National Park Service
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Natural Resource Program Center

Hopewell Furnace National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2010/214

THIS PAGE:
In the late 18th and 19th centuries, iron furnaces like Hopewell Furnace laid the foundation for the transformation of a fledgling nation into an industrial powerhouse.

ON THE COVER:
This view shows the restored “furnace group” structures of Hopewell Furnace National Historic Site. The stone structure in the middle is the actual furnace. The cast house is the white structure to the right; the wheel house and bridge house are to the left.

National Park Service photographs.

Hopewell Furnace National Historic Site

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Ft. Collins, Colorado

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Executive Summary

This report accompanies the digital geologic map for Hopewell Furnace National Historic Site in Pennsylvania, produced by the Geologic Resources Division 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.

Hopewell Furnace National Historic Site is located within the greater Schuylkill River watershed of southeastern Pennsylvania. Forested valleys and hills characterize the landscape, and disturbed forest covers three quarters of the site. Elevations within the park range from 140 m (460 ft) to 280 m (920 ft). French Creek State Park and Pennsylvania State Game lands surround the site on three sides, creating a large protected area in the densely populated Pennsylvania Piedmont.

Mark Bird founded the Hopewell Furnace operation in 1771, choosing the site because of its abundance of local natural resources necessary for such an enterprise—water, topographic relief, forests (for charcoal), local limestone (for flux and building materials), and iron ore deposits. The furnace operated from 1771 to 1883, transforming raw materials into iron, and fashioning the molten iron into various necessities. Ore was supplied from three local mines. Hopewell Furnace National Historic Site commemorates the enterprising spirit of the industrial age and educates the public about this pivotal time in American history.

The site is in the western Piedmont physiographic province near the junction of three sections: Gettysburg-Newark Lowland, Piedmont Upland, and Piedmont Lowland. The rocks in this area range from metamorphosed and deformed Precambrian mafic to felsic gneisses and Paleozoic metasediments to the gently tilted, much younger sedimentary strata of the Mesozoic rift basins. Within the park itself, Triassic-age gray to red sandstone, mudstone, shale, and conglomerate outcrop near Cambrian quartzite-bearing units across a 300-million year unconformity. These rocks may contain fossils and hold clues to the geologic history of the area. Thus, the site's geologic resources and their role in history can be an integral part of interpretation for park visitors.

Geology provides the foundation of the ecosystem. Understanding the geology of southeastern Pennsylvania enhances understanding of the unique relationship between geology and the environment. Geologic processes initiate complex responses that give rise to rock formations, topographic expression, surface and subsurface fluid movement, and soils. At Hopewell Furnace, human land use disturbances are part of the site's historical relevance. Furnace operators sculpted the landscape, logged the surrounding forest slopes, impounded and diverted local streams, and imported ore and flux from surrounding mines and quarries. The following issues have a high level of resource management importance at Hopewell Furnace National Historic Site:

- Water issues. The park protects the headwaters area of French Creek. This creek is impounded upstream to form Hopewell Lake. Ongoing water quality studies seek to understand the impacts of heavy metal concentrations resulting from iron smelting.
- Disturbed lands and mineral development. Regionally, abandoned and inactive mines and quarries pose safety, environmental, and health problems. These features could interrupt the regional hydrologic regime and could threaten park resources. Remediation of mine- and industry-affected areas in southeastern Pennsylvania is a cooperative effort.
- Preservation of the natural environment. The geologic features and processes on display at the park lend themselves to interpretation and educational opportunities. The park also strives to relate the history of the area to the geologic resources responsible for the location being chosen for the iron furnace.
- Slope processes. Slopes throughout the park area can be prone to mass wasting. Boulder fields and talus deposits form primarily during freeze-thaw cycles and from plant root wedging.
- Paleontological resources. Fossils can record the depositional environment and paleoclimate, as well as provide information on post-burial conditions. Fossils have not yet been found in the park. However the geologic units in the park are known to contain fossils elsewhere. Locally known fossils and trace fossils include *Skolithos* burrows.

The rocks within and surrounding the park record a long geologic history—from the Proterozoic Eon through the Quaternary Period—that involves the intermittent uplift of mountains, tectonic forces of compression and extension, inundation of oceans, accretion of land masses, and long periods of erosion and deposition. This geologic history is part of the story at Hopewell Furnace National Historic Site.

The glossary on page 27 contains explanations of many technical terms used in this report, including terms used in the Map Unit Properties Table.

Acknowledgements

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The GRI is administered by the Geologic Resources Division of the Natural Resource Program Center.

The Geologic Resources Division relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

Special thanks to: Ron Sloto (U.S. Geological Survey) for his comments and suggestions regarding water quality and mining history in the Hopewell Furnace area. Frances Delmar and Rebecca Ross (Hopewell Furnace NHS) provided images and information of the park.

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Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Hopewell Furnace National Historic Site.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Inventory and Monitoring Program. The GRI, administered by the Geologic Resources Division of the Natural Resource Program Center, is designed to provide and enhance baseline information available to park managers. The GRI team relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. 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 these goals, the GRI team is systematically conducting a scoping meeting for each of the 270 identified 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 Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps. The digital data sets provide geologic data for use in park GIS and facilitate the incorporation of geologic considerations into a wide range of resource management applications. The newest maps contain interactive help files. This geologic report assists park managers in the use of the map and provides 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/).

Park Setting

Hopewell Furnace National Historic Site sits within the French Creek drainage (designated as a Scenic River by the State of Pennsylvania in 1982) in the greater Schuylkill River watershed of southeastern Pennsylvania (fig. 1). Tributaries to the creek include Spout Run and Baptism Creek. Forested valleys and hills characterize the landscape at the site. Disturbed forest types cover three quarters of the land, recording the site's history of furnace operations that used trees to make charcoal. Elevations within the park range from a high of 280 m (920 ft) in the north to a low of 140 m (460 ft) where French Creek exits the park to the east. The larger French Creek State Park (3,035 ha [7,500 ac]) and Pennsylvania State Game lands surround the historic site on three sides, creating a large protected area in the densely populated Piedmont of southeastern Pennsylvania (Inners and Fergusson 1996; Glaser 2005).

Geologic Setting

Precambrian crystalline rocks, Lower Paleozoic metamorphosed sedimentary and sedimentary rocks, and Triassic sedimentary rocks underlie the landscape at Hopewell Furnace National Historic Site, directly controlling its highly irregular topography (Inners and Fergusson 1996). Relatively undeformed conglomerate and shale sit beneath the south-facing slope in the northern areas of the site. The Triassic Hammer Creek Formation contains quartz conglomerate and sandstone that is more resistant to erosion than the sandstone, siltstone, and mudstone of the Triassic Stockton Formation that sits below the lower areas throughout the center of the park (Podniesinski et al. 2005). As mapped by Bascom and Stose (1938), Cambrian-age Vintage Dolomite (a soluble carbonate rock) underlies the lowest-lying areas drained by French Creek and lowlands southeast of the village of Hopewell. The older geologic units in the Hopewell Furnace vicinity are faulted and deformed with varying degrees of metamorphism preserved in outcrop exposures. Precambrian gabbro and gneiss and erosion-resistant Cambrian quartzite crop out beneath the steepest topography in the southern reaches of the park (National Park Service 2009).

The geology influences soil patterns at Hopewell Furnace. Soils developed atop the Precambrian rocks tend to be deep and well drained, whereas soils along the major creeks are poorly drained. Soils tend to be very stony on conglomeratic substrates to the north (National Park Service 2009).

Hopewell Furnace sits near the junction of two physiographic provinces—the Piedmont province and the Valley and Ridge province—as described below (fig.2). More specifically, the park is near the junction of three subprovinces of the Piedmont province: the southern edge of the Gettysburg-Newark (Triassic) Lowland section, the Piedmont Lowland section, and the Piedmont Upland section.

Piedmont Province

Encompassing the Fall Line westward to the Blue Ridge Mountains is the Piedmont physiographic province. The "Fall Line" (also known as "Fall Zone") marks a transitional area at which 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 ridges, waterfalls, and rapids. Examples of the rapids formed by Piedmont rocks exist in the Potomac Gorge of Chesapeake and Ohio Canal National Historical Park (Maryland) and at Great Falls Park (Virginia).

The eastward-sloping Piedmont formed through a combination of folds, faults, uplifts, and erosion. The resulting eastern landscape of gently rolling hills starts at an elevation of 60 m (200 ft), and becomes gradually steeper westward toward the western edge of the province to reach 300 m (1,000 ft) above sea level. The Piedmont Plateau is composed of hard, crystalline igneous and metamorphic rocks, such as schist, phyllite, slate, gneiss, and gabbro. Soils in the Piedmont Plateau are highly weathered and generally well drained.

A series of Triassic-age extensional ("pull-apart") basins are superposed on the Piedmont. Normal faulting formed these basins during Mesozoic crustal extension. The faults opened basins (grabens), and these basins were rapidly filled with roughly horizontal layers of sediment. Examples include the Frederick Valley in Maryland, the Gettysburg-Newark Basin in Pennsylvania (fig. 3), and the Culpeper Valley of Northern Virginia. In general, depositional contacts define the western boundary of the basins with the Piedmont Plateau. Normal faults sharply define the western boundaries of the basins, west of which are the Blue Ridge and Valley and Ridge provinces.

History of Hopewell Furnace

Hopewell Furnace provides a fine example of a 19th century rural American iron plantation. Mark Bird, the first ironmaster, founded the furnace in 1771. The plantation operated until 1883, transforming raw materials into molten iron to make the stove plates, plowshares, cook pots, shot, weights, and other articles necessary for living in 19th century America. Included in the products of Hopewell Furnace were armaments for the Continental forces during the Revolutionary War (Demer 2003).

Authorized as Hopewell Village National Historic Site on August 3, 1938 (during the Franklin Delano Roosevelt presidential administration), and renamed as Hopewell Furnace National Historic Site on September 19, 1985, the site preserves the historic landscape of one of the nation's early iron forge communities (Glaser 2005). In accordance with its Long Range Interpretive Plan, the overall themes of Hopewell Furnace National Historic Site are: 1) exemplifying the state of the iron-making industry in the nascent United States, an industry central to the growth of the nation; and 2) demonstrating a microcosm of the social, political, economic, and technological developments in America throughout 112 years of the plantation's operation, from the colonial period to the post-Civil War era (Hopewell Furnace National Historic Site 1993).

A geologically relevant sub-theme involves the dependence of iron-making on the raw materials of the area (limestone, iron ore, hardwood forests, and waterpower), how that dictated the location of the iron plantation, and how the operation in turn altered the surrounding natural environment (Demer 2003).

The site covers approximately 343 ha (848 ac) southeast of Pottstown, spanning the boundary between Berks and Chester Counties. Among the historic structures at the site are a blast furnace, an ironmaster's mansion, and numerous outbuildings (figs. 1 and 4). For further information on the purpose, history, and setting of the site, please consult the administrative history document by Glaser (2005) or the Hopewell Furnace National Historic Site website: http://www.nps.gov/hofu.

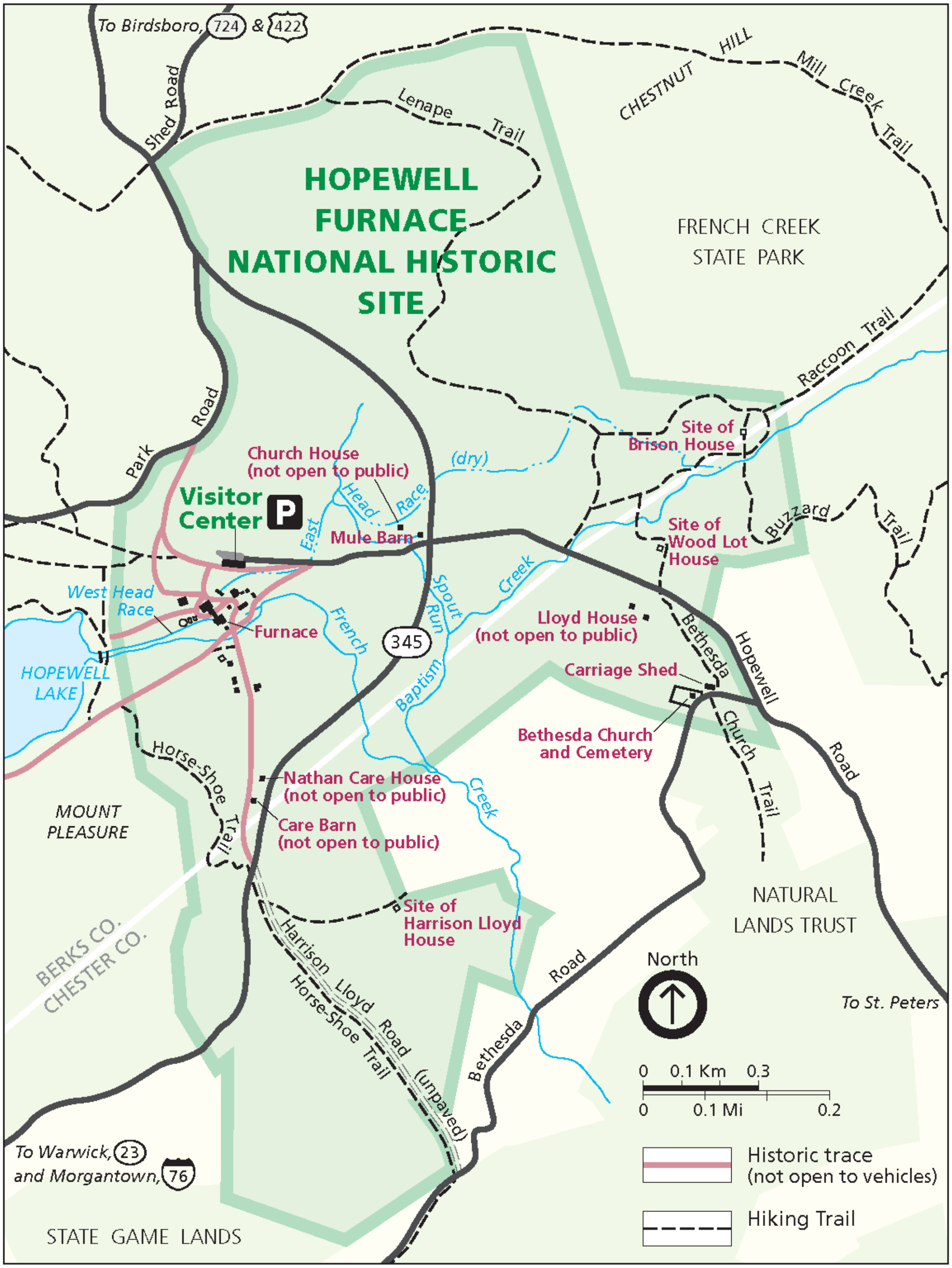


Figure 1. Map of Hopewell Furnace National Historic Site. National Park Service map.

