requires knowing how water is traveling through the subsurface. Monitoring inputs and outputs of the hydrologic system will facilitate predicting the response of the system to contaminants, acid- mine drainage, and other wastes. Input sources include rainfall, wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. The output is streamflow. Streams integrate the surface runoff and groundwater flow of their watersheds, providing a cumulative measure of the watershed's hydrologic condition. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Inventory, Monitoring, and Research Needs for Water Issues

- Define the influences of bedrock, including acid-neutralizing limestones and geologic structures, and topography on local watersheds at Friendship Hill National Historic Site.
- Map and quantify subsurface water recharge zones especially in areas known to contain mine features. Investigate additional methods to characterize groundwater recharge areas and flow directions.
- Research alternatives for flood mitigation in the event of extreme flooding along rivers and streams at Friendship Hill National Historic Site. Estimate impact to surrounding areas of runoff from low pH acid- mine drainage during a flood event.
- Consult Pennsylvania Geological Survey water reports for further data on the site's hydrologic system.
- Install monitoring stations to measure atmospheric inputs of important chemical components (e.g., nitrogen, mercury, and pH), and outputs to groundwater.

Paleontology Issues

According to the *Paleontological Resource Inventory and Monitoring—Eastern Rivers and Mountains Network Report*, two Pennsylvanian geologic units occur within Friendship Hill National Historic Site. Although these geologic units are fossiliferous elsewhere, neither the National Park Service nor its cooperators have formally recorded any fossils within the boundaries of the national historic site.

The oldest geologic unit at Friendship Hill is the Upper Pennsylvanian Casselman Formation, which is composed of shale, siltstone, sandstone, limestone, and coal. The lowest portion of the formation contains a marine zone of fossiliferous shale (Edmunds et al. 1993).

Additionally, fossils of non- marine bivalves (Eager 1975) and vertebrate fauna (Raymond 1911; Lund 1975) occur in the Casselman Formation. One of the more interesting fossil findings in the Casselman Formation is a pair of "problematic tracks" in Cambria County (Marks et al. 1998). Comparison with an analogous trackway found in similarly aged rocks in Scotland suggests that a giant myriapod (6- foot- [1.8 m] long millipede- type invertebrate) created the trackway (Marks et al. 1998).

The other Pennsylvanian geologic unit found at Friendship Hill National Historic Site is the Upper Pennsylvanian Monongahela Group. This group consists of limestone, shale, sandstone, and coal. Eager (1975) comments on the non- marine bivalves in this unit, and Lund (1975) describes fossil vertebrates found in the Monongahela Group. In southeastern Ohio, Bain (1992) reports stromatolites from the Monongahela Group, which vary in size from masses that are 12 inches (30 cm) in diameter to continuous beds,.

Inventory, Monitoring, and Research Needs for Paleontology Issues

- Promote paleontological research in the Friendship Hill National Historic Site area. Focus on areas previously ignored during coal exploration.
- Conduct an onsite inventory of paleontological resources at Friendship Hill.

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Friendship Hill National Historic Site.

Geology and History Connections

The history of the Friendship Hill area extends thousands of years before the first European settlers established forts here. Geology is intimately tied to this long story. The earliest known evidence of human activity in the area—from Sheep Rock, near Huntingdon, in south- central Pennsylvania—dates back 10,000 years. Early inhabitants were Native Americans of the Allegheny group. The name Allegheny, so prevalent in the geography and culture of Pennsylvania, stems from the mound- building Alligewi or Allegheny Indians from the western part of the state (Wells 1973). Monongahela is also a Native American derivative. Native Americans used the resources in this area as food, shelter, and stone for making tools. The area also served as a travel route to the south and west.

Excavations of proto- historic sites such as McKees Rocks Village and Eisiminger have produced pottery fragments and other artifacts that record the movements of populations of Native Americans in the area (George 2002). The onsite museum preserves artifacts representing the Late Archaic (4000 to 1000 B.C.) and Late Woodland (A.D. 900 to 1000) periods. However, neither the National Park Service nor its cooperators have conducted a systematic archaeological survey of early Native American sites at Friendship Hill (NPS Web site at http://www.nps.gov/frhi).

The national historic site contains many cultural features that require protection, including protection from geologic processes such as erosion and mass wasting. The enabling legislation requires that these features be made available for public enjoyment but without compromising the natural resources or the historical context. Congress designated Friendship Hill National Historic Site in 1978, to honor Albert Gallatin and his 70-year contribution to the development of the United States. His home served as a retreat for Gallatin and his family during the most illustrious and busy years of his career. When construction on the house began in 1789, the estate was in a region considered part of the western frontier. Over the years, the residence has changed hands and undergone extensive renovation (fig. 1).

The National Park List of Classified Structures (LCS) contains 21 historic features at Friendship Hill National Historic Site including buildings, ruins, and roads. The house, a wooden- frame barn, and a younger gazebo on a nearby knoll are among the intact historic structures.

The national historic site also preserves many features that are culturally significant but no longer intact such as foundations and other remnants of outbuildings associated with the estate. Ruins of a gardener's cottage, the Painter House (ca. 1900), the River Tenant's house, a silo, a stone cistern and wells, and a dairy barn are part of the site. A network of old roads possibly used for mining, farming, and logging are part of the cultural landscape as are several gravesites and a small cemetery.

One of the major goals of the National Park Service is to preserve the historical context (buildings and the landscape) of the area. Issues arise, however, from balancing cultural and natural resource values. For example, a proposal for restoration of a historic building may include removing surrounding natural resources (i.e. fill material, stones, and trees), installing buttresses, or planting non- native crop species to reflect the historic landscape surrounding the structure. The park maintains several open spaces ranging from less than 1 acre (0.4 ha) to more than 60 acres (24 ha) for historical context. Maintaining this landscape often means resisting natural geologic changes (e.g., erosion) and not restoring disturbed lands, which presents several management challenges. A study of the evolution of historic land use would help prioritize interpretive and restoration efforts at Friendship Hill National Historic Site.

Geologic slope processes such as landsliding, slumping, physical and chemical weathering, block sliding, and slope creep are constantly changing the landscape. Runoff erodes sediment from open areas and carries it down streams and gullies. Erosion naturally removes higher areas and fills in the lower areas, which distorts the historical context of the landscape.

Friendship Hill is located on the Monongahela River atop a knoll. Slopes of this knoll are susceptible to erosion. Bluffs, cliffs, and banks along the river and its tributaries such as Ice Pond Run are prone to debris slides. This erosion also exposed commercially viable coal and limestone resources that sparked extensive mine activity in the area. Early European settlers recognized the potential of the area's rivers to transport raw materials and manufactured goods. The Monongahela supported industries such as boat building, coal mining, iron smelting , and the manufacturing of steel and glass (Pennsylvania Environment Council 2006).

Extensive coal mining and other activities such as logging and farming have changed the regional topographic expression. Associated with local mining is the potential collapse of underground workings. The knoll supporting the Gallatin House is riddled with approximately 15 acres (6 ha) of mine workings. The frame barn north of the main house rests on an unsound foundation near a mineshaft collapse. Subsidence in this area is prevalent, and park staff monitors the entire knoll.

Geology and Biology Connections

Geology forms the basis of the entire ecosystem at Friendship Hill National Historic Site. The rivers and tributaries in the area are flowing over and eroding through geologic units. Dissolved minerals affect water chemistry and riparian habitats along waterways, which support numerous plant and animal species, including the occasional bald eagle. The geologic structures in the subsurface form a vital component of the hydrogeologic system. Water flows through the rock along fractures and intergranular pore spaces, so knowledge of the physical properties (e.g., porosity, permeability) of geologic units, even those not exposed at the surface, is important for resource management.

Geologic units also weather and break down giving rise to soils, which support a variety of habitat types at the park including forests, early and mid- successional openings or thickets, meadows, and wetlands. Soil types vary by slope. At Friendship Hill, soils in areas of steep slope are typically shallow, weakly developed, poorly drained, with high erosion potential, whereas soils on gentle slopes or flat ground in the area are generally deep, fertile, and poor to well developed (Pennsylvania Environment Council 2006). Most of the soils at Friendship Hill occur on the level alluvial deposits along the river and upland terraces. The Pennsylvania State conservationist has designated much of the landscape at Friendship Hill as prime farmland. This land has supported various agricultural uses for several hundred years (Kopas 1991; National Park Service 2005).

