National Park Service
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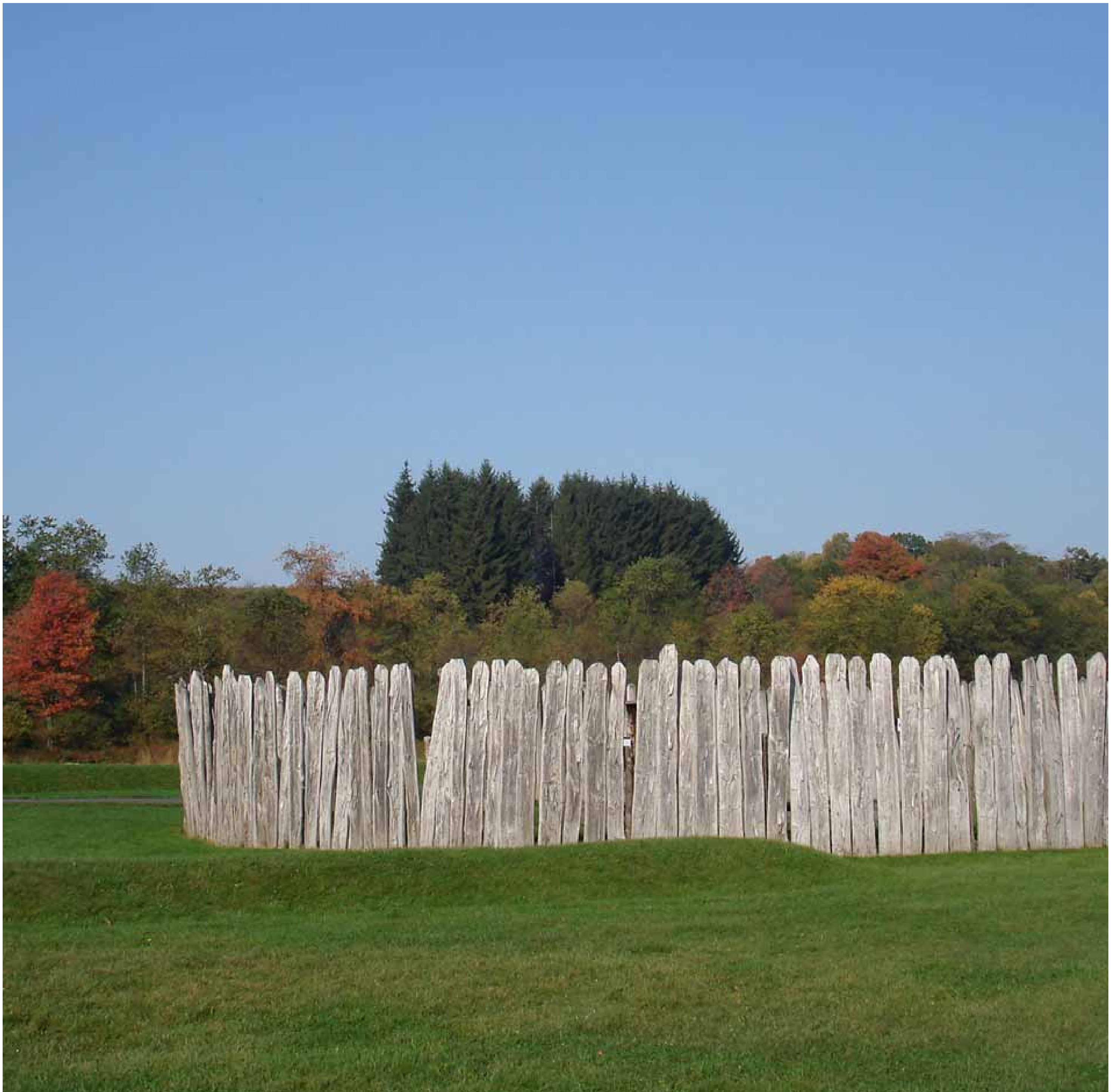
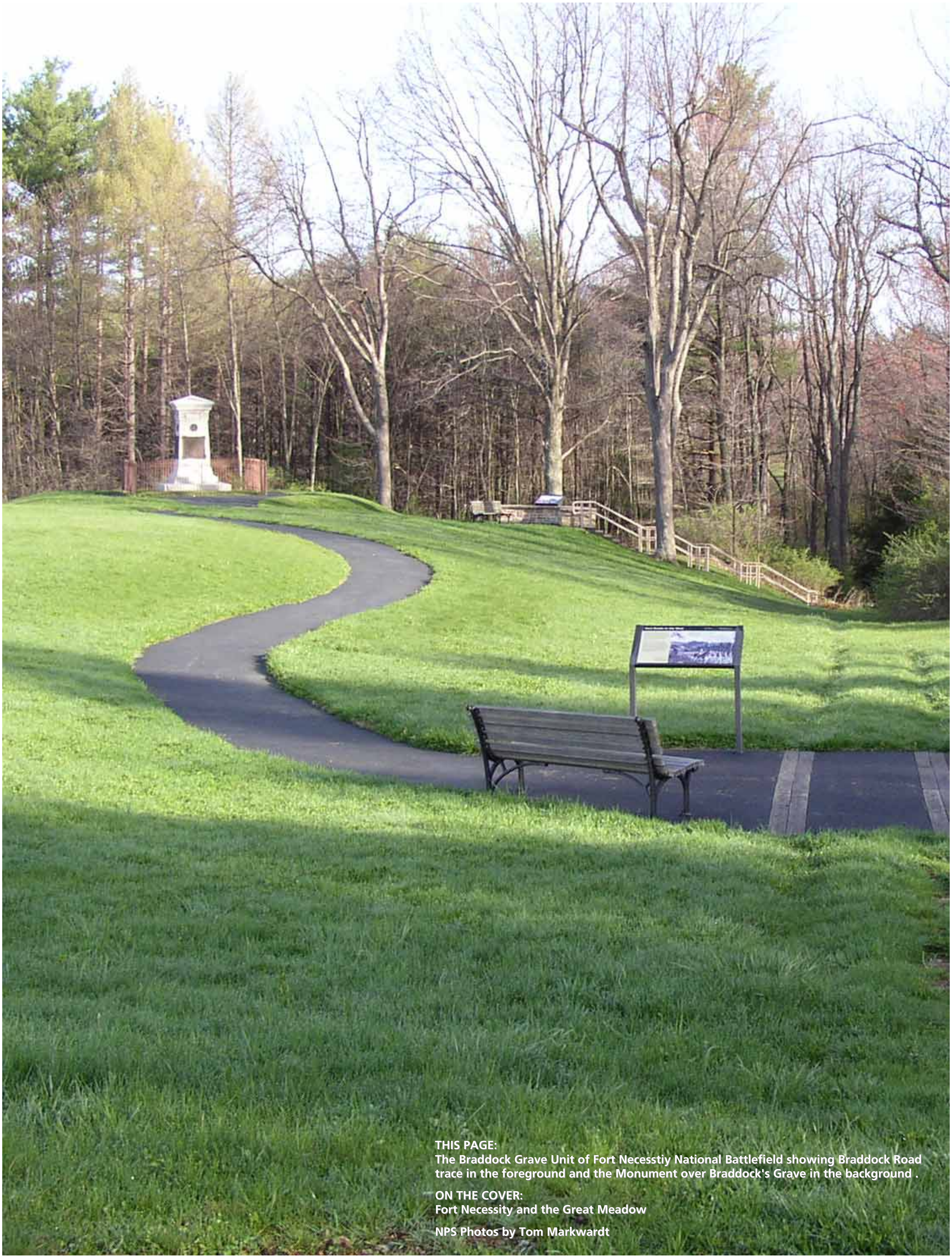
Natural Resource Program Center

Fort Necessity National Battlefield
Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/082





THIS PAGE:
The Braddock Grave Unit of Fort Necesstiy National Battlefield showing Braddock Road trace in the foreground and the Monument over Braddock's Grave in the background .

ON THE COVER:
Fort Necessity and the Great Meadow

NPS Photos by Tom Markwardt

Fort Necessity National Battlefield

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Natural Resource Program Center
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June 2009

U.S. Department of the Interior
National Park Service
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Denver, Colorado

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Please cite this publication as:

Thornberry-Ehrlich, T. 2009. Fort Necessity National Battlefield Geologic Resources Inventory Report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/082. National Park Service, Denver, Colorado.

NPS D-71, June 2009

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Executive Summary

This report accompanies the digital geologic map for Fort Necessity National Battlefield in Pennsylvania, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

In 1754, a young George Washington helped carve a road deep into the Pennsylvania wilderness. At the time, the dense virgin forests and rugged topography were proving as difficult an obstacle to westward expansion of the British interests as was competition from the French. In a rare clearing, the "Great Meadows," Washington set up a temporary camp and later a palisade-style stockade to defend his position against attacks by French troops and Indian allies. A brief battle followed a skirmish on the slopes of Chestnut Ridge at Jumonville Glen. This was Washington's first test of military leadership. Poor understanding of the local terrain ultimately led to Washington's one and only surrender. The French and Indian War thus began, and the geology of the frontier lands was to play a significant role in the war campaigns. In 1931, Fort Necessity National Battlefield was designated to protect this pivotal site in North American history.

Fort Necessity is in the Allegheny Mountains section of the Appalachian Plateaus physiographic province. The rocks in this province are relatively flat lying and undeformed in contrast to the rocks of the Valley and Ridge province, just to the east of Fort Necessity and beyond the sharp eastern front of the Allegheny Mountains. Chestnut Ridge is the westernmost large-scale regional fold. In the Fort Necessity area, geologic surface exposures consist primarily of Pennsylvanian through Permian sedimentary rocks. These include conglomerate, sandstone, shale, claystone, limestone, and dolomite. These rocks contain fossils, commercially viable coals, and some iron- and sulfide-rich minerals. These geologic units hold clues to the geologic history of the area. Explaining the role that the geologic resources played in the history of the area will likely enhance the visitor's experience.

Geology provides the foundation of the ecosystem. Understanding the geology of western Pennsylvania enhances one's understanding of the unique relationship between geology and the environment. Geologic processes initiate complex responses that give rise to rock formations, the topography, surface and subsurface fluid movement, and soils. These processes develop a landscape that influences human use patterns. At Fort Necessity, human disturbances of the land are obvious. Slopes and meadows have been logged and cleared for agricultural use while shaft and strip coal mines and limestone quarries have altered the landscape. Nearby abandoned mines continue to threaten natural and cultural resources at the park with acid mine drainage.

The following issues have a high level of management significance within the park:

- Surface-Water Issues and Hydrogeology
  Great Meadows Run and Indian Run flowed through the setting of Washington's fort. Wetlands associated with these are located in the three park areas (Fort Necessity, Braddock Grave, Jumonville Glen). The dynamic nature of wetland environments makes them an indicator of overall ecosystem health. Wetlands, in addition to being a reservoir of water and nutrients, also contain a record of information about the ecosystem, such as changing vegetation, biogeochemistry, predevelopment conditions, and increased human influences.
- Geologic Hazards
  Hazards at Fort Necessity National Battlefield include radon gas contamination in the Washington Tavern and park infrastructure, and shrink-and-swell clays. The steep terrain of valleys between ridges and rolling hills that defines the Allegheny Mountains region is prone to such geologic hazards as landslides, slumps, and rockfalls. The geologic unit underlying the main site at Fort Necessity contains a heterogeneous mix of sandstone, siltstone, mudstone, clay shale, and limestone. Clay-rich units, such as shale and mudstone, may disintegrate or swell when they become saturated with water and are prone to fail in a slide or slump when exposed on a slope. At Fort Necessity, relatively weak, clay-rich units underlie the resistant Ames Limestone and pose rockfall hazards on local slopes.

Incorporating the geologic landscape of the park into interpretative programs could highlight the importance of geologic features to the park's history. Paleontological resources have not yet been documented in the park, but there is potential for their discovery. Likewise cave or karst features have not yet been documented within the park but are present in the surrounding area.

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Fort Necessity National Battlefield.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRI team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRI products.

The goal of the GRI 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 GRI team is systematically conducting a scoping meeting for each of the identified 270 natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI 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. This geologic report aids in the use of the map 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 current GRI contact information please refer to the Geologic Resources Inventory Web site (http://www.nature.nps.gov/geology/inventory/).

Geologic Setting

The landscape at Fort Necessity is largely pastoral. Nearby streams include Indian Run, Great Meadows Run, Chaney Run, McIntire Run, Stony Fork, Mill Run, Meadow Run, Beaver Creek, Cucumber Run, and several seasonal unnamed courses and springs. Most local streams are tributaries to the Youghiogheny River, which joins the Ohio River system in Pittsburgh along with the Monongahela and Allegheny Rivers. Elevation ranges from just above 640 m (2,100 ft) to just below 557 m (1,830 ft) above sea level at the main area and Braddock Grave area. The Jumonville Glen area sits in a ravine on the slopes of Chestnut Ridge, at approximately 732 m (2,400 ft) in elevation. Nearby peaks include Fulton Knob, with an elevation of more than 799 m (2,620 ft) (fig. 1).