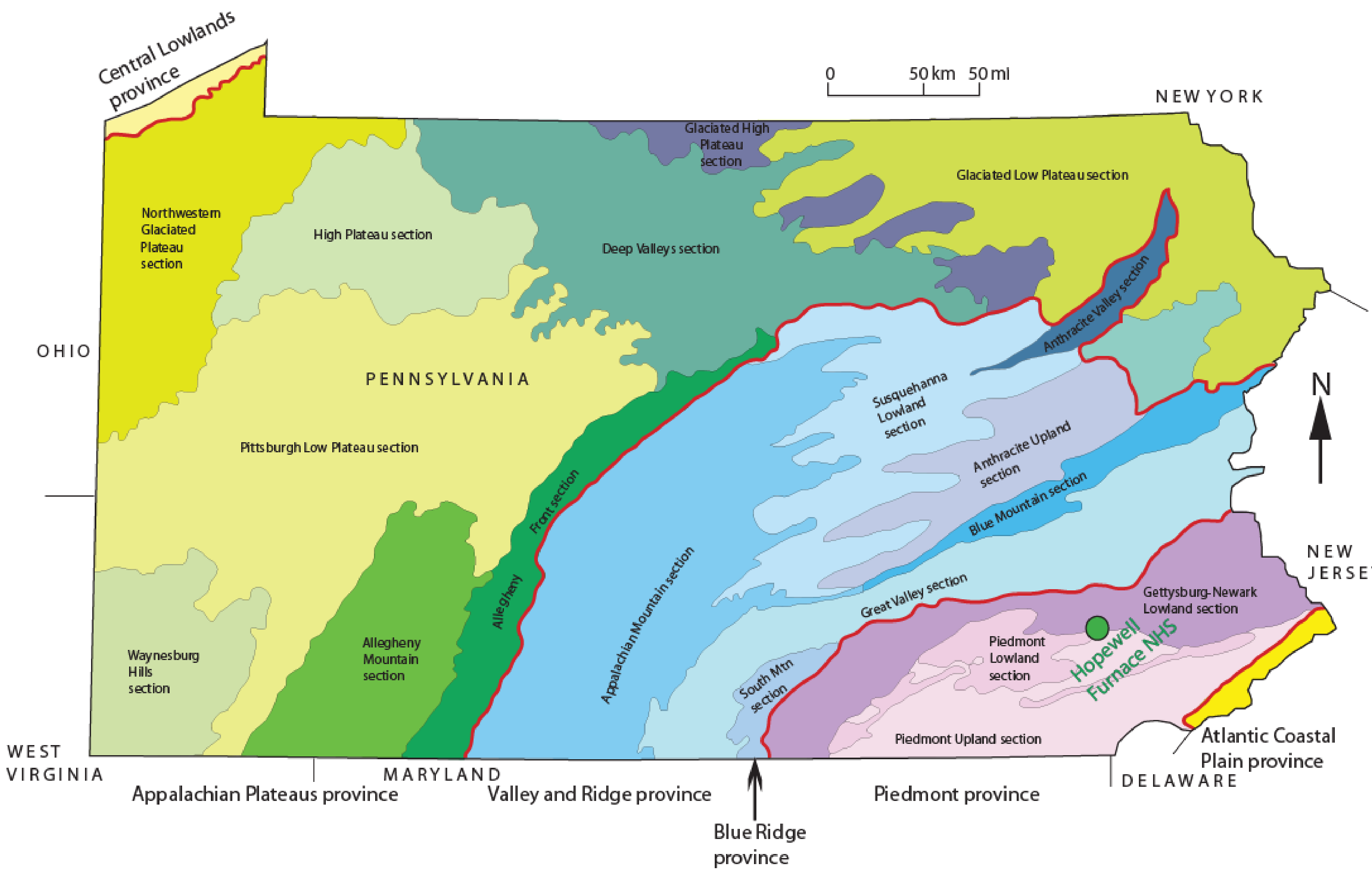


Figure 2. Physiographic provinces of Pennsylvania. The map graphic shows the physiographic setting of Hopewell Furnace National Historic Site. The green circle marks the location of the park and historic site. The red lines indicate boundaries between major physiographic provinces. The black arrow locates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

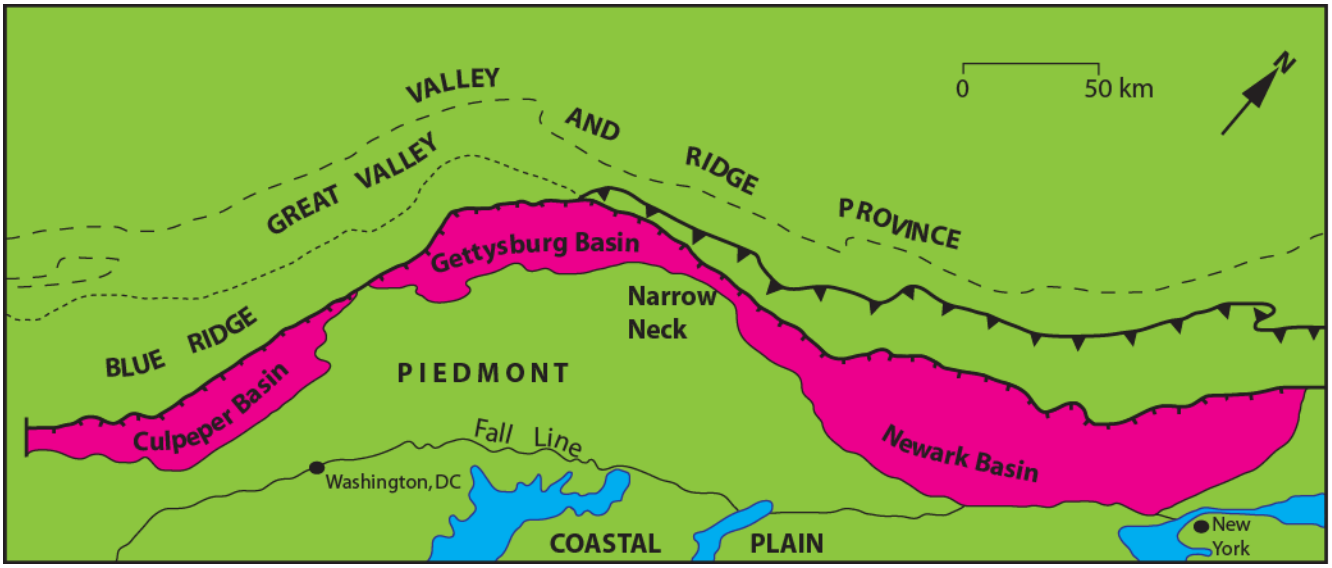


Figure 3. Mesozoic rift basins. Mesozoic rift basins are shown related to the structural patterns along the East Coast. Note how the trend of the basins is roughly parallel to the overall geologic trend of the surrounding physiographic provinces. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 1 in Root (1989).

Figure 4. Hopewell Furnace. The reconstructed wheel house is on the left, stone furnace in the center and reconstructed casting and moulding house on the right. National Park Service photograph reproduced in Glaser (2005).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Hopewell Furnace National Historic Site on June 22–24, 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. Contact the Geologic Resources Division for technical assistance.

Water Issues

French Creek flows through the heart of Hopewell Furnace National Historic Site (figs. 1 and 5). In 1982, the Commonwealth of Pennsylvania designated the waterway as a Scenic River due to its natural and scenic values. This creek and its tributaries, Spout Creek and Baptism Run, are primary natural resources at the park. Additional water resources include wetlands, numerous natural springs, flanking riparian zones and floodplains, and the underlying groundwater system (National Park Service 2009).

The park's waterways and their adjoining riparian habitats provide a vital sanctuary for many species of birds. Rivers and streams cut through the various rock layers, creating valleys, ravines, and gullies. Erosion and small-scale flooding occur along park waterways during seasonal storms and could threaten park infrastructure (GRI, scoping notes, 2004).

The surrounding natural lands provide buffers between the park and the increasing urban development in Berks and Chester Counties. Three Pennsylvania Natural Diversity Sites (Pine Swamp, Sixpenny Creek, and French Creek) are within or adjacent to Hopewell Furnace National Historic Site or French Creek State Park. Berks County identified these sites as having statewide significance for biodiversity protection (National Park Service 2009). Surrounding areas also pose concerns for park resource managers. Such concerns include the stability of and impacts to water quality from the earthen dam that impounds Hopewell Lake just upstream from the park's western boundary (GRI, scoping notes, 2004).

Damming of French Creek and other local streams began during the furnace operations of the early 19th century. The east head race and west head race were constructed to supply water to the furnace's water wheel (figs. 1 and 6). As part of the New Deal work relief programs of the 1930s, Civilian Conservation Corps workers constructed Hopewell Dam to impound Hopewell Lake, the space for which they also cleared.

National Park Service (1998) compiled and summarized baseline water quality data for Hopewell Furnace and the surrounding area. The U.S. Geological Survey (USGS) and NPS Mid-Atlantic Inventory and Monitoring Network (MIDN) are currently conducting a water quality study along French and Baptism creeks within and near the park. The study focuses on understanding heavy metal transport following the smelting of iron ore within the furnace (R. Sloto, USGS, personal communication, May 2010). The iron ores used at the Hopewell Furnace contained elevated concentrations of arsenic, cobalt, lead and other metals (R. Sloto, USGS, personal communication, May 2010).

The underlying geology is a primary determinant on any groundwater flow system. In the Hopewell Furnace area, much of the groundwater is stored in weathered Triassic-age rock. Hydrogeologic models of similar rocks elsewhere in Pennsylvania characterize this as a complex, heterogeneous, multiaquifer system (Sloto and McManus 1996). The aquifer system can be envisioned as layers of gently tilting rocks of high permeability separated by layers of rocks of relatively low permeability. In general, the more permeable rock layers are arkosic sandstones and conglomerates, whereas the siltstone and shale units tend to be softer and less permeable. Each layer has different hydrologic properties such as fractures, bedding planes, and joints to accommodate groundwater movement (Sloto and McManus 1996). In localized settings, a single fracture can control local groundwater flow, independent of the overall hydrogeologic structure (Schuller et al. 1982). Also underlying the Hopewell Furnace area are Cambrian carbonate rocks, whose increased permeability along dissolved conduits could strongly influence the local hydrogeologic system.

The park's water supply is from two groundwater wells (National Park Service 2009). One of these wells is a domestic well providing water to the Lloyd House, and is not connected to the rest of the park (R. Sloto, U.S. Geological Survey personal communication, May 26, 2010). Understanding the hydrogeologic system at the park can provide information for resource management. Applied geophysical techniques provide valuable tools in observing hydrologic properties, characterizing groundwater flow systems, and detailing subsurface geology. Potential techniques include surface resistivity, magnetometer, shallow seismic, electric logging, and cross hole seismic (Emrich 1984). Additionally, streams integrate the surface runoff and groundwater flow of their watersheds—combining input from sources such as wind, surface runoff, groundwater, sewage outfalls, landfills, dredged fill dirt, and rainfall—thus providing a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Contact the NPS Water Resources Division (Fort Collins, Colorado) for technical assistance with water resource issues.

Disturbed Lands and Mineral Development

The rocks and mineral resources within and surrounding Hopewell Furnace National Historic Site have long attracted people. Copper mines and abundant iron forges attest to this interest. Iron ore mines provided raw materials for the furnace. Extensive quarrying of the Paleozoic limestones for flux in the furnace and building material left numerous scars on the landscape. In 1885, Davis Knauer (first president of the French Creek Granite Company, established in 1910) opened a quarry into Jurassic diabase near St. Peters, a few kilometers southeast of the park (R. Sloto, USGS, personal communication, May 2010). The diabase was polished for ornamental and architectural stone, which was marketed as "black granite" (Topinka 2005).

Three local mines (Hopewell, Jones, and Warwick), all outside of park boundaries, supplied ore for the Hopewell Furnace (R. Sloto, USGS, personal communication, May 2010). Most of the mining was accomplished via small open pits although several shafts exist. The mines are now on private and state lands. Some of the open pits are flooded (R. Sloto, personal communication, May 2010).

Abandoned and inactive mines and quarries outside the park boundaries still pose safety, environmental, and health issues to the greater Hopewell Furnace area. These features interrupt the regional hydrologic regime and could threaten the park's soils, groundwater, and small streams and springs. Remediation of mine- and industry-affected areas in southeastern Pennsylvania is a cooperative effort. In addition to the National Park Service, agencies such as the U.S. Geological Survey, the Pennsylvania Department of Environmental Protection, and the Pennsylvania Environmental Council, as well as many local offices, are all contributing to environmental preservation and human health and safety (Anonymous 2002). None of the three Hopewell area mines have been reclaimed (R. Sloto, USGS, personal communication, May 2010).

Park interpreters aim to tie into the narrative of the park information about the surrounding areas, as they provided the materials necessary for the Hopewell Furnace processes of iron extraction, moulding, and casting (GRI, scoping notes, 2004). Though not contained within the boundaries of Hopewell Furnace National Historic Site, many of the surrounding map quadrangles of interest contain quarries, mines, and shafts that could augment the story of the park, if captured in the digital geologic data for the park (GRI, scoping notes, 2004).

Preservation of the Natural Environment

The NPS views a cultural landscape as a geographic area containing both natural and cultural resources (Glaser 2005). According to the park's 1994 Resource Management Plan, one of the largest threats to the park is the impending loss of the rural environment and natural resources:

> In its heyday, Hopewell Furnace was an industrial island in an agricultural sea; today [the area] is a small island of open space endangered by a rapidly rising sea level of residential and commercial development.

Though most visitors are interested in the historical context of the Hopewell Furnace National Historic Site landscape, the park provides an ideal outdoor classroom for earth science students (see Geologic Features and Processes section). It also protects a significant tract of intact forest in southeastern Pennsylvania (Glaser 2005).

Issues can arise from the differing strategies of cultural and natural resource management. For example, a proposal for the restoration of a historic garden, creation of a viewshed, or development of landscaping could involve the removal of surrounding natural resources, installation of stabilization structures, or planting of exotics. The conservation of today's natural beauty at Hopewell Furnace National Historic Site is somewhat compromised by the interpretation of an early industrial landscape that would have been utilitarian, non-aesthetic, and much disturbed (Glaser 2005).