According to standards established by the Pennsylvania State conservationist, farmland soils, though well drained, are not especially fertile (Kopas 1991; National Park Service 2005). Forest types growing in the soils at Friendship Hill include typical hardwood oak forest (second growth and mixed), mixed mesophytic hardwoods, pine and spruce groves, and old- growth white oak.

Records at the national historic site indicate that the ecosystem supports 61 varieties of trees, 311 species of herbs and shrubs, as well as moss and fern species. Multitudes of mammal, bird, amphibian, reptile, and fish species thrive in the diverse ecosystem (National Park Service 2005).

As described in the geologic issues section above, one of the major impacts is acid- mine drainage. A flooded mine area beneath the Gallatin House has a pH of 2.7. The acid mine drainage from surrounding areas, including Friendship Hill, negatively affects the fish population in the Monongahela River. Across Pennsylvania Route 166 (outside of the national historic site) was the site of deep coal shaft and extensive surface mining activities. Now, this area supports mixed hardwood forests.

Wetlands

The western boundary of the national historic site is along the Monongahela River. A series of locks and dams allow boat navigation in this area. Near the northeastern portion of the park boundary is a navigational dam and transportation lock (lock and dam number 7). The 100- and 500- year floodplain levels near this structure are wetlands. Friendship Hill National Historic Site controls approximately 5 acres (2 ha) of wetlands (National Park Service 2005).

Two small wetland areas are present where two park streams—Ice Pond Run (<3 acres [1.2 ha]) and Dublin Run (<1 acre [0.4 ha])—drain into the Monongahela River. Both streams, 2.9 km (1.8 miles) and 1.5 km (0.9 miles) long respectively, originate within Friendship Hill National Historic Site. An abandoned coal drift mine in the southeast corner of the national historic site is the discharge location for acid- mine drainage generated by oxidation of pyrite exposed in the abandoned mine tailings. This drainage has severely polluted Ice Pond Run, which the National Park Service and the Bureau of Mines have intentionally manipulated into a series of wetlands filling formerly drained (~2 acre [0.8 ha]) pond areas.

In July 2000, the National Park Service and partners diverted up to 230 liters (60 gallons) of water per minute from Ice Pond Run through an eight- phase treatment facility. The facility pumps water into four pulsed- bed limestone reactors, which buffer the low pH before returning it to the watershed. As water pH rises at Ice Pond Run, yellow iron compounds precipitate out of solution and color the stream sediments.

Many NPS cooperators have made this ongoing large-scale remediation possible: Bureau of Mines, U.S. Geological Survey (Leetown Science Center), Canon U.S.A., Inc., Conservation Fund's Freshwater Institute, Pennsylvania Department of Environmental Protection, and California University of Pennsylvania (Reeder 2000).

Monongahela River

The Monongahela River runs 187 km (116 miles) in a meandering pattern north from the confluence of the West Fork and Tygart rivers near Fairmont, West Virginia, towards its confluence with the Allegheny River in Pittsburgh. It flows through the coal seams and mountains of West Virginia and into western Pennsylvania, draining a watershed area of 19,010 km^2 (7,340 sq. miles) (Pennsylvania Environment Council 2006). This river, a major tributary to the Ohio River, has a significant place in the history and natural resources of the Friendship Hill area.

The Monongahela has functioned as the essential element in the area's settlement and development. The first industry on the river was boat building. Builders took advantage of the abundant timber resources to produce boats that would transport farm goods and other materials downriver on a one- way trip to New Orleans, Louisiana. Here the boats were dismantled and used for lumber. The first steamboat launched on the river in 1811. In 1837, the Monongahela Navigation Company began building a series of seven locks and dams extending from Pittsburgh up the Monongahela to make the river more navigable. The federal government built an additional eight locks and dams upriver as far as Fairmont, West Virginia (U.S. Army Corps of Engineers 2004).

Today, the river is highly engineered to facilitate the movement of large watercraft. Following the Civil War, the U.S. Army Corps of Engineers continued constructing locks and dams on the river as well as renovating older structures. Modernization increased lock size and mechanized operations, thereby reducing the number of structures necessary for navigation. Today, nine locks and dams remain on the river providing 3 m (9 ft) of depth. These features allow boats to travel in a series of steps down the45 m (147 ft) elevation difference from Fairmont to Pittsburgh. Coal is the primary shipment, moving in both directions from mines to steel mills and power plants (U.S. Army Corps of Engineers 2004).

Ancient Lake Monongahela and Paleodrainage

The modern Monongahela River and most of western Pennsylvania's creeks and rivers flow southwesterly into the Ohio River. Approximately 0.8- 1 Ma, the Monongahela was the dominant drainage in western Pennsylvania and flowed northwestward toward Canada. Based on studies of regional topography, river terraces, and erosional depth to bedrock in major river valleys (Harper 1997; Marine and Donahue 2000), investigators have found that the Monongahela River flowed coincident with its present course towards the Pittsburgh area then followed the channel of the Ohio River to the present site of Beaver, Pennsylvania. From there, it flowed north, up the modern Beaver River valley towards an ancestral Erie basin.

This drainage pattern changed when glacial ice masses, flowing south from Canada blocked the northwest-flowing streams, causing lakes to pool along the leading glacial edge. These lakes, collectively termed Ancient Lake Monongahela (fig. 6), eventually overflowed their drainage divides and reversed the ancient drainages of the Monongahela and Allegheny rivers to southerly courses (fig. 7). The rivers continue to cut through thick layers of silt, sand, gravel, and other sediments (Harper 1997). Lacustrine deposits from this episode, called the Carmichael Formation, spread throughout the Monongahela and Allegheny drainages. These deposits consist of a clay, silt, and sand matrix with larger sandstone clasts derived from local bedrock, possibly the Lower Pennsylvanian Allegheny Group (Kirchner and Donahue 2001).

The glacial advances during the Pleistocene Epoch caused repeated damming of rivers in western Pennsylvania. The outflow of the first flood cut new drainage patterns and lowered the outlets; hence, subsequent flood events occurred at progressively lower elevations, leaving lacustrine and river terrace deposits perched high in the valleys of the Monongahela, Allegheny, and Ohio rivers. The highest of these is located at approximately 335 m (1,100 ft) in elevation. At least five levels of terraces around Morgantown, West Virginia, record flood events of Ancient Lake Monongahela (Marine and Donahue 2000). John James Stevenson was the first to document these terraces in the Friendship Hill area:

> Coming from the south to Point Marion, where the Cheat and Monongahela rivers unite, one finds all the Stewartstown benches distinct except the third, which has been destroyed by erosion on the east side of the Monongahela…. Crossing the Ferry at Point Marion and taking the hill- road to New Geneva, at the mouth of George's creek, one reaches the third bench at half a mile from the river.
>
> —John James Stevenson
> Presentation to the American Philosophical Society (1880)

