National Park Service
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Natural Resource Program Center

Valley Forge National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2010/236

THIS PAGE:
Reconstruction of a hut built by soldiers of Washington's Continental Army to survive the winter of 1777-1778.

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ON THE COVER:
The Grand Parade ground of Valley Forge National Park, view from the Huntington Camp. Mount Joy rises in the background.

National Park Service photograph by Megan Carfioli, courtesy Amy Ruhe and Kristina Heister (Valley Forge National Historical Park).

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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Executive Summary

This report accompanies the digital geologic map data for Valley Forge National Historical Park 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.

In December 1777, after a series of battles, British forces occupied Philadelphia and George Washington sought a suitable winter encampment site for his tired troops. Washington chose Valley Forge, an easily defended location on the southern banks of the Schuylkill River. This position buffered the colonial army against British surprise attacks, while providing them enough proximity to apply constant pressure to the British forces. Harsh conditions and lack of adequate provisions tested the resolve and endurance of the army, eventually hardening them and inspiring the French to join the revolution toward American independence from Britain. Valley Forge National Historical Park commemorates the spirit of independence and educates the public about this pivotal moment in American history.

Valley Forge is located in the eastern Piedmont physiographic province, adjacent to the Atlantic Coastal Plain and near the junction of the Gettysburg-Newark Lowland, Piedmont Upland, and Piedmont Lowland sections. The rocks in this area range from metamorphosed and deformed Precambrian gneisses and Paleozoic metamorphosed sedimentary rocks to the gently tilted, much younger sedimentary strata of the Mesozoic rift basins. Within the park, Triassic-age red shales lay juxtaposed against Cambrian carbonate-bearing units in an approximately 300-million-year unconformity. These rocks contain fossils and hold clues to the geologic history of the area. Like its historical resources, the park's geologic resources deserve emphasis and interpretation.

Geology provides the foundation for the entire ecosystem. Geologic processes initiate complex responses that produce rock formations, topographic expression, surface and subsurface fluid movement, and soils. At Valley Forge, human land-use disturbances are also apparent. Prospectors dug pits and quarries in search of limestone, altering the topographic expression of the landscape. Slopes and meadows have been logged and cleared for agricultural use, and dredged river-bottom sediments now line riparian zones. The following issues have a high level of resource management importance at Valley Forge National Historical Park:

- Karst Issues. Karst processes and features are important evolutionary factors for the landscape of this historical park. Karst landscapes are produced by the dominant geomorphic processes of chemical erosion and weathering of limestone or dolomite. When this dissolution occurs underground, voids and conduits can develop into a vast karst network. Cambrian limestones were quarried extensively in the area, and dissolution of these limestones formed caves and sinkholes, such as Bone Cave (Port Kennedy Cave). Karst processes are still active at Valley Forge National Historical Park and may threaten park infrastructure and visitor safety.
- Water and Sediment Issues. The Schuylkill River and several tributaries flow through the historical park. Surrounding urbanization and industrial activities threaten the surface and groundwater, as well as the sediments within the area's streambeds. It is crucial that park management be knowledgeable about the area's hydrogeologic system. Recent studies have focused on understanding the multilayered aquifer system underlying Valley Forge National Historical Park. A nearby Superfund site is a point source of groundwater contaminants. Other research within the park has examined contaminant-laden sediment loads in local streams and potential sources of contaminants.
- Paleontological Resources. Fossils can record information that allows researchers to reconstruct past depositional environments and paleoclimates. They may also provide information on post-burial taphonomic conditions, including geochemical changes, deformational regimes, and changes in bedding orientation. Several geologic units in the park are fossiliferous, containing stromatolites, *Skolithos* burrows, trilobites, and conodonts. One of the most important Pleistocene-age fossil deposits in North America is located in a karst feature within park boundaries. This feature contains unique species and a rich record of numerous plants, insects, reptiles, and mammals. Currently buried beneath industrial fill, the site's historic significance is related to paleontology and limestone quarrying.

Other issues of resource management concern at Valley Forge National Historical Park include slope processes, disturbed lands and mineral development, and geologic influences on the park's history. Since American Indians first inhabited the region, humans have come to Valley Forge to take advantage of the natural resources, including geological resources. George Washington chose Valley Forge as the encampment site of the colonial army because of landscape features shaped by geologic processes.

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.

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Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Valley Forge National Historical Park.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by 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/).

Geologic Setting

Precambrian crystalline rocks, Lower Paleozoic metamorphosed sedimentary rocks (metasediments) and sedimentary rocks, and Triassic sedimentary rocks underlie the landscape at Valley Forge National Historical Park. The Triassic-age sediments overlap the Precambrian rocks from the north in the northwestern corner of the park. To the south, Lower Paleozoic rocks cover the Precambrian complex. The older, Paleozoic geologic units in the Valley Forge area are faulted and deformed, with varying degrees of metamorphism preserved in outcrop exposures. The younger Triassic-age rocks are generally flat-lying and undeformed, with surface variations due to erosion and downcutting of rivers through the horizontal layers.

The Schuylkill River flows eastward through the northern reaches of the park, and rolling hills dominate the southern park landscape (fig. 1). The eastern termination of the North Valley Hills is at Mount Misery and a small portion of Chester Valley to the south. Mount Joy is located east of the confluence of Valley Creek and the Schuylkill River. Other tributaries to the Schuylkill flow through the park, including Trout Creek, Myer's Run, and Lamb Run. Within park boundaries, elevations range from less than 25 m (80 ft) above sea level along the banks of the Schuylkill River to just over 120 m (400 ft) above sea level atop Mount Joy.

Valley Forge National Historical Park is located near the junction of the Atlantic Coastal Plain and the Piedmont province, described below (fig. 2). Three Piedmont subprovinces meet in this area; from west to east, these are the Gettysburg-Newark (Triassic) Lowland Section, the Piedmont Lowland Section, and the Piedmont Upland Section. A general east-to-west description of several physiographic provinces of the Appalachian Mountains follows.

Atlantic Coastal Plain Province

The Atlantic Coastal Plain province is predominantly flat terrain, with elevations ranging from sea level to less than 100 m (300 ft) above sea level in the southeastern corner of Pennsylvania. This province extends from New York to Mexico, and from the Fall Line east to Chesapeake Bay and the Atlantic Ocean. It was formed by the intermittent deposition of a wedge-shaped sequence of sediments eroding from the Appalachian Highlands to the west, during periods of elevated sea level in the past 100 million years. The sediments are more than 2,400 m (8,000 ft) thick at the Atlantic coast. These deposits were reworked by fluctuating sea levels and the continual erosive action of waves along the coastline. The province continues 120 km (75 miles) to the east as the submerged Continental Shelf. Coastal Plain surface soils are commonly well-drained sands or sandy loams. Large streams and rivers, including the Delaware and Schuylkill rivers, transport sediment that continues the eastward expansion of the Coastal Plain.

Piedmont Province

The Piedmont physiographic province extends from the Fall Line to the Blue Ridge Mountains. The "Fall Line," or "Fall Zone," marks a transitional zone of ridges, waterfalls, and rapids where the softer, less-consolidated sedimentary rocks of the Atlantic Coastal Plain intersect the harder, more-resistant metamorphic rocks of the Piedmont province . Examples of the rapids formed by Piedmont rocks are present in the Potomac Gorge of Maryland's Chesapeake and Ohio Canal National Historical Park, and at Great Falls Park in Virginia.

The eastward-sloping Piedmont formed through a combination of folds, faults, uplifts, and erosion. The resulting eastern landscape of gently rolling hills becomes gradually steeper to the west; elevations range from 60 m (200 ft) to 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 basins are superposed on the Piedmont. These basins were formed by normal faults during crustal extension (pulling apart). The faults opened basins (grabens), which were rapidly filled with roughly horizontal layers of sediment. Examples include Frederick Valley in Maryland, the Newark-Gettysburg Basin in Pennsylvania, and Culpeper Valley in northern Virginia. In general, depositional contacts define the eastern boundary of the basins with the Piedmont Plateau. The western boundaries of the basins, which border the Blue Ridge province, are defined sharply by normal faults.