Slope Processes

The resistant quartzites of the Cambrian Chickies Formation form rolling hills across the southern portion of the park (Podniesinski et al. 2005). The Chickies Formation also underlies the steep northern slopes and crest of Mount Pleasure along the western edge of the park (fig. 7; Appendix A) (Inners and Fergusson 1996). Weathering and gravity-driven slope processes of the Chickies quartzite gives rise to a steep boulder field formation along the west-central edge of the park, which stands as a testament to active slope processes (Podniesinski et al. 2005). Boulders of quartzite at this location, many with diameters of 1m (3 ft) or more, form a continuous blanket of talus that extends upslope more than 30 m (100 ft) to a jumbled and fractured bench of quartzite (Inners and Fergusson 1996). Freeze-and-thaw cycles or plant roots could wedge other blocks of rock loose from this formation and threaten resources and infrastructure downslope. However, the talus slope appears stable (R. Sloto, USGS, personal communication, May 2010).

Downcutting streams such as French and Baptism creeks and other erosive agents created valleys, ravines, and gullies on the landscape at Hopewell Furnace National Historical Site. Weathering processes, both mechanical and chemical, have also weakened the underlying geologic units that include sandstone, siltstone, mudstone, and shale. Among these units are the Triassic Hammer Creek and Stockton formations, which are heterogeneous and include weak, clay-rich mudstones interlayered with resistant sandstones and conglomerates (fig. 7; Appendix A) (Inners and Fergusson 1996). Clay-rich units such as shale and mudstone can disintegrate or swell when they become water saturated, and are prone to fail when exposed on a slope, resulting in a slide or slump. Where a resistant layer such as a conglomerate or sandstone overlies a clay-rich layer, mass wasting potential exists due to preferential erosion (undercutting) of the clay layer, leaving no support for the resistant layer on top. Unstable slopes within the park may fail, especially when saturated with water after seasonal rainfall events.

Talus and colluvial deposits at the bases of slopes attest to mass movements in the past. Today, the processes of slope creep and slumping can threaten roads and trails throughout the park (GRI, scoping notes, 2004). Three-dimensional investigations of colluvium could shed light on the exact nature of their formation, how they influence groundwater flow, and the potential for future movements. Such studies involve test pits and deep borings, observations on colluvial composition, layering, and degree of weathering, as well as permeability measurements (Layton et al. 2006).

Paleontological Resources (Fossils)

Fossils add to the understanding of the geologic history of the Piedmont province and Mesozoic rift basins in the Hopewell Furnace area. Certain fossils are useful in correlating units across time and space. Others offer clues about the depositional environment when they were alive. Still others provide post-burial information, including geochemical changes, deformational regimes, and changes in bedding orientation. Fossil resources, when present, require science-based resource management as directed by the 2009 Paleontological Resources Preservation Act (Public Law 111-11). The National Park Service is currently developing regulations associated with the Act (J. Brunner, Geologic Resources Division, personal communication, May 2010). Santucci et al. (2009) suggest strategies for monitoring in situ paleontological resources.

The NPS conducted a paleontological inventory from literature of known and potential fossil occurrences in Hopewell Furnace National Historic Site (Kenworthy et al. 2006). No formal, field-based paleontological resource inventories have been completed, and the park has no collections of paleontological material (Kenworthy et al. 2006).

Some of the geologic units located on park lands are known to contain fossils regionally (fig. 7). Heavy vegetative cover and deeply weathered bedrock preclude extensive outcrop exposure. The highly erosion-resistant quartzite of the Cambrian-age Chickies Formation contains the trace fossil *Skolithos* (worm-like burrows). At the western end of Mount Pleasure, blocks of the Chickies quartzite contain specimens of the conspicuous sediment-filled *Skolithos* tubes (Inners and Fergusson 1996). The Triassic Stockton Formations outcrops within the park boundaries and regionally contains plant fossils, invertebrate body and trace fossils, mollusk fossils, fish and amphibian remains, and reptilian and dinosaurian body fossils and footprints, although none are known in the park (Kenworthy et al. 2006). Investigators have noted dinosaur footprints locally in sedimentary rocks of the Gettysburg-Newark Basin (GRI, scoping notes, 2004). Approximately 200-million-year-old fossil dinosaur tracks are within rocks of the same age at the Limerick Nuclear Power Station, located approximately 16 km (10 mi) to the east of Hopewell Furnace (Inners and Fergusson 1996). Field-based paleontological resource inventories at Hopewell Furnace National Historic Site may uncover similar resources within the park.

Figure 5. French Creek flows through Hopewell Furnace National Historic Site. Left: U.S. Geological Survey photograph by Ron Sloto. Right: Following a thunderstorm; National Park Service photograph courtesy Frances Delmar (Hopewell Furnace NHS).

Figure 6. Water was needed to drive the water wheel powering the blast machinery. The east head race (left; 1939 photo after retaining wall restoration) and west head race and flume (right; 2006 photo after reconstruction) were man-made structures that transported water to the wheel house. Their locations are indicated on figure 1. National Park Service photographs in Yocum (2008).

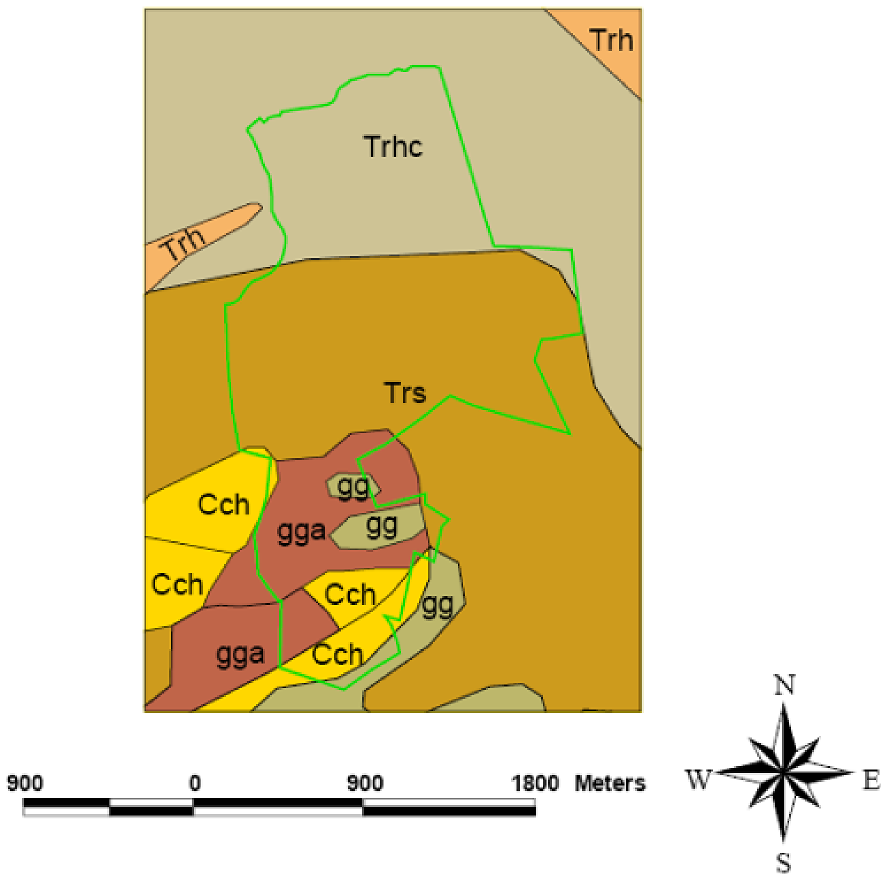


Figure 7. Geologic map of units within the boundaries of Hopewell Furnace National Historic Site. Unit gga is Precambrian banded mafic gneiss; unit gg is Precambrian graphitic felsic gneiss; unit CCh is Cambrian Chickies Formation; unit Trs is Triassic Stockton Formation; unit Trh is Triassic Hammer Creek Formation; unit Trhc is Triassic Hammer Creek conglomerate. The green line is the national historic site boundary. Note that Cambrian dolomite is missing from the mapped units, but was observed by the NPS along the lowest reaches of French Creek (National Park Service 2009) and mapped by Bascom and Stose (1938). Graphic from Podniesinski et al. (2005) with data from Miles et al. (2001). Refer to Appendix A for an overview of the digital geologic data for the park.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Hopewell Furnace National Historic Site.

Geologic Influences on the Furnace and Smelting Iron

Underlying the historic site area are Precambrian to Cambrian metamorphic and sedimentary rocks, as well as Triassic-age mudstones, siltstones, sandstones, and conglomerates in gently tilted and folded beds (Appendix A). Weathering and erosion of these rocks shaped the rolling hills and narrow valleys characteristic of the Hopewell Furnace area. French Creek flowed through a narrow valley between two forested hills (Mount Pleasure and Brush Hill) and frequently flooded, leaving marshy conditions that were unfavorable for farming but suitable for industrial purposes (Glaser 2005).

In 1771, Mark Bird, the first ironmaster, chose to build an iron furnace in Union Township, Berks County, Pennsylvania due to the abundant natural resources (ore, limestone, and charcoal) in the area (O'Neill 1976; Demer 2003). Bird constructed the furnace against a hillslope, so it would be appropriately configured for the loading of iron ore, limestone, and charcoal (known as "charging") and to take advantage of running water as a potential power source by funneling it downslope to a water wheel (figs. 6 and 8) (Inners and Fergusson 1996; Demer 2003; Glaser 2005). Limestone was used as a flux to fuse impurities from the ore, and it was mined from local quarries in Hopewell or imported from sources east of Morgantown.

The furnace is nearly 9 m (30 ft) high by 4 m (12 ft) deep by 4 m (12 ft) wide, and is composed of heavy limestone blocks lined with refractory sandstone. The furnace design incorporated three primary features: 1) an upper-tapering interior chamber; 2) a tuyere (interior pipe), which supplies a blast of air; and 3) a small hole at its base that allows molten iron to flow (fig. 8). Taking advantage of the local topography, Bird used a water wheel to supply the stream of air to the tuyere to accelerate combustion and increase the interior temperature (Demer 2003).

The conversion of ore to viable iron is a time-consuming process. In the early 1800s, a typical half-hour charge required 15 bushels of charcoal, 400 to 500 pounds of iron ore, and 30 to 40 pounds of limestone flux (O'Neill 1976). These substances had to be heated to temperatures of 2,600 to 3,000 °F to produce the chemical reaction ($Fe_2O_3 + 3CO = 3CO_2 + 2Fe$), wherein iron oxide ore loses (via reduction) its oxygen atoms to carbon monoxide produced by the burning charcoal (Demer 2003). Once the iron was molten, the founder would extract the material, and moulders would create iron products using casting sand. At Hopewell Furnace, moulders used the green-sand process for smaller articles, and dry-sand or loam for larger castings. According to historic estimates, moulders formed and poured no fewer than 75,000 flasks to produce approximately 5,000 iron stoves at Hopewell Furnace (Demer 2003).

Iron Ore Mines

Early iron ore mining for the Hopewell Furnace was performed by open pit and bell pit mining (O'Neill 1976). Three local mines supplied iron ore to Hopewell Furnace: Warwick, Hopewell, and Jones mines. These mines were within three different ore bodies only a few kilometers from the furnace (fig. 9). The mines began as open-pit operations; however, as mining technology advanced, some regional mines such as the Warwick Mine developed shaft operations. Initially, it was common to extract high-grade ore (40 to 60 % iron was common); however, the quality of iron ore usually decreased as mining progressed (Lewis and Hugins 1983; Inners and Fergusson 1996). Magnetite (Fe_3O_4) was the primary iron-bearing mineral of the local ore, with accessory hematite (Fe_2O_3), calcite ($CaCO_3$), and pyrite (FeS_2). Examples of this ore exist in a rock pile adjacent to the furnace at the Hopewell Furnace National Historic Site (Inners and Fergusson 1996; Demer 2003). In 1926, a study detailed the presence of fine magnetite crystals, as well as some interesting quartz pseudomorphs after datolite in scraps of ore from the Hopewell mine (Vaux 1926). The iron ores originated as part of the "Morgantown pluton" (see "Geologic History" section). Accompanying this igneous intrusion were superheated, iron-rich gaseous and watery solutions that altered and/or replaced the surrounding rock (limestone or marble in this case), creating the iron ore that became the focal resource of Hopewell Furnace (Inners and Fergusson 1996). The Jurassic-aged diabase dikes mapped north of the park were also associated with the Morgantown pluton.

The Warwick Mine, located in Warwick Township, was the last major mine opened for ore extraction at Hopewell Furnace. It now sits within State Game Lands (north of State Route 23) and on private land (south of State Route 23). A total of five shafts—ranging in depth from 8 to 31 m (25 to 102 ft)—existed during the 120 years of operation at Warwick Mine, although most of the mining was open pit or "bell pit" mining (R. Sloto, USGS, personal communication, May 2010)The principal ore at the Warwick mine was gray magnetite-rich rock.

The Hopewell Mine (also known as the Birdtown Mine) is contained within Pennsylvania State Game Lands on the south side of Thomas Hill (National Park Service 1997; Inners and Fergusson 1996). This mine consists of three open pits, three shafts and a slope (R. Sloto, USGS, personal communication, May 2010). It cuts through rocks of the Triassic Stockton Formation and Jurassic diabase.

The Jones Mine was started in 1773 by Mark Bird and shut down in the early 1900s. This mine and the Hopewell Mine were the most crucial to Hopewell Furnace operations. Jones Mine is 120 m (400 ft) wide and approximately 60 m (200 ft) deep. It sat amidst 16 ha (40 ac) in Caernarvon Township between Elverson and Joanna (National Park Service 1997; Inners and Fergusson 1996). Today, the mine is flooded and located on private property (R. Sloto, USGS, personal communication, May 2010).

Geologic Influences on Human History

The 1968 establishment of an Environmental Study Area (ESA) at Baptism Creek partially focused on the interaction between human beings and nature, reviewing the ecological background of the forested area and the impact of the furnace and charcoal pollution. Today, the park does not include the ESA in its interpretive efforts; however, the ESA helped to shape visitors' understanding of the rural-industrial landscape at Hopewell Furnace (Glaser 2005).