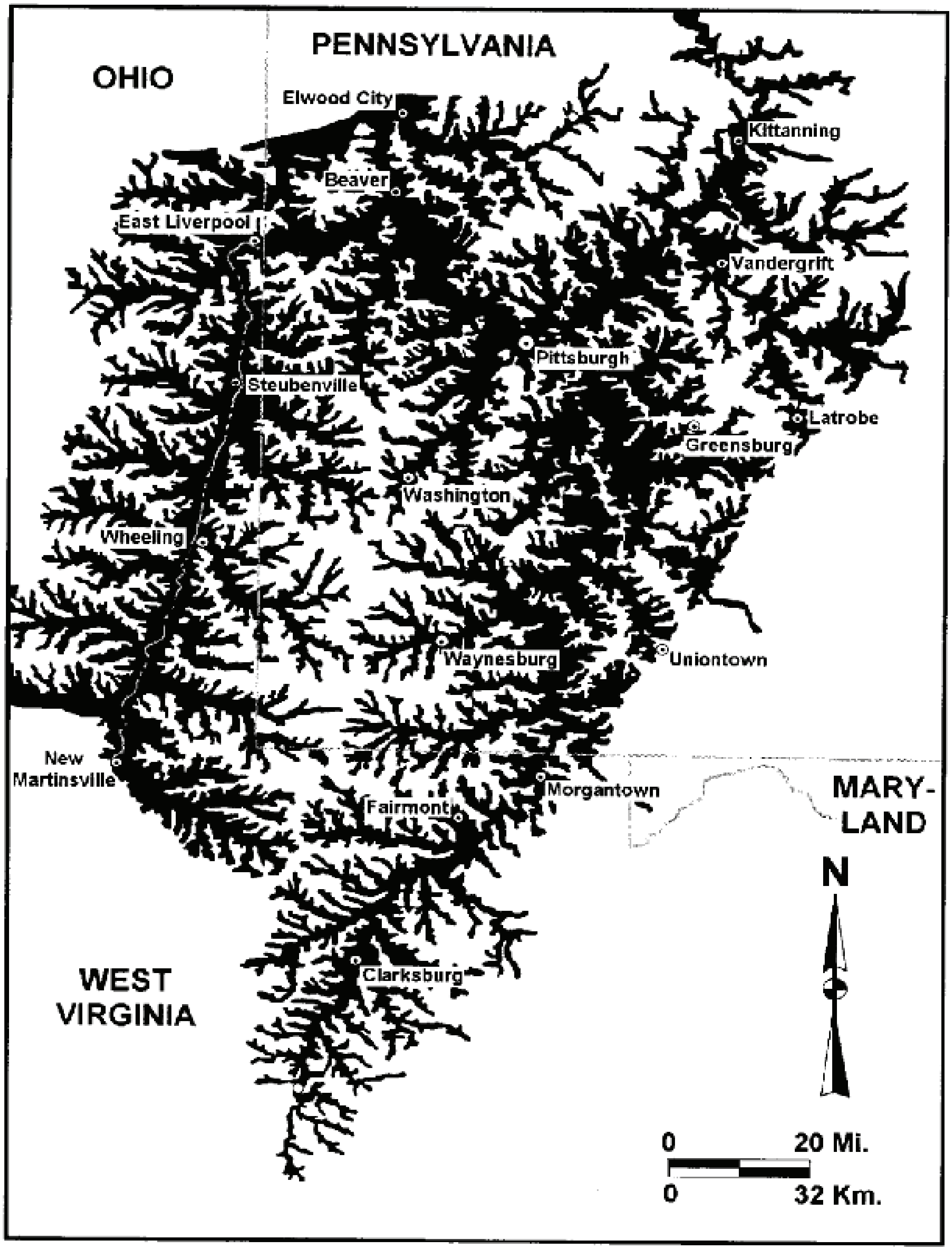

Figure 6. Reconstruction of Ancient Lake Monongahela. The reconstruction in the figure is based on a 335 m (1,100 ft) maximum lake elevation during a Pleistocene glacial maximum. ***Source*****: Marine and Donahue (2000), figure 23.**

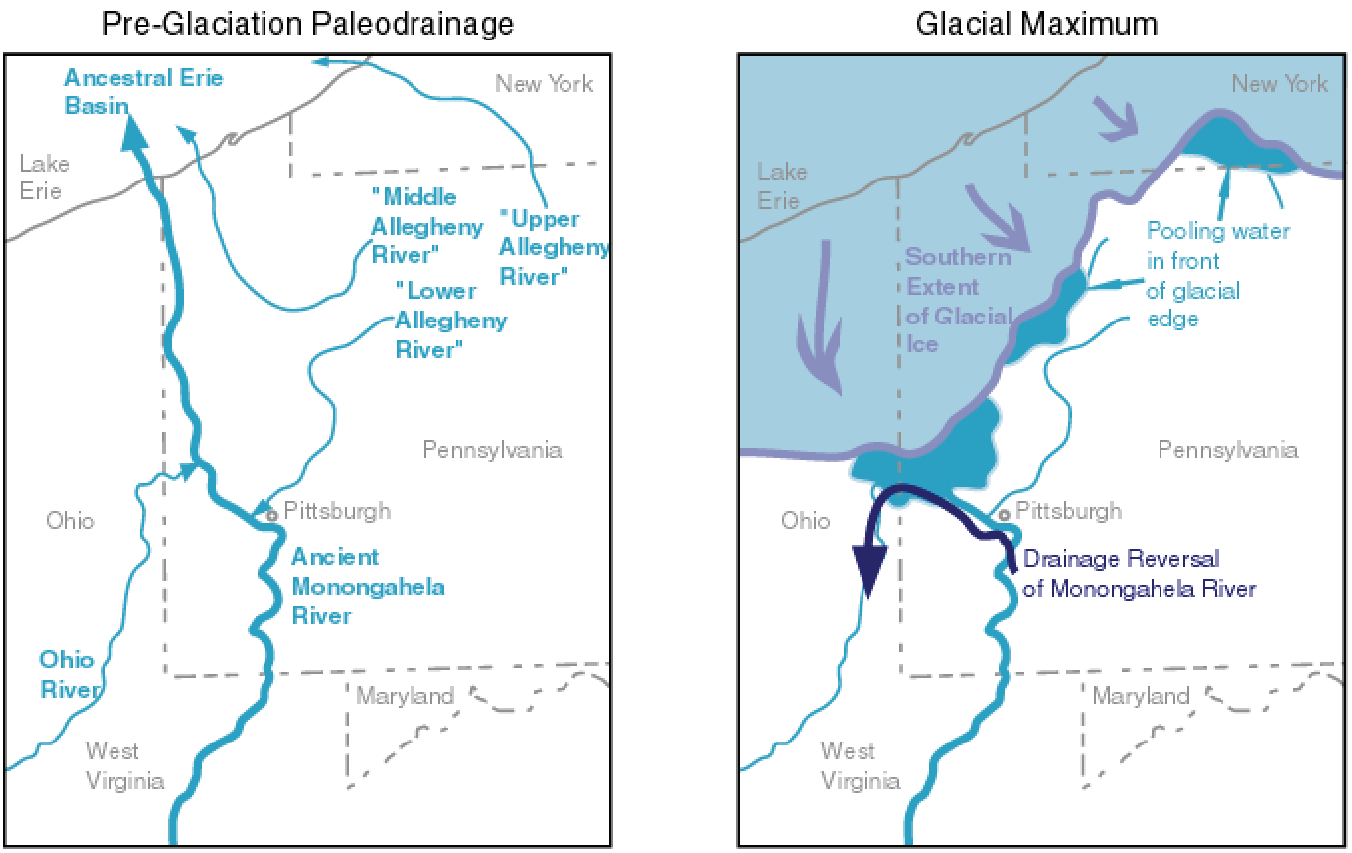

Figure 7. Maps showing drainage of Ancient Monongahela River. Prior to glacial activity, the river drained towards an ancestral Erie basin. Glacial maximum (right figure) shows the southernmost glacial extent and where the ice dammed the rivers, forming lakes that eventually flooded basins and directed river flow towards the south—the modern Ohio River drainage. *Source*: Harper (1997). *Graphic design*: Trista L. Thornberry-Ehrlich. Maps are not to scale.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Friendship Hill National Historic Site. 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. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.

The oldest rocks in the area are the grayish- red sandstones, siltstones, shales, and mudstones of the Devonian Catskill and Foreknobs formations. This combined unit locally is conglomeritic and forms a resistant ridge cap on Chestnut Ridge to the east of the national historic site (Berg et al. 1980; McElroy 1988).

Late Devonian–Early Mississippian age units include the sandstone, siltstone, and shale of the Shenango and Oswayo formations. Above the Oswayo Formation are the Burgoon Sandstone and Mauch Chunk Formation (shale, siltstone, and limestone) (Berg et al. 1980; McElroy 1988).

The cyclic sequences of sandstones, conglomerates, shales, claystones, limestones, and coals from former marshy peat swamps and wetlands (Freeport, Kittanning, and Brookeville- Clarion coals) of the Pennsylvanian Pottsville and Allegheny Groups are buried beneath the Glenshaw and Casselman formations (Conemaugh Group) and the Monongahela Group. These three units dominate the rock exposures within and immediately surrounding Friendship Hill (Berg et al. 1980; Whitfield et al. 2001; Milici 2005).

The Glenshaw Formation consists of sequences of shale, sandstone, red beds, and thin limestone and coal interbeds. The Ames Limestone separates this unit from the overlying Casselman Formation of shale, siltstone, sandstone, red beds, and scant coal and limestone layers. The Monongahela is eroding into this unit south of the national historic site. The Monongahela Group contains cyclic sequences of limestone, shale, sandstone, and coal including the commercially valuable Pittsburgh coal at its base.