The geologic units at Fort Necessity are generally flat lying and undeformed; erosion and downcutting of rivers through the horizontal layers caused surface variations. This is typical of the Appalachian Plateaus physiographic province. Fort Necessity is near the junction of two physiographic subprovinces—the Pittsburgh Low Plateau and Allegheny Mountain sections, described below (fig. 2) (Sevon 2000). To the west of the park are the undulating hills and steep valleys of the Allegheny Mountains, including Laurel Hill, Sugarloaf Knob, and Tharp Knob. To the east of the park, the valleys of Pine, Long, and Laurel runs rise steeply towards Chestnut Ridge. Mississippian to Devonian sandstone caps this ridge.

A general, east-to-west description of several of the different physiographic provinces of the Appalachian Mountains follows. The information is relevant to understanding the geologic history of Fort Necessity National Battlefield.

Piedmont Province

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

Blue Ridge Province

The Blue Ridge province is located along the eastern edge of the Appalachian Mountains and includes the highest elevations in the Appalachian Mountains system, in Great Smoky Mountains National Park in North Carolina and Tennessee. Precambrian and Paleozoic igneous, sedimentary, and metamorphic rocks were uplifted during several orogenic events forming the steep, rugged terrain. Resistant Cambrian quartzite forms most of the high ridges, whereas Precambrian metamorphic rocks underlie the valleys. The elongate belt of the Blue Ridge stretches from Georgia to Pennsylvania. Eroding streams have narrowed the northern section of the Blue Ridge Mountains into a thin band of steep ridges that rise to heights of approximately 1,200 m (3,937 ft).

Valley and Ridge Province

Long, parallel ridges separated by valleys 100–200 m (330–660 ft) below the ridges characterize the landscape of the Valley and Ridge physiographic province. The valleys formed in areas of easily eroded shale and carbonate formations, and the ridges are commonly composed of resistant sandstone units. The province contains strongly folded and faulted sedimentary rocks in central Pennsylvania. The Valley and Ridge province averages approximately 80 km (50 mi) in width. The eastern part of the Valley and Ridge province is the Great Valley section, a rolling lowland formed on folded carbonate rocks and shale. It is connected to the Piedmont province by streams that cut through the Blue Ridge Mountains.

Appalachian Plateaus Province

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

The Waynesburg Hills section (farthest west) is composed of narrow hilltops separated by steep-sided narrow valleys; relief is typically between 180 and 300 m (600 and 1,000 ft). Elevations in this section range from 150 to 500 m (500 to 1,650 ft). Smooth, undulating terrain cut by numerous shallow river valleys characterizes the Pittsburgh Low Plateau section. This section 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 (650 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 (e.g., Chestnut Ridge) in this section are exposed anticlinal cores of very resistant rocks, such as Devonian sandstone. Relief in this section is greater than 300 m (1,000 ft), and elevations range from the highest point at Mount Davis (979 m, or 3,212 ft) to the lowest point at 236 m (774 ft) (Pennsylvania Geological Survey 2000). A steep and abrupt mountain front separates this section from the Allegheny Front section to the east. The Allegheny Front section separates the Valley and Ridge, and Appalachian Plateaus physiographic provinces.

History of Fort Necessity

In 1754, Fort Necessity was on the brink of the western frontier in the wilderness of the Allegheny Mountains in southwestern Pennsylvania. Lieutenant Colonel George Washington of the Virginia Militia had gathered 186 men to reinforce a fort built at the fork of the Ohio and Allegheny Rivers. Following a skirmish on May 28 at Jumonville Glen, where Washington's troops ambushed a suspected French raiding party, British colonial troops under the leadership of the 22-year-old Washington were attacked on July 3 and defeated in the small stockade within the "Great Meadow" (fig. 3). This was an inauspicious beginning for one of the great military leaders of the American Revolution. The skirmish at Jumonville Glen is considered by many historians to be the true "shot heard around the world" since it was the first battle of the French and Indian War in America and the Seven Years War (Queen Anne's War) in Europe and in the colonies around the world. This "First World War" between Great Britain and France decided the ultimate control of North America.

Fort Necessity was established as a national battlefield site by the War Department on March 4, 1931. It was transferred to the National Park Service in 1933 and designated a national battlefield on August 10, 1961, during the administration of President John F. Kennedy. In 1966, it was added to the National Register of Historic Places. The national battlefield covers approximately 365 ha (900 acres) over three separate units—the main area, the Braddock Grave area (2.4 km [1.5 mi] west), and the Jumonville Glen unit (11 km, [7 mi] northwest) (fig. 1). For further information on the history and setting of the park, consult the Web site: http://www.nps.gov/fone or Alberts (1975).

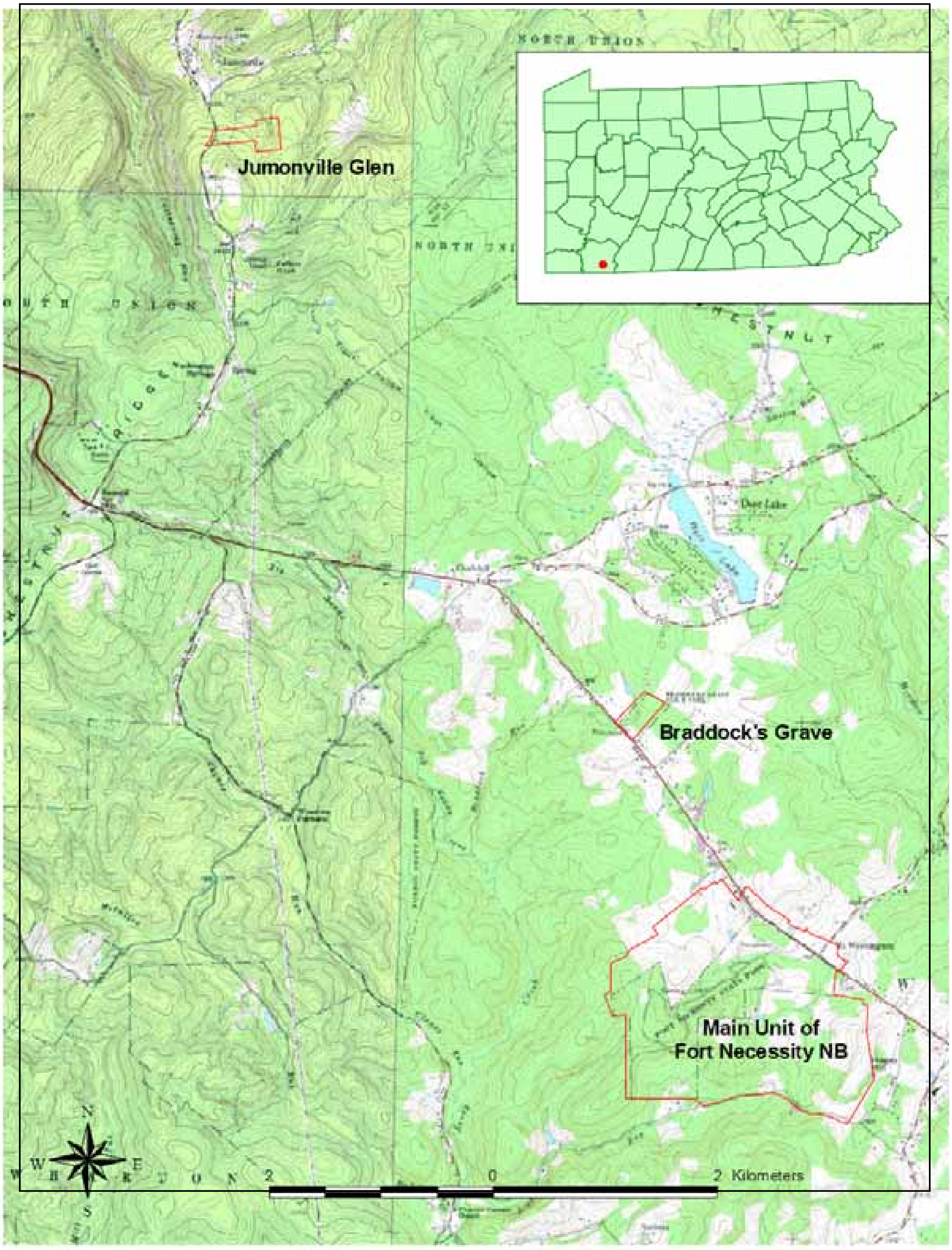


Figure 1. Location of the three areas (outlined in red) of Fort Necessity National Battlefield, Pennsylvania. Base map from Fort Necessity and Uniontown 1:24,000 topographic quadrangle maps, U.S. Geological Survey. Index map of Pennsylvania showing county boundaries and location of Fort Necessity National Battlefield. Graphic provided by Vincent Santucci (NPS-GWMP).

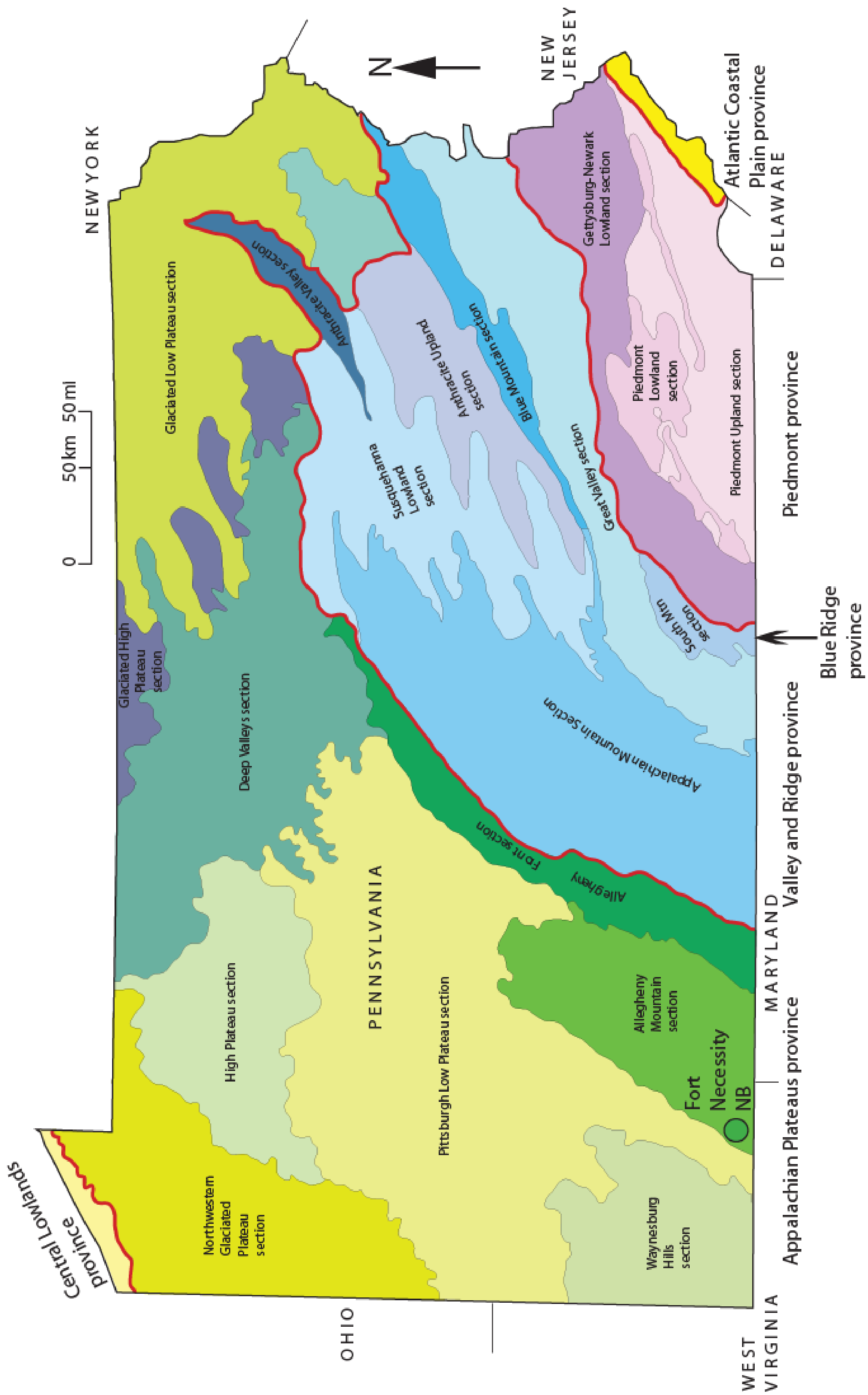


Figure 2. Physiographic Provinces of Pennsylvania. The map graphic shows the physiographic setting of Fort Necessity National Battlefield. The green circle marks the location of the park and historic site. Red lines indicate boundaries between major physiographic provinces. The black arrow locates the northern terminus of the Blue Ridge province. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University) after Sevon (2000).