The diversity of geologic phenomena in the Hopewell Furnace area can illustrate many geologic concepts in a learning environment. The concept of geologic time is readily accessible in the Precambrian- to Mesozoic-age rocks within and surrounding the park. Rocks and fossils indicate depositional environments and conditions of life in the distant past (Inners and Fergusson 1996; Kenworthy et al. 2006). The geologic structures in the area record several episodes of mountain building and continental rifting. The Triassic rocks within the park record a large rift basin superimposed on the Piedmont physiographic province as the eastern coast of the North American continent underwent extension following the mountain-building Alleghany orogeny. Periglacial conditions affected the area during the Pleistocene by changing the courses of rivers, causing floral and faunal migrations, wedging apart the rock units, and leaving vast talus deposits. Relating geology to human concerns such as floods, slope failures, iron ore mining, water pollution, limestone quarrying, 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 blast furnace and ironworks would lend deeper meaning to the human history of the area.

One of the major goals of the park is to preserve the historical context of the area—including the recreation of some of the village land use patterns (orchards and gardens) and structures, and the preservation and restoration of historic structures from the time of the furnace operation. Maintaining any historic landscape often means resisting natural geologic changes. Features such as streams naturally erode and meander. French Creek, vital to the cultural story of Hopewell Furnace, is part of a dynamic hydrogeologic system prone to change.

Geologic processes such as slumping, chemical weathering, block sliding, and slope creep are constantly changing the park landscape. Runoff erodes sediments from any open areas, carrying them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas, distorting the historical context of the landscape. Extensive mining, deforestation, manipulation of the stream system, and other land use practices (including urban development and farming) have changed the regional topographic expression.

Geologic Influences on Biological Resources

The geologic framework at Hopewell Furnace National Historic Site, including the underlying bedrock and resulting geomorphology, have greatly influenced the type and distribution of vegetation and ecology (Podniesinski et al. 2005). According to a 2005 cooperative vegetation mapping study between the U.S. Geological Survey and the NPS, the thin, rocky, well-drained soils above the erosion-resistant bedrock of the northern slopes and southern hills of the park favor the development and growth of oak-dominated forests and woodlands. The less-resistant bedrock in the central areas of the park—including Triassic sandstone, mudstone, and siltstone—underlies deeper, richer soils that support mesic and wet forest vegetation. The low-slope valley areas favor forested seeps and shrub wetland assemblages. Along French Creek, poorly drained, fine-textured alluvial deposits characterize the flat floodplain soils and support palustrine shrublands and forests (Podniesinski et al. 2005).

To operate the furnace for just one day required an acre of forest resources (Glaser 2005). Little to none of the original forest types remain in Berks and Chester Counties, due to the large-scale regional deforestation throughout the 18th and 19th centuries, as well as agriculture and pasture land use practices in support of the community at Hopewell Furnace (Podniesinski et al. 2005). In 1985, Hopewell Furnace National Historic Site received funding for a biological study to identify plant communities for "historic scene restoration" (Glaser 2005). In 1987, 504 species of vascular plants were documented in a vegetation study within park boundaries. Many of these species were invasive, but settlers might have introduced them during the historic furnace period. The NPS identified the need to research the specific species that should be considered part of the historic scene and judge the risks of allowing them to remain (National Park Service 2009). Geology, as a great influence on species distribution, merits particular notice in such research.

Cambrian-Triassic Unconformity

Hopewell Furnace National Historic Site contains interesting geological features called unconformities, erosional surfaces between rock units of different ages (fig. 10). Among the most profound is the unconformity between the heavily deformed and metamorphosed Cambrian Chickies Formation (quartzite) and the relatively undeformed, mixed sedimentary strata of the Triassic Stockton Formation. This tangible gap in geologic history spans more than 300 million years (Inners and Fergusson 1996; W. Kochanov, Pennsylvania Geological Survey, written communication, 2010). Another profound unconformity exists between the metamorphosed, approximately 1-billion-year-old

Precambrian gneisses (among the oldest rocks in Pennsylvania) and the Cambrian Chickies Formation.

Another important juxtaposition of rocks of different ages is the intrusive contact between Jurassic diabase dikes and surrounding Triassic-age country rock. Resistant diabase forms Millers Point and Monocacy Hill in the Hopewell Furnace area. These ridges are along the edge of the Morgantown pluton (Inners and Fergusson 1996).

Mount Pleasure

Mount Pleasure is a 270-m-high (885-ft-high) hill located south of Hopewell Lake on the western edge of Hopewell Furnace National Historic Site. This feature contains the oldest geologic units in the park area (Appendix A). Erosion-resistant Cambrian quartzites of the Chickies Formation underlie the steep northern slopes and crest of the hill, whereas Precambrian banded mafic gneisses support the gentler eastern slopes. Several pervasive faults cut and displace the rock units of Mount Pleasure in a haphazard manner (Inners and Fergusson 1996).

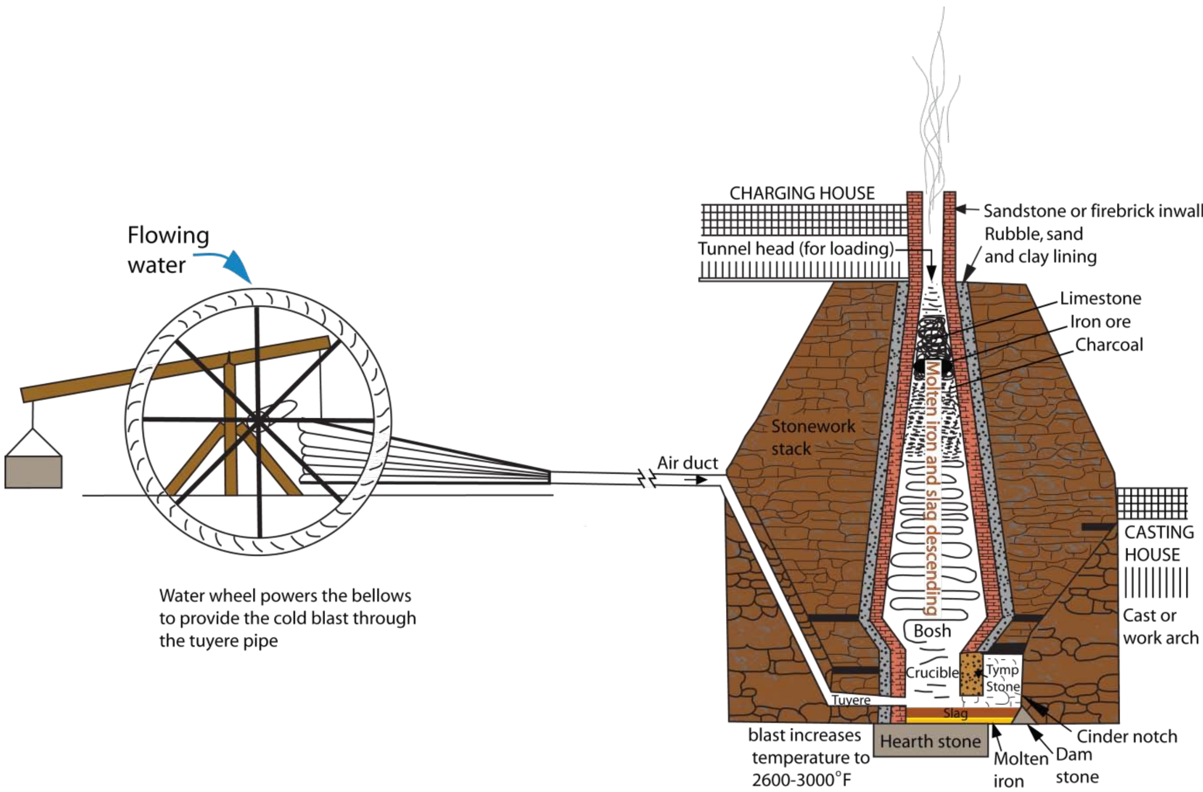


Figure 8. Diagram of a typical cold-blast furnace. By 1852 pistons inside "blowing tubs" were used supply the blast of air to the furnace. Diagram by Trista Thornberry-Ehrlich (Colorado State University) after NPS graphic (waterwheel) and WITF (Harrisburg, PA)/Courtney Howell graphic (furnace) available at http://explorepahistory.com/displayimage.php?imgId=4266 (accessed June 2010).

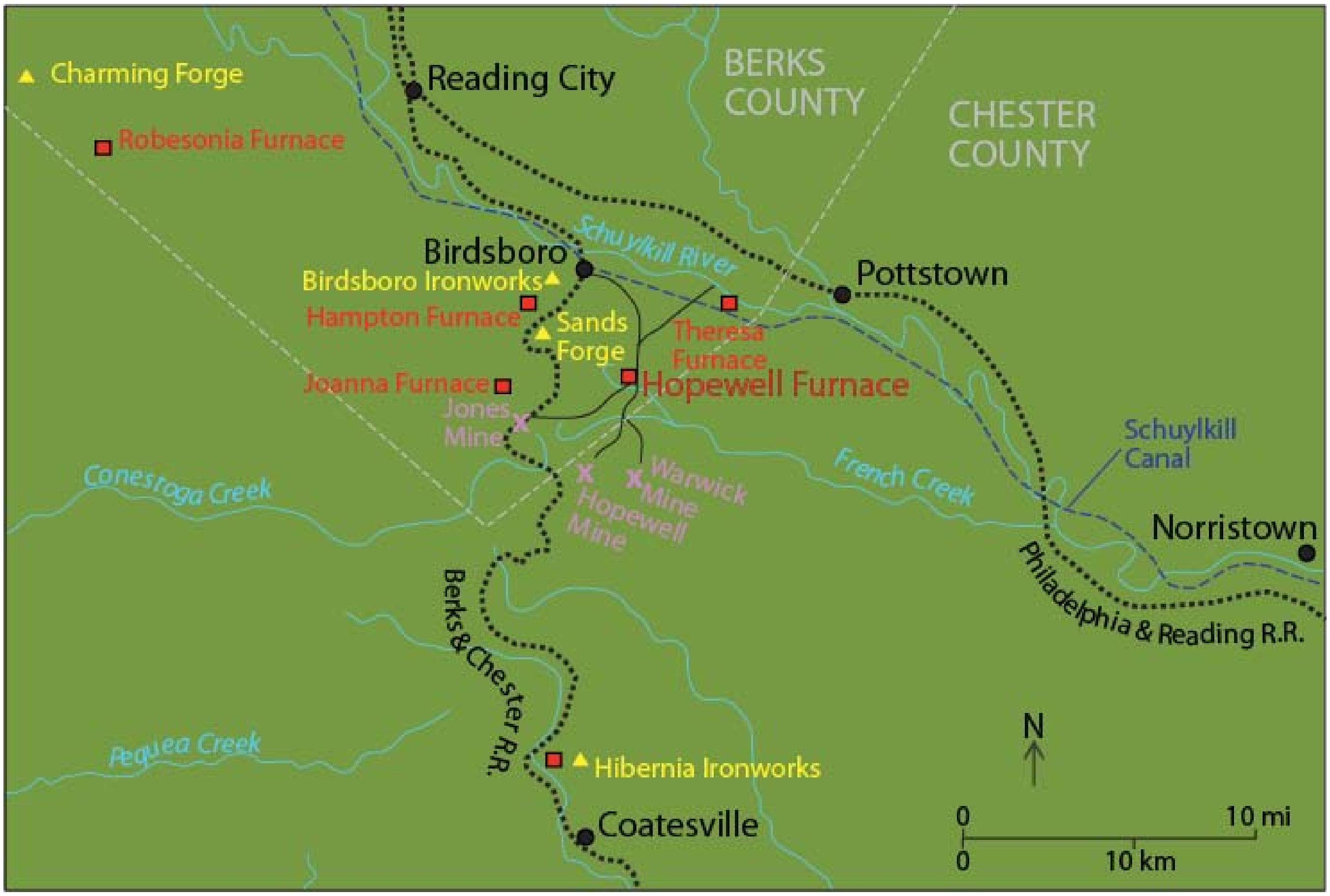


Figure 9. Map of iron furnaces and ironworks surrounding Hopewell Furnace. The three locations marked with a purple X indicate the mines that supplied iron ore to Hopewell Furnace. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after an unnumbered figure by the NPS from Lewis and Hugins (1983).

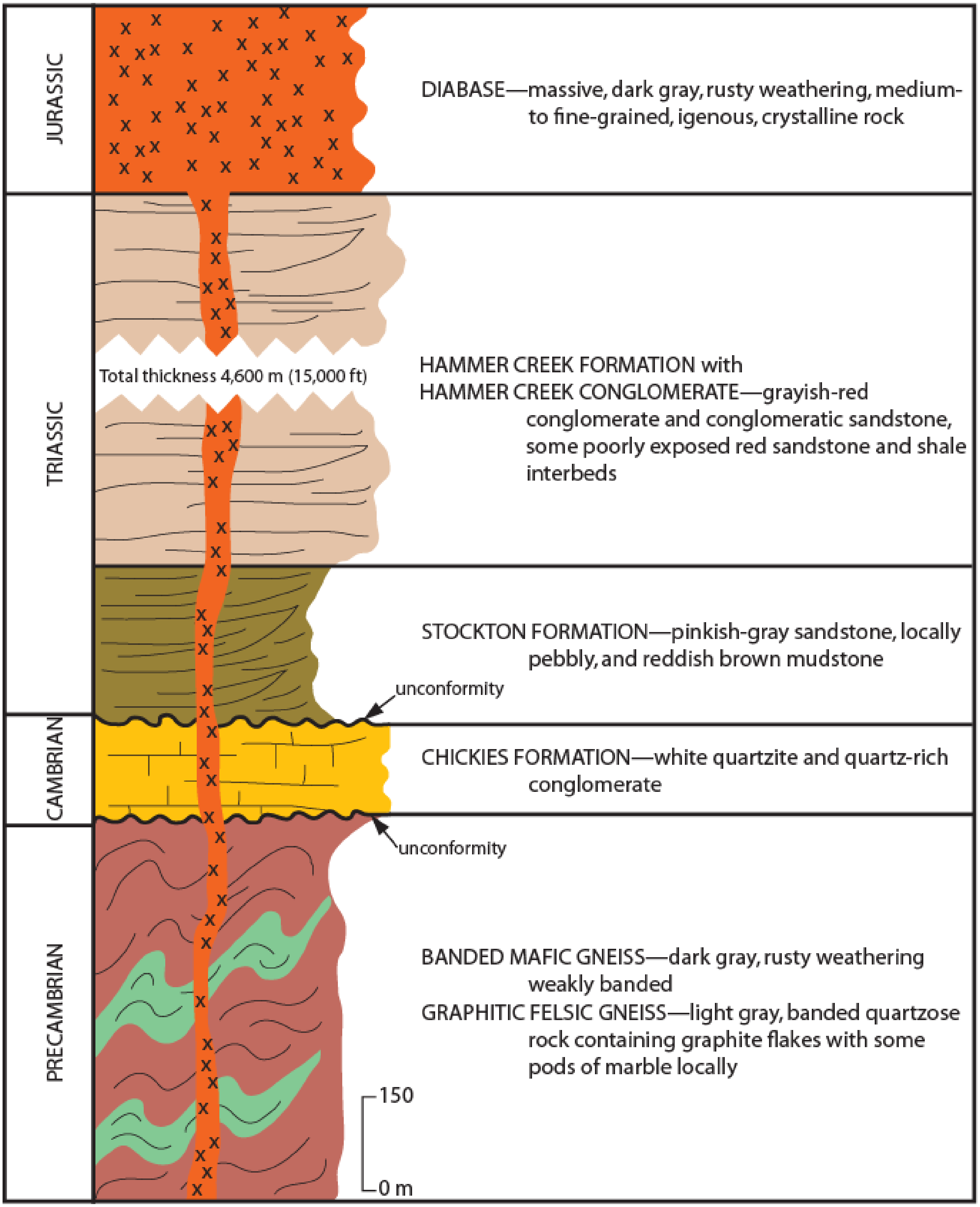


Figure 10. Geologic column of rock units exposed within Hopewell Furnace National Historic Site. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after an unnumbered figure by Inners and Fergusson (1996).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Hopewell Furnace National Historic Site. 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.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Hopewell Furnace National Historic Site provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report. Geologic maps are two-dimensional representations of complex three-dimensional relationships; their color coding illustrates 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 among geologic features, 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 are not soil maps, and do not show soil types, 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. Similarly, map units show areas that have been susceptible to hazards such as landslides, rockfalls, and volcanic eruptions. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by depicted geomorphic features. For example, alluvial terraces may have been preferred use areas 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. The table highlights characteristics of map units such as: susceptibility to erosion and hazards; the occurrence of paleontological resources (fossils), cultural resources, mineral resources, and caves or karst; and suitability as habitat or for recreational use. Some information on the table is conjectural and meant to serve as suggestions for further investigation.