The sandstones, shales, limestones, and coals of the Waynesburg Formation record the transition between the Pennsylvanian and Permian periods. The base of this unit is at the bottom of the commercial Waynesburg coal, one of several economically viable seams from this unit. Above the Waynesburg Formation are the Permian Washington and Greene formations. These units dominate the eastern Waynesburg Hills section. They are composed of sequences of sandstone, shale, red beds, and some impure limestones and coals separated by the upper Washington limestone. The Washington Formation contains the Washington coal deposit (Berg et al. 1980).

Most Mesozoic and all but the most recent Cenozoic rock units are missing from the landscape surrounding Friendship Hill National Historic Site. Jurassic mica-peridotite igneous rocks of the Gates- Adah Dike represent a local intrusive event (McElroy 1988). Pleistocene lacustrine deposits from Ancient Lake Monongahela are present as high- level terraces on bluffs above the river and tributaries. The Carmichaels Formation contains silts, clays, and sands as intergranular matrix to larger quartzarenite (quartz sandstone) clasts (Kirchner and Donahue 2001).

Quaternary alluvium lines local river and stream valleys. Alluvial deposits are also present on floodplains; in some places, they form low terraces above the river valleys. Terraces consist of unconsolidated clay, silt, sand, gravel, and occasional boulder deposits derived from local bedrock units (McElroy 1998).

The following pages present a tabular view of the stratigraphic column and an itemized list of features for each map unit. This table highlights properties specific to each unit in the stratigraphic column, including map symbol, name, description, resistance to erosion, suitability for development, hazards, potential paleontologic resources, cultural and mineral resources, potential karst issues, recreational use potential, and global significance.

Geologic History

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

Friendship Hill sits near the eastern edge of the Appalachian Plateaus physiographic province near the boundaries of the Waynesburg Hills, Pittsburgh Low Plateau, and Allegheny Mountains sections of the Appalachian Plateaus physiographic province (fig. 5). To the east, marked by the Allegheny Mountains, is the Valley and Ridge province. As such, Friendship Hill National Historic Site contains features intimately tied to the long geologic history of the Appalachian Mountains and the evolution of the eastern coast of North America.

The recorded history of the Appalachian Mountains begins in the Proterozoic (fig. 8). During the Grenville orogeny in the mid- Proterozoic, a supercontinent (Pangaea) formed, composed of most of the continental crust in existence at that time, including North America and Africa. The metamorphic granites and gneisses in the core of the modern Blue Ridge Mountains south and east of Friendship Hill manifest the sedimentation, deformation, plutonism, and volcanism at the time (Harris et al. 1997). Deposited over a period of 100 million years, these rocks are more than a billion years old, making them among the oldest rocks known in this region. Following uplift, erosion beveled the land surface for hundreds of millions of years, leaving a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001).

Tensional forces, including rifting, characterized the area during the late Proterozoic, roughly 800–600 million years ago. Crustal extension created fissures that extruded massive volumes of basaltic magma (fig 9A). Volcanic activity lasted for tens of millions of years alternating between flood basalt flows and ash falls. The volcanic rocks covered the basement rocks (i.e., granite and gneiss) in the south- central Pennsylvania area.

The rifting broke up the supercontinent, and formed a sea basin, which became the Iapetus Ocean, the proto-Atlantic Ocean. This basin subsided and collected sediments that later formed the Appalachian Mountains (fig. 9B). These sediments were deposited in alluvial fans, large submarine landslides, and turbidity flows (Southworth et al. 2001). Later deposits of sands, silts, and muds covered these previous sediments in nearshore, deltaic, barrier- island, and tidal flat areas along the eastern margin of the continent (Schwab 1970; Kauffman and Frey 1979; Simpson 1991).

A grand marine platform, thickening to the east, was the depositional setting for huge masses of carbonate, sandstone, and shale that persisted during from the Cambrian through the Ordovician periods (545–480 Ma) (Means 1995). Ordovician units exposed east of Friendship Hill record the transition from carbonate platform to more nearshore terrestrial deposition associated with nascent uplift during the Taconic Orogeny.

Taconic Orogeny

From Early Cambrian through Early Ordovician time, orogenic activity along the eastern margin of the continent began again. During the Taconic Orogeny (~440–420 million years ago in the central Appalachians), an island arc converged with the main continent. Oceanic crust and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of North America. The Taconic Orogeny involved the closing of the ocean basin, subduction of oceanic crust, the creation of volcanic arcs, and the uplift of continental crust (Means 1995). Initial metamorphism of the deeply buried igneous and nearshore sediments into metabasalts, quartzites, and phyllites occurred during this orogenic event.

The crust bowed downwards west of the rising mountains in response to the overriding plate thrusting. The resulting deep foreland basin filled with mud and sand eroded from the highlands to the east (fig. 9C) (Harris et al. 1997). The center of this so- called Appalachian Basin was in what is now West Virginia.

During the Late Ordovician, the oceanic sediments of the shrinking Iapetus Ocean were thrust westward onto other deepwater sediments of the western Piedmont province. Sandstones, shales, siltstones, quartzites, limestones, and other Silurian- age rocks became part of the shallow marine and deltaic environment of the Appalachian Basin. These rocks, now metamorphosed, currently underlie the Valley and Ridge physiographic province east of Friendship Hill (Fisher 1976).

Appalachian Basin

Most of the rock units of the Appalachian Plateaus physiographic province were deposited in the long-standing Appalachian Basin. As mentioned previously, this foreland basin formed in response to tectonic downwarping (thrust loading) during the Taconic Orogeny; however, it continued in response to later sediment loading (Milici 2005). Downwarping was balanced by eustatic crustal adjustments.

The depositional setting of the basin was predominantly shallow marine with some fluvial and deltaic components. Basin formation continued intermittently for approximately 200 million years during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian periods, resulting in very thick deposits of sandstone, siltstone, mudstone, and shale deposited above basal Cambrian units. The major source of these sediments was the highlands to the east, which rose during the Taconic and later orogenies (e.g., Acadian Orogeny [Devonian] and Alleghenian Orogeny [Permian]).

Basal sandstone units of Cambrian, Silurian, Mississippian, and Pennsylvanian strata in the basin are representative of sediment influx induced by orogenic uplift. By contrast, laterally extensive shale and limestone deposits such as the Ordovician Martinsburg Formation and Devonian black shale units record times of relative tectonic quiescence and resulted from sediment trapping and chemical precipitation (Fedorko et al. 2004).

The units deposited in the Appalachian Basin record geographic (e.g., the movement of continents through paleolatitudes) and climatic conditions during sedimentation (table 1). Paleolatitude and climate played major roles in the deposition of coal resources in the Appalachian Basin. The central Appalachian Basin region drifted northward from about latitude 40° south in the Proterozoic and Early Cambrian to about latitude 30° south during the Early Ordovician where it remained well into the Mississippian Period. The continent continued to move northward from about latitude 30° south in the Early Mississippian to about latitude 3° north by the beginning of the Permian (Fedorko et al. 2004).

During the Early Mississippian and Early Triassic periods, the paleoclimate of the area was arid. However, during the intervening Pennsylvanian and Permian periods, this basin was centered in tropical, equatorial latitudes. This tropical climate produced vast amounts of organic material in peat swamps and other wetlands (Cecil and Englund 1989). The rising mountains to the east also produced significant amounts of sand, silt, and clay that are interspersed with the organic layers. These units, notably the Conemaugh, Allegheny, and Monongahela groups, are associated with numerous coal systems that vary in rank (lignite to anthracite), thickness, geometry, aerial extent, petrology, and geochemistry (Milici 2005).

Interbedded shales, sandstones, limestones, and thin coals dominated the local Dunkard Basin, a sub- basin of the Appalachian Basin, in southwestern Pennsylvania. Within this basin, the Monongahela Group formed from the cycling of freshwater bay, river channel- deltaic, alluvial fan, and marine storm surge environments (Reynolds and Capo 2000; Edwards and Nadon 2001; Cassle et al. 2003).

The Allegheny Group and Monongahela Group coals were formed during wetter climatic conditions than the intervening Conemaugh Group, which contains thinner, more discontinuous coal lenses, reflecting a slightly drier climate (Milici 2005).