Figure 3. Painting of George Washington at Jumonville Glen, note the Burgoon Sandstone exposures in the background. Original painting by Bryant White, commissioned by and image courtesy of Vincent Santucci (NPS-GWMP).

Geologic Issues

The National Park Service held a Geologic Resources Inventory scoping session for Fort Necessity National Battlefield on June 22, 2004, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Introduction

Issues in this section are identified in relative order of significance for resource management with the most critical listed first. Potential research projects and topics of scientific interest are presented at the end of this section.

Surface-Water Issues and Hydrogeology

Several small-scale streams and springs, as well as associated wetlands, are located within the three park areas (Fort Necessity, Braddock Grave, and Jumonville Glen). All surface water in the park is part of the larger Youghiogheny River watershed and ultimately flows into the Ohio River system. In the main area, Indian Run and Great Meadows Run are very short streams and occasionally disappear during dry summer months. Annual average precipitation in the area is 107 cm (42 in) (Pennsylvania Environmental Council 2006). The rest of the park's water comes from groundwater and springs.

Water quality is an important management issue at Fort Necessity. The dynamic nature of wetland environments makes them an indicator of the overall status or "health" of the ecosystem. It may prove beneficial for resource management to work with the NPS Water Resources Division to develop an appropriate inventory and monitoring strategy for its wetland environments. This may include identifying, describing, and mapping wetlands in detail. Once sites are identified and compared with past photographs and records, it will be possible to monitor trends. Parameters may include water chemistry, sediment influx, and vascular plants. The wetland soils and sediments, in addition to being a reservoir of water and nutrients, also contain a record of the system, including changing vegetation, biogeochemistry, predevelopment conditions, and increased human influences

The quality of water resources in the watershed has suffered from industrial development and natural resource extraction throughout the watershed, Cooperative efforts are underway to remediate both point and non-point sources of pollution in the watershed.

Resource managers need to know how water travels through the subsurface to predict hydrologic response to inputs such as contaminants, acid-mine drainage (see following discussion), and other wastes. The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow.

Other input sources include wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. Streams in effect integrate the surface runoff and groundwater flow in watersheds. Thus, they provide a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Inventory, Monitoring, and Research Suggestions for Surface-Water Issues and Hydrogeology

- Work with the NPS Water Resources Division to develop an appropriate inventory and monitoring strategy for wetlands.
- Consult Pennsylvania Geological Survey water reports to obtain further data on the hydrologic system of the park.
- Map and quantify subterranean water-recharge zones, especially in areas known to contain mine features. Investigate additional methods to characterize groundwater recharge areas and flow directions.
- Consider the influences of bedrock, including neutralizing limestone and geologic structures, and topography on local watersheds at Fort Necessity National Battlefield.

Geologic Hazards

The clay-rich units underlying Fort Necessity National Battlefield contain abundant organic material. Soils derived from these units support agriculture and vast forests. In the early 19th century, George Washington cut a road through to the Ohio country, now referred to as the National Road, or "Old Pike." To cater to travelers, the Mount Washington Tavern (today a museum) was constructed near Fort Necessity as a stagecoach stop (NPS Web site). The lower levels of this structure may be susceptible to radon gas (carcinogenic) contamination due to the decay of uranium found in granite, as well as local Pennsylvanian organic-rich shale. Radon is the heaviest noble gas and is radioactive. It tends to settle in the lower levels of a structure, such as the basement. If elevated radon levels are found through testing, remediation via the instillation of a ventilation system may be required

The steep terrain of valleys and ravines between ridges and rolling hills that defines the Allegheny Mountains region is prone to several geologic hazards, including landslides, slumps, and rockfalls. The geologic unit underlying the valleys at Fort Necessity (Glenshaw Formation) contains a heterogeneous mix of sandstone, siltstone, mudstone, clay shale, and limestone. Clay-rich units, such as shale and mudstone, may disintegrate or swell when they become saturated with water and when exposed on a slope are prone to fail as a slide or slump. Shrink-and-swell clays (which swell when saturated with water, then shrink upon drying) undermine the stability of the ground as their volume changes. When resistant rock units, such as sandstone and limestone, overlie weaker units, preferential erosion undercuts the resistant rock creating rockfall hazards. The Jumonville Glen area—located in a ravine on the slopes of Chestnut Ridge, where there are scenic outcrops of the Burgoon Sandstone—is susceptible to mass wasting, such as toppling, rockfall, debris flows, and landslides.

A unique and potentially hazardous stratigraphic setting exists in the Fort Necessity area. Between the clay-rich Pennsylvanian Glenshaw Formation and the overlying Casselman Formation is the resistant Ames Limestone. The likelihood of instability in this situation is significant: the weak clays may fail during storms and the undercut limestone layer may pose a slide hazard. A site investigation by a geologic hazards expert could determine if these clays and the Ames Limestone are present on the slopes within the park.

Inventory, Monitoring, and Research Suggestions for Geologic Hazards

- Determine the composition of clays in surficial deposits. Identify and map radioactive (radon-emitting) clays and shrink-and-swell clays for use in the siting of future facilities at the park, as well as for identifying problem areas for existing infrastructure.
- Monitor slope processes at the Jumonville Glen location.
- Investigate clay-rich layers and friable limestone exposed on slopes to determine vulnerability to slope failure.

Active and Past Mining in the Area

The rocks surrounding Fort Necessity National Battlefield have long attracted humans for their mineral resources. Jurassic igneous dikes (Gates-Adah dike) in the area contain olivine, pyroxene, amphibole, and mica and are commonly referred to as “kimberlites.” Limestone-rich units, such as the Monongahela Group, Glenshaw Formation, and Mauch Chunk Formation, are a potential source of building materials and aggregate for regional developers (Berg et al. 1980; McElroy 1988). A quarry near the Jumonville Glen site extracts limestone for aggregate used in roads and construction. Even ash beds and chert nodules in the area were mined regionally. However, the primary mining interest is the vast fields of bituminous coal that underlie the region.

Coal and iron mining have long been associated with west-central Pennsylvania, which ranks fourth in the nation among states today in annual production (Anonymous 2002). One-sixth of all abandoned coal mine areas in the United States are located in the 12 southwestern counties of the state (Bogovich 1992). Approximately half of the coal-mine discharges in Pennsylvania are acidic, having pH levels less than 5 (Anonymous 2002).

The commercially viable Freeport, Kittanning, and Brookville-Clarion coal seams all exist within the park area. These are associated with the Pennsylvanian Allegheny Group. The Pittsburgh Coal—also in the area—is located in the base of the Monongahela Group (Berg et al. 1980; McElroy 1988). Other smaller scale, impure coal seams are present locally in younger rock units. The Pennsylvanian units contain some of the largest underground coal mines in North America, and it is estimated that 50%–60% of the reserves have been extracted (Donovan and Leavitt 2002). These coalbeds are currently being investigated for coalbed methane resources (Markowski 2001). Extensive shaft and strip mining has resulted in lasting effects on the landscape, including mappable areas of altered land surface. Negative effects of mining vary from acid-mine drainage to potential subsidence and collapse. The Pennsylvania Department of Environmental Protection has maps showing mined areas and that document past mine-subsidence.

Abandoned and inactive mines pose safety, environmental, and health problems for the Fort Necessity area. While there are no abandoned mine features within the park, surrounding mine features could pose acid mine pollution (and residual heavy-metal) problems for the park’s soils, ground water, and small streams and springs.

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

These conditions are present at coal mines in the hills surrounding Fort Necessity National Battlefield.

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.

In addition, there is increasing interest in the potential of for iron-rich sludge associated with mine drainage to be a salvageable resource. Nationwide, 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).

Remediation of mine-affected areas in southwestern Pennsylvania is a cooperative effort. In addition to the National Park Service, agencies such as the U.S. Geological Survey, the Office of Surface Mining Reclamation and Enforcement, the U.S. Department of Agriculture, the Pennsylvania Department of Environmental Protection, the Bureau of Mines, and the Pennsylvania Environmental Council, as well as many local offices, are all contributing to the process (Anonymous 2002).

As part of the Allegheny-Monongahela National Water Quality Assessment, nearby Friendship Hill National Historic Site is among the first sites to employ a low-cost acid-mine-drainage treatment process based on limestone neutralization. Limestone is the least expensive material available to raise the pH of mine drainage (Reeder 2000). Hampering this low-cost method is the accumulation of gypsum, Fe-Al hydroxysulfate, and Fe (III) oxyhydroxide coatings on the limestone grains, which prevents contact between the acidic water and neutralizing limestone. However, a technique developed at the U.S. Geological Survey Leetown Science Center adds 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 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.

Inventory, Monitoring, and Research Suggestions for Active and Past Mining in the Area

- Work with the NPS Geologic Resources Division and Water Resources Division to develop appropriate inventory, monitoring, and remediation strategies addressing the potential for acid mine drainage in the park.
- Survey and monitor aquatic species and riparian zones for heavy-metal contamination.
- Use well data, groundwater flow modeling, and GIS to generate maps showing the history of groundwater contamination through time.

Geologic Interpretation

From the slopes of Chestnut Ridge or Laurel Hill, which are underlain by uplifted and folded rocks, the view of the relatively flat valley traversed by Great Meadows and Indian runs shows why this location would have been attractive to a young George Washington, who was eager to establish a defensive position. There are many opportunities at Fort Necessity to interpret the role that geology played in the events surrounding the battle at the site.

In early 1754, French and British forces were competing for territory west of the original 13 colonies along the frontier. Washington had been sent to ask the French to remove their forces from the Ohio Territory—a request they declined. After this, he set off with orders to march troops towards Ohio and aid in the effort of constructing fortresses to protect the interests of the British king against the enterprises and hostilities of the French (NPS Web site).

En route to the Ohio Territory, Washington had to cross the rough and difficult terrain of the Piedmont Plateau, Blue Ridge, and Valley and Ridge physiographic provinces. Here, uptilted, folded, and deformed rocks are great topographic obstacles. Washington had to amend and alter existing roads as well as build new ones during this campaign. He also looked to establish a water route along the Youghiogheny River, but the uptilted stratigraphic layers in the area created riffles, rapids, and waterfalls that would allow no safe passage downstream towards the Forks of the Ohio (now Pittsburgh) (NPS Web site).

On Friday, May 24, Washington's regiment made camp within an angle formed between Great Meadows and Indian runs. They then hiked to a glen nearby (Jumonville Glen), where they skirmished with French troops who had been encamped there for several days among outcrops of the Burgoon Sandstone. This glen is on the slopes of Chestnut Ridge, overlooking the valley from the west. The first test of Washington's military leadership was his order to open fire on the French soldiers below the cliffs at Jumonville Glen. Colonel du Jumonville died in the battle that bears his name. Fearing French retaliation, Washington hurried to fortify the camp in the valley, creating his "Fort of Necessity." He constructed a stockade in the middle of the natural wetland meadow, theorizing that any attacker would have to cross the open stretch of meadow and recognizing that the natural resources of the area (grass and water) were bountiful (NPS Web site).

On Wednesday, July 3, a French force under De Villier's direction attacked the fort. Washington miscalculated the fort's position, and the French and Indian allies were able to take shelter behind trees and fire from all sides. Instead of taking the fort by force, the French successfully negotiated surrender (NPS Web site). The

French and Indian War thus began and affected the entire frontier as passing armies burned and destroyed nascent settlements. In many battles throughout the conflict, knowledge of terrain and local landforms gave great advantage to one side or another. Native American allies provided much of this knowledge.

The diversity of the geology in the Fort Necessity area can illustrate many geologic concepts. The concept of geologic time is evident in the context of the Pennsylvanian age rocks surrounding the park. Rocks and their fossils indicate depositional environments and the conditions of life in the distant past. Tropical species recorded in the fossil record of Pennsylvanian age strata are an opportunity to introduce the concept of plate tectonics and reveal that the area was once in the equatorial latitudes (Nikitina 2003).

Structures of Chestnut Ridge and Laurel Hill are products of the complex deformational history of the area, which includes three Paleozoic mountain-building events. Glaciers affected the area during the Pleistocene by scouring the landscape, changing the courses of rivers, and leaving vast deposits. Relating geology to such human concerns as floods, slope failures, coal mining, water pollution, oil and gas exploration, waste management, and urban development would make the science meaningful to park visitors (Nikitina 2003). Relating geology and geologic processes to the history of the battlefield lends deeper meaning to the human history of the area.

Inventory, Monitoring, and Research Suggestions for Geologic Interpretation

- Develop an interpretive program highlighting the area's underlying geologic units and structures. Discuss how the geology affects terrain and thus Washington's decision to build the fort there.
- Discuss the role of geologic features, such as the Allegheny Front, Ohio River, Youghiogheny River, and Chestnut Ridge, in the French and Indian War.
- Expand the interpretation of the area's geology to a regional context by highlighting the struggle for westward expansion and control in the face of natural obstacles.