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 the sources for the GRI digital geologic data for Hopewell Furnace National Historic Site:

Berg, T.M., A. D. Glover, S. I. Root, W. E. Edmunds, D. M. Hoskins, W. D. Sevon, A. R. Geyer, D. B. MacLachlan, A. A. Socolow. 1980. *Geologic map of Pennsylvania*. Scale 1:250,000. 4th ser., PA DCNR Map 1. Bureau of Topographic and Geologic Survey.

Miles, C. E., T. G. Whitfield (compilers). 2001. Bedrock geology of Pennsylvania. Scale 1:250,000. Digital dataset extracted from *Geologic map of Pennsylvania*. 4th ser., PA DCNR Map 1. Bureau of Topographic and Geologic 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, and increases the overall utility of the data. GRI digital geologic map products include data in ESRI personal geodatabase and shapefile 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 and connects the help file directly to the map document. 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: Hopewell Furnace National Historic Site

Colored rows indicate geologic units mapped within Hopewell Furnace NHS.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
QUATERNARY	Trenton Gravel (**Qt**)	Unit includes some alluvium and swamp deposits, contains gray or reddish-brown gravelly sand interbedded with sand, clay, and silt beds. Crossbeds present locally.	Very low	Avoid stream edge/riparian and wetland areas for heavy development, especially for wastewater treatment facilities due to proximity to water and high permeability.	Unit is associated with stream banks and riparian zone areas, and may be unstable if exposed on a slope or water saturated.	May contain ice age and modern remains.	May contain remains from historic events and settlements.	None.	Sand, clay, silt, gravel.	Unit supports riparian habitats, and marshlands.	Unit is suitable for light recreation unless at a stream edge or wetland.	Unit records modern geomorphological changes in the park area landscape.
TERTIARY	Pensauken and Bridgeton Formations, undifferentiated (**Tpb**) Bryn Mawr Formation (**Tbm**)	**Tpb** contains dark reddish-brown feldspathic quartz sand beds with interlayered fine gravel and some clay and silt. **Tbm** consists of gravelly sand and silt in reddish-brown high-level terrace deposits.	Very low	Avoid most terrace deposits for heavy development due to instability of slopes and high permeability.	Unconsolidated nature of the units render them susceptible to mass wasting on steep to moderate slopes.	May contain plant fragments.	Terrace areas may contain traces of Native American campsites.	None.	Sand, clay, silt, gravel.	Unit supports riparian habitats and well-drained soils.	Suitable for most recreation unless high slopes are present.	Units record history of erosion and deposition throughout the Tertiary.
CRETACEOUS	Patapsco(?) Formation (**Kp**)	Unit is intensely colored, variegated, iron-rich clay with some isolated interbedded sand.	Low	Variations in bedding, sediment, and degree of cementation may render unit unstable on slopes; generally suitable for most development.	Clay-rich massive bedded layers may spall in large blocks when unit is exposed on slope; susceptible to slumps and slides.	May contain Cretaceous age fossils.	None documented.	None.	Sand, clay.	Supports eastern hardwood forests regionally.	Suitable for most recreation unless exposed on slopes.	Widespread unit records Cretaceous depositional environment.
JURASSIC	Sedimentary strata at Jacksonwald and Aspers (**Js**) Diabase (**Jd**)	**Js** is arkosic sandstone with some gray to black shale and limestone interbeds, ripple-cross-laminated siltstone, and boulder conglomerate. **Jd** consists of medium- to coarse-grained tholeiite in dikes, sheets, and scant flows. Individual bodies vary in titanium content and presence of plagioclase phenocrysts.	Moderate to high	Variations in rock type and degree of cementation may render unit unstable on slopes.	**Jd** may form resistant ridges that are prone to rockfall when undercut and/or weathered.	**Js** is fossiliferous.	Diabase was popular building stone. Iron ore for Hopewell Furnace.	Limestone units are prone to dissolution.	Iron Ore. Labradorite, pyroxene, plagioclase phenocrysts (cm-size), diabase.	**Jd** weathers to support iron-, and magnesium-rich substrates.	Suitable for most recreation unless heavily altered or fractured.	Iron ore utilized at Hopewell Furnace associated with Morgantown pluton and intrusion of **Jd. Jd** includes the dark gray York Haven Diabase and the younger Rossville Diabase.
TRIASSIC	Brunswick Formation (**TRb**) Limestone fanglomerate (**TRfl**) Quartz fanglomerate (**TRfq**)	**TRb** is primarily reddish-brown mudstone, siltstone, and shale with some green and brown interbedded shale. Some red and dark gray argillite interlayers near the base. **TRfl** is yellowish-gray to medium gray quartz matrix with limestone and dolomite pebbles, cobbles, and fragments. Some shale-clast beds are locally interlayered. **TRfq** contains a reddish-brown sandy matrix with well-rounded quartzite pebbles, cobbles, and rare boulders.	Moderate	Heterogeneous nature of units may render them unstable on slopes.	Unit is prone to rockfall where weathered shale lies beneath resistant sandstone ledges or where limestone has dissolved beneath overlying rock layers.	May contain Triassic age fossils.	None documented.	Limestone cobbles in **TRfl** may dissolve away creating voids and compromise unit integrity.	None documented.	Units weather to create myriad substrates.	Suitable for most recreation unless heavily weathered and friable.	**TRb** spans the Jurassic-Triassic boundary.

Colored rows indicate geologic units mapped within Hopewell Furnace NHS.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
TRIASSIC	Hammer Creek Formation (**TRh**) Lockatong Formation (**TRl**) Hammer Creek conglomerate (**TRhc**)	**TRh** contains quartzose sandstone, siltstone, and mudstone that appear gray and pale red in outcrop with fine- to coarse-grained textures. **TRl** is dark gray to black, thickly bedded argillite. Lenses and layers of thin-bedded black shale, impure limestone, and calcareous shale present locally. **TRhc** is composed of interbedded cobble and pebble quartz conglomerate with red sandstone.	Moderate	Suitable for most development unless highly fractured, weathered, or undercut on a slope.	Weathered mudstone or dissolved limestone underlying more resistant sandstone or argillite can create rockfall hazards.	May contain Triassic age fossils.	None documented.	Impure limestone layers are susceptible to dissolution and may compromise integrity of units.	Sandstone.	None documented.	Unit is fine for most recreation unless heavily weathered on slopes.	Units record deposition within a Triassic rift basin of varying depth.
TRIASSIC	Stockton Formation (**TRs**) Stockton conglomerate (**TRsc**)	**TRs** contains light gray to buff, coarse-textured arkosic sandstone, with some reddish-brown to purple sandstone, siltstone, and mudstone interbeds. **TRsc** contains cobbles of quartz in a sandy, poorly sorted matrix with some conglomeratic sandstone present locally.	Moderate	Heterogeneous nature of units may render them unstable on slopes.	Units form alternating ridges that may be prone to rockfall and landslides, especially where resistant sandstone layers are underlain by weathered red shales.	May contain Triassic age fossils.	None documented.	None documented .	Sandstone.	None documented.	Conglomeratic outcrops may attract climbers.	Units record deposition and reworking within a Triassic rift basin.
ORDOVICIAN	Martinsburg Formation (**Om**) Hamburg sequence rocks (**Oh**) Shale and Graywacke of Hamburg sequence (**Ohsg**) Limestone of Hamburg sequence (**Ohl**)	**Om** contains dark gray to gray shale and slightly metamorphosed slate. **Oh** includes greenish-gray, purple, and maroon shale, siltstone, and graywacke with some flysch beds containing some of unit **Om**. **Ohsg** consists of shale with conspicuous zones of graywacke. **Ohl** is thick-bedded limestone of the Hamburg sequence.	Moderate	Avoid dissolved units for development of wastewater treatment facilities; weathered units may fail on slopes.	Unit is prone to rockfall where weathered shale is beneath resistant sandstone ledges or where limestone has dissolved beneath overlying rock layers.	May contain Ordovician age fossils.	Slate may have been locally quarried.	Unit **Ohl** is susceptible to dissolution and may undermine stability of overlying units.	Slate.	Cave habitat.	Dissolved caves and cavities may attract attention.	Units record deep water marine depositional environment.
ORDOVICIAN	Cocalico Formation (**Oco**) Jacksonburg Formation (**Ojk**) Annville Formation (**Oan**)	**Oco** includes gray phyllitic shale, maroon shale, and siltstone with silty siliceous interbeds. Some argillaceous and quartzose sandstones present locally. **Ojk** contains dark gray, shaly limestone with slaty cleavage. Some medium- to thick-bedded limestone is present in basal sections. **Oan** consists of light gray, massive-bedded, limestone. Unit is calcium rich and mottled in the basal layers.	Moderate	Avoid heavily dissolved units for development due to weakness of friable textures.	Limestone cements are prone to dissolution and may compromise outcrops of **Ojk**.	May contain Ordovician age fossils.	None documented.	Limestone layers and units are susceptible to dissolution, forming caves, sinkholes, and cavities.	Sandstone, slate.	**Oan** weathers to produce Ca-rich substrates.	Cave-bearing units may attract attention.	**Oco** has allochthonous and autochthonous elements.

Colored rows indicate geologic units mapped within Hopewell Furnace NHS.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
ORDOVICIAN	Beekmantown Group (**Ob**) Ontelaunee Formation (**Oo**) Epler Formation (**Oe**) Rickenbach Formation (**Ori**) Stonehenge Formation (**Os**)	**Ob** includes **Oo**, **Oe**, **Ori**, and **Os**. **Oo** is light to dark gray dolomite with very fine to medium crystalline textures; interlayered light gray limestone; and interbedded nodular, dark gray chert beds at the base. **Oe** includes light gray limestone with fine-grained textures interlayered with gray dolomite. Some coarsely crystalline lenses are present locally. **Ori** contains medium to dark gray coarsely crystalline dolomite in the basal beds topped by medium to light gray fine crystalline dolomite. Chert lenses, interbeds, and nodules are present locally. **Os** includes medium light gray to medium gray, fine crystalline, massive limestone with some dark, siliceous layers and conglomeratic beds.	Moderate	Avoid heavily dissolved units for heavy development due to weakness of friable textures; dissolved units are inherently porous, and thus do not act as effective filters for wastewater.	Resistant chert nodules and beds pose rockfall hazard when surrounding limestone and dolomite dissolve preferentially.	**Os** has fossil fragments in discrete lenses.	Chert nodules may have provided tool material to Native Americans.	Interlayered limestone and dolomite are susceptible to dissolution.	Limestone, dolomite.	Unit may dissolve to form cave habitats and produce Ca- and Mg-rich substrates.	Dissolved caves and cavities may attract attention.	Widespread thick unit that shows facies changes geographically, recording shifting depositional environments.
ORDOVICIAN AND CAMBRIAN	Conestoga Formation (**OCc**)	**OCc** contains light gray, thinly bedded contorted impure limestone with shaly partings. Conglomeratic layers present at base of unit. Locally metamorphosed to phyllite.	Moderate	Unit weathers easily to sand, which may render it too permeable for septic systems or too unstable for heavy development.	Unit is associated with rockfalls and slumps when exposed on slopes; alternating resistant and weaker layers are prone to fail if undercut. Black shale units may contain arsenic that could be released to groundwater and soils.	May contain Cambrian-Ordovician age fossils.	Scant chert nodules may have provided tool material for Native Americans.	Impure limestone layers may partially dissolve and compromise integrity of unit.	Pink marble locally.	Unit underlies deep sandy, well-drained soils.	Unit is friable and may be unstable base for trails on slopes.	Unit spans Cambrian to Ordovician boundary.
CAMBRIAN	Richland Formation (**Cr**) Allentown Formation (**Cal**) Millbach Formation (**Cm**) Elbrook Formation (**Ce**)	**Cr** contains gray dolomite with some oolitic beds and medium gray limestone and dark gray oolitic chert present locally. **Cal** is medium to medium dark gray, thick-bedded interlayered dolomite and impure limestone. Some chert stringers and nodules present locally with oolitic and stromatolitic calcareous siltstones at the base that weather to orange-brown. **Cm** includes pink to white and gray limestone and finely laminated crystalline dolomite. **Ce** is microcrystalline limestone with dolomite and metamorphosed layers of phyllite and marble.	Moderate to moderately high for metamorphic layers	Units are suitable for most development unless highly dissolved and/or fractured.	Units may be associated with karst hazards if dissolution is prevalent. When undercut, units pose rockfall hazards.	Stromatolites in **Cal** and **Cm**.	Chert nodules may have provided tool material for Native Americans.	Interlayered limestone and dolomite are susceptible to dissolution.	Marble, limestone.	None documented.	Units may attract caver attention and provide cave habitats.	Units contain evidence of life along a Cambrian-aged sea.
CAMBRIAN	Leithsville Formation (**Clv**) Buffalo Springs Formation (**Cbs**) Lower (Middle?) Cambrian rocks, undivided (**Cul**) Zooks Corner Formation (**Czc**)	**Clv** contains medium to dark gray crystalline dolomite that weathers to light yellowish-brown and gray. Unit is massive with some oolitic, pink to gray, mottled chert, thin shale and dolomitic shale interbeds with scattered sand grains. **Cbs** contains light pinkish-gray limestone and dolomite with fine to coarse crystalline textures. Numerous siliceous and clay-rich laminae are present. **Cul** includes tectonic slices of **Czc**, **Cl**, **Ck**, **Cv**, **Ca**, **Cah**, and **Ch**. **Czc** includes medium gray dolomite with fine crystalline textures and interlayered siliceous to argillaceous stingers.	Moderate	Heterogeneous nature of units may render them unstable on slopes, but suitable for most light development.	Limestone units may be associated with karst dissolution and processes, creating voids that may cause failure.	Stromatolites in **Cbs** near the top of the unit.	Chert nodules may have provided tool material for Native Americans.	Interlayered limestone and dolomite are susceptible to dissolution, forming caves, sinkholes, and smaller cavities.	Dolomite, limestone.	Units weather to form myriad substrates that support many types of forests.	Units are suitable for most recreation unless heavily dissolved or fractured; caves provide habitats for bats and other fauna.	**Cul** is arranged in tectonic slices, recording the depositional environments and tectonic history of the area. Units contain evidence of life along a Cambrian-aged sea.