Blue Ridge Province

The Blue Ridge province extends from Georgia to Pennsylvania along the eastern edge of the Appalachian Mountains. It contains the highest elevations in the Appalachian Mountain system, at Mt. Mitchell near North Carolina's Great Smoky Mountains National Park. Precambrian and Paleozoic igneous and metamorphic rocks were uplifted during several mountain-building events to form the steep, rugged terrain. Resistant Cambrian quartzite forms Blue Ridge, Bull Run Mountain, South Mountain, and Hogback Ridge, whereas Precambrian metamorphic rocks underlie the valleys. South and Catoctin mountains, both anticlines, are two examples of the pervasive folding in the Blue Ridge province.

Eroding streams have caused the narrowing of the northern Blue Ridge Mountains into a thin band of steep ridges, reaching elevations of more than 1,200 m (3,900 ft) above sea level. The Blue Ridge province is typified by steep terrain covered by thin, shallow soils, resulting in rapid runoff and low groundwater recharge rates.

History of Valley Forge

In the winter of 1777-1778, General George Washington and the Continental Army, some 11,000 men, wintered for six months at Valley Forge. The site was about 32 km (20 mi) northwest of then British-occupied Philadelphia, close enough to the capital to maintain pressure on the British forces, yet far enough away to avoid a surprise attack. Conditions were harsh; the army faced a severe winter, rampant disease, and an overall lack of provisions. Preserved earthworks, archaeological sites, and historic structures document the army's struggle to overcome this adversity. Resourceful soldiers from all 13 original states foraged supplies, built some 2,000 log cabins in planned military avenues, dug miles of trenches, constructed a bridge over the Schuylkill River, built five earthen redoubts, and defended the camp. The army matured into a more professional military force during their tenure at Valley Forge, which ultimately impressed the French into recognizing the United States as a sovereign power and joining the fight against the British. As Washington noted in a February 16, 1778 letter to Governor George Clinton,

> "Naked and starving as they are, we cannot enough admire the incomparable patience and fidelity of the soldiery."

Originally established as a public park in 1893, Valley Forge was administered by the State of Pennsylvania until 1976. Valley Forge National Historical Park was authorized on July 4, 1976, during the administration of Gerald R. Ford, and subsequent boundary changes were made on June 28, 1980. This park preserves the historic landscape at the site of the Continental Army's winter encampment. It covers approximately 14 km^2 (3,465 acres), about 12.4 km^2 (3,067 acres) of which are Federal lands, in Lower Providence and West Norriton townships in Montgomery County. For further information on the history and setting of the park, consult the park's web site: http://www.nps.gov/vafo.

Figure 1. Map of Valley Forge National Historical Park. National Park Service map.

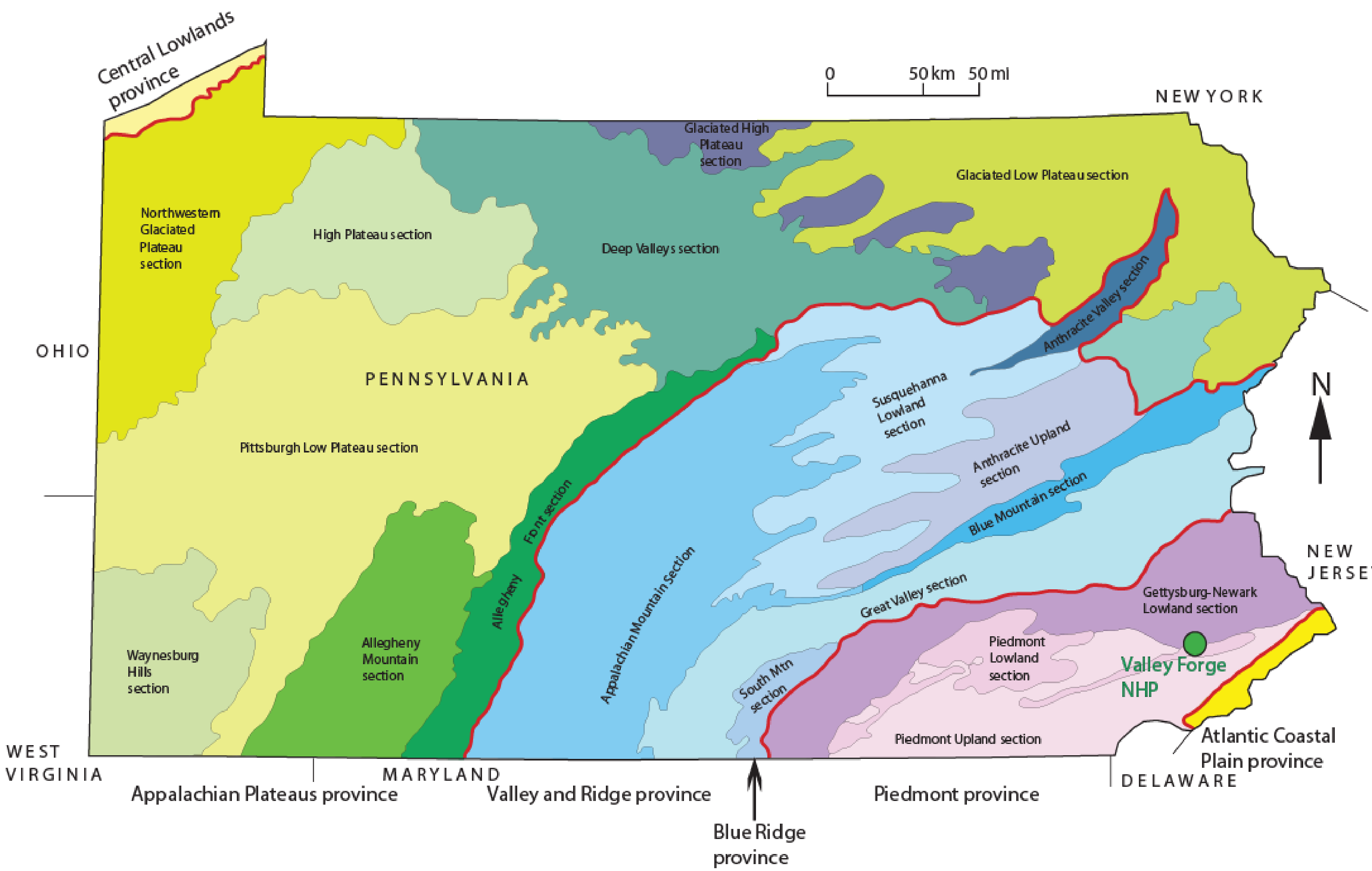

Figure 2. Physiographic provinces of Pennsylvania. The map shows the physiographic setting of Valley Forge National Historical Park. The green circle marks the location of the park and historic site. Red lines indicate boundaries between major physiographic provinces. The black arrow locates the northern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

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Valley Forge National Historical Park 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.

Introduction

Issues in this section are presented in relative order of resource management significance, as identified by the scoping participants and literature-based research. The most critical issues for Valley Forge National Historical Park are listed first. Potential research projects and topics of scientific interest are presented at the end of each section.

Karst Issues

The term "karst" refers to a characteristic terrain produced by the chemical erosional processes of limestone or dolostone (carbonate rocks) over a large area (Palmer 1984). These carbonate rocks are common constituents of the rock units within and surrounding Valley Forge National Historical Park. They dissolve in the process of karst formation, when acidic water reacts with rock surfaces along cracks and fractures. Over hundreds of thousands of years, dissolution occurs between intergranular pores and along fractures and joints to create progressively larger voids. Many Cambrian- and Ordovician-age units (e.g., Ledger and Elbrook formations) in the park contain enough limestone to have been significantly affected by karstic dissolution (Rader 1951; Berg et al. 1980).

Because of the increased permeability and porosity associated with karst processes, these features have a significant impact on the hydrogeologic system of an area. This is described in greater detail in Kochanov (1999). In extreme cases, streams and rivers flow underground into subterranean passages. Springs appear where the percolating water intersects a less permeable unit and flows along the boundary to the Earth's surface.