Paleontological Resources

Fossils add to the understanding of the geologic history of the Appalachian Plateaus province. Certain fossils are useful to correlate geologic units across time and space. Others give clues as to the depositional environment when they were alive. Still others provide information about post-burial conditions, including geochemical changes, deformational regimes, and changes in bedding orientation. Fossil resources, when present, merit careful inventory and protection.

Fossils have not yet been formally recorded within the boundaries of the three park areas (Fort Necessity, Braddock Grave, and Jumonville Glen). However, the geologic units located in park lands are known to contain fossils outside of the park. The oldest of these units, the Mississippian Burgoon Sandstone, contains non-marine, fluvial sandstone, conglomerate, shale, and coal (located in Jumonville Glen). This unit contains trace fossils, as well as plant fossils, from several localities in Pennsylvania (Koch and Santucci 2004). The Upper Mississippian Mauch Chunk Formation contains a limestone unit (the Wymps Gap Limestone Member) exposed along Highway 40 on the eastern limb of Chestnut Ridge that reveals a rich assemblage of fossil specimens in the park area, including foraminifera, bryozoans, brachiopods, pelecypods, cephalopods, gastropods, trilobites, ostracodes, crinoids, blastoids, and conodonts (Simonsen 1987).

The Pennsylvanian Glenshaw Formation is located in the Fort Necessity and Braddock Grave areas of the park and contains shale, sandstone, limestone, and coal. This widespread unit is rich in fossils throughout Ohio, West Virginia, and Pennsylvania. It contains the fossiliferous Brush Creek, Pine Creek, and Ames zones of marine origin. The fossils are predominantly concentrated in the limestone and calcareous shale beds within the formations. Fossils are mostly marine in origin, associated with biogenic mounds and abundant vertical burrows (from malacostracan crustaceans?). Other fossils are foraminifera (palaeotexturlariid and endothyroid), fusulinids, corals, bryozoans, brachiopods, bivalves, gastropods, cephalopods, trilobites, crinoids, echinoderms, conodonts, shark's teeth, and fish fragments (Koch and Santucci 2004).

Inventory, Monitoring, and Research Suggestions for Paleontological Resources

- Inventory any and all fossil resources in the three park areas.
- Attempt to locate any samples removed from park lands and develop a park collection.
- Map all fossil localities, analyzing fossils and sediments at each location to determine depositional conditions and post-burial histories of each park area.
- Develop an interpretive program that incorporates the fossil story along with the geologic history of the park area.
- Develop a plan to protect fossil resources from degradation and theft.

Caves and Karst

Limestone is a common rock in and surrounding Fort Necessity National Battlefield. Limestone quarries are present near the Jumonville Glen area and throughout the region. Limestone dissolves when acidic water reacts with rock surfaces along cracks and fractures. Most meteoric water, acid mine discharge notwithstanding, is of relatively low pH and becomes more acidic as it flows through decaying plant debris and soils (Florida Geological Survey 2005).

Over hundreds of thousands of years, dissolution between the intergranular pores and along fractures and joints creates larger and larger voids. Units such as the Monongahela Group, the Glenshaw Formation, and the

Mauch Chunk Formation contain enough limestone to be significantly affected by acidic groundwater percolating through the rocks.

"Karst" refers to a characteristic terrain produced by the chemical erosion of limestone or dolomite (carbonate rocks). Karst features include caves and caverns, sinkholes, solution holes, pinnacles, and karst formations (speleothems). Because of the increased permeability and porosity associated with karst, these features have a significant impact on the hydrogeologic system of an area. In extreme cases, streams and rivers disappear underground into subterranean passages. Springs appear where the percolating water intersects a less permeable unit and flows along the boundary to Earth's surface.

There are no known caves located within park boundaries. However, nearby Laurel Caverns is the largest known concentration of caverns in Pennsylvania. These caves are 80 km (50 mi) south of Pittsburgh, east of Uniontown, on the Chestnut Ridge. Laurel Caverns are not typical limestone caves. They formed in sandstone where the carbonate cements holding the quartz grains together were dissolved along fractures in the folded strata. The resistant quartz grains washed away, forming voids (Patrick 2004). The proximity of this feature to Fort Necessity National Battlefield indicates that karst features may be affecting the environment at the park.

Inventory, Monitoring, and Research Suggestions for Caves and Karst

- Use detailed geologic mapping to determine rock units within the park containing significant layers of limestone and/or carbonate-cemented sandstone. Determine if dissolution is karstic.
- Study springs in the park area to determine if they are fed or connected by solutional voids.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Fort Necessity National Battlefield.

Chestnut Ridge

The terrain surrounding Fort Necessity National Battlefield illustrates the control of local topography by underlying rock type and structure (Sevon 1997). Looking west from the reconstructed Fort Necessity, one sees Chestnut Ridge, which rises to more than 1,067 m (3,500 ft). It is a major regional feature of the Allegheny Mountains and the westernmost high-relief fold in the Allegheny Mountains (Shumaker 1997). This long, narrow anticline trends northeast-southwest.

The Jumonville Glen area of the park is on the eastern limb of the anticline (fig. 4). The western limb forms part of a 185-km (115-mi) boundary (the Intra-Plateau Front) between the Allegheny Mountains and Pittsburgh Plateau physiographic subprovinces of the Appalachian Plateaus province. The shorter structural culmination of the Chestnut Ridge anticline is known as the Dulany anticline. To the west of the ridge is the Uniontown syncline, and on the east is the Ligonier syncline (Shumaker 2002). Fort Necessity is in a valley underlain by part of the Ligonier syncline.

The Chestnut Ridge anticline is asymmetrical, the structural relief between the Dulany anticline and the Uniontown syncline is approximately 914 m (3,000 ft); the relief between the anticline and the Ligonier syncline to the east is only 610 m (2,000 ft). This means that the Mississippian and Upper Devonian rocks exposed on the top of the anticline are buried deep below the adjacent synclines. The western limb of the fold dips between 15° and 20° as compared to shallower dips of 10° or less on the narrower eastern limb. The structure beneath the anticline is complex, composed of flexural bends, faulted folds, and imbricated rocks above a much deeper detachment surface that is possibly located in the Silurian Salina salt layer, the Martinsburg Shale, or the Marcellus Shale (Gwinn 1964; Shumaker 1997; Shumaker 2002). More data and interpretation are needed in the area to specify the exact detachment level.

The crest of Chestnut Ridge is also the focus of oil and gas exploration. Since the 1890s, the Oriskany Sandstone reservoir in the Appalachian Basin has produced gas from structural and stratigraphic traps. Prospectors drilled the discovery well on the anticlinal crest of Chestnut Ridge in 1937. North and South Summit fields were producing throughout the 1950s and 1960s. Producing units under the ridge include the Helderberg Formation, Tonoloway Limestone, and Tuscarora Sandstone.

Petroleum originating in these units migrated to the Oriskany Sandstone reservoir. Along Chestnut Ridge, fold closure predominantly traps the petroleum (Shumaker 2002). Today, North and South Summit fields are still in use, though predominantly for gas storage for eastern markets (Shumaker 2002).

Great Meadows

In the midst of the Allegheny Mountains, between Chestnut Ridge and Laurel Hill, the Ligonier syncline underlies a stream valley (Shumaker 2002). On a triangular piece of land between Great Meadows and Indian Runs, a boggy wetland meadow was the site of the opening battle of the French and Indian War. Great Meadows was a rare large, natural clearing in the midst of a dense oak- and hemlock-dominated hardwood forest.

In 1754, George Washington chose this site for a temporary camp because of its abundance of water and grasslands, as well as being an open area in the Pennsylvania wilderness. After the skirmish at Jumonville Glen, Washington rushed to fortify the camp, fearing French reprisal. He and his troops erected a crude palisade-style "Fort of Necessity" (fig. 5). They eventually dug trenches around the fort for added defense (fig. 6) (NPS Web site).

Washington underestimated the distance between his position in the midst of the meadow and the dense hardwood forest. French troops and Indian allies were able to use the protective cover of the forest in the attack of July 3, 1754—the Battle of the Great Meadows (NPS Web site). Washington also misjudged the substrate in the meadow: the position of the fort was in a marshy depression (fig. 7). Heavy rains the day of the battle swamped the fort and flooded the trenches, ruining most of Washington's resources and hastening the only surrender of his career.

The Pennsylvanian Glenshaw Formation underlies the valley. This formation is rich in clay and thin limestone layers. The heavily weathered clay and thin limestone layers are almost impermeable, and lie almost flat below the valley floor. This geologic setting is conducive to wetland development if an ample supply of water is available.

Because it contains a fragile wetland, the condition and biodiversity of the meadow reflects the overall health of the ecosystem. Species include small trees, shrubs, and herbs (meadow rue, goldenrod, ironweed, holly, alder, and sedge). The steady deposition of organic and inorganic material in the meadow also influenced the call in the park's General Management Plan for restoration of the surrounding forest to its 18th century (pre-logging) state. Soil cores contain pollen and other materials that indicate the original 18th-century species as well as the history of land use, how this use varies with topographic expression, and how the biodiversity of the area has changed through time (Kelso et al. 1993).

Connections between Geology and History

The history of the Fort Necessity area extends thousands of years before the first European forts were established, and the geology of the area is a part of this long story. The Youghiogheny watershed is a fork of the larger Ohio River and ultimately the Mississippi River watersheds. The Youghiogheny River and its tributaries cut through the folded geologic units of the Allegheny Mountains to form the hills, ridges, valleys, and ravines that characterize the area.

This erosion also exposed commercially viable coal and limestone resources that sparked extensive mining in the area. Early European settlers recognized the potential of the area's rivers to transport raw materials and manufactured goods. The nearby Monongahela River spurred industries such as boat building, coal mining, smelting of iron, and the manufacturing of steel and glass (Pennsylvania Environmental Council 2006).

The earliest known evidence of human activity in the area is dated at 10,000 years ago from Sheep Rock, near Huntingdon, Pennsylvania. These early settlers were Native Americans of the Allegheny group. The name "Allegheny," so common in Pennsylvania, stems from the mound-building Alligewi, or Allegheny, Indians from the western part of the state (Wells 1973). Native Americans depended on this area for food, shelter, access to quarries for making stone tools, and as a route to the south and west.

Nearby 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). A systematic archaeological survey of early Native American sites remains to be accomplished at Fort Necessity National Battlefield (NPS Web site).

George Washington and his Virginia Militia built roads over the rough terrain that allowed rapid western expansion of the colonies. People used these roads for years and even today some modern roads, such as U.S. Highway 40, traverse some of the same stretches. The roads led to settlement, which in turn led to agriculture, urban development, and mining. These changes are part of the evolution of land use at Fort Necessity. Between 1856 and 1880, the surrounding forest was cleared and converted to pasture land (Kelso et al. 1993). Use of the forest and Great Meadows for pasture and agriculture has changed the historic landscape, including the limits of the forest, the topography, soil composition, species distribution, and drainage patterns.

Mississippian Burgoon Sandstone outcrops provided cover during the skirmish at Jumonville Glen, when colonial troops and Native American allies ambushed a French encampment at the base of the Burgoon Sandstone cliffs. The outcrop of sandstone is a very scenic and much-visited area. In local exposures, the Burgoon Sandstone is a buff-colored, medium-grained, crossbedded sandstone and some local shale and coal interbeds. It is resistant to erosion, forming cliffs and spalling off steep slopes in large blocks.

One of the major goals of the park is to preserve the historical context of the area, including recreating the palisades-style stockade, preserving monuments, and restoring the landscape to 18th-century conditions (fig. 8). Maintaining this landscape often means resisting natural geologic changes. A study of the evolution of historic land-use patterns at the park would help prioritize interpretive and restorative efforts at Fort Necessity National Battlefield.

Geologic slope processes, such as landsliding, slumping, chemical weathering, block sliding, and slope creep are constantly changing the landscape at the park. Runoff erodes sediments from any open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas, distorting the historical context of the landscape. Extensive coal mining and other land use, including logging and farming, have changed the regional topographic expression. Issues can potentially arise from opposing values in cultural and natural resource management. For example, a proposal for restoration of a historic trench or encampment may consist of removing surrounding natural resources, installing stabilization structures, or planting exotics.

Ancient Lake Monongahela and Paleodrainage

The modern Youghiogheny River, as well as most of western Pennsylvania's creeks and rivers, joins with the Monongahela and Allegheny Rivers and flows southwesterly into the Ohio River and before flowing toward the Gulf of Mexico. The Youghiogheny follows a channel pattern that predates regional folding and flows at right angles to it (Sevon 1993). However, prior to the Pleistocene Epoch ice-age events, approximately 0.8–1 million years ago, the Monongahela River, west of Chestnut Ridge, was the dominant drainage in western Pennsylvania and drained northwestward toward Canada. The Monongahela and Youghiogheny Rivers flowed north, coincident with their present courses towards the Pittsburgh area.