Colored rows indicate geologic units mapped within Hopewell Furnace NHS.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
CAMBRIAN	Ledger Formation (**Cl**) Kinzers Formation (**Ck**) Vintage Formation (**Cv**)	**Cl** contains massive pure dolomite with some siliceous grading near the center of the beds. Unit appears light gray and mottled in outcrop. **Ck** consists of dark brown shale, gray to white spotted limestone, and marble in the lower beds, and sandy friable limestone in the upper beds. **Cv** is dark gray argillaceous dolomite with knotty textures and light gray marble in the basal layers locally.	Moderate	Units are suitable for most development unless highly dissolved and/or fractured.	Units weather to form friable, porous rocks that are unstable and may fail easily.	May contain Cambrian age fossils.	None documented.	Limestone and (to a lesser extent) dolomite are susceptible to dissolution.	Marble.	Units weather to well-drained sandy soils with abundant clay clasts.	Units are suitable for most recreation unless steep slopes are present; caves may attract attention.	Units record oscillating Cambrian marine and nearshore depositional environments.
CAMBRIAN	Antietam and Harpers Formations, undivided (**Cah**) Antietam Formation (**Ca**) Hardyston Formation (**Cha**) Harpers Formation (**Ch**) Chickies Formation (**Cch**)	**Cah** includes **Ca** and **Ch**. **Ca** consists of gray quartzite that appears buff in weathered outcrops. **Cha** includes light gray, fine- to medium-grained quartzite and feldspathic sandstone in massive beds. Some quartz pebble conglomerate in basal beds. **Ch** contains dark greenish-gray phyllite and schist with thin quartzite interbeds. **Cch** consists of light gray massive quartzite and quartz schist, with some thin interlayered slate in the upper beds and conglomeratic beds at base.	Moderate to very high for quartzite	Quartzite units cap ridges, and are suitable for most development unless highly fractured and/or exposed on steep slopes.	Units are associated with steep slopes and rockfall.	*Skolithos* in **Cha** and **Cch**.	Quartzite provided building material regionally.	None documented.	Quartzite.	Units underlie ridgetop, a well-drained habitat.	Resistant quartzite layers may attract rock climbers.	Units contain evidence of life along a Cambrian-aged sea.
PROBABLY LOWER PALEOZOIC	Pegmatite (**Xpg**) Granitic gneiss and granite (**Xgr**) Mafic gneiss (**Xmgh**) Ultramafic gneiss (**Xu** Octoraro Formation (**Xo**) "Glenarm Wissahickon" formation (**Xgw**) Wissahickon Formation (**Xw**)	**Xpg** contains coarse- to medium-grained textures and granitic compositions. **Xgr** is metamorphosed granodiorite. **Xmgh** is dark, medium-grained gneiss of metamorphosed sedimentary rocks. **Xu** includes serpentinite, steatite, and other altered peridotites and pyroxenites. **Xo** consists of albite-chlorite schist, phyllite, and hornblende gneiss. Granitized members are present locally. **Xgw** contains oligoclase-mica schist and lenticular amphibolite bodies of ocean floor basalt origin. **Xw** consists of oligoclase-mica schist, hornblende gneiss, augen gneiss, and some granitized quartz and feldspar rich members locally.	Moderately high to high	Avoid areas of intense preferential compositional weathering (along foliation and between heterogeneous lenses). Suitable for most development unless highly weathered and/or fractured.	Rockfall hazard when unit is exposed on slope, especially if slope and dominant foliation planes are parallel.	None.	**Xpg** crystals may have provided trade material.	None.	Pegmatite, augen gneiss.	None documented.	Units are suitable for most recreation unless highly altered, cleaved, and/or fractured.	Units record early metamorphic history and depositional environments.

Colored rows indicate geologic units mapped within Hopewell Furnace NHS.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
PRECAMBRIAN	Metadiabase (**md**) Anorthosite (**a**) Graphitic felsic gneiss (**gqm**) Felsic and intermediate gneiss (**ggd**) Banded mafic gneiss (**gga**) Graphitic felsic gneiss (**gg**) Franklin Marble (**fm**)	Unit **md** is dark gray (greenish), fine-grained altered diabase intrusions. Unit **a** contains medium- to coarse-grained, bluish-gray plagioclase-rich rock with alteration minerals present locally. Unit **gqm** is medium-grained, dark gray, gneissic feldspar and quartz with some altered areas. Unit **ggd** contains medium-grained, pink to greenish-gray gneiss of quartz, feldspar, and mica. Unit **gga** interfingers with **ggd** and contains dark, fine- to medium-grained banded gneiss of sedimentary origin. Unit **gg** contains medium-grained gray gneiss and marble with quartz, feldspar, graphite, and metamorphic minerals. Unit **fm** is coarse-grained, white, crystalline marble with disseminated graphite flakes.	High	Units are fine for most development unless heavily altered and/or fractured.	Rockfall hazard when units are exposed on slope, especially if slope and dominant cleavage direction are parallel.	None.	Marble may have provided quarry material.	Some dissolution of marble beds possible.	Gneiss, marble, graphite.	None documented.	Units are suitable for most recreation unless highly altered, cleaved, and/or fractured.	Units record accretion of distinct crustal blocks onto the North American continent. At approximately 1 billion years old, these are some of the oldest rocks in Pennsylvania
PRECAMBRIAN	Felsic and intermediate gneiss (**fgh**) Felsic gneiss (**fgp**) Hornblende gneiss (**hg**) Mafic gneiss (**mgh**) Mafic gneiss (**mgp**); Felsic to mafic gneiss (**gn**)	Unit **fgh** contains light-appearing gneiss with medium-grained textures likely of sedimentary origin. Unit **fgp** consists of light, medium-grained silicic gneissic rocks. Unit **hg** is dark, medium-grained gneiss likely of sedimentary origin. Units **mgh** and **mgp** are similar, consisting of dark, medium-grained gneiss likely of sedimentary origin. Unit **gn** is quartz and light feldspar-bearing gneiss of medium-grained texture and likely igneous origin.	High unless highly weathered	Avoid areas of intense preferential compositional weathering (along foliation and between heterogeneous lenses). Suitable for most development unless highly weathered and/or fractured.	Units may pose rockfall hazard if undercut or exposed on a slope.	None.	None documented.	None.	Gneiss.	Mafic gneiss develops into Fe-, Mg-, and Ca-rich substrates that support myriad forest types.	Units are suitable for most recreation unless highly altered, cleaved, and/or fractured.	Metamorphosed rocks retain features and compositions characteristic of sedimentary and/or igneous origin. At approximately 1 billion years old, these are some of the oldest rocks in Pennsylvania

Geologic History

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

Hopewell Furnace National Historic Site (along with neighboring French Creek State Park) straddles the boundary between two sections of the Piedmont physiographic province: the Piedmont Upland and the Gettysburg Newark Lowland sections (Sevon 2000). The geologic units in the mapped area within and surrounding Hopewell Furnace National Historic Site reflect a vast period of geologic history from the Proterozoic Eon through the Quaternary Period (figs. 10 and 11). The following text presents a regional perspective to connect the landscape and geology of the park to its surroundings.

Precambrian Mountain-Building and Extension (prior to 542 million years ago)

During the mid-Proterozoic, approximately 1 billion years ago, the Grenville orogeny (mountain-building episode) resulted in the formation of a supercontinent that contained most of the continental crust in existence, including the cratonic masses of North America and Africa. Where land masses collided, high mountains formed. The metamorphic granites and gneisses in the core of the modern Blue Ridge Mountains, west of Hopewell Furnace, record the sedimentation, deformation, plutonism (intrusion of igneous rocks), and volcanism associated with this geologic period (Harris et al. 1997). Precambrian-age gneisses outcrop as small boulders east of Mt. Pleasure at Hopewell Furnace National Historic Site (Inners and Fergusson 1996; Brown 2002). Regionally, geologic units of this time include mafic to felsic gneisses, marbles, and metadiabase (Berg et al. 1980).

Following the Grenville orogeny, regional uplift and hundreds of millions of years of subsequent erosion beveled the landscape. Erosion of the Grenvillian highlands formed a basement surface for the younger rocks of the Appalachian Mountains (Southworth et al. 2001). Roughly 800 to 600 million years ago, extensional tectonic forces created rift zones and fissures through which massive volumes of basaltic magma extruded (fig. 12A). The volcanic rocks covered the Precambrian crystalline basement in southern Pennsylvania. Now metamorphosed into greenstones, the Catoctin Formation outcrops in central Maryland at Catoctin Mountain Park (Thornberry-Ehrlich 2009).

Paleozoic Events (542 to 251 million years ago)

Extensional tectonic forces caused the supercontinent to break up and opened a sea basin that eventually expanded to become the Iapetus Ocean (fig. 12B). Depositional environments associated with this open basin include alluvial fans, large submarine landslides, and turbidity flows (Southworth et al. 2001). Deposits of sand, silt, and mud covered older sediments in nearshore, deltaic, barrier island, and tidal flat areas along the eastern margin of the North American continent (Schwab 1970; Kauffman and Frey 1979; Simpson 1991).

Exposed within Hopewell Furnace National Historic Site are the massive quartzite and quartz schist of the Chickies Formation (Berg et al. 1980). The erosion-resistant quartzite, prominent on the ridges in the Hopewell Furnace area, is a late Precambrian to early Cambrian (~ 550 million years ago) metasedimentary rock, originally deposited in near-shore marine environments as quartz-rich sandstones (Inners and Fergusson 1996; Brown 2002; Topinka 2005). Regionally, units such as the Harpers and Antietam formations also formed in this depositional environment (Berg et al. 1980).

Approximately 500 million years ago, the ocean basin deepened and the shoreline transgressed onto the continental margin, forming the depositional setting for chemical sediments (Bechtel et al. 2005). A carbonate platform, thickening to the east, was the depositional setting for huge masses of carbonate, sandstone, and shale rocks that persisted during the Cambrian throughout the Ordovician Period (545 to 480 million years ago) (Means 1995). The ocean basin deepened, and carbonate units precipitated in this depositional environment (Means 1995; Bechtel et al. 2005). Carbonates (perhaps dolomite of the Vintage Formation) may be exposed in the lowest-lying stretches of French Creek at Hopewell Furnace (National Park Service 2009). Regionally, other Cambrian carbonate units include the Ledger, Kinzers, Elbrook, Millback, and Richland formations (Berg et al. 1980). Limestone quarried from these units were incorporated into many local buildings and structures, including the furnace at Hopewell.

Cambrian to Ordovician units within the regional map area of Hopewell Furnace, such as the Conestoga Formation, record the transition from the carbonate platform to the more nearshore terrestrial deposition associated with initial uplift during the Taconic orogeny.

Taconic Orogeny

Following approximately 50 million years of tectonic quiescence and sedimentation, orogenic activity along the eastern margin of the North American continent began again as a volcanic arc collided with the continental mass approximately 440 to 420 million years ago (Means 1995; Bechtel et al. 2005). During the Taconic orogeny, compressional tectonic forces closed the Iapetus Ocean, created volcanic arcs, thrust oceanic crust and the volcanic arc from the Iapetus basin onto the eastern edge of the North American continent, and uplifted the continental crust. The intense heat and pressure accompanying deep burial and compressional tectonic forces caused metamorphism of igneous and nearshore sediments into metabasalts, quartzites and phyllites.

The crust bowed downward west of the rising mountains in response to the overriding tectonic plate thrusting westward onto the continental margin of North America, creating a deep foreland basin that filled with mud and sand eroded from the highlands to the east (fig. 12C) (Harris et al. 1997). This so-called Appalachian basin, centered on what is now West Virginia, collected vast amounts of sediments throughout the Paleozoic Era (fig. 11).

Acadian Orogeny

The Acadian orogeny (~360 million years ago) continued the mountain building of the Taconic orogeny north of the Hopewell Furnace area as the African continent moved toward North America (Harris et al. 1997). The Acadian event involved collision of land masses (North American, Europe, and Avalonia [now parts of western Europe, eastern North America]), mountain building, and regional metamorphism similar to the preceding Taconic orogeny (Means 1995; Barnes and Sevon 2002). The Acadian mountains formed east of Pennsylvania during this event (Barnes and Sevon 2002). Tectonic quiescence following the Acadian orogeny led to vast regional deposition of sediments shed from the eroding highlands into the Appalachian basin throughout the Mississippian and Pennsylvanian periods (fig. 12C) (Barnes and Sevon 2002).

Alleghany Orogeny

During the Late Paleozoic (fig. 11), the proto-Atlantic Ocean closed as the North American continent collided with the African continent. This formed a super-continent named Pangaea, and, as a result, formed the present-day Appalachian Mountains. The Alleghany orogeny (~325 to 265 million years ago) was the last major mountain-building event to affect the Appalachians (fig. 12D) (Means 1995).