Karst features include caves and caverns, sinkholes, solution holes, pinnacles, and cave formations (speleothems). Karst topography underlies two-thirds (about 850 ha or 2,100 acres) of Valley Forge National Historical Park. The park contains at least five small caves and at least 100 sinkholes, although an comprehensive inventory of these features has not yet been undertaken (Kristina Heister, Valley Forge National Historical Park, Natural Resource Manager, personal communication, September 12, 2010). Karst processes such as subsidence, sinkhole formation, intermittent stream disappearance, and dissolution also affect the park and region. For example, a hole in the wall of a nearby quarry is emitting a stream of air due to pressure differences between the quarry and another opening. The location of this other opening is unknown (GRI scoping meeting notes 2004).

Sinkholes are subsidence features that are most commonly circular, but may also be elliptical, linear, or irregular in shape (Kochanov 1999). In general, the surface expression of a sinkhole or depression is caused by the water transport of residual material and soil through subsurface pathways established by chemical dissolution (Kochanov and Reese 2003). These features may form quickly when overlying material collapses into subsurface cavities. Sinkholes in Pennsylvania range from 1 to 6 m (4–20 ft) in both diameter and depth. Neighboring sinkholes may coalesce to form a single large sinkhole (Kochanov 1999). The Grand Parade grounds are underlain by carbonate rocks and contain many sinkholes (Kristina Heister, Valley Forge National Historical Park, Natural Resource Manager, personal communication, September 12, 2010).

Sinkholes such as Bone Cave—a paleo-sinkhole, probably formed during the Pleistocene approximately 670,000 to 600,000 years ago (Bell et al. 2004)—continue to form in the park today (National Park Service 2010). Bone Cave, also known as Port Kennedy Cave, is an historic feature at Valley Forge National Historical Park that once contained important Pleistocene fossils (Santucci et al. 2001). Discovered in 1871 and lost by flooding in 1896, Bone Cave is located in a dolomite quarry near Port Kennedy. It is one of a series of caves found in the Valley Forge region during the mining of the area's abundant carbonate rocks (McCarthy 1994). The cave is approximately 12 m (40 ft) deep, 3 to 6 m (10–20 ft) wide (Santucci et al. 2001), and 9.2 to 12.2 m (30–40 ft) below ground surface (Hojdila et al. 2005).

The quarry containing Bone Cave was filled in the early 1900s with hazardous asbestos-containing slurry waste material from a neighboring boiler and insulating company (Ehret Magnesia Manufacturing Company) (Daeschler et al. 2005). Lack of adequate mapping and revegetation obscured its location until recent literature searches and noninvasive geophysical survey techniques such as microgravity, electrical resistivity imaging, and magnetometry identified the quarry walls, quarry fill, and the filled cavity of Bone Cave (Hojdila et al. 2005; Baughman et al. 2006). These techniques operated on the hypothesis that whatever filled the fissure would be less dense than the surrounding dolomite of the quarry walls

(Bechtel et al. 2005), and would thus appear as an anomaly.

Of particular concern for resource management, karst features and processes may affect park infrastructure, health, and human safety. Common issues with karst features and processes include flooding, subsidence, and collapse (Drumheller 1985). For example, the location of a recently installed water line behind the park office is in an area prone to sinkholes. A site-specific approach to each sinkhole within the park is needed, with action items customized to meet the site conditions (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). Approaches to the identification and investigation of sinkholes vary from visual inspection and excavation of subtle ground depressions, to test borings with continuous standard penetration testing, shallow subsurface radar technology, and electromagnetic profiling (Drumheller 1985; Ozdemir et al. 1992; Qubain et al. 1995). Detailed site characterization using test boring, consolidation tests, and other geophysical techniques can provide invaluable information for future planning (Qubain and Sekinsky 1998). If identified, problematic sinkhole areas can be stabilized with an installation of rip rap, various grout compositions, geotextiles, concrete plugs, and other fill materials (Drumheller 1985; Reifsnyder et al. 1988; Qubain et al. 1995).

In addition to many useful geologic publications relevant to Valley Forge, the Pennsylvania Bureau of Topographic and Geologic Survey produced maps of sinkholes and karst-related features of Montgomery County (Kochanov 1993). Karst density maps indicate that portions of Montgomery County along the Schuylkill River contain more than 150 karst features per km^2 (400 karst features per mi^2) (Kochanov and Reese 2003).

To meet resource management objectives, the park is interested in undertaking a comprehensive inventory and assessment of cave and karst resources within the park. An NPS Project Management Information System (PMIS) proposal has been submitted to fund such an inventory, but has not yet been approved (Kristina Heister, Valley Forge National Historical Park, Natural Resource Manager, personal communication, September 12, 2010). Ongoing research within the park, including gravity and conductivity surveys, continues to yield vital information for resource management. The park is also promoting a regional study of any unique cave flora and fauna, including plants and bats (GRI scoping meeting notes 2004). Toomey (2009) has suggested techniques for the monitoring of caves and karst landscapes. As discussed below in the “Paleontological Resources” section, the karst features at Valley Forge National Historical Park also contain fossil remains.

Water and Sediment Issues

The Schuylkill River and its tributaries are important features in the landscape of Valley Forge National Historical Park. These waterways and their adjoining riparian habitats contribute to Pennsylvania’s scenic character and provide a vital sanctuary for many bird species. Rivers and streams cut through the rock layers to create valleys, ravines, and gullies.

Streams are sites of active geomorphological processes such as streambank erosion, mass wasting, and downcutting. Downcutting streams often undercut their banks, removing material (commonly alluvium) at the base of steep terrace slopes. Streambank stabilization is a resource management issue in the gap between Mt. Joy and Mt. Misery (GRI scoping meeting notes 2004). Some stream erosion and flooding within the park threaten facilities and resources. Erosion occurs along every streambank within the park, most obviously on Valley Creek at Washington’s Headquarters (National Park Service 2010). Widespread erosion may affect sewer and water lines, historic structures, and archaeological resources along Valley Creek (GRI scoping meeting notes 2004).

The effects of stream flow and erosion were also evaluated in several runs on the north side of, and tributary to, the Schuylkill River, including Meyer’s Run, Lamb Run, and Fawn Run (Ellsworth and Noon 2009). At the confluence of the tributaries, the floodplain is deeply incised. It was concluded that erosion will continue on the side slopes of the runs, as a result of intense herbivore grazing. Recommendations to reduce erosion include reducing the grazing impacts and to plant the side slopes of the runs with shrubs and herbaceous cover (Ellsworth and Noon 2009).

The Schuylkill River has a long flooding history. While little park infrastructure is located within the active floodplain, a large-scale flood could still threaten visitor safety and the park’s natural and cultural resources. For example, a picnic area and restroom on the north side of the river are located in an area prone to flooding damage (GRI scoping meeting notes 2004). Dredged materials in many floodplain areas along the river could contain contaminants from distant and local sources (Reif and Sloto 1997).

Valley Creek was the subject of a spatial distribution study (Fraley et al. 2005) that aimed to understand the effects of surrounding urbanization and subsequent increases in peak flows (due to the proliferation of impervious surfaces in the watershed) on sediment storage and transport patterns. The study involved extensive channel characterization, surveying and resurveying of eroding stream banks and channel cross-sections, and field monitoring. Data collection included particle-sized spatial distribution patterns, the depth of the mobile layer, and the sediment particle sizes mobilized as a function of discharge (Fraley et al. 2005). Similar studies and subsequent monitoring efforts at other sites within Valley Forge National Historical Park would help to determine the source(s) of sediment input. This input could derive from local erosion, or from offsite upstream sources that may be contaminated with urban waste that is carried into the Schuylkill River corridor.