The rivers merged and then followed the channel of the modern Ohio River to the present site of Beaver, Pennsylvania. From there, the river flowed north, up the modern Beaver River Valley towards an ancestral Erie basin. This interpretation stems from studies of regional topography, river terraces, and erosional depth to bedrock in major river valleys (Harper 1997; Marine and Donahue 2000).

This all changed when glacial ice masses flowing south from Canada blocked the northwest-flowing streams and rivers, causing lakes to pool along the leading glacial edge. These lakes eventually overflowed drainage divides, reversing the ancient drainages of the

Youghiogheny, Monongahela, and Allegheny Rivers to southerly courses (fig. 9). The rivers continue to cut through thick piles of silt, sand, gravel, and other sediments (Harper 1997).

The ice masses and/or significant glacial outwash deposits dammed the northerly course of the rivers during several Pleistocene glacial periods. This damming developed a lacustrine (lake) environment herein referred to as Ancient Lake Monongahela (fig. 10).

This lake caused the deposition of lacustrine sediments throughout the area's river drainages, referred to as the Carmichael Formation. This formation consists of deposits of clay, silt, and sand matrix with larger sandstone clasts derived from local bedrock—possibly the Lower Pennsylvanian Allegheny Group (Kirchner and Donahue 2001).

Because there were four major glacial advances during the Pleistocene, ice lobes dammed western Pennsylvania rivers several times. Because the outflow of the first flood cut new drainage patterns, the outlets were lowered and subsequent floods occurred at progressively lower elevations, depositing high-level lacustrine and river terraces high in the valleys of the Monongahela, Youghiogheny, Allegheny, and Ohio Rivers. The highest of these is located at approximately 335 m (1,100 ft) in elevation.

At least five terrace levels exist near Morgantown, West Virginia, recording at least five flood events of Ancient Lake Monongahela (Marine and Donahue 2000). More research is necessary to determine an accurate interpretation of the formation, age, and depositional history of Ancient Lake Monongahela and to identify the bedrock source of lacustrine sediments near Fort Necessity National Battlefield.

Figure 4. Outcrops at Jumonville Glen. Photograph provided by Vincent Santucci (NPS-GWMP)

Figure 5. Photograph of Fort Necessity and surrounding Great Meadows. Photograph is by Galen R. Frysinger (used with permission).

Figure 6. Photograph of Fort Necessity palisade stockade and surrounding trenches and earthworks located as they were in the 18th century. Photograph is by Galen R. Frysinger (used with permission).

Figure 7. Photograph of Fort Necessity from a French attacker's vantage point in the heavy surrounding forest. Note the topographically low position of the fort amidst the swampy Great Meadows. Photograph is by Galen R. Frysinger (used with permission).

Figure 8. Historic photograph of the original Fort Necessity foundations following an archaeological excavation. Photograph is courtesy of www.fortnecessity.org (accessed August 1, 2006).

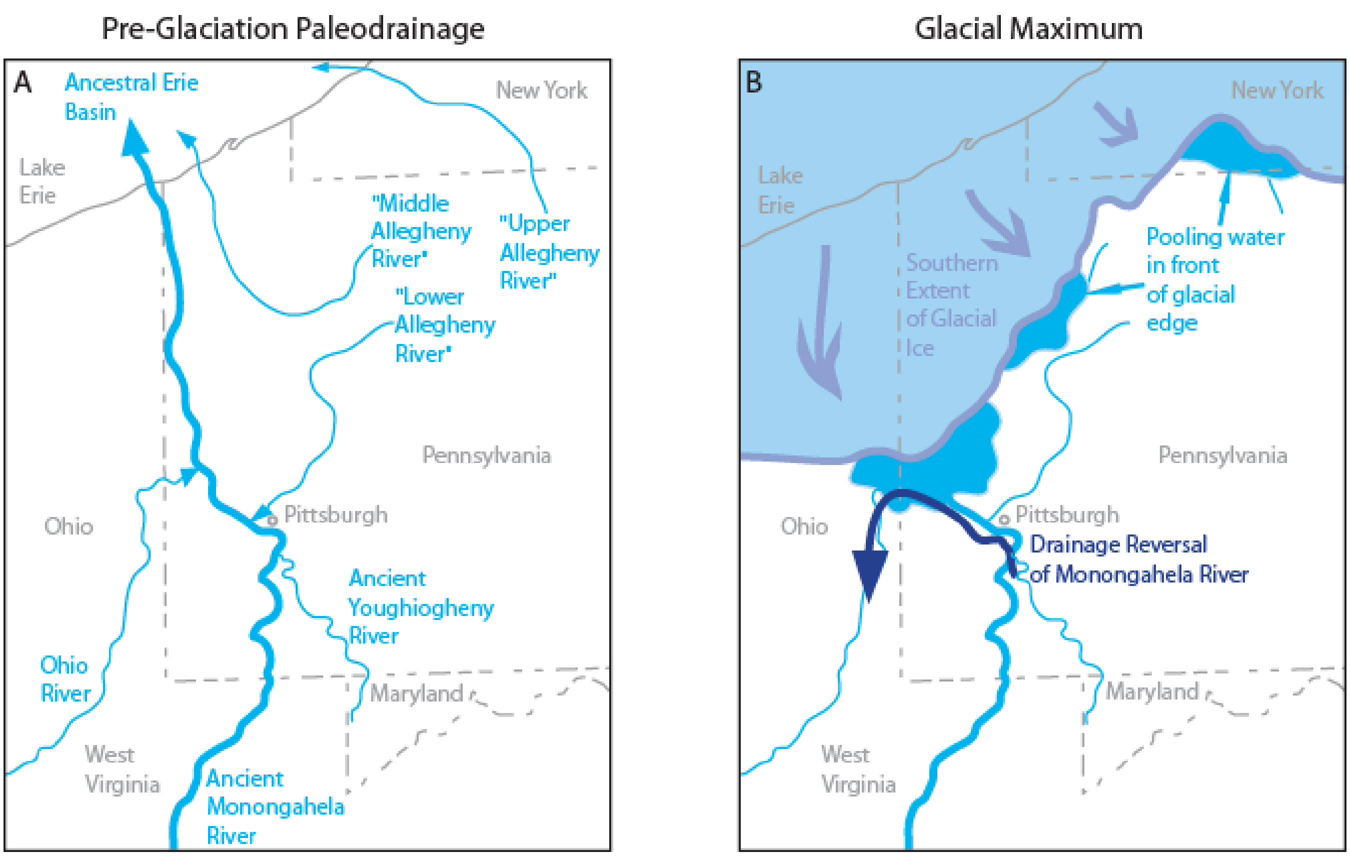


Figure 9. Maps showing effects of glaciation on flow direction of Youghiogheny and Monongahela rivers. (*A)* Rough paleodrainage of ancient Youghiogheny and Monongahela Rivers towards an ancestral Erie basin. (*B)* Southern glacial maximum extent. Ice dammed the rivers, forming lakes that eventually flooded basins and directed river flow towards the south—the modern Ohio River drainage. Maps are not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from Harper (1997).

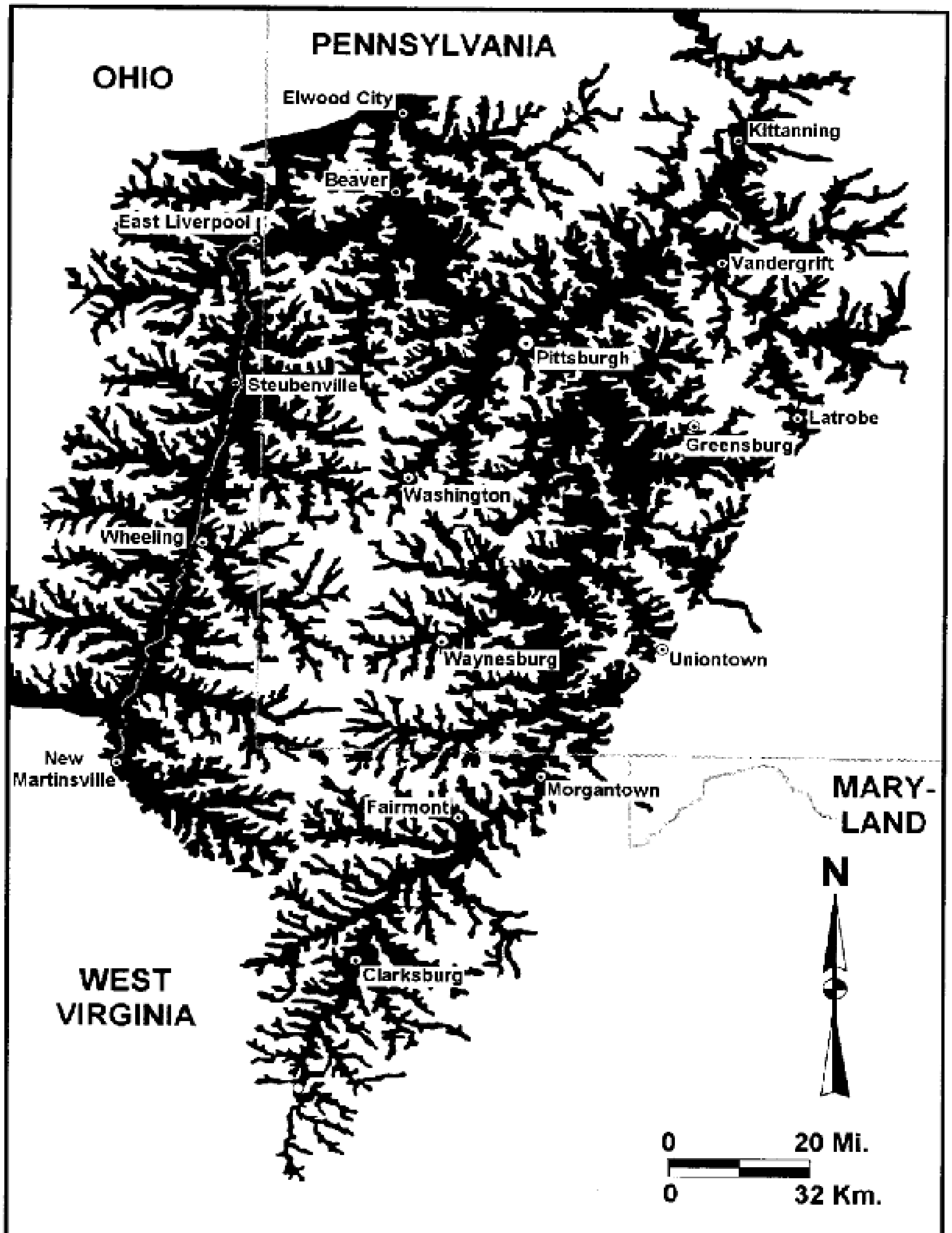


Figure 10. Reconstruction of Ancient Lake Monongahela based on a 335-m (1,100-ft) maximum lake elevation during a Pleistocene glacial maximum. Graphic is from Marine and Donahue (2000, fig. 23).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Fort Necessity National Battlefield. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Fort Necessity National Battlefield is near the boundary between the Pittsburgh Low Plateau and Allegheny Mountains sections of the Appalachian Plateaus physiographic province. The oldest rocks in the greater park area are the grayish-red sandstone, siltstone, shale, and mudstone of the Devonian Catskill and Foreknobs formations. Both units contain siltstone, sandstone, and shale, and they locally contain conglomerate. Folding and subsequent erosion exposed these units, which form a resistant ridge cap on Chestnut Ridge to the west of the park and Laurel Hill to the east (Berg et al. 1980; McElroy 1988).

Late Devonian–Early Mississippian rocks in the vicinity of Fort Necessity include the Shenango and Oswayo formations. These units consist of greenish-gray, olive, and buff sandstone and siltstone interbedded with minor gray shale. Atop the Oswayo Formation are the Burgoon Sandstone and the Mauch Chunk Formation. These are both of Mississippian age. The Burgoon Sandstone is buff-colored, medium-grained, crossbedded sandstone containing some local shale and coal interbeds, whereas the Mauch Chunk Formation consists of grayish-red shale, siltstone, and some sandy limestone (Berg et al. 1980; McElroy 1988).

The cyclic sequences of sandstone, conglomerate, shale, claystone, limestone, and mineable coal formed from marshy peat swamps and wetlands of the Pennsylvanian Pottsville and Allegheny Groups are buried beneath the Glenshaw and Casselman formations (Conemaugh Group), and the Monongahela Group (Berg et al. 1980; Whitfield et al. 2001; Milici 2005). The Glenshaw Formation is the predominant unit exposed in the main area of Fort Necessity and at Braddock Grave.