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

An estimate of the highest paleoelevation of the Alleghany-era Appalachian Mountains is approximately 6,100 m (20,000 ft), making them analogous to the modern-day Himalaya Range in Asia. Since their uplift, erosion beveled these mountains to elevations less than 730 m (2,400 ft) above sea level west of Hopewell Furnace National Historic Site (Means 1995). Erosion exposed the early Paleozoic formations, including the quartzites and carbonates, following the Alleghany orogeny (Bechtel et al. 2005).

Mesozoic Extension (251 to 65.5 million years ago)

During the late Triassic Period, approximately 230 to 200 million years ago, extensional tectonic forces pulled apart the supercontinent Pangaea, creating the Atlantic Ocean. Along the eastern margin of the North American continent, many block-fault basins developed, accompanied by volcanism (figs. 12E and 13) (Harris et al. 1997; Southworth et al. 2001). The uplifted Paleozoic units, including the quartzite and carbonate rocks, in the Hopewell Furnace area sank in the half-graben Gettysburg-Newark Rift Basin formed by reactivated Paleozoic thrust faults (Schlische and Olsen 1988; Bechtel et al. 2005).

Forces of gravity, wind, and running water eroded and transported thick deposits of unconsolidated gravel, sand, and silt from the Alleghanian Mountains into rift basins such as the Gettysburg-Newark Basin (see figs. 12E and 3). Throughout the basin, Triassic sandstone and shale red beds rest unconformably on the Cambrian-age units (Bechtel et al. 2005). The sandstone and conglomerate of the Stockton Formation and the sandstone, siltstone, and mudstone of the Hammer Creek Formation formed in this depositional environment in the area of Hopewell Furnace (Inners and Fergusson 1996; Brown 2002). The rapid lithologic changes within the Triassic rocks record shifting depositional regimes from near-shore, fluvial, lacustrine, and alluvial fan (Sloto and McManus 1996).

Regional volcanic activity accompanied the rift basin formation throughout the Mesozoic. During the Jurassic, diabase magma intruded the rift basin sediments. Magma that did not reach the surface solidified approximately 185 to 200 million years ago as diabase dikes, which are now exposed by erosion in the Hopewell Furnace area (Inners and Fergusson 1996; Brown 2002; Topinka 2005). Magma came into contact with the existing native/country rock, causing changes in its mineralogy (W. Kochanov, written communication, 2010). This igneous activity formed magnetite ($Fe^{3+}_2Fe^{2+}O_4$) ore bodies that became the source of the iron produced at Hopewell Furnace National Historic Site (Inners and Fergusson 1996).

At nearby Millers Point, the exposure of diabase on the edge of the escarpment overlooking the Schuylkill River is part of the Morgantown Pluton, a bowl-shaped body of igneous intrusive rock exposed on the eastern and northern edges of French Creek State Park (Inners and Fergusson 1996). The pluton occurs at a depth of about 1.6 km (1 mi) near Hopewell Lake. A normal fault, along which rocks to the south are downdropped relative to the rocks to the north, cuts the pluton north of Millers Point (Topinka 2005).

As the rift basins filled with sediment, deposition continued to spread eastward to form the Atlantic Coastal Plain province. Thick layers of Cretaceous units (such as the Patapsco Formation) and Tertiary units (such as the Pensauken, Bridgeton, and Bryn Mawr Formations) east of Hopewell Furnace record this environment (fig. 12F) (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Berg et al. 1980). An immense amount of deposited material is inferred from the now-exposed metamorphic rocks in the Blue Ridge province. Many of the rocks exposed at the surface were at least 20 km (~10 mi) below the surface prior to regional uplift and erosion.

Cenozoic Landform Evolution (65.5 million years ago until today)

The North American plate continues to move toward the west since the breakup of Pangaea and the uplift of the Appalachian Mountains. The isostatic adjustments that uplifted the continent after the Alleghany orogeny continued at a slower rate throughout the Cenozoic Era (Harris et al. 1997). Over these millions of years, weathering and erosion have beveled the highlands, muting the topography, and removing soluble, less resistant rocks such as carbonates. Quartzites, being more resistant to erosion, stand out as ridges and high ground such as Mt. Pleasure. Other rocks weathered to produce thick layers of clay-rich saprolite (Barnes and Sevon 2002).

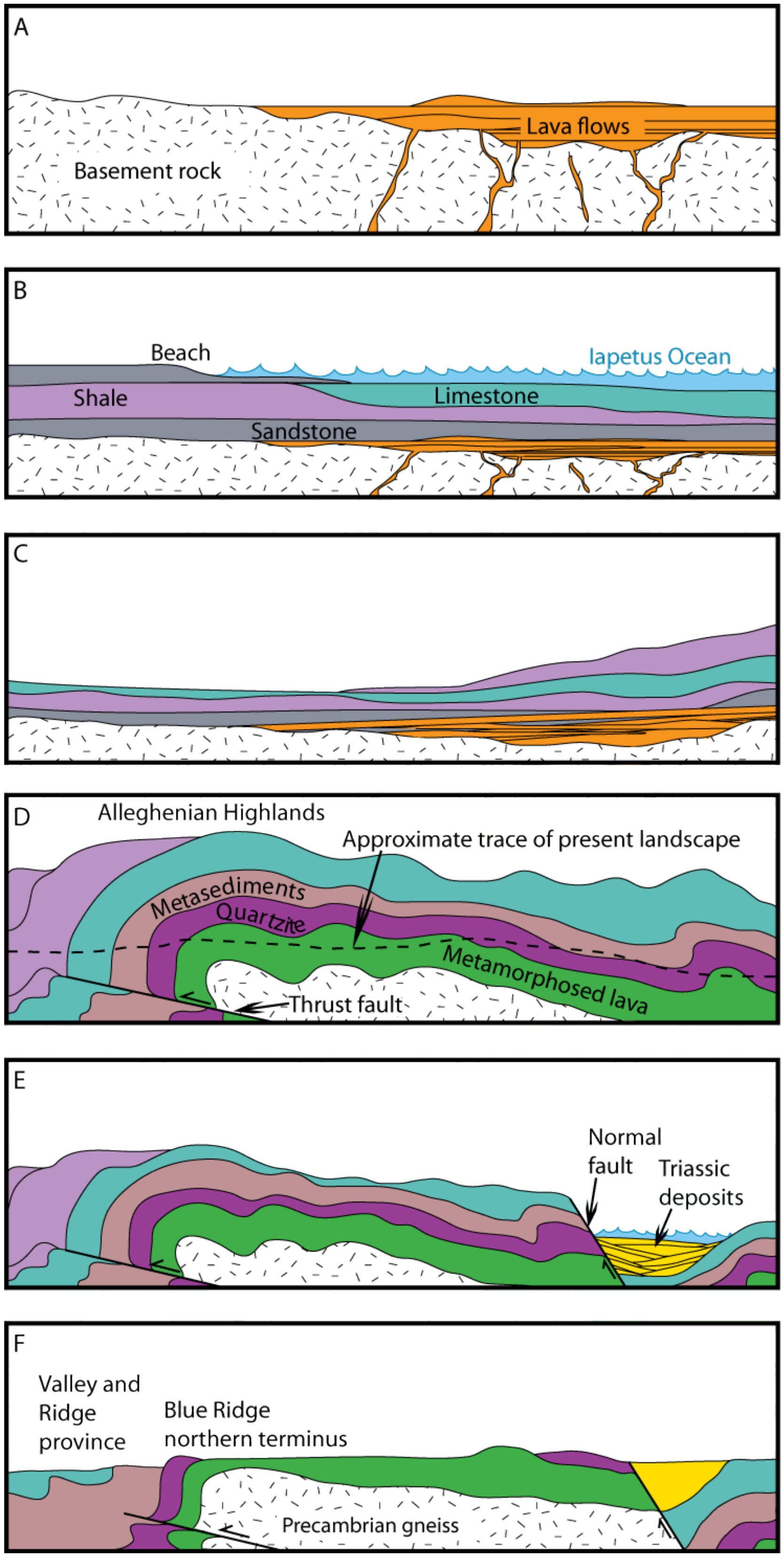
Following the early stages of modern drainage development in the late Mesozoic and early Cenozoic, rivers such as French Creek (that were initially short) grew longer through the process of headward erosion. Headward erosion generally involves a stream extending at its source, but can also include stream piracy in which the head of one stream intersects the head of another and captures a part of the other’s drainage (Barnes and Sevon 2002).

The masses of continent-scale ice sheets from the Pleistocene Ice Ages (most recent advance was about 19,000 years ago) never reached the Hopewell Furnace area in southeastern Pennsylvania. The southern terminus was at an elevation of 365 to 610 m (1,200 to 2,000 ft) in northern Pennsylvania. In the northern part of Pennsylvania, glaciers carved upland surfaces into rounded ridges and left behind 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 the national historic site. The periglacial conditions that existed in close proximity to the ice sheets intensified weathering and other erosional processes such as frost wedging and congelifluction in which a relatively thin layer of soil and earth thawed and moved (slid) during the summer months above a permafrost layer (Harris et al. 1997; Sevon and Fleeger 1999). Talus deposits containing large boulders of Chickies quartzite flanking the slopes of Mount Pleasure at Hopewell Furnace National Historic Site record the periglacial accelerated physical weathering processes during the Ice Age (Inners and Fergusson 1996). Landforms and gravel deposits such as the Trenton Gravel (found east of Hopewell Furnace) formed when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into the ancestral river channels, enhancing downcutting and erosion by waterways and causing subsequent increases in downstream deposition (Means 1995; Zen 1997a, 1997b).

Erosion throughout the Quaternary Period continues to shape the present landscape, with the Schuylkill River and its tributaries eroding through thick piles of sediments, lowering hill slopes, and depositing alluvial terraces along the rivers. Mass wasting processes supplement stream erosion, beveling the undulating topography. Streams redistribute sediments in riparian zones along waterways and intermittently transport them toward the Atlantic Ocean to become part of the Atlantic Coastal Plain. Anthropogenic land disturbance activities such as agriculture, industrialization, deforestation, quarrying, and widespread urban development exacerbate natural erosion throughout the area.

Eon	Era	Period	Epoch	Ma		Life Forms	North American Events
Phanerozoic	Cenozoic	Quaternary	Holocene		Age of Mammals	Modern humans	Cascade volcanoes (W)
				0.01			
			Pleistocene			Extinction of large mammals and birds	Worldwide glaciation
				2.6			
		Tertiary: Neogene	Pliocene			Large carnivores	Sierra Nevada Mountains (W)
				5.3		Whales and apes	Linking of North and South America
			Miocene				
				23.0			Basin-and-Range extension (W)
		Tertiary: Paleogene	Oligocene				
				33.9			
			Eocene			Early primates	Laramide Orogeny ends (W)
				55.8			
			Paleocene				
				65.5			
	Mesozoic	Cretaceous			Age of Dinosaurs	**Mass extinction** Placental mammals Early flowering plants	Laramide Orogeny (W) Sevier Orogeny (W) Nevadan Orogeny (W)
				145.5			
		Jurassic				First mammals **Mass extinction**	Elko Orogeny (W) Breakup of Pangaea begins
				199.6			
		Triassic				Flying reptiles First dinosaurs	Sonoma Orogeny (W)
				251			
	Paleozoic	Permian			Age of Amphibians	**Mass extinction** Coal-forming forests diminish	Supercontinent Pangaea intact Ouachita Orogeny (S) Alleghanian (Appalachian) Orogeny (E)
				299			Ancestral Rocky Mountains (W)
		Pennsylvanian				Coal-forming swamps Sharks abundant	
				318.1			
		Mississippian				Variety of insects First amphibians	
				359.2		First reptiles	Antler Orogeny (W)
		Devonian			Fishes	**Mass extinction** First forests (evergreens)	Acadian Orogeny (E-NE)
				416			
		Silurian				First land plants	
				443.7			
		Ordovician			Marine Invertebrates	**Mass extinction** First primitive fish Trilobite maximum Rise of corals	Taconic Orogeny (E-NE)
				488.3			
		Cambrian				Early shelled organisms	Avalonian Orogeny (NE) Extensive oceans cover most of North America
				542			
Proterozoic		Precambrian				First multicelled organisms Jellyfish fossil (670 Ma)	Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
				2500			
Archean						Early bacteria and algae	
				≈4000			Oldest known Earth rocks (≈3.96 billion years ago)
Hadean						Origin of life?	Oldest moon rocks (4–4.6 billion years ago)
				4600		Formation of the Earth	Formation of Earth's crust

Figure 11. Geologic time scale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic 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/ with additional information from the International Commission on Stratigraphy. http://www.stratigraphy.org/view.php?id=25.



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

B: 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.

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

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

E: 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.

F: 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 southern Pennsylvania. Tectonic changes are shown from the Precambrian through the present. Ma = Millions of years ago. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Means (1995) and Fedorko et al. (2004). Note: graphic is not to scale.

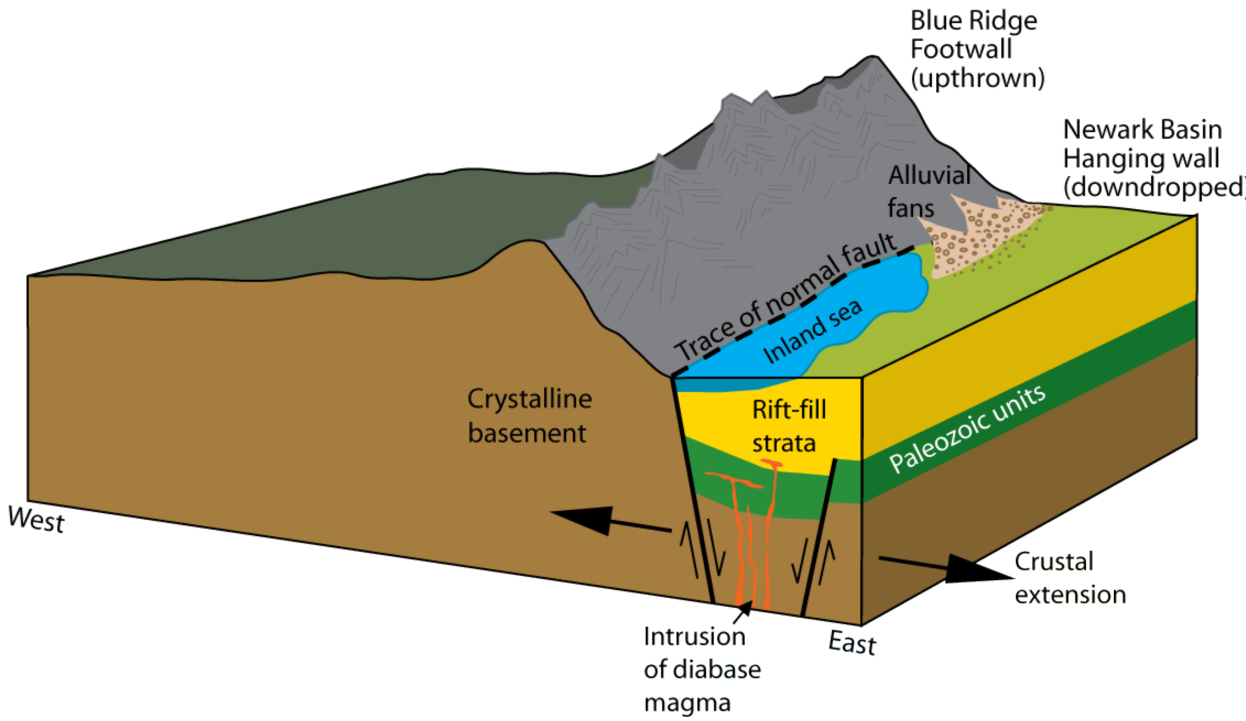


Figure 13. Triassic extension of the Newark Basin. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University). Note: graphic is not to scale.