Fluvial processes include sedimentation and erosion. Due to pervasive industrial development and natural resource extraction throughout the Schuylkill River watershed, the quality of water resources and sediments has suffered. The river flows through industrial, residential, and agricultural areas that may be sources of contaminants (Reif and Sloto 1997). Cooperative efforts to remediate the watershed of point and non-point sources of pollution are underway. Standard engineering practices for contaminant containment include passive cut-off walls, chemical immobilization, and top sealing, as well as active pumping and treatment. Other techniques include regrading, surface sealing, revegetation, and electrochemical remediation technologies. The latter technique passes electrical current between electrodes driven into the ground to force reduction/oxidation reactions that remediate at the pore level (Emrich and Beck1981; Doering et al. 2001).

The Schuylkill River is a target for remediation of contaminated sediments. A 1997 study (Reif and Sloto 1997) detected metals, pesticides, and semivolatile organic compounds adsorbed to particles in Schuylkill River sediments within Valley Forge National Historical Park. Arsenic, chromium, zinc, iron, manganese, copper, and lead were detected. The pesticides DDE, dieldrin, chlordane, DDD, DDT, and heptachlor epoxide were also present. Samples contained 17 semivolatile organic compounds, including fluoranthene, phenanthrene, and pyrene. The highest concentrations of contaminants were found in the sediments of Lamb Run, a tributary to the Schuylkill whose headwaters are in an industrial corporate center that includes the Commodore Semiconductor Group National Priorities List Superfund Site. While Lamb Run contributes contaminated sediment to the Schuylkill River system, Myer's Run contributes relatively clean sediments (Reif and Sloto 1997).

Among many other industrial sites in eastern Pennsylvania, the Commodore Semiconductor Group National Priorities List Superfund Site, located in the Valley Forge Corporate Center, is a local point source for volatile organic contaminants. A 1996 cooperative study (Sloto and McManus 1996) conducted by the U.S. Geological Survey and the NPS revealed the presence of a groundwater divide that forms a hydraulic barrier to the flow of contaminated groundwater from the site to Valley Forge National Historical Park. The divide stems from a cone of depression around six public wells. The cessation of pumping at these wells would allow the water levels to recover, forcing a hydraulic gradient between the site and the Schuylkill River and causing contaminated groundwater to flow through the park. In such a case, park management would need to investigate the implementation of multiple groundwater and soil sampling techniques, analyses, and treatment options such as granulated activated carbon, direct aeration, and counter-current airflow stripping (Schuller et al. 1982; Johnson et al. 1986; Gonclaves et al. 1988; Vitale et al. 1991; Vitale et al. 2006). Volatile organic compounds can infiltrate and accumulate through building foundations as vapors, making their presence a potentially significant threat to surrounding buildings and park infrastructure (Symms et al. 1995).

An impoundment desilting basin with at least six ponds is located in the park, north of Schuylkill River and west of Myer's Run (Reif and Sloto 1997). This complex is comprised of approximately 10 palustrine (marsh) emergent wetlands surrounded by forested wetland (Ellsworth and Noon 2009). This wetland complex has high functional value, providing habitat for several listed endangered or threatened species. Varying hydrologic conditions support a diverse plant assemblage with a variety of canopy structures, providing a range of habitat opportunities. The ponds are situated at the bottom of a watershed and have no surface water outlet, so they recharge the river-related aquifers (Ellsworth and Noon 2009). Another stock pond is spring-fed and impounded by a dam. These low-lying features contain layers of silt and coal debris, and also provide wetland habitat (GRI scoping meeting notes 2004). They may also contain contaminants such as those found in Schuylkill River sediments. The park confirmed in 2004 that the basin should remain unmitigated to protect its current biodiversity and facilitate resource management efforts (GRI scoping meeting notes 2004).

Groundwater flow systems have primarily geologic determinants. Most groundwater in the Valley Forge area is stored in weathered Triassic-age rock (Stockton Formation [see Map Unit Properties Table]) near the surface in a complex, heterogeneous multiaquifer system (Sloto and McManus 1996). This system is comprised of layers of gently tilting rocks of high transmissivity, separated by layers of rocks of relatively low transmissivity. The more permeable rock layers are generally arkosic sandstones and conglomerates, whereas the siltstone and shale units tend to less permeable. Each layer has different hydrologic properties; fractures, bedding planes, and joints accommodate groundwater movement (Sloto and McManus 1996). As an aquifer, the Stockton Formation is characterized by the presence of discrete water-yielding zones, strongly directional transmissivities, and unpredictable flow boundaries (Kraus and Dunn 1983). Groundwater flow within this system can vary at any scale. A single fracture can control local groundwater flow, independent of the overall hydrogeologic structure (Schuller et al. 1982). Cambrian dolomites (Ledger Formation) also underlie Valley Forge National Historical Park. Precipitation filters through the more permeable sandstones above, contacts the surface of the dolomite. The water then flows out as springs through fractures and crevices along the contact between the sandstone and carbonate rocks. These springs supply and influence the hydrology of the wetlands in the park (fig. 3) (Ellsworth and Noon 2009).

Resource management should understand the hydrogeologic system at Valley Forge National Historical Park. Applied geophysical techniques provide valuable tools for the observation of hydrologic properties, characterization of groundwater flow systems, and detailed mapping of subsurface geology. Dye tracing techniques are particularly useful for the delineation of groundwater flow paths and groundwater basin boundaries in carbonate bedrock units (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). Potentially useful methods include surface resistivity, magnetometry, shallow seismic reflection or refraction, electric logging, and cross hole seismic survey (Emrich 1984; Candon 1986). Streams combine input from multiple sources within watersheds, such as wind, surface runoff, groundwater, sewage outfalls, landfills, dredged fill dirt, and rainfall. Thus, they provide a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these parameters is crucial to the establishment of watershed baselines.

Several ongoing resource management projects and research within the park area address fluvial processes and water issues. These include a multi-component fluvial geomorphological study of the entire watershed, new storm-water regulations, consideration of the removal of the Valley Creek dam, potential sediment removal in silted areas, and water quality studies. The National Science Foundation (NSF) has funded several water-related projects within Valley Forge National Historical Park (GRI scoping meeting notes 2004). Lord et al. (2009) have suggested techniques for monitoring stream systems. Contact the NPS Water Resources Division for additional technical assistance regarding water issues.

Paleontological Resources

Fossils add to the understanding of the geologic history of the Piedmont province and Mesozoic rift basins in the Valley Forge area. Fossils can correlate geologic units across time and space, provide information about depositional environments, and record post-burial processes such as geochemical changes, deformational regimes, and changes in bedding orientation.

The NPS conducted a literature-based paleontological inventory of known fossil occurrences in Valley Forge National Historical Park (Kenworthy et al. 2006). No formal, field-based paleontological resource inventories have been completed for the park, and it lacks museum collections of paleontological material (Kenworthy et al. 2006). Fossil resources include those found in caves, as well as invertebrate fossils and stromatolites in regional geologic units.

Several geologic units in the park (e.g., the Cambrian-age Chickies, Ledger, and Elbrook formations) are known to contain fossils regionally. Some of the park's monuments and building materials also contain fossil resources. Heavy vegetative cover and deeply weathered bedrock preclude extensive outcrop exposure. The Chickies Formation contains the trace fossil *Skolithos*, which is the fossilized tubular burrow of an unknown worm-like organism (fig. 4). The Ledger Formation contains some conodonts (teeth of extinct marine animals), trilobites (not locally), and stromatolites (Kenworthy et al. 2006). Stromatolites (fossil algae mats) are present within the Ledger Formation in the main visitor parking lot (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). The Elbrook Formation contains trilobite remains. The Triassic Stockton Formation contains plant fossils, invertebrate body and trace fossils, mollusk fossils, fish and amphibian remains, as well as reptilian and dinosaurian body fossils and footprints (Kenworthy et al. 2006). At present, Triassic-age fossil plants are not known from locations within the park, but occur along the Pennsylvania Turnpike some 8 km (5 mi) away (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010).