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, consisting of shale, siltstone, sandstone, redbeds and scant coal and limestone layers. The Monongahela Group derives its name from the Monongahela River, west of Chestnut Ridge. This unit contains cyclic sequences of limestone, shale, sandstone, and commercially valuable coals.

The sandstone, shale, limestone, and coal of the Waynesburg Formation record the transition between the Pennsylvanian and Permian Periods. Atop the Waynesburg Formation are the Permian Washington and Greene formations. They are composed of sequences of sandstone, shale, redbeds, and some impure limestone and coals separated by the upper Washington Limestone (Berg et al. 1980).

Most Mesozoic and all but the most recent Cenozoic rock units are missing from the landscape surrounding Fort Necessity National Battlefield. There are Jurassic mica-peridotite (kimberlite) igneous rocks of the Gates-Adah dike representing a local intrusive event (McElroy 1988).

Pleistocene lacustrine deposits of silt, clay, and sand as intergranular matrix for larger quartzarenite sandstone clasts from Ancient Lake Monongahela (the Carmichaels Formation) are present in abandoned channels and on rock terraces on high-level surfaces in the east half of Fayette County (Kirchner and Donahue 2001).

Recent, unconsolidated Quaternary alluvial deposits line local river and stream valleys, covering much of the valley floor on which Fort Necessity was built. These are also present on floodplains, and in some places they form low terraces above the larger river valleys. These consist of unconsolidated clay, silt, sand, gravel, and a few boulder deposits derived from the local bedrock units described above (McElroy 1998).

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

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships to other natural resources and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

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

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 11) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following references are source data for the GRI digital geologic map for Fort Necessity National Battlefield:

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

Stone, J. D., D. R. Williams, T. F. Buckwalter, J. K. Felbinger, and K. L. Pattison. 1987. *Water resources and the effects of coal mining, Greene County, Pennsylvania*. Scale 1:50,000. Water Resource Report W 63. Harrisburg, PA: Pennsylvania Geological Survey.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, increasing the overall quality and utility of the data. GRI digital geologic map products include data in ESRI personal geodatabase, shapefile, and coverage GIS formats, layer files with feature symbology, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map. GRI digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/).

Map Unit Properties Table

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Specimens	Karst Issues	Mineral Resources	Habitat	Recreation	Global Significance
QUATERNARY	Alluvium (Qal); Carmichaels Formation (Qcm.	Unconsolidated gravel, sand, silt, and clay in floodplain deposits and along streams and low terraces, some cobbles present. Unit Qcm contains lacustrine deposits of unconsolidated clay, silt, sand, gravel, cobbles, and boulders of sandstone (silica- cemented quartzarenite), some small limonite nodules. Deposits in abandoned channels and on rock terraces in the eastern half of Fayette County.	Low	Wells in these units report sufficient water for domestic needs (high Fe and Mn, low pH); acid mine drainage may be a concern for development of wells. Avoid for waste facility development due to high permeability.	Unit is highly susceptible to slides, rockfall, slumping, and mass movement if exposed on bare and/or undercut slopes.	Perched terraces record paleolake levels and may contain remains from Pleistocene Ice Ages.	May contain Native American artifacts and campsites.	None documented.	None	Gravel, sand, silt, clay, cobbles, some sandstone boulders.	Habitat for cliff-dwelling birds and burrowing animals on terraces, riparian habitat along rivers.	Good for most use unless undercut along a slope or adjacent to a waterway; avoid bare slopes.	Unit Qcm represents the paleolake levels of Ancient Lake Monongahela and records the glacial setting during the Pleistocene; boulders in unit Qcm are from Pottsville Group.
JURASSIC	Gates- Adah dike (Jk.)	Present on surface in Fayette County as the only igneous rock found there, swarm of three or more mica- peridotite dikes.	High	Present only locally.	Rockfall potential if unit is exposed on slope.	None	May have been source of stone prized for Native American trade.	Sold as kimberlite; may contain olivine, pyroxene, amphibole, and mica.	None	Kimberlite	None	Present only locally; good for most uses.	Unit is the only Jurassic (Mesozoic) rock in the area.
PERMIAN	Greene Formation (Pg); Washington Formation (Pw)	Unit Pg consists of shale, sandstone, siltstone, thin limestone beds, claystone, carbonaceous shale, and impure coal interbeds (Ten Mile coal is less than 24 in. thick). Most units are micaceous with variable thickness and crossbeds. Unit Pw contains an upper olive to dark- gray limestone member; a middle shale, siltstone, and micaceous, olive- gray sandstone member; and a lower argillaceous limestone member that is 0.5–2 ft thick and contains shale interbeds. Jollytown coal beds are less than 24 in. thick, and the Washington coal is impure and shaly and is close to 48 in. thick	Low to medium in shale- rich beds, medium to high in massive sandstone- limestone beds.	Unit is suitable for most development unless exposed on undercut or unvegetated slope; poor aquifer with hard to very hard water (high barium, Fe, and Mn, moderate pH).	Slides and slumps are a hazard for claystone and shale- rich members; heterogeneous layering may prove unstable on slopes; rockfall hazard exists when resistant beds are undercut.	Freshwater ostracodes, *Spirorbis*, and fish remains.	Nodules may have provided tool material.	Siderite (ironstone) and limestone nodules.	Not enough massive carbonate units present for karst.	Ten Mile coal is impure and lenticular; Jollytown coal and Washington coals are impure.	Units support forests in middle to upper parts of stream basins.	Good for most uses unless highly fractured and exposed on bare slopes.	Represent Permian Period with dateable coal horizons and fresh- water fossils.
PERMIAN - PENNSYLVANIAN	Waynesburg Formation (PPNw).	Unit is between 85 and 210 ft thick. Upper member is predominantly gray to black shale containing some calcareous layers and gray sandstone interbeds, and a basal layer of impure Little Washington coal. Middle member consists of medium- gray shale, sandstone, and light- gray siltstone with the shaly, impure Waynesburg B and A coals as much as 84 in. thick locally. Lower member comprises shale, light- gray, massive, crossbedded sandstone, and siltstone. The viable Waynesburg coal is at the base of the formation and is as much as 84 in. thick.	Medium	Suitable for most development except near unremediated mined areas. Several wells record elevated Fe, Mn, chloride, and hydrogen sulfide (10% of wells showed high Ca, Mg, Pb, Al); where mines are present, low pH and high dissolved solids.	Mined areas pose safety hazards and acid- mine- drainage problems. Slides and slumps are a hazard for shale- rich members; heterogeneous layering may prove unstable on slopes; rockfall hazard exists when resistant beds are undercut.	Previously believed to be wholly Permian, but Pennsylvanian fossils were recently found in this unit.	Nodules may have provided tool material.	Siderite nodules.	Not enough massive carbonate units present for karst.	Thin and impure Little Washington coal, thin and locally impure Waynesburg B and A coals; viable Waynesburg coal mined in eastern map areas.	Units support forests and riparian habitat in lower parts of stream basins.	Good for most uses unless near mine- altered areas, or highly fractured and exposed on bare slopes.	Records depositional environments during Pennsylvanian to Permian transition.
PENNSYLVANIAN	Monongahela Group (PNm).	Unit PNm consists of black to light- gray, massive limestone and some argillaceous limestone containing thin- bedded to massive, gray sandstone, carbonaceous shale, and coal interbeds. Unit is dominated by repetitive sequences (cyclothems) of shale, mudstone, claystone, sandstone, coal, and limestone. Continental (fresh- water) cyclothems are present in this unit. Group contains the Uniontown and Pittsburgh formations, which have well- documented coal horizons.	Medium to high, lower in shale- rich beds.	Suitable for most development except near areas of extensive mining, where subsidence is possible. Ground- water is hard to very hard with dissolved solids, Fe, Mn, Ca, Mn; chloride commonly high.	Rockfall hazard exists when resistant beds (such as massive limestone and sandstone) are undercut by erosion of shale and friable claystone.	Pennsylvanian fossils.	Artifacts relevant to the land- use history at the Gallatin House .	None documented.	Some dissolution possible in massive limestone units.	Thin and impure Little Waynesburg coal, Uniontown bony coal beds; massive limestone may provide building material.	Unit supports forests on bluffs and low- level terraces.	Good for most uses unless highly fractured and exposed on bare slopes.	Records depositional environments in the long- standing Appalachian Basin. Source areas include the equatorial Allegheny Mountains in an arid climate.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Specimens	Karst Issues	Mineral Resources	Habitat	Recreation	Global Significance
PENNSYLVANIAN	Casselman Formation (PNcc); Glenshaw Formation (PNcg); Allegheny Group (PNa); Pottsville Group (PNp).	Upper formations contain sequence of thin-bedded, green and red calcareous claystone; gray siltstone; massive, gray sandstone; and impure limestone. Scant coal beds are present locally. Four prominent clay, shale, or limestone marine horizons in Glenshaw (including Ames Limestone) with some coarse- grained sandstone and minor fresh- water limestone. Lower formations include sequences of olive to dark-gray claystone, thin to massive sandstone, nodules of limestone, gray siltstone, and coal beds. Unit is dominated by repetitive sequences (cyclothems) of shale, mudstone, claystone, sandstone, coal, and limestone. Fresh- water cyclothems are present in unit PNa. Lowermost unit is gray, crossbedded sandstone and quartz-pebble conglomerate containing some thin beds of carbonaceous black shale, siltstone, claystone, and thin, nonpersistent coal.	Low to medium in upper beds, medium in lower beds.	Units yield very hard water with excessive iron, manganese, and sulfate. Heterogeneity of layers may lead to instability on slopes.	Ledge- forming sandstone may be undercut in softer shale units, posing rockfall hazard.	Marine fossils, plant fossils. Unit PNcg contains vertical burrows, biogenic mounds, crinoids, trilobites, foraminifera, fusulinids, bryozoans, brachiopods, fish fragments. Unit PNcc contains bivalves, myriapods.	Native American sites, and artifacts relevant to the land- use history at the Gallatin House .	Nodular limestone, siderite.	Some dissolution in limestone interbeds.	Coal (Freeport, Kittanning, and Brookville-Clarion), high-alumina clay deposits.	Dissolution features may provide burrow and nesting habitat.	Good for most recreation unless soft shale units are exposed along slopes.	Cyclothems in units represent arid conditions with a river floodplain and wetlands of a foreland basin at equatorial latitudes. Classic coal deposits.
MISSISSIPPIAN	Mauch Chunk Formation (Mmc); Burgoon Sandstone (Mb).	Upper beds consist of grayish- red shale, siltstone, sandstone and several limestone members (Wymps Gap, Deer Valley, and highly crossbedded, gray, siliceous Loyalhanna), containing some conglomerate. Middle beds consist of buff, medium- grained sandstone interbedded with some coal and shale, some conglomerate at base. Lower beds consist of light- gray to olive and buff, medium- grained sandstone containing minor siltstone and several gray shale layers.	Medium, medium to high in lower unit.	Iron- rich ground water from these units. Suitable for most development unless highly fractured or on shale- rich slopes.	Rockfall is possible if units are undercut on a slope; slumping possible in shale- rich units.	Plant fossils. Unit Mmc contains fish fragments, worm burrows, corals, conularids, bryozoans, brachiopods, gastropods, pelecypods, echinoids, cephalopods, crinoids, trilobites, foraminifera, conodonts, ostracodes.	None documented.	None documented.	Some dissolution in limestone members.	Coal beds	None documented.	Good for most recreation unless soft shale units are exposed along slopes.	Mississippian coal deposits.
MISSISSIPPIAN –DEVONIAN	Shenango Formation through Oswayo Formation, undivided (MDso).	Upper units consist of greenish- gray, olive, and buff sandstone and siltstone containing some gray shale interbeds.	Medium	Suitable for most developments unless highly fractured.	Carbonate cements may weather to friable sandstone and have potential for rockfall.	Marine fossils	None documented.	Diamictite	Not enough carbonate present.	Sandstone for building materials.	Dissolution features may provide burrow and nesting habitat.	Good for most uses unless highly fractured and undercut.	Records Devonian–Mississippian transition in Pennsylvania.
DEVONIAN	Catskill Formation (Dck); Foreknobs Formation (Df).	Upper unit consists of fining- upward cycles of grayish- red sandstone, siltstone, shale, and mudstone; contains a few conglomerate lenses locally. Next lowest unit consists of interbedded gray to olive (grading to red at top) sandstone, siltstone, and shale bounded by basal and upper conglomerate beds.	Medium to high, highest in conglomerate beds.	Heterogeneous nature of the layered units may prove unstable for development. Tioga bentonite member has shrink- and- swell potential.	Fractured sandstone and siltstone pose rockfall potential when undercut due to weathering of weaker shale units. Shrink- and- swell clay may cause buckling and warping of roads and trails.	Some marine fossils. Unit Df contains pelecypods. Unit Dc contains plants, spores, fish, and vertebrates.	Chert in lower units may have provided tool material for Native Americans.	Siderite concretions.	Not enough carbonate present in upper beds, some dissolution possible in unit Doo.	Tioga Ash beds (clays) for industrial material fabrication.	Weaker units may provide burrowing habitat; supports climax forests.	Avoid clay units due to slippery conditions for trails and other visitor areas.	Widespread Devonian units for correlation throughout the Appalachians; Tioga Ash marker bed records major Middle Devonian volcanic activity.