Table 1. Deposition in the Appalachian Basin

Period		Climate	Deposits
Triassic	Early	semiarid to arid	sandstone, conglomerate
Permian	Late	cyclic moist subhumid to semiarid	sandstone, shale, red beds, thin limestone, coal
	Early	cyclic moist subhumid to semiarid	coal, non-marine limestone, sandstone
Pennsylvanian	Late	dry subhumid	calcareous red beds, paleosols, scant coal
	Middle	moist subhumid	siliciclastics, non- marine limestone, coal
	Early	humid to perhumid	sandstone, limestone, paleosols, coal
Mississippian	Late	semiarid to humid	limestone, eolianites, red beds
	Early	subhumid to arid	sandstones, red beds, evaporites
Devonian	Late	semiarid to dry subhumid	black shale, sandstones
	Early	arid	subtidal carbonates, sandstones
Silurian	Upper	arid	peritidal carbonates, evaporites
	Early	arid	sandstones
Ordovician	Late	semiarid to dry subhumid	siliciclastics red beds
	Early	arid	limestone, dolomite, evaporites
Cambrian	Middle	arid	limestone, dolomite, evaporites
	Early	semiarid	siliclastics

Source: Fedorko et al. (2004).

Acadian Orogeny

The Acadian Orogeny (~360 million years ago) continued the mountain building of the Taconic Orogeny as the African continent approached North America (Harris et al. 1997). The Acadian event involved landmass collision, mountain building, and regional metamorphism similar to the preceding Taconic orogeny (Means 1995). However, this event affected areas farther north. The Acadian event caused further uplift of Taconic highlands in central Pennsylvania. Erosion of these highlands provided more sediments leading to the basin- wide (Appalachian Basin) deposition of the Devonian Catskill Formation, exposed on Chestnut Hill in the Friendship Hill area.

The tectonic quiescence between the Acadian and Alleghenian orogenic events led to the deposition of the vast marsh and wetland deposits of the Mississippian and Pennsylvanian periods. Buried and compressed, these deposits became the vast coal- bearing units of the Mississippian Burgoon Sandstone and the Pennsylvanian Casselman and Glenshaw formations and Allegheny and Pottsville groups (Berg et al. 1980; Whitfield et al. 2001).

Alleghenian Orogeny

Following the Acadian orogenic event, the proto-Atlantic Iapetus Ocean completely closed as African collided with North America. This collision formed the supercontinent Pangaea and the Appalachian mountain belt. The Alleghenian Orogeny (~325–265 Ma) is the last major orogeny of the Appalachian evolution (fig. 9D) (Means 1995). The rocks were deformed during as many as seven phases of folding and faulting to produce the Sugarloaf Mountains and Frederick Valley in the western Piedmont province, the Blue Ridge–South Mountain anticline structure, and the numerous folds of the Valley and Ridge province west of Friendship Hill (Nickelsen 1983; Southworth et al. 2001). The strata of the Appalachian Basin (now the Appalachian Plateaus province) remained relatively undeformed; however, small- scale thrust faults and parallel low- amplitude regional folds exist throughout the area (Boen 1972).

Rocks of the Valley and Ridge, Blue Ridge, and Piedmont provinces were transported during this orogeny as a massive block (Blue Ridge–Piedmont thrust sheet) westward onto younger rocks of the Valley and Ridge along the North Mountain fault. The amount of compression was extreme; estimated shortening was 20%–50%, 125- 200 km (75–125 miles) (Harris et al. 1997).

Estimates of the elevation of the Alleghenian Mountains are around 6,000 m (20,000 ft), which is analogous to the present- day Himalayas in Asia. Erosion has beveled these mountains to elevations less than 730 m (2,400 ft) above sea level east of Friendship Hill (Means 1995).

Triassic Extension to the Present

During the late Triassic following the Alleghenian orogeny (~230–200 million years ago), a period of rifting began as the joined continents began to break apart. Pangaea fragmented into roughly the continents that persist today. This episode of rifting initiated the formation of the Atlantic Ocean and caused many block-fault basins to develop with accompanying volcanism (fig. 9E) (Harris et al. 1997; Southworth et al. 2001).

The dominant geologic process in the Friendship Hill region during the Mesozoic Era was erosion. The Allegheny Mountains shed thick deposits of unconsolidated gravel, sand, and silt. Some of this sediment remained at the base of the mountains as alluvial fans; it also spread eastward as part of the Atlantic Coastal Plain province and westward to cover the Appalachian Basin sediments (Duffy and Whittecar 1991; Whittecar and Duffy, 2000; Southworth et al., 2001)., The amount of material was immense, as inferred from the now- exposed metamorphic rocks in the Blue Ridge province. Many of the rocks exposed at the surface must have been at least 12 miles (20 km) below the surface prior to regional uplift and erosion. These Mesozoic rocks are now "missing" from the Friendship Hill landscape. Erosion continues to create the present landscape; the Monongahela, Allegheny, and Juniata rivers and their tributaries take sediment from the lowering mountains and deposit it as alluvial terraces along their banks (fig. 9F).

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

Pleistocene glaciers never reached as far south as Friendship Hill. The southern terminus reached 365 to 610 m (1,200 to 2,000 ft) in elevation in northwestern and northeastern Pennsylvania. Here glacial processes eroded the upland surfaces into rounded ridges, and glacial outwash (i.e., sand and gravel) filled the valleys (Davies 2005). However, the colder climates of the ice ages, as well as the movement of glacial ice, played a significant role in the formation of the modern landscape at Friendship Hill National Historic Site.

Prior to glacial activity, the Monongahela River flowed north towards an ancestral basin became Lake Erie. It was the dominant drainage in western Pennsylvania (Harper 1997; Marine and Donahue 2000). However, advancing glacial ice dammed the north flowing rivers in northern Ohio, Pennsylvania, and New York, forming large ponded areas and flooding river valleys. These lakes (including Ancient Lake Monongahela) eventually overflowed their drainage divides, transforming flow of the ancient Monongahela and Allegheny rivers to their modern southerly courses (Harper 1997).

Glacial damming occurred at least four times during the Pleistocene. The first flood event left remnant lacustrine terrace deposits high above the pre- glacial river valleys. Subsequent lake levels were lower, leaving a traceable pattern of different flood events along the Monongahela River (Marine and Donahue 2000).

Since the Pleistocene, the rivers and tributaries in the Friendship Hill area continue to cut through thick deposits of glacial and alluvial sediments. Today, human activities augment natural erosion processes.