Bone Cave, located in a dolomite quarry into the northwest-dipping Cambrian Ledger Formation, contains one of the most important middle Pleistocene fossil deposits (about 670,00-600,000 years before present) in North America (Baughman et al. 2006; Bell et al. 2004; Santucci et al. 2001). The fossils are preserved in water-saturated sand and mud strata that are "concave-up" below sediments derived from the Triassic Stockton Formation. A layer of black, organic-rich clay underlies the fossiliferous layer (Santucci et al. 2001). Until the early 2000s, the location of Bone Cave remained enigmatic. As described in the above "Karst Issues" section, the location is now known and potential resource management issues may arise regarding the preservation and/or excavation of the fossiliferous deposits.

Bone Cave excavations in the late 1800s revealed the extremely fragile condition of its fossils. Some crumbled to pieces when removed from the clay, and others were the consistency of "cream cheese" or "over-ripe pears" (Mercer 1899; Daeschler et al. 1993). The investigators thus tended to focus on the larger, more intriguing specimens (McCarthy 1994). Any future plans to investigate or excavate the cave would require rigorous planning and professional execution. In addition to the issues raised by the condition of the fossils, some of the cave's artificial fill contains asbestos that deters excavation in the area (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). The importance and significance of the deposit at Bone Cave may require security measures to be taken at the site if activities are undertaken there in the future (Bechtel et al. 2005).

Fossil resources require science-based resource management, as directed by the 2009 Paleontological Resources Preservation Act (Public Law 111-11). The NPS is currently developing regulations associated with the Act (Julia Brunner, NPS Geologic Resources Division, personal communication, May 2010). Santucci et al. (2009) have suggested strategies for monitoring *in situ* paleontological resources.

Slope Processes

Downcutting streams, such as Valley Creek, and other erosive agents created valleys, ravines, and gullies on the landscape at Valley Forge National Historical Park. Mechanical and chemical weathering processes have also weakened the underlying geologic units that contain sandstone, siltstone, mudstone, clay shale, and limestone. For example, the heterogeneous Stockton Formation includes weak, clay-rich mudstones interlayered with resistant sandstones and conglomerates (Sloto and McManus 1996). Clay-rich units such as shale and mudstone may disintegrate or swell when they become water–saturated, and are prone to fail when exposed on a slope. This weakness may cause a slide or slump. Where a resistant layer such as sandstone overlies a clay-rich layer, preferential erosion (undercutting) of the clay layer causes a dangerous blockfall situation in which the upper resistant layer is left unsupported. Slopes throughout the park are prone to fail, especially when saturated with water following seasonal rainfall events.

Talus and colluvial deposits at slope bases such as Mount Joy and Mount Misery attest to mass movements in the past. Today, the processes of slope creep, slumping, and sliding may threaten roads and trails throughout the park (GRI scoping meeting notes 2004). Erosion caused by precipitation is particularly active along trails (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). The Chickies Formation crops out directly upslope from the Upper Forge Site bridge, and blocks of this quartzite unit form extensive talus slopes to the south along the trail (Wiswall 1993). Blockfall in this setting may put trail users in danger. Likewise, blockfall is evident near the comfort station (fig. 5).

Three-dimensional investigations of colluvium could shed light on the exact nature of their formation, their influence on groundwater flow, and the potential for future movements. Such studies typically involve test pitting and deep boring, permeability measurements, and observational determination of colluvial composition, layering, and degree of weathering (Layton et al. 2006). Wieczorek and Snyder (2009) have suggested techniques for the monitoring of slope processes.

Disturbed Lands and Mineral Development

The mineral resources of rocks within and surrounding Valley Forge National Historical Park have long attracted humans. The ruins of pre-encampment copper mines and iron forges are present in the park and surrounding area (McCarthy 1994; GRI scoping notes, 2004). Extensive quarrying of the Cambrian-age limestones for building material and lime left many scars on the landscape. A small quarry is present on Mt. Joy and a deep limestone quarry is located in the southwestern corner of the park (GRI scoping meeting notes 2004). Some quarries, such as that in which Bone Cave is located, were flooded and filled with hazardous (asbestos-laden) industrial fill and waste material. The long outcrop on the south side of the visitor's parking lot is part of the wall of an abandoned dolostone quarry (Wiswall 1993).

Abandoned and inactive mines and quarries pose safety, environmental, and health problems in the Valley Forge area. According to the NPS Abandoned Mineral Lands (AML) database, there are four AML sand and gravel quarry sites (containing 6 features) within the park. Mine and quarry features interrupt the regional hydrologic regime and 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 NPS, 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, contribute to ongoing remediation and restoration projects (Anonymous 2002). These projects include the removal of the Mt. Joy road and parking lot, restoration of encampment-era topography in areas obscured by quarries, trail restoration, and the relocation of old mining sites using charcoal horizons in the substrate, dips, and waste material piles (GRI scoping meeting notes 2004). Despite constituting potential hazards, many of the quarries (particularly those in park maintenance areas) have administrative and educational multi-use capabilities (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). Geologic mapping takes advantage of such quarry features to determine the location of geologic features. The outcrop near the visitor parking lot illustrates tilting of originally horizontal sedimentary layers during mountain building. This outcrop also contains the thin, irregular to wavy laminations of stromatolites, some of the earliest recorded life forms on Earth (Wiswall 1993).

Geologic Influences on Cultural Resources

Prior to the Revolutionary War, an iron forge was located on Valley Creek; however, the park's emphasis is primarily on the Continental Army's sojourn. Since the 1777-1778 encampment at Valley Forge, multiple landowners and landscape changes have altered or obscured the area's historical cultural resources (Parrish and Cohen 1987). Such cultural noise can mask many original historical features. An integrated geophysical-biogeochemical survey prior to archaeological excavation can help direct attention to areas likely to reveal cultural resources; this approach is superior to a random sampling technique in such contexts (Parrish et al. 1987). Geophysical methods such as cesium magnetometer surveys, soil-penetrating radar scans, and soil resistometry have contributed to the identification of subsurface prehistoric and historic geological and cultural features at Valley Forge National Historical Park (Schenck 1978). In 1987, a detailed magnetic gradient survey revealed the locations of numerous hearth sites in the park by identifying peaked concentrations of calcium, phosphorous, and potassium (Parrish and Cohen 1987; Parrish et al. 1987). Biogeochemical techniques such as the analysis of broom sedge (*Andropogon virginicus*) crops for chemical anomalies (soils developed over former hearths often have high calcium, phosphorous, and potassium levels that are sequestered into the plants) have also revealed cultural remains on the encampment landscape (Parrish and

Cohen 1987). Noninvasive gravity surveys, electrical resistivity transects, and magnetometers helped to relocate Bone Cave after 110 years (Hojdila et al. 2005).

Although most visitors are primarily interested in the historical context of the Valley Forge National Historical Park landscape, the park also provides an ideal outdoor classroom for Earth science students. Endeavors by local college professors provided lessons to teachers for grades 6–12 on general scientific inquiry, surficial geology, environmental geology, hydrology, geomorphology, sedimentology, and meteorology as part of a local school's Earth science curriculum (Good 1998; Cannon 1999).

The diversity of geologic phenomena in the Valley Forge area can be used to educate geology students. The concept of geologic time is readily accessible in the Precambrian- to Mesozoic-age rocks within and surrounding the park. Rocks and their fossils indicate depositional environments and conditions of life in the distant past. 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 was extended following the Alleghanian orogeny. Pleistocene periglacial conditions changed the courses of rivers in the area, causing floral and faunal migrations and leaving vast deposits that included glacial till and outwash. The fossil record from Bone Cave attests to this environment. A meaningful scientific contribution to the experience of park visitors could be developed by relating the geology to human concerns such as floods, slope failures, coal mining, water pollution, oil and gas exploration, waste management, and urban development (Nikitina 2003). The relation of the geology and geologic processes visible in the park to the history of the encampment and forge lends deeper meaning to the human history of the area.

One of the major management goals at Valley Forge National Historical Park is to preserve its historical context by recreating log cabin and hut structures, preserving earthworks and redoubts, and restoring historic structures dating to the encampment. Some structures, such the Maurice Stephens House built around 1816 (once thought to be Huntington's Quarters), postdate the encampment. An accurate recreation of the encampment landscape would require the removal of these structures and the construction of others. Total restoration of the cultural landscape of the encampment in this case is likely not possible in keeping with the NPS protection policies for historic structures defined in the Cultural Resource Management Guideline (DO-28) (Scott and Ofenstein 2008). A study of the evolution of historic land use patterns at the park could help prioritize interpretive and restorative efforts.