Geologic History

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

Fort Necessity National Battlefield is near the eastern edge of the Appalachian Plateaus physiographic province. To the east, on the other side of the sharp Allegheny Front, is the Valley and Ridge province. The landscape of the Fort Necessity area contains features that developed over the long geologic history of the Appalachian Mountains and the evolution of the eastern coast of the North American continent. A regional perspective is presented here to connect the landscape and geology of the park to its surroundings.

The recorded history (reflected in exposed rocks) of the Appalachian Mountains begins in the Proterozoic (fig. 11). In the mid-Proterozoic, during the Grenville orogeny, a supercontinent formed that consisted of most of the continental crust in existence at that time. This included the crust of North America and Africa. Sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism are all apparent in the metamorphic granite and gneiss in the core of the modern Blue Ridge Mountains to the southeast of Fort Necessity (Harris et al. 1997). These rocks formed over a period of 100 million years and are more than 1 billion years old, making them among the oldest rocks known in this region. They were later uplifted and thus exposed to erosion for hundreds of millions of years. Their leveled surface forms a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001).

The late Proterozoic, roughly 800–600 million years ago, brought extensional rifting to the area. The crustal extension created fissures through which massive volumes of basaltic magma were extruded (fig. 12*A*). The volcanism lasted tens of millions of years and alternated between flows of flood basalt and ash falls. The volcanic rocks covered the granitic/gneissic basement in the south-central Pennsylvania area.

The tectonic tension caused the supercontinent to break up, and a sea basin formed that eventually became the Iapetus Ocean. This basin subsided and collected many of the sediments that would eventually form the rock units of the Appalachian Mountains (fig. 12*B*). Some of the sediments were deposited as alluvial fans, large submarine landslides, and turbidity flows (Southworth et al. 2001). Other, later deposits of sand, silt, and mud covered these previous sediments in near-shore, deltaic, barrier-island, and tidal-flat areas along the eastern margin of the continent (Schwab 1970; Kauffman and Frey 1979; Simpson 1991).

A grand carbonate platform, thickening to the east, was the depositional setting for huge masses of carbonate rocks, sandstone, and shale that persisted during the Cambrian throughout the Ordovician Period (545–480 million years ago) (Means 1995). Ordovician units exposed east of Fort Necessity record the transition from carbonate platform to near-shore terrestrial deposition associated with burgeoning 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. The Taconic orogeny (≈440–420 million years ago in the central Appalachians) was a volcanic arc–continent convergence. Oceanic crust and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of the North American continent. The Taconic orogeny resulted in the closing of the ocean, subduction of oceanic crust, formation of volcanic arcs, and uplift of continental crust (Means 1995). Initial metamorphism of the deeply buried igneous and near-shore sediments into metabasalt, quartzite, and phyllite occurred during this orogenic event.

The crust bowed downwards west of the rising mountains in response to the overriding plate thrusting westward onto the continental margin of North America, to create a deep foreland basin that filled with mud and sand eroded from the highlands to the east (fig. 12*C*) (Harris et al. 1997). This so-called Appalachian basin was centered on what is now West Virginia (described below).

The oceanic sediments of the shrinking Iapetus Ocean were thrust westward during the Late Ordovician onto other deepwater sediments of the western Piedmont. Sand, mud, silt, and carbonate sediment and other Silurian sediments were then deposited in the shallow marine to deltaic environment of the Appalachian basin. The rocks that formed—sandstone, shale, siltstone, and limestone, all now metamorphosed—currently underlie the Valley and Ridge physiographic province, east of Fort Necessity (Fisher 1976).

Appalachian Basin

Most of the geologic units of the Appalachian Plateaus physiographic province were deposited in the long-standing Appalachian basin. The Appalachian foreland basin formed in response to tectonic downwarping (thrust loading) initially during the Taconic orogeny and later deepened in response to continued sediment loading (Milici 2005). Eustatic crustal adjustments balanced this downwarping. The depositional setting of the basin was predominantly shallow marine to fluvial-deltaic. It continued intermittently for approximately 200 million years during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian periods. This resulted in very thick piles of sediments deposited on basal Cambrian units. The major source of these sediments was the highlands that were rising to the east during the Taconic (Ordovician), Acadian (Devonian), and Alleghanian (Permian) orogenies.

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

The sediments deposited in the Appalachian basin record important geographic location (the movement of continents through paleolatitudes) and climate conditions present during sedimentation. Paleolatitude and climate played a major role in the deposition of coal and petroleum resources in the Appalachian basin. The central Appalachian basin region drifted northward from about lat 40°S in the latest Precambrian and Early Cambrian to lat 30°S ± 5° during the Early Ordovician, where it remained well into the Mississippian. The continent continued to move northward from about lat 30°S in the Early Mississippian to about lat 3° N by the beginning of the Permian (Fedorko et al. 2004).

During the Early Mississippian Period and later the Early Triassic Period, 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—peat swamps to wetlands (Cecil and Englund 1989). The rising mountains to the east also produced significant amounts of sand, silt, and clay, which are interspersed with the organic layers. These units, notably the Conemaugh, Allegheny, and Monongahela Groups, are associated with commercial mining in Pennsylvania.

Interbedded shale, sandstone, limestone, and thin coals dominated the local basin, called the Dunkard Basin in southwestern Pennsylvania. Within this basin, the Mongongahela Group formed from the cycling of fresh-water 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 and Monongahela Group coals 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, redbeds, thin limestone, coal
	Early	cyclic moist, subhumid to semiarid	coal, nonmarine limestone, sandstone
Pennsylvanian	Late	dry subhumid	calcareous redbeds, paleosols, scant coal
	Middle	moist subhumid	siliciclastics, nonmarine limestone, coal
	Early	humid to perhumid	sandstone, limestone, paleosols, coal
Mississippian	Late	semiarid to humid	limestone, eolianites, redbeds
	Early	subhumid to arid	sandstones, redbeds, evaporites
Devonian	Late	semiarid to dry subhumid	black shale, sandstones
	Early	arid	subtidal carbonates, sandstones
Silurian	Late	arid	peritidal carbonates, evaporites
	Early	arid	sandstones
Ordovician	Late	semiarid to dry subhumid	siliciclastics redbeds
	Early	arid	limestone, dolomite, evaporites
Cambrian	Middle	arid	limestone, dolomite, evaporites
	Early	semiarid	siliclastics

Source: Fedorko, Nick, William C. Grady, Cortland F. Eble, Blaine C. Cecil. 2004. U. S. Geological Survey Circular: 84-88. Reston, VA: U. S. Geological Survey.

Acadian Orogeny

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

The Acadian orogeny caused further uplift of Taconic highlands in central Pennsylvania. Erosion of these highlands provided more sediment, leading to the basin-wide (Appalachian Basin) deposition of the Devonian Catskill formation (exposed on Chestnut Ridge and Laurel Hill) in the Fort Necessity area.

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

Alleghanian Orogeny

During the Late Paleozoic and following the Acadian orogeny, the proto-Atlantic Iapetus Ocean closed as the North American continent collided with the African continent. The collision formed a supercontinent (Pangaea) and the Appalachian mountain belt we see today. This mountain-building episode, known as the Alleghanian orogeny (≈325–265 million years ago), is the last major orogeny that affected the Appalachians (fig. 12*D*) (Means 1995). The rocks deformed during as many as seven phases of folding and faulting, producing the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge–South Mountain anticlinorium, and the numerous folds of the Valley and Ridge province in the Allegheny Portage Railroad area (Nickelsen 1983; Southworth et al. 2001). The strata of the Appalachian Basin (now the Appalachian Plateaus province) remained relatively undeformed. Small-scale thrust faults exist throughout the area and parallel low-amplitude regional folds (such as Chestnut Ridge) that formed in response to some compressional stress (Boen 1972).

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

Paleoelevations of the Alleghanian Mountains are estimated at approximately 6,096 m (20,000 ft), analogous to the modern day Himalaya Range in Asia. These mountains have been beveled by erosion to elevations less than 734 m (2,408 ft) above sea level east of Fort Necessity (Means 1995).

Triassic Extension to the Present

Following the Alleghanian orogeny, during the late Triassic (230–200 million years ago), a period of rifting began as the deformed rocks of the joined continents began to break apart. The supercontinent Pangaea was segmented into roughly the same continents that persist today. This episode of rifting initiated the formation of the current Atlantic Ocean and caused many block-fault basins to develop with accompanying volcanism (fig. 12*E*) (Harris et al. 1997; Southworth et al. 2001).

The dominant geologic process during the Mesozoic era in the vicinity of Fort Necessity was erosion. Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroding Allegheny Mountains. These were deposited at the base of the mountains as alluvial fans and spread eastward to become part of the Atlantic Coastal Plain and westward to cover the Appalachian Basin sediments (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The amount of material that was deposited has been inferred from the now-exposed metamorphic rocks in the Blue Ridge province to have been immense. Many of the rocks exposed at the surface must have been at least 20 km (≈10 mi) below the surface prior to regional uplift and erosion.

With the exception of the Gates-Adah igneous dike in Fayette County, Mesozoic geologic units are missing from the Fort Necessity landscape, eroded away over millions of years. The erosion continues to affect the present landscape: the Youghiogheny, Monongahela, Allegheny, and Juniata rivers and their tributaries erode sediments from the lowering mountains and deposit alluvial terraces along the rivers (fig. 12*F*).

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

Glaciers from the Pleistocene Ice Ages never reached as far south as the Fort Necessity area, in western Pennsylvania. The southern terminus was at 365–610 m (1,200–2,000 ft) in elevation in northwestern and northeastern Pennsylvania. In northern Pennsylvania, glaciers beveled upland surfaces to rounded ridges and left sand- and gravel-filled valleys (Davies 2005). However, the colder climates of the Ice Ages played a role in the formation of the landscape at Fort Necessity National Battlefield.

Prior to the Pleistocene Epoch ice-age events, approximately 0.8-1 million years ago, the Youghiogheny and Monongahela Rivers flowed north towards an ancestral basin that was to become Lake Erie. The Monongahela was the dominant drainage in western

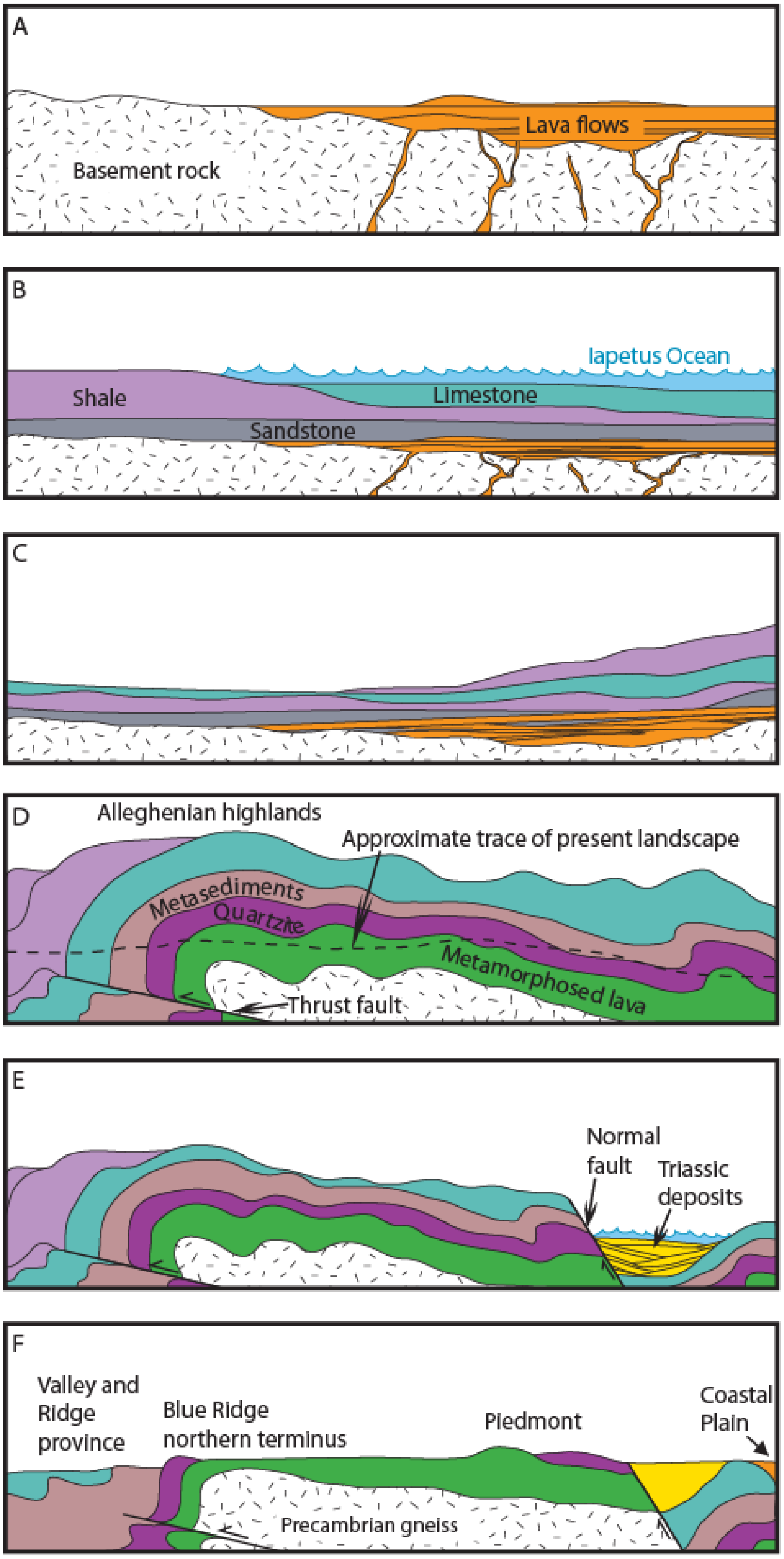
Pennsylvania (Harper 1997; Marine and Donahue 2000). However, advancing glacial fronts dammed the north-flowing rivers in northern Ohio, Pennsylvania, and New York, forming large ponded areas and flooded river valleys. These lakes (including Ancient Lake Monongahela) eventually overflowed drainage divides, reversing the ancient drainages of the Monongahela and Allegheny Rivers to their modern southerly courses (Harper 1997).