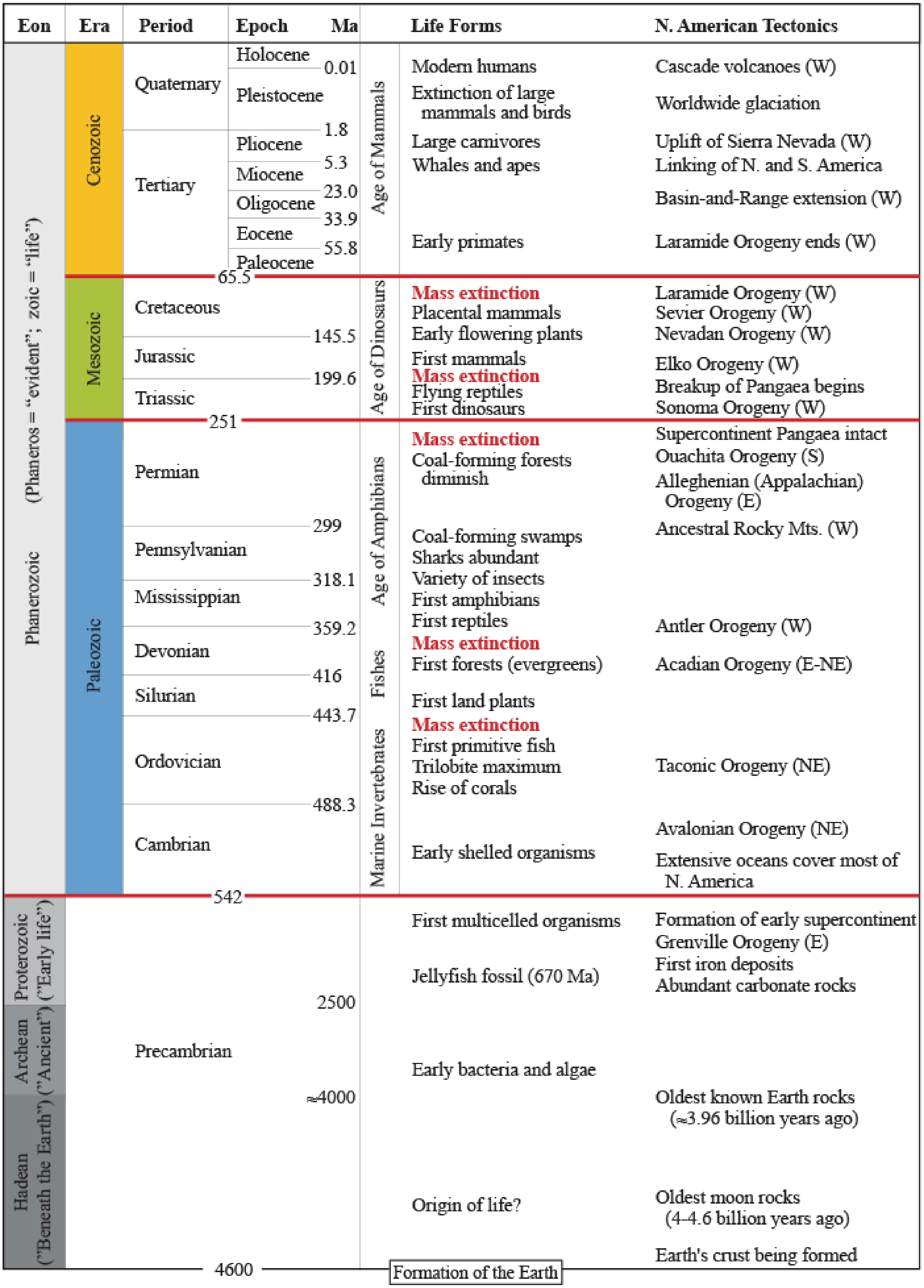

Figure 8. Geologic Time Scale. Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years (Ma). Source: U.S. Geological Survey. Graphic design: Trista L. Thornberry-Erlich (Colorado State University).

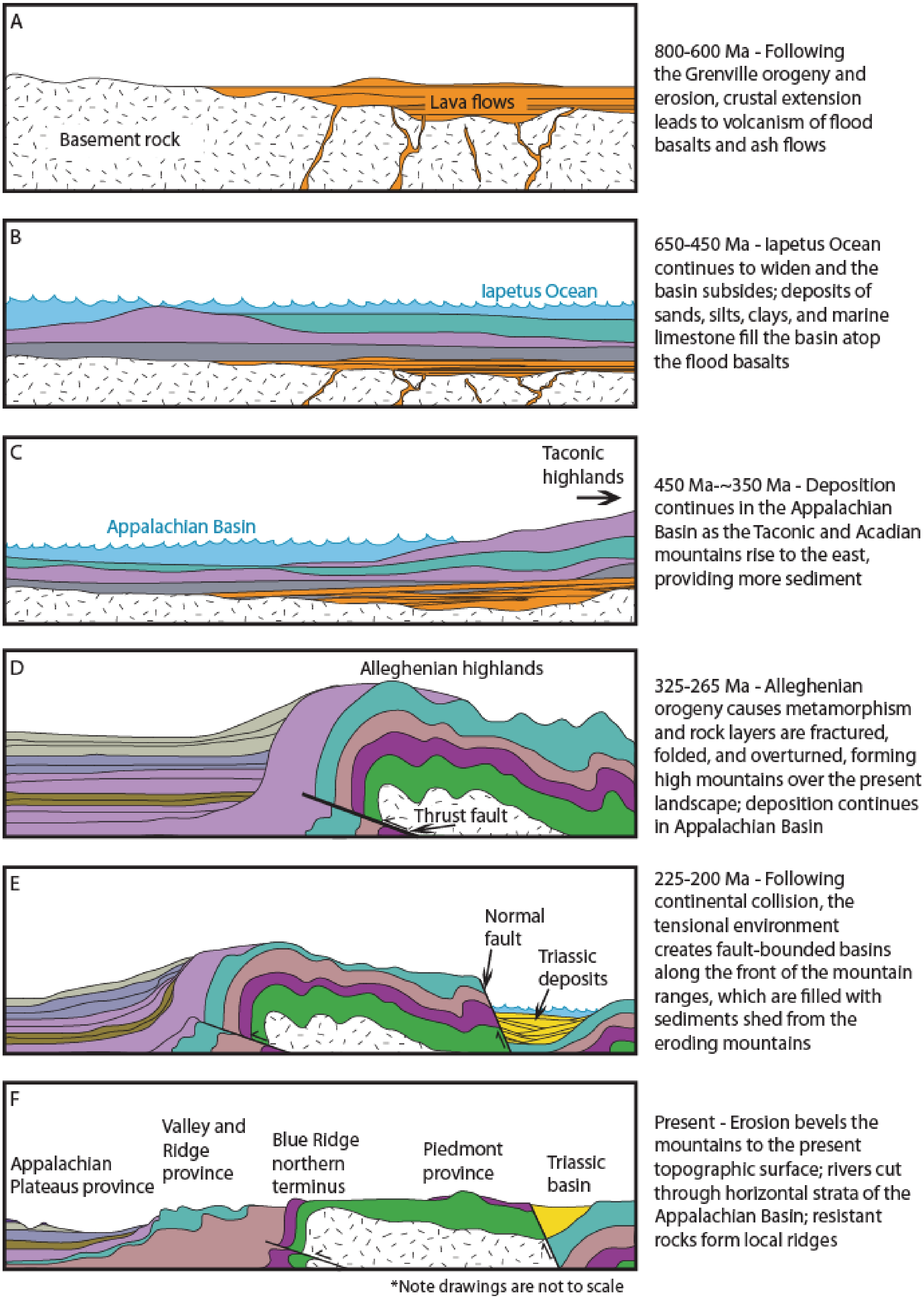

Figure 9. Evolution of the Landscape in the Friendship Hill National Historic Site Area. The figure shows landscape-scale changes from the Proterozoic (A) to the present (F). ***Sources*****: Means (1995); Fedorko et al. (2004).** ***Graphic design*****: Trista L. Thornberry-Ehrlich.**

Glossary

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

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.

barrier island. A long, low, narrow island formed by a ridge of sand that parallels the coast.

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.

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.

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

calcareous. A rock or sediment containing calcium carbonate.

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

clay. Clay minerals or sedimentary fragments the size of clay minerals (2 or 4 micrometers).

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 and a density of approximately 2.7 grams per cubic centimeter.

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, or stratigraphy in the third (vertical) dimension based on mapped and measured geologic extents and attitudes depicted in an oriented vertical plane.

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

debris flow. A rapid and often sudden flow or slide of earth materials 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 the mouth of a river where it flows into a lake or sea.

dike. A tabular, discordant igneous intrusion.

eolian. Formed, eroded, or deposited by or related to the action of wind.

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

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)

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

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

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

landslide. Any process or landform resulting from rapid mass movement under gravitational influence.

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

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

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.

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

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

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

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 3–4 miles (5–6 km) thick and generally of basaltic composition.

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

outwash. Glacial sediment transported and deposited by meltwater streams.

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

Pangaea. A supercontinent that existed during the Permian and Triassic periods that included most of the continental crust.

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

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

plutonism. A general term used for the phenomena associated with the formation of plutons (i.e., deep-seated igneous magma intruded into preexisting rock).

recharge. Infiltration processes that replenish groundwater.

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

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.

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

sedimentary rock. A consolidated and lithified rock consisting of detrital or chemically precipitated sediment(s).

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 variable- lithified sedimentary rock with silt-sized grains.

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

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

spring. A site where water flows out of the ground because the water table intersects the surface at this point.

strata. Tabular or sheet- like masses or distinct layers of rock.

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

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

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.

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

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

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

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

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).

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

References

This section provides a listing of references cited in this report. A more complete geologic bibliography is available from the NPS Geologic Resources Division.

Berg, T. M., W. E. Edmunds, A. R. Geyer, A.D. Giover, D.M. Hoskins, D.B. MacLachlan, S.I. Root, W.D. Sevon, A.A. Socoiow (compilers). 1980. Geologic map of Pennsylvania. Map 1 (scale 1:250,000). In *Atlas of preliminary geologic quadrangle maps of Pennsylvania*, compiled and edited by T. M. Berg and C. M. Dodge. Map 61 (scale 1:62,500). Harrisburg, PA: Pennsylvania Geological Survey.