The maintenance of any historic landscape often entails monitoring or slowing natural geologic processes. Geologic slope processes such as landsliding, slumping, chemical weathering, block sliding, and slope creep are slowly, but constantly, changing the landscape at the park. Runoff erodes sediments from any open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in lower areas, distorting the historical landscape. Extensive quarrying and other land-use practices (e.g., urban development and farming) have changed the regional topographic expression. Issues may also arise from the differing goals of cultural and natural resource management. For example, a proposal for the restoration of a historic trench or encampment may entail the removal of surrounding natural resources, installation of stabilization structures, and/or planting of exotic flora.

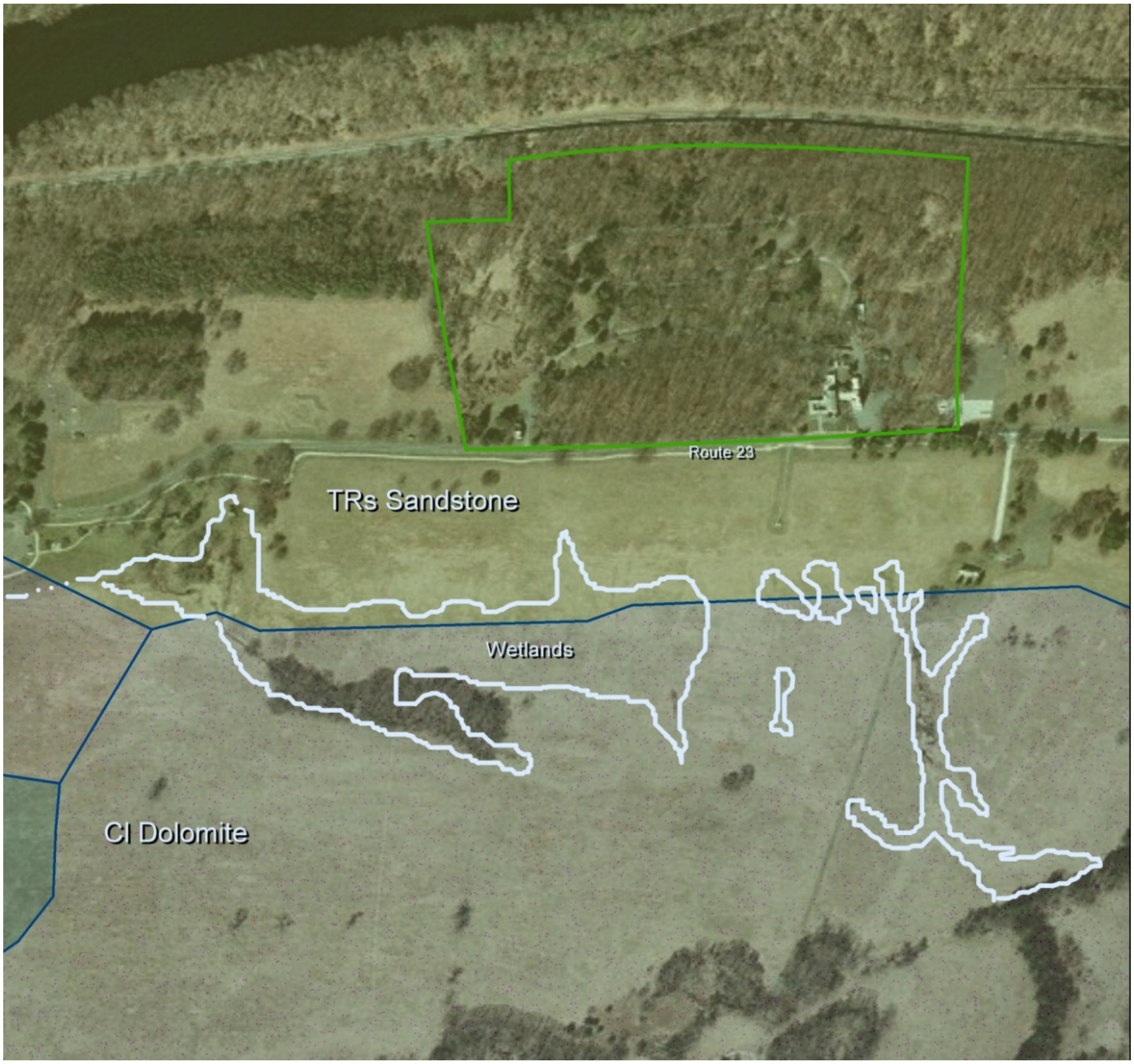

Figure 3. Wetlands are present near the contact between the Triassic sandstones (Stockton Formation; TRs) and Cambrian dolomite (Ledger Formation; Cl). Green line outlines land associated with Washington Memorial Chapel (non Federal land) within the park. The Schuylkill River is visible in the upper left of the image. National Park Service graphic utilizing GRI digital geologic data and aerial imagery from ESRI Arc Image Service, USA Prime Imagery. Annotated by K. Noon (NPS Water Resources Division). Graphic from Ellsworth and Noon (2009).

Figure 4. Cross-sections of *Skolithos* (worm burrow) trace fossils are visible within the building stone of the comfort station near the visitor center. Local Chickies Quartzite was quarried for the structure. Photograph by and courtesy of Vincent Santucci (George Washington Memorial Parkway).

Figure 5. Exposure of Ledger Formation in abandoned dolostone quarry near the visitor center. Fallen blocks of material accumulated at the base of the exposure. Photograph by and courtesy of Vincent Santucci (George Washington Memorial Parkway).

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Valley Forge National Historical Park.

Cambrian-Triassic Unconformity

Valley Forge National Historical Park contains a unique geological feature called an angular unconformity that exists between the limestone-bearing Cambrian Ledger Formation and the mixed sedimentary strata of the Triassic Stockton Formation. The red sandstones and shales of the Stockton Formation dip gently to the north, whereas the layering within the Ledger Formation dips steeply to the south (Wiswall 1993). This tangible gap in geologic history spans more than 300 million years. This feature helped researchers relocate Bone Cave. The two rock types on either side of the unconformity are visible in the Port Kennedy quarry (Wiswall 1993). Early illustrations show red shale directly overlying the limestone of the quarry at the site of Bone Cave (see historic photograph in Daeschler et al. 2005). This red shale formed much of the sediment that had collapsed into the sinkhole uncovered during fossil excavation (Daeschler et al. 2005). The unconformity is mapped on the GRI digital geologic map derived from Berg et al. (1980) (Appendix A). Recent large-scale mapping by Kochanov (in prep.) details the nature of this feature (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010).

Caves and Karst

Bone Cave

Bone Cave is a vertical 12-m-deep (40-ft-deep) solution cavity (paleo-sinkhole) in the Cambrian Ledger Formation that was briefly opened to the surface, creating a natural trap for the accumulation of remains (Santucci et al. 2001; Daeschler et al. 2005). More than 1,200 fossils from the cave are held at the Academy of Natural Sciences in Philadelphia. The Bone Cave site is one of the most significant Middle Pleistocene (approximately 600,000 to 670,000 years ago) vertebrate fossil finds in North America. The fossiliferous deposit was not exhausted before flooding groundwater inundated the cave in 1896. The quarry was later filled with 9–12 m (30–40 ft) of industrial waste from a nearby factory (Daescher et al. 2005).

Edward Drinker Cope was among the leading paleontologists describing fossils from the cave in the late 1800s. Numerous fossils were recovered, representing 14 plant species, nine coleopterid insects, five reptiles (four turtles, one snake), one bird, and 33 mammal species (Daeschler et al. 1993; Santucci et al. 2001; Baughman et al. 2006). Significant fossils include the only known representatives of a skunk (*Osmotherium spelaeum*) and a muskrat species (*Ondatra hiatidens*). The diluvian fisher (*Martes diluviana*) is also only known from the site. Other notable fossils include ground sloths, mammoths, the earliest record of American black bear (*Ursus americanus*), the type locality of the gracile sabertooth (*Smilodon gracilis*) (fig. 6), and the only population sample of large North American Pleistocene tapirs (fig. 7) (Baughman et al. 2006; Santucci et al. 2001).