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://geomaps.wr.usgs.gov/parks/misc/glossarya.html. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).

absolute age. The geologic age of a fossil, rock, feature, or event in years; commonly refers to radiometrically determined ages.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountainous area into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

anticline. A convex-upward ("A" shaped) fold. Older rocks are found in the center.

anticlinorium. A large, regional feature with an overall shape of an anticline. Composed of many smaller folds.

aquifer. A rock or sedimentary unit that is sufficiently porous that it has a capacity to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.

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

batholith. A massive, discordant pluton, larger than 100 km^2 (40 mi^2), and often formed from multiple intrusions of magma.

bedding. Depositional layering or stratification of sediments.

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

calcareous. Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).

carbonate rock. A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).

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. Chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances; commonly results in a change in chemical composition more stable in the current environment.

clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts).

clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

claystone. Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

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

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented, rounded clasts larger than 2 mm (0.08 in).

continental crust. Crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

convergent boundary. A plate boundary where two tectonic plates are colliding.

country rock. The rock surrounding an igneous intrusion or pluton. Also, the rock enclosing or traversed by a mineral deposit.

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

creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.

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 a vertically oriented plane.

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

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

deformation. A general term for the process of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

delta. A sediment wedge deposited where a stream flows into a lake or sea.

dike. A narrow igneous intrusion that cuts across bedding planes or other geologic structures.

dip. The angle between a bed or other geologic surface and horizontal.

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

dolomite. A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).

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

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

extrusive. Describes igneous material that has erupted onto Earth's surface.

facies (metamorphic). The pressure and temperature conditions that result in a particular, distinctive suite of metamorphic minerals.

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

fanglomerate. A sedimentary rock of heterogeneous materials that were originally deposited in an alluvial fan and have since been cemented into solid rock.

fault. A break in rock along which relative movement has occurred between the two sides.

footwall. The mass of rock beneath a fault surface (also see "hanging wall").

formation. Fundamental rock-stratigraphic unit that is mappable, 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, or fault).

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

graben. A down-dropped structural block bounded by steeply dipping, normal faults (also see "horst").

hanging wall. The mass of rock above a fault surface (also see "footwall").

horst. Areas of relative "up" between grabens, representing the geologic surface left behind as grabens drop. The best example is the Basin-and-Range province of Nevada. The basins are grabens and the ranges are weathered horsts. Grabens become a locus for sedimentary deposition (also see "graben").

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

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

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

isostacy. The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere. Crustal loading (commonly by large ice sheets) leads to isostatic depression or downwarping; removal of the load leads to isostatic uplift or upwarping.

joint. A 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. Very thin, parallel layers.

landslide. Any process or landform resulting from rapid, gravity-driven mass movement.

lava. Still-molten or solidified magma that has been extruded onto Earth's surface though a volcano or fissure.

limestone. A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

lineament. Any relatively straight surface feature that can be identified via observation, mapping, or remote sensing, often reflects crustal structure.

lithify. To change to stone or to petrify; especially to consolidate from a loose sediment to a solid rock through compaction and cementation.

lithology. The physical description or classification of a rock or rock unit based on characters such as its color, mineral composition, and grain size.

mafic. Describes dark-colored rock, magma, or minerals rich in magnesium and iron. Compare to "felsic."

magma. Molten rock beneath Earth's surface capable of intrusion and extrusion.

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

mass wasting. A general term for the downslope movement of soil and rock material under the direct influence of gravity.

mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with "physical weathering."

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

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

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 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

orogeny. A mountain-building event.

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

parent material. Geologic material from which soils form.

passive margin. A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America. (also see "active margin").

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

phyllite. A metamorphosed rock, intermediate in grade between slate and mica schist, with minute crystals of graphite, sericite, or chlorite that impart a silky sheen to the surfaces ("schistosity").

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

pluton (plutonic). A body of intrusive igneous rock that crystallized at some depth beneath Earth's surface.

porosity. The proportion of void space (e.g., pores or voids) in a volume of rock or sediment deposit.

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

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

radiometric age. An age expressed in years and calculated from the quantitative determination of radioactive elements and their decay products.

recharge. Infiltration processes that replenish groundwater.

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

relative dating. Determining the chronological placement of rocks, events, or fossils with respect to the geologic time scale and without reference to their numerical age.

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

rift. A region of crust where extension results in formation of many related normal faults, often associated with volcanic activity.

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

sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

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

scarp. A steep cliff or topographic step resulting from displacement on a fault, or by mass movement, or erosion. Also called an "escarpment."

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

sedimentary rock. A consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

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 to 1/16 mm [0.00015 to 0.002 in]).

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

slope. The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "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 often overlying the parent material from which it formed.

spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

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

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

stream. Any body of water moving under gravity flow in a clearly confined channel.

stream channel. A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

stream terrace. 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).

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

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault. Said to be "sinistral" (left-lateral) if relative motion of the block opposite the observer appears to be to the left. "Dextral" (right-lateral) describes relative motion to the right.

structure. The attitude and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusions.

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.

syncline. A downward curving (concave up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.

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

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

terrace. A relatively level bench or steplike surface breaking the continuity of a slope (see "marine terrace" and "stream terrace").

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

terrestrial. Relating to land, Earth, or its inhabitants.

thrust fault. A contractional dip-slip fault with a shallowly dipping fault surface (less than 45°) where the hanging wall moves up and over relative to the footwall.

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

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

trace fossil. Tracks, trails, burrows, coprolites (dung), etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

transgression. Landward migration of the sea as a result of a relative rise in sea level.

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

type locality. The geographic location where a stratigraphic unit (or fossil) is well displayed, formally defined, and derives its name. The place of original description.

unconformity. An erosional or non-depositional surface bounded on one or both sides by sedimentary strata that marks a period of missing time.

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

volcanic. Describes anything related to volcanoes. Can refer to igneous rock crystallized at or near Earth's surface (e.g., lava).

water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.

weathering. The physical, chemical, and biological processes by which rock is broken down.

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Additional References

This section lists additional references, resources, and web sites that may be of use to resource managers.

Geology of National Park Service Areas

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NPS Geologic Resources Inventory Publications. http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

U.S. Geological Survey Geology of National Parks (includes 3D photographs). http://3dparks.wr.usgs.gov/

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NPS Geoscientist-in-the-parks (GIP) internship and guest scientist program. http://www.nature.nps.gov/geology/gip/index.cfm

Resource Management/Legislation Documents

NPS 2006 Management Policies (Chapter 4; Natural Resource Management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

NPS-75: Natural Resource Inventory and Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf.

NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/

Geologic Monitoring Manual
R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado. [Website under development]. Contact the Geologic Resources Division to obtain a copy.

NPS Technical Information Center (Denver, repository for technical (TIC) documents): http://etic.nps.gov/

Geological Survey Websites

Pennsylvania Geological Survey: http://www.dcnr.state.pa.us/topogeo/index.aspx

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U.S. Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geological Institute: http://www.agiweb.org/
Association of American State Geologists: http://www.stategeologists.org/

Other Geology/Resource Management Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator").

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

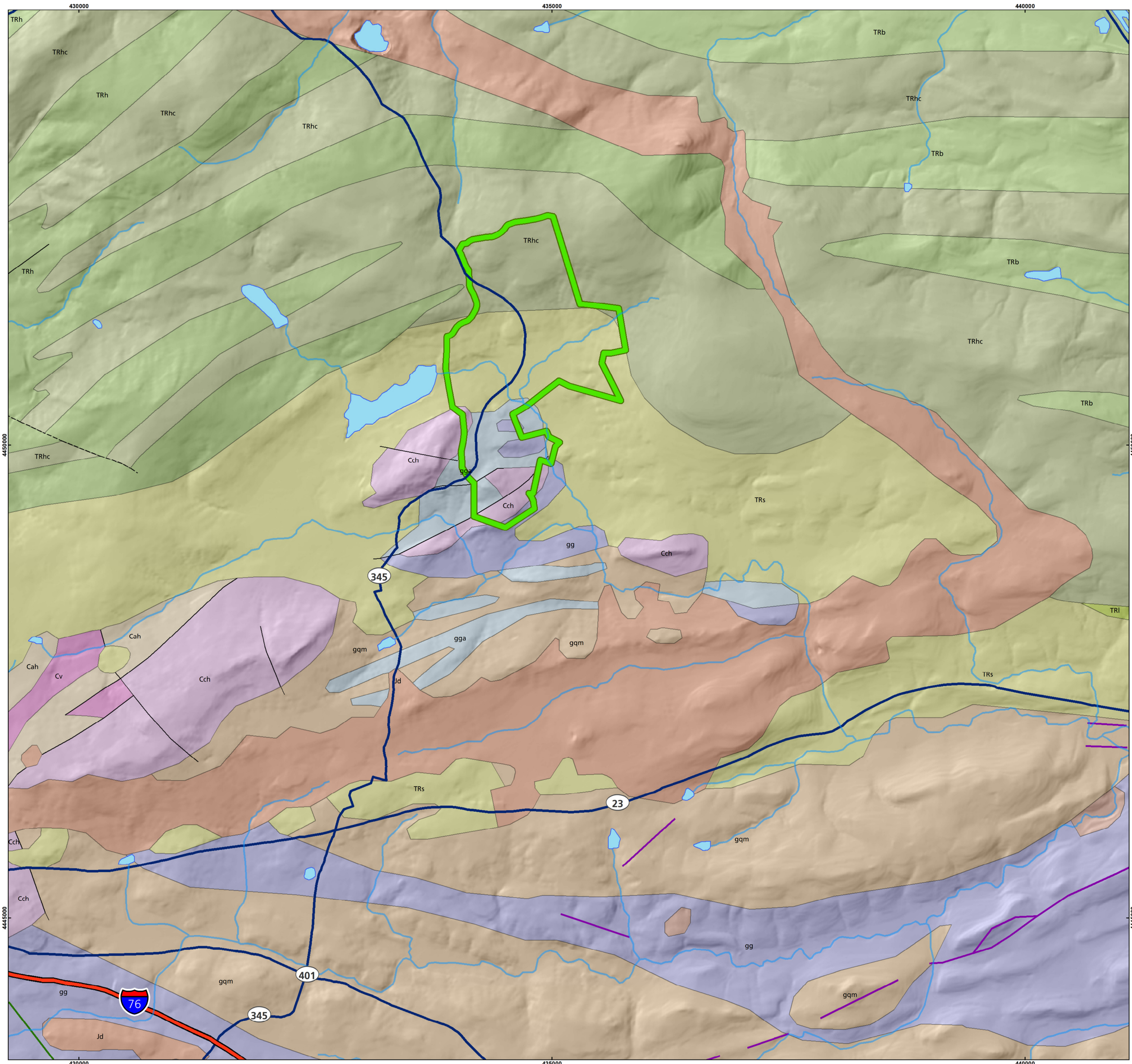
Appendix A: Overview of Digital Geologic Data

The following page is an overview of the digital geologic data for Hopewell Furnace National Historic Site. For a poster-size PDF of this overview and complete digital data, please see the included CD or visit the Geologic Resources Inventory publications web site (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Hopewell Furnace National Historic Site
Pennsylvania

National Park Service
U.S. Department of the Interior

Overview of Digital Geologic Data for Hopewell Furnace National Historic Site



UTM Zone 18N NAD 83

scale greater than source data

Miles: 0, 1, 2

Kilometers: 0, 1, 2

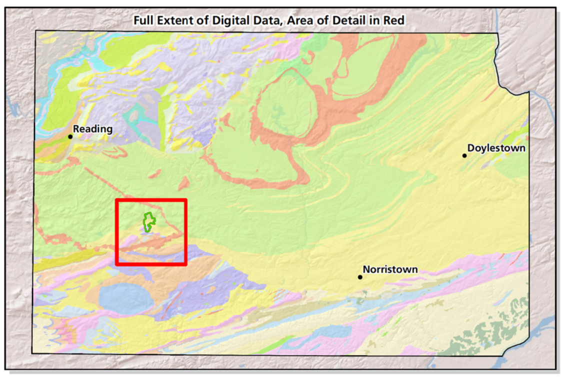
This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. The source map used in creation of the digital geologic data product was:

Miles, C. E. and Whitfield, T. G. (compilers). 2001. *Digital Bedrock Geology of Pennsylvania: Pennsylvania Geological Survey, 4th series*. 1:250,000 scale from: Berg, T.M. 1980. Geologic Map of Pennsylvania. Pennsylvania Geological Survey. PA DCNR Map 1. 1:250,000 scale.

Digital geologic data for Hopewell Furnace National Historic Site, 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/

N

Full Extent of Digital Data, Area of Detail in Red



NPS Boundary

Faults
- unknown offset/displacement, known or certain
- unknown offset/displacement, approximate

Dikes
- Xpg, known or certain
- md, known or certain

Geologic Contacts
- known or certain
- approximate

Geologic Units
- Jd - Diabase
- TRb - Brunswick Formation
- TRh - Hammer Creek Formation
- TRl - Lockatong Formation
- TRhc - Hammer Creek Conglomerate
- TRs - Stockton Formation
- Cv - Vintage Formation
- Cah - Antietam and Harpers Formations, undivided
- Cch - Chickies Formation
- gqm - Graphitic felsic gneiss
- gga - Banded mafic gneiss
- gg - Graphitic felsic gneiss
- fm - Franklin Marble

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