Bain, R.J. 1992. Significance of the microstratigraphy of Pennsylvanian stromatolites from southeastern Ohio. *Geological Society of America Abstracts with Programs* 24 (4): 4.

Boen, J.B. 1972. *A small- scale thrust fault associated with low- amplitude flexural- slip folding*. U.S. Geological Survey Professional Paper 800- D: D25- D27.

Bogovich, W. M. 1992. Twelve years of abandoned mineland reclamation activities by the United States Department of Agriculture–Soil Conservation Service in southwest Pennsylvania. In *Land reclamation: Advances in research & technology*, eds. T. Younos, P. Diplas, and S. Mostaghimi, 230–239. Proceedings of the International Symposium, ASAE Publication 14- 92.

Cassle, C. F., E. H. Gierlowski- Kordesch, and R. L. Martino. 2003. Late Pennsylvanian carbonates of the northern Appalachian Basin: Criteria to distinguish brackish and freshwater conditions. *Geological Society of America Abstracts with Programs* 35(6):600.

Cecil, C. B., and K. J. Englund. 1989. Origin of coal deposits and associated rocks in the Carboniferous of the Appalachian Basin. In *Coal and hydrocarbon resources of North America*, volume 2 of *Carboniferous geology of the Eastern United States*, eds. B. C. Cecil, C. F. Eble, J. C. Cobb, D. R. Chestnut, Jr., H. H. Damberger, and K. J. Englund, 84–104. Washington, D.C.: American Geophysical Union.

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

Donovan, J. J., E. Werner, and B. R. Leavitt. 2000. Flooding of abandoned below- drainage underground coal mines: An example from an Appalachian Basin syncline. *Geological Society of America Abstracts with Programs* 32(7):340.

Donovan, J. J., and B. R. Leavitt. 2002. Regional flooding of acid- producing underground mines in the Pittsburgh coal basin. *Geological Society of America Abstracts with Programs* 34(6):143.

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

Eager, R.M.C. 1975. Some nonmarine bivalve faunas from the Dunkard Group and underlying measures. In *The Age of the Dunkard, Proceedings of the First I.C. White Memorial Symposium,* eds. Barlow J.A., S. Burkhammer, West Virginia Geological and Economic Survey: 23- 67.

Edmunds, W. E. 1993. Depositional history and environments. In *Carboniferous geology of the anthracite fields of eastern Pennsylvania and New England*, eds. J. R. Eggleston, W. E. Edmunds, D. P. Murray, J. R. Levine, P. C. Lyons, and C. Wnuk, 21–35. Champaign, IL: Illinois Geological Survey.

Edwards, C. L., and G. C. Nadon. 2001. Contrasting fluvial styles within Late Pennsylvanian strata of the distal Appalachian foreland basin. *Geological Society of America Abstracts with Programs* 33(4):52.

Fedorko, N., W. C. Grady, C. F. Eble, and B. C. Cecil. 2004. Stop 1: Upper Conemaugh and lower Monongahela Group strata on the north side of the Morgantown Mall complex on Interstate 79 at Exit 152, Morgantown, W.Va. In *Geology of the National Capital Region,* eds. S. Southworth, and W. Burton. Field Trip Guidebook. Circular 84- 88. Reston, VA: U.S. Geological Survey.

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

George, R. L. 2002. Comparing pottery from the proto-historic McKees Rocks Village and Eisiminger sites of southwestern Pennsylvania. *Annals of Carnegie Museum* 71(2):63–86.

Hammarstrom, J. M, P. L. Sibrell, and H. E. Belkin. 2003. Characterization of limestone reacted with acid- mine drainage in a pulsed limestone bed treatment system at the Friendship Hill National Historical Site, Pennsylvania, USA. *Applied Geochemistry* 18(11):1705–1721.

Harper, J. A. 1997. Of ice and waters flowing: The formation of Pittsburgh's three rivers. *Pennsylvania Geology* 28(3–4):2–8.

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

Hedin, R. S., R. W. Narin, and R. L. P. Kleinmann. 1994. Passive treatment of coal mine drainage. In *Bureau of Mines Information Circular*. Washington, D.C.: U.S. Bureau of Mines.

Kairies, C. L., R. C. Capo, R. S. Hedin, and G. R. Watzlaf. 2000. Characterization of iron- rich mine drainage precipitates associated with Monongahela and Allegheny Group coals. *Geological Society of America Abstracts with Programs* 32(7):477.

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

Kirchner, B. T., and J. Donahue. 2001. Likely non- glacial origin of sandstone clasts in a glacial lake deposit: The Carmichaels Formation, western Pennsylvania. *Northeastern Geology and Environmental Sciences* 23(3):270–275.

Klusman, R. W., D. H. Dvorak, and A. L. Borek. 1993. Modeling of wetlands and reactor systems used for mine drainage treatment. In *The challenge of integrating diverse perspectives in reclamation*, eds. B. A. Zamora and R. E. Connolly, 685–704. American Society for Surface Mining and Reclamation. Proceedings of the Annual National Meeting. Volume 10.

Koch, A.L., Santucci, V.L. 2004. Paleontological Resource Inventory and Monitoring- Eastern Rivers and Mountains Network. National Park Service, TIC #D- 265.

Kopas, F. A. 1991. *Soil survey of Fayette County, Pennsylvania*. U.S. Department of Agriculture, Soil Conservation Service; Pennsylvania State University, Agriculture Experiment Station and Agricultural Extension Service; Pennsylvania Department of Agriculture, State Soil and Water Conservation Commission.

Lund, R. 1975. Vertebrate- fossil zonation and correlation of the Dunkard Basin. In *the Age of the Dunkard Proceedings of the First I.C. White Memorial Symposium,* eds. Barlow, J.A., S. Burkhammer, West Virginia Geological and Economic Survey: 171- 182.

Madison, J. P., J. D. Lonn, R. K. Marvin, J. J. Metesh, and R. Wintergerst. 1998. *Upper Clark Fork River drainage*. Volume 4. Abandoned- Inactive Mines Program, Deer Lodge National Forest. MBMG Open- File Report.

Marine, J. T., and J. Donahue. 2000. Terrace deposits associated with ancient Lake Monongahela. In *Pittsburgh at the millennium: The impact of geoscience on a changing metropolitan area*, ed. J. A. Harper, 28–37. Guidebook for the Annual Field Conference of Pennsylvania Geologists. Volume 65.

Markowski, A. K. 2001. Coalbed methane resources in Pennsylvania: From old hazard to new energy. *Geological Society of America Abstracts with Programs* 33(1):74.

Marks, W.J., R.I. Marks, A.M. Pompa. 1998. Problematic tracks in the Casselman Formaiton of Cambria County. *Pennsylvania Geology* 29 (2- 3_: 2- 6.

McAuley, S. D., J. B. Brown, and J. L. Sams III. 1997. *National Water- Quality Assessment Program, Allegheny- Monongahela River basin*. Open- File Report OF 97- 0246. Reston, VA: U.S. Geological Survey.

McElroy, T. A. 1988. *Groundwater resources of Fayette County, Pennsylvania*. Water Resource Report W 60 (scale 1:50,000). Harrisburg, PA: Pennsylvania Geological Survey.

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.

Milici, R. C. 2005. Appalachian coal assessment: Defining the coal systems of the Appalachian Basin. In *Coal systems analysis*, ed. P. D. Warwick, 9–30. Geological Society of America Special Paper 387.

Moore, J. N., and W. W. Woessner. 2000. *Geologic, soil water and groundwater report—2000, Grant- Kohrs Ranch National Historic Site*. Deer Lodge, MT: National Park Service.

National Park Service. 2001. *Reclamation summary of abandoned mineral lands in the National Park Service*. Disturbed Lands Restoration Program, Geologic Resources Division. http://www2.nature.nps.gov/geology/distlands/amlreports/AMLinventory02- 23- 01.pdf (accessed February 6, 2006).

National Park Service. 2005. *Assessment of effect for fire management plan, Fort Necessity National Battlefield and Friendship Hill National Historic Site*. Draft Environmental Assessment.

Nickelsen, R. P. 1983. Aspects of Alleghanian deformation. In *Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge,* ed. R. P. Nickelsen and E. Cotter, 29–39. Guidebook for the Annual Field Conference of Pennsylvania Geologists. Volume 48.