A description of all the fossil remains and history of excavation of Bone Cave is beyond the scope of this report. Prior to its rediscovery in 2005, Daeschler et al. (1993) presented a thorough review and geologic contextualization of the Bone Cave fauna and flora.

Karst Processes

Bone Cave is one example of the action of karst processes on the landscape at Valley Forge National Historical Park. The lack of streams in areas underlain by dolostone, such as those visible from Inner Line Drive, County Line Road, and Gulph Road, is typical of karst topography (Wiswall 1993). Karstic dissolution occurs when acidic water reacts with carbonate rock surfaces along cracks and fractures. Most meteoric water is of relatively low pH due to the reaction between carbon dioxide in the atmosphere and water. The product of this reaction is carbonic acid (Palmer 1984). Groundwater may become more acidic as it flows through decaying plant debris and soils. The acid dissolves calcium carbonate, producing soluble ions (Palmer 1984). Most of the carbonaceous limestones and dolomites in southeastern Pennsylvania are inherently porous, consisting of voids and underground drainage systems.

Many large surface karst features, including sinkholes formed by mechanical processes such as collapse, were triggered by subsurface solution. Sinkholes are produced by the collapse of overlying rock and soil into a void. They may also form where cracks in the underlying limestone are widened by dissolution, so that soil and pieces of bedrock subside into the enlarging solutional openings (Palmer 1981). They are typically funnel-shaped topographic depressions that are elliptical to circular in landscape view (Palmer 1981; Drumheller 1985). A sinkhole occurring in a streambed may capture the water flow to create a disappearing stream.

Active karst processes in the Valley Forge area include limestone dissolution, underground cavity development, spring activity, sinkhole collapse, and erosion (fig. 8). The dominant carbonate-bearing units in the region include the Cambrian-age Ledger and Elbrook formations. These units contain thick deposits of soluble limestone and dolostone interlayered with shales, siltstones, and sandstones (quartzites). The rocks record a longstanding marine basin on the subsiding margin of the continent during the Cambrian Period. Detrital sand, silt, and mud were deposited on this margin, followed by the deepening of the basin and the deposition of carbonate chemical sediments approximately 500 million years ago (Bechtel et al. 2005).

Caves in Valley Forge National Historical Park likely formed by both vadose (above the water table) and phreatic (at or below the water table) solution. Such formation occurs when a nascent passage conducts water through the vadose zone to the phreatic zone, and solutional enlargement of the conduit occurs simultaneously in both zones. The local water table is highly irregular and discontinuous. Features characteristic of both solution types are present in a conduit described by Palmer (1984, 1990); these references could be valuable for researchers attempting to interpret the cave features at Valley Forge National Historical Park.

Historic Connections with Geology

The known history of the Valley Forge area begins thousands of years before the army encampment, and was continuously influenced by the area's geology. A Late Archaic–Early Woodland (more than 1,000 years ago) site was located on the Schuylkill River floodplain near Valley Forge National Historical Park. Holocene river dynamics, such as incised meanders, infilling, meander migration, and small-scale channel fluctuations, created a topographically elevated site that early inhabitants chose for settlement. This location had thick deposits of overbank sediments that may have provided rich soils for agriculture (Ervin 1985).

Triassic-age mudstones, siltstones, sandstones, and conglomerates underlie the northern highlands near Schuylkill River in gently tilted and folded beds. The Stockton Formation locally strikes east-west and dips 15° to the north. This unit unconformably rests on Paleozoic and Precambrian rocks (Sloto and McManus 1996). Some quarries within the park and surrounding region mark the contact between the Cambrian carbonates and the Triassic clastics (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). Weathering and erosion of these sedimentary rocks created the rolling hills and narrow valleys characteristic of the Valley Forge area (figs. 9, 10) that made it an ideal location for the encampment.

George Washington chose Valley Forge as an encampment site because it provided enough level area for the construction of quarters and facilities (fig. 11). The encampment was underlain by resistant geologic units (such as quartz-rich layers of the Chickies Formation) that formed high ground. This location was also easily defensible, bordered by Schuylkill River to the north and adjacent to Mt. Joy and Mt. Misery. Freshwater was provided by several streams and rivers within a small area. Dolostone underlies the broad, rolling upland along Outer Line Drive between park headquarters and the National Memorial Arch, whereas more soluble limestones underlie the valley at the base of a linear surface slope. This dolostone plateau at Valley Forge provided the Continental Army with a height advantage over enemy troops advancing from the south (Wiswall 1993).

As is interpreted at nearby Hopewell Furnace National Historic Site (Thornberry-Ehrlich 2010), Pennsylvania contributed much to the colonial iron industry. Valley Forge was named after the location of an iron forge on Valley Creek. Such forges took advantage of the abundant local iron ore, limestone (for flux), wood (for charcoal), and water in their operations. This area has long attracted prospectors in search of mineral wealth. One of the earliest copper mines in the country was located within Valley Forge National Historical Park (the site now occupied by a parking lot). Mineral specimens from this mine included quartz crystals, malachite, and pyrite (McCarthy 1994). The area's abundant limestone-bearing rocks provided lime, produced by burning, to use in making cement. In 1805, Alexander Kennedy purchased property near Valley Forge that became Port Kennedy. When the Schuylkill Canal opened in 1825, this area was a prosperous village with up to 100 schooners and barges transporting lime up and down the waterway each day (McCarthy 1994). Limestone quarries throughout the area (often within the Cambrian Ledger Formation) exposed caverns, caves, and sinkholes, some of which contained invaluable fossil remains. Other caverns may contain stalactites and stalagmites. Most of these caves were quarried away before conservation of such features became general practice. Other caves were destroyed during the construction of Route 422, the highway that runs beside Valley Forge National Historical Park (McCarthy 1994).

Figure 6. Fossil jaw of gracile sabretooth (*Smilodon gracilis*) recovered from Bone Cave. Bone Cave is the type locality for this species. This specimen is on display at the park, from the collections of the Academy of Natural Sciences (Philadelphia). The rear portion of the skull is not preserved. Photograph by and courtesy of Vincent Santucci (George Washington Memorial Parkway).

Figure 7. Fragmentary jaw of a large tapir (*Tapirus copei*) discovered at Bone Cave. Bone Cave contains the only population sample of large Pleistocene-aged tapirs from North America. Scale bar is 10 cm. Specimen is on display at the park, from the collections of the Academy of Natural Sciences (Philadelphia). Photograph by and courtesy of Vincent Santucci (George Washington Memorial Parkway).