The glacial damming occurred several times during the Pleistocene, coincident with the four major glacial advances. The first flood left remnant lacustrine terrace deposits high above the pre-glacial river valleys. Subsequent lake levels were lower, leaving a traceable pattern of different floods along the region's rivers (Marine and Donahue 2000).

Since the Pleistocene, the rivers and tributaries in the Fort Necessity area have continued to cut through thick piles of glacial and alluvial sediments. Human land-disturbing activities—such as agriculture, coal mining, drilling, quarrying, and development—supplement natural erosion throughout the area.

Eon	Era	Period	Epoch	Ma		Life Forms	North American Events
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Holocene	0.01	Age of Mammals	Modern humans	Cascade volcanoes (W)
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada (W)
			Miocene	23.0		Whales and apes	Linking of North and South America
			Oligocene	33.9			Basin-and-Range extension (W)
			Eocene	55.8			
			Paleocene	65.5		Early primates	Laramide Orogeny ends (W)
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	**Mass extinction** Placental mammals Early flowering plants	Laramide Orogeny (W) Sevier Orogeny (W) Nevadan Orogeny (W)
		Jurassic		199.6		First mammals	Elko Orogeny (W)
		Triassic		251		**Mass extinction** Flying reptiles First dinosaurs	Breakup of Pangaea begins Sonoma Orogeny (W)
	Paleozoic	Permian		299	Age of Amphibians	**Mass extinction** Coal-forming forests diminish	Supercontinent Pangaea intact Ouachita Orogeny (S) Alleghanian (Appalachian) Orogeny (E)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant	Ancestral Rocky Mountains (W)
		Mississippian		359.2		Variety of insects First amphibians First reptiles	Antler Orogeny (W)
		Devonian		416	Fishes	**Mass extinction** First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	**Mass extinction** First primitive fish Trilobite maximum Rise of corals	Taconic Orogeny (E-NE)
		Cambrian		542		Early shelled organisms	Avalonian Orogeny (NE) Extensive oceans cover most of North America
Proterozoic ("Early life")		Precambrian		2500		First multicelled organisms Jellyfish fossil (670 Ma)	Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean ("Ancient")				≈4000		Early bacteria and algae	Oldest known Earth rocks (≈3.96 billion years ago)
Hadean ("Beneath the Earth")				4600		Origin of life?	Oldest moon rocks (4–4.6 billion years ago) Earth's crust being formed
						Formation of the Earth	

Figure 11. Geologic Timescale. Included are major events in life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Absolute ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, http://pubs.usgs.gov/fs/2007/3015/.



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

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

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

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

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

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

Figure 12. Evolution of the landscape in the area of Fort Necessity National Battlefield from the Precambrian through the present. Graphic adapted from Means (1995). Ma, millions of years (mega-annum). Drawings not to scale.

Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

bedding. Depositional layering or stratification of sediments.

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

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

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

calcareous. A rock or sediment containing calcium carbonate.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

dike. A tabular, discordant igneous intrusion.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

lithification. The conversion of sediment into solid rock.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–4 mi) thick and generally of basaltic composition.

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

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

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

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

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

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

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

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

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

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

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

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

pluton. A body of intrusive igneous rock.

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

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

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

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

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

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

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

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

recharge. Infiltration processes that replenish ground water.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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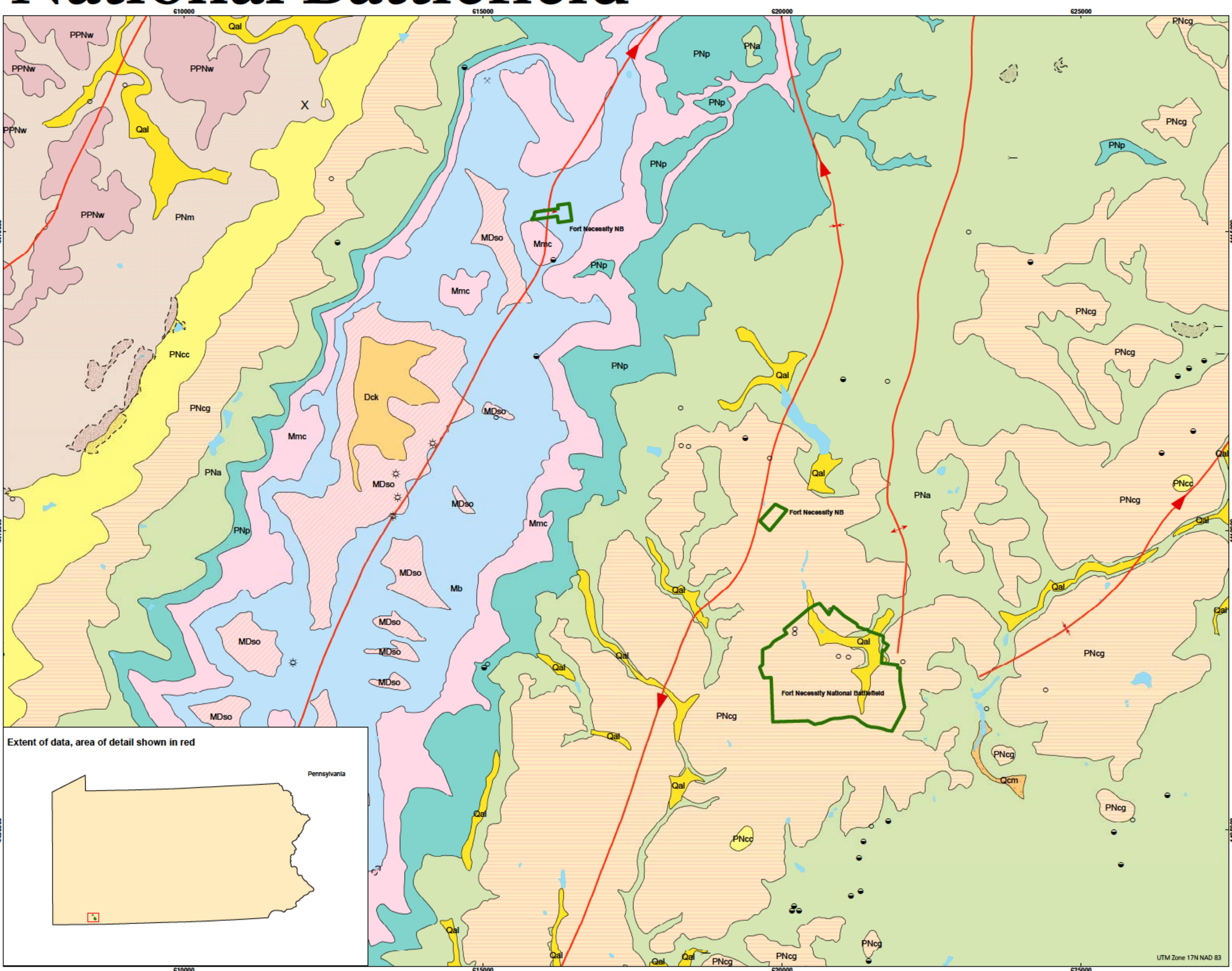
Appendix A: Geologic Map Graphic

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

Geologic Map of Fort Necessity National Battlefield



NPS Boundary

Mine Point Features
- well
- groundwater testing well
- gas well
- oil well
- gravel pit
- quarry
- adit
- mine
- mine dump
- tipple; mine related structure

Mine Area Feature Boundaries
- Mine Area Feature Boundaries

Mine Area Features
- area mine
- mine dump
- tailings pond

Fault and Fold Map Symbology
- anticline symbol
- fold plunge arrowhead
- left-lateral fault symbol
- syncline symbol

Folds
- known or certain

Linear Dikes
- Jk: Gates-Adah Dike, Queried

Geologic Contacts
- known or certain
- approximate
- concealed
- concealed and queried
- quadrangle/map boundary
- shoreline
- subaqueous

Surficial Geologic Units
- Qal - Alluvium
- Qcm - Carmichaels Formation
- Water

Geologic Units
- Pg - Greene Formation
- Pw - Washington Formation
- PPNw - Waynesburg Formation
- PNm - Monongahela Group
- PNu - Uniontown Formation
- PNpb - Pittsburgh Formation
- PNcc - Casselman Formation
- PNcg - Glenshaw Formation
- PNa - Allegheny Group
- PNp - Pottsville Group
- Mmc - Mauch Chunk Formation
- Mb - Burgoon Sandstone
- MDso - Shenango Oswayo Rm. Undivided
- Dck - Catskill Formation
- Df - Foreknobs Formation

0 2 4 Kilometers

0 1 2 Miles

Display scale is greater than the scale map.

N

This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. The source maps used in creation of the digital geologic data product were:

McElroy, T.A., 1988. Groundwater Resources of Fayette County, Pennsylvania. Scale 1:50,000. Water Resource Report W 60. Pennsylvania Geological Survey

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Digital geologic data and cross sections for Fort Necessity National Battlefield and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

Produced by the Geologic Resources Inventory

April 2009

Appendix B: Scoping Summary

The following excerpts are from the GRI scoping summary for Fort Necessity National Battlefield. The contact information and Web addresses in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Summary

A geologic resources inventory workshop was held for Fort Necessity National Battlefield (FONE) on June 22, 2004, to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), NPS ALPO and JOFL units, as well as local geologic experts, were present for the workshop.

Geologic Mapping

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 FONE and nearby Friendship Hill National Historic Site (FRHI) the GRI will use PA GA w-60 (groundwater resources of Fayette County) at 1:50,000 scale. This will likely need to be digitized from paper. The PA Geological Survey has 1:250,000 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 based upon 1:24,000 scale (Coal resources of Fayette county, PA, Part 1).

Other Topics of Discussion

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

(Note: No NPS representatives from FONE were present at this meeting: thus the discussion was based on consensus of the group present):

- Aeolian: Not applicable.
- Fluvial (surface water) Processes: FONE has some small streams and wetlands.
- Ground water: Not applicable; but can reference the PA GS water reports as well.
- Hazards: Washington Tavern may have radon from organic-rich shales that might have closed this building.
- Paleontology: See Vince Santucci's report on ERMN paleontology.
- Mineral Extraction: Jumonville 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 PA. No caves known on NPS land though.
- Glacial: Glacio-lacustrine Lake Monangahela backed up a minimum of three times in Pleistocene; Carmichaels Formation is lacustrine.
- Coastal/Marine: Not applicable.
- Geologic interpretation: Chestnut Ridge serves as good place to interpret the local geologic story; see glacial story.

  FONE is sited in a flat valley fill between uplifted, folded rocks, so that is part of why the fort was put there.
  Also see http://www.watershedatlas.org site map.
- Unique geologic features: Chestnut Ridge, Great Meadows.
- Geothermal: Not applicable.
- Disturbed lands—nearby mines and subsidence: None known on park lands

Meeting Attendees and Contact Information

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Fort Necessity National Battlefield

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/082

National Park Service

Acting Director • Dan Wenk

Natural Resource Stewardship and Science

Associate Director • Bert Frost

Natural Resource Program Center

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

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NPS D-71, June 2009

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