Pennsylvania Department of Environmental Protection. 2007. www.depweb.state.pa.us/southwestro/site/ (accessed January 14, 2008).

Pennsylvania Environmental Council. 2006. *Watershed Atlas of the Monongahela and Allegheny rivers*. www.watershedatlas.org/index.html (accessed January 31, 2006).

Pennsylvania Geological Survey. 2000. *Physiographic provinces of Pennsylvania*. Map 13. Pennsylvania Department of Conservation and Natural Resources. http://www.dcnr.state.pa.us/topogeo/map13/map13.aspx (accessed January 26, 2006).

Reeder, K. K. 2000. Restoring a watershed: Applying new technology to migrate acid mine drainage in the Northeast. In *Natural Resource Year in Review—2000*. http://www2.nature.nps.gov/YearinReview/yir2000/pages/07_new_horizons/07_02_reeder.html (accessed February 2, 2006).

Reynolds, A. C., and R. C. Capo. 2000. Paleoenvironmental reconstruction of the Pennsylvanian- Permian Dunkard basin: Geochemical evidence from lacustrine core and associated Paleosols. *Geological Society of America Abstracts with Programs* 32(7):524.

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.

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

Southworth, S., D. K. Brezinski, R. C. Orndorff, P. G. Chirico, and K, M. Lagueux. 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). Open- File Report 01- 0188. Washington, D.C.: U.S. Geological Survey.

Stevenson, J. J. 1880. Surface geology of southwest Pennsylvania and adjacent portions of West Virginia and Maryland. *Proceedings of the American Philosophical Society*, 289–316.

Tewalt, S. J., M. Sato, E. I. Robbins. 2004. The use of ozone to remediate dissolved manganese from coal mine drainage. *Geological Society of America Abstracts with Programs* 36(2):82.

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

U.S. Army Corps of Engineers. 2004. *Monongahela River*. http://www.lrp.usace.army.mil/nav/monback.htm (accessed January 26, 2006)

Vandivort, T. F., J. Donovan, B. Leavitt, and P. F. Ziemkiewicz. 2001. Predicting the location of discharge of flooding abandoned mines. *Geological Society of America Abstracts with Programs* 33(6):134.

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

Whitfield, T. G., C.E. Miles, R.A. Fox, E.M. Ballerstein, J.M Taylor, G.A. Smith, J.G. Kuchinski, F.G. McCartney (compilers). 2001. *Digital bedrock geology of Pennsylvania: Johnstown and Tyrone 30' x 60' quadrangles, Pennsylvania* (scale 1:250,000). Harrisburg, PA: Pennsylvania Geological Survey.

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

Appendix A: Geologic Map Graphic

The following page is a preview or snapshot of the geologic map for Friendship Hill National Historic Site. 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://www2.nature.nps.gov/geology/inventory/gre_publications).

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Friendship Hill National Historic Site. The scoping meeting occurred on June 22, 2004; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

The Geologic Resources Evaluation Program hosted a geologic resources evaluation workshop for Friendship Hill National Historic Site on June 22, 2004, to view and discuss the park's geologic resources, address the status of geologic mapping for compiling both paper and digital maps, and assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Allegheny Portage Railroad and John Fitzgerald Kennedy national historic sites, and local geologic experts participated in the workshop.

Overview of Geologic Resource Evaluation

The NPS GRE has the following goals:

- to assemble a bibliography of associated geologic resources for NPS units with significant natural resources ("GRBIB"),
- to compile and evaluate a list of existing geologic maps for each unit,
- to conduct a scoping session for each park,
- to develop digital geologic map products, and
- to complete a geologic report that synthesizes much of the existing geologic knowledge about each park.

The emphasis of the evaluation program is not to routinely initiate new geologic mapping projects but to aggregate existing "baseline" information and identify where serious geologic data needs exist in the National Park System. In cases where map coverage is nearly complete or maps simply do not exist, then funding may be available for geologic mapping.

After introductions by the participants, GRD staff presented overviews of the Geologic Resources Division, the NPS I&M Program, the status of the natural resource inventories, and the GRE in particular.

They also presented a demonstration of some of the main features of the GRE digital geologic database. This has become the prototype for the NPS digital geologic map model as it reproduces all aspects of a paper map, including cross sections, legend, and other map- related information, with the added benefit of being geospatially referenced.

Map products are displayed in ESRI ArcView shape files and feature a built- in Microsoft Windows help file system to identify the map units. Products can also display scanned JPG or GIF images of the geologic cross sections supplied with the paper "analog" map. Geologic cross section lines (e.g., A- A') are subsequently digitized as a line coverage and are hyperlinked to the scanned images.

The team further demonstrated the developing NPS Theme Manager for adding GIS coverages into projects "on- the- fly." With this functional browser, users can add numerous NPS themes to an ArcView project with relative ease. Such themes might include geology, paleontology, hypsography (topographic contours), vegetation, and soils.

GRBIB

At the scoping session, individual Microsoft Word documents of geologic bibliographies for Friendship Hill National Historic Site and surrounding parks were distributed.

The sources for this compiled information are

- AGI (American Geological Institute) GeoRef
- USGS GeoIndex
- ProCite information taken from specific park libraries

GRE staff validated these bibliographic compilations to eliminate duplicate citations and typographical errors, as well as check for applicability to the specific park. After validation, they become part of a Microsoft Access database parsed into columns based on park, author, year of publication, title, publisher, publication number, and a miscellaneous column for notes.

From the Access database, they are exported as Microsoft Word documents for easier readability and eventually turned into PDF documents. They are then posted to the GRE Web site at http://www2.nature.nps.gov/grd/geology/gri/products/geobib/ for general viewing.

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 Friendship Hill National Historic Site.

The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverages were developed based on various scales (e.g., 1:24,000, 1:100,000) 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.

For both Friendship Hill National Historic Site and nearby Fort Necessity National Battlefield the GRE will use PA GA W- 60 (*Groundwater Resources of Fayette County*) at 1:50,000 scale. GRE staff will likely need to digitize this data.

However, for Friendship Hill National Historic Site, the GRE team needs to inquire with park staff whether more detail to the west in Greene County (i.e., Masontown quadrangle), which is available from W- 63 (*Groundwater Resources of Greene County*), would be useful for resource management.

These W reports should be more detailed than the atlas maps (1981), Map 61.

The Pennsylvania Geological Survey has 1:250,000- scale digital geology of the entire state to compare/contrast to larger scale (1:50,000) maps.

M- 91 has coal information at 1:62,500 scale based upon 1:24,000 scale (*Coal Resources of Fayette County, Pennsylvania*, Part 1).

Other Topics of Discussion

A discussion of geologic resource management issues followed the mapping discussion and touched upon the following features and processes (Note: No FRHI representatives were present at this meeting, thus the discussion was based on the consensus of the group present):

- Eolian: NA
- Fluvial (surface water) processes: FRHI has some deposition of sediment at bottom of hill from river
- Groundwater: NA; but can reference the Pennsylvania Geological Survey water reports
- Hazards: Rockfall potential likely at Jumonville based upon stratigraphy of Mauch Chunk and Pottsville formations
- Paleontology: See Koch and Santucci (2004) report about Eastern Rivers and Mountains Network
- Mineral extraction: Jumonvill area has had limestone quarrying for mostly aggregate; not likely building stone quality
- Caves/karst: Potential because of nearby limestones being mined. Laurel Caverns are nearby and are largest caverns in Pennsylvania; no known caves in Friendship Hill National Historic Site though.
- Glacial: Glacio- lacustrine Lake Monangahela backed up a minimum of three times during the Pleistocene Epoch.
- Lacustrine: Carmichaels formation is lacustrine
- Coastal/Marine: NA
- Geologic interpretation: Chestnut Ridge serves as good place to interpret the local geologic story.
- Monangahela River meandering is part of story too
- Also see http://www.watershedatlas.org SITE MAP
- Unique geologic features: Chestnut Ridge, Great Meadows
- Geothermal: NA
- Disturbed lands: Subsidence at Friendship Hill National Historic Site from coal mining; has bad acid- mine drainage problem from sulfur in coal (e.g., Ice Pond Run)

Monitoring Issues

Monitor for landslides and rockfalls beneath Friendship Hill.

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Friendship Hill National Historic Site

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/022
NPS D-46, February 2008

National Park Service

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