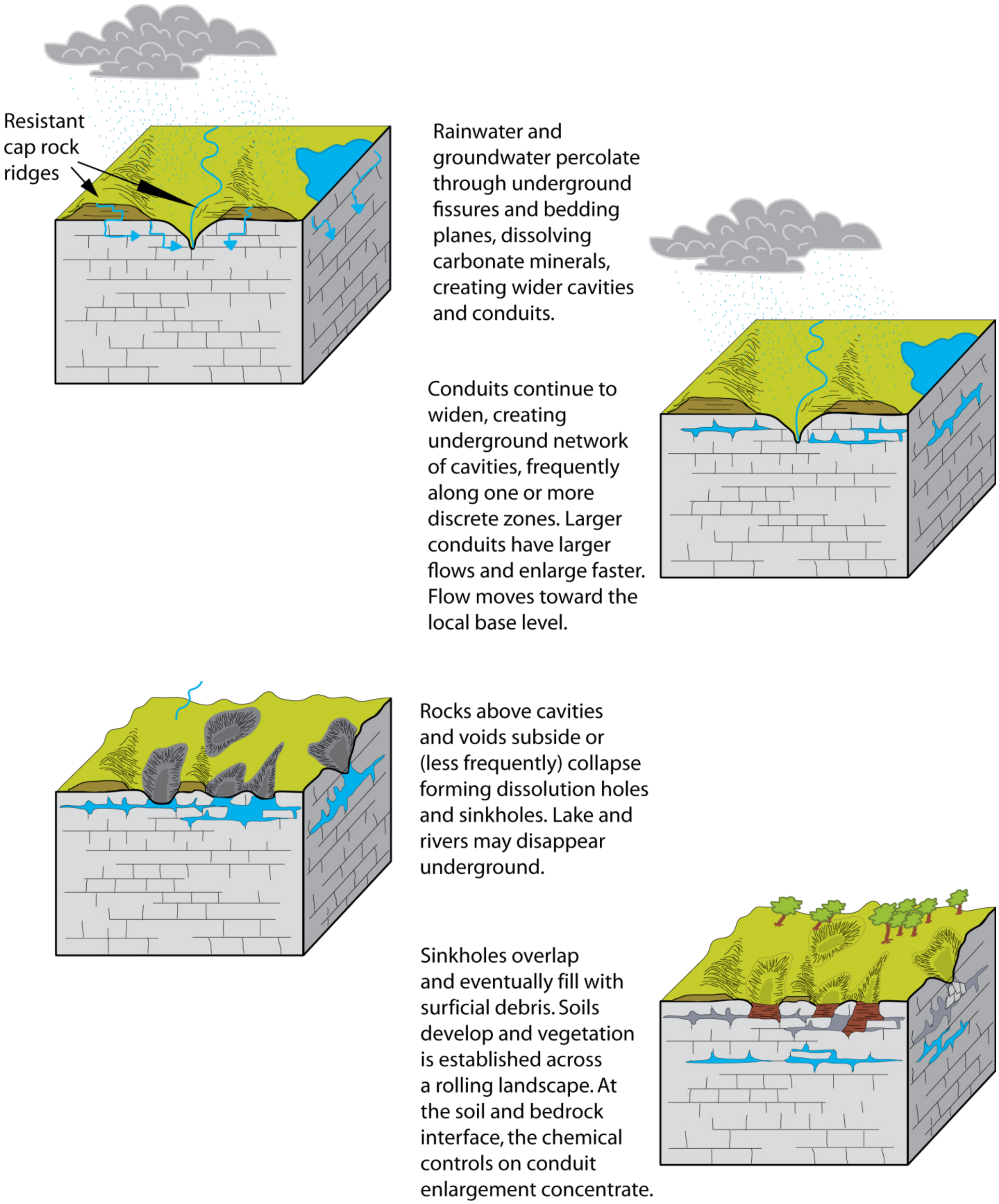

Figure 8. Generalized cross-sectional view of the development of a karstic landscape through dissolution and collapse. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 9. View looking west from the Statue of General Anthony Wayne at Valley Forge National Historical Park. Note the relatively steep slope and flat valley bottom. The break in slope marks the contact between the carbonate and non-carbonate bedrock units (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February 16, 2010). Photograph is from http://www.worldfromtheweb.com/Parks/Philadelphia/P5110782.html (accessed December 23, 2008). Used with permission.

Figure 10. Rolling karst landscape as seen from Huntington Camp (looking west) at Valley Forge National Historical Park. The large hill in the background is Mt. Joy, composed of schist and phyllites of the Harpers Formation. National Park Service photograph courtesy Amy Ruhe and Kristina Heister (Valley Forge National Historical Park).

Figure 11. Recreation of cabins at Muhlenberg Camp to appear typical of the Colonial Army's winter quarters. Most cabins housed 12 men. Note the level ground in the encampment area atop carbonate rocks of the Ledger Formation. Photograph by and courtesy of Vincent Santucci (George Washington Memorial Parkway).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Valley Forge National Historical Park. 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 Valley Forge National Historical Park 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. 12) 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 Valley Forge National Historical Park:

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

Miles, C. E., and T. G. Whitfield (compilers). 2001. Bedrock geology of Pennsylvania (scale 1:250,000). Digital dataset extracted from Geologic map of Pennsylvania (scale 1:250,000). 4th ser., Pennsylvania Department of Conservation and Natural Resources (PA DCNR): Map 1. Bureau of Topographic and Geologic Survey, Middletown, PA.

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/). Data will be available on the Natural Resource Information Portal when the portal goes online. As of August 2010, access is limited to NPS computers at http://nrinfo/Home.mvc.

Map Unit Properties Table: Valley Forge National Historical Park

Colored rows indicate geologic units mapped within Valley Forge National Historical Park

Age	Map Unit (Symbol)	Features and Detailed Geologic 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 landscape.
TERTIARY	Pennsauken 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 units renders them susceptible to mass wasting on steep to moderate slopes.	May contain plant fragments	Terrace areas may contain traces of American Indian campsites	None	Sand, clay, silt, gravel	Units support riparian habitats and well-drained soils.	Units are 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	Unit supports eastern hardwood forests regionally.	Unit is 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 historically popular building stone	Limestone units are prone to dissolution.	Labradorite, pyroxene, plagioclase phenocrysts (cm-size), diabase	**Jd** weathers to support iron- and magnesium-rich substrates.	Units are suitable for most recreation, unless heavily altered or fractured.	**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.	Units are prone to rockfall where weathered shale underlies 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 completely, creating voids and compromis-ing unit integrity.	None documented	Units weather to create myriad substrates.	Units are suitable for most recreation, unless heavily weathered and friable.	**TRb** spans the Jurassic-Triassic boundary.

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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 comprised of interbedded cobble and pebble quartz conglomerate with red sandstone.	Moderate	Units are 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	Units are suitable 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 arkosic sandstone, with some reddish-brown to purple sandstone, siltstone, and mudstone interbeds. **TRsc** contains quartz cobbles 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.	Variety of body and trace fossils documented outside of park. Fossils not yet documented from TRs within the park.	None documented	None documented	Sandstone	None documented	Conglomeratic outcrops may attract climbers.	Units record deposition and reworking within a Triassic rift basin. Upper unit of Cambrian-Triassic unconformity documented within park.
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.	Units are prone to rockfall where weathered shale underlies resistant sandstone ledges or where limestone has dissolved beneath overlying rock layers.	May contain Ordovician-age fossils	Slate may have been locally quarried historically.	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 calcium-rich substrates.	Cave-bearing units may attract attention.	**Oco** has allochthonous and autochthonous elements.
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 fine-grained limestone 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 finely crystalline dolomite. Chert lenses, interbeds, and nodules are present locally. **Os** includes medium-light-gray to medium-gray, finely crystalline massive limestone with dark siliceous layers and conglomerate beds.	Moderate	Avoid heavily dissolved units for heavy development due to weakness of friable textures; dissolved units are inherently porous and do not act as good 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 American Indians.	Interlayered limestone and dolomite are susceptible to dissolution.	Limestone, dolomite	Units may dissolve to form cave habitats and produce calcium- and magnesium-rich substrates.	Dissolved caves and cavities may attract attention.	Widespread, thick units that show geographic facies changes and record shifting depositional environments.

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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 readily 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- to Ordovician-age fossils	Scant chert nodules may have provided tool material to American Indians.	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 form an unstable base for trails on slopes.	Unit spans Cambrian to Ordovician boundary.
CAMBRIAN	Richland Formation (Cr); Allentown Formation (Cal);[1] Millbach Formation (Cm);[1] 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.** Rare trilobite fossils in **Ce**, not yet documented in the park or surrounding area.	Chert nodules may have provided tool material to American Indians.	Interlayered limestone and dolomite are susceptible to dissolution.	Marble, limestone	None documented	Cave-bearing units may attract attention.	Units record marine depositional environments.
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 coarsely 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 finely crystalline dolomite with 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 to American Indians.	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 forest types.	Units are suitable for most recreation, unless heavily dissolved or fractured; cave habitats for bats and other fauna.	**Cul** is arranged in tectonic slices, recording the depositional environments and tectonic history of the area.
CAMBRIAN	Ledger Formation (Cl); Kinzers Formation (Ck); Vintage Formation (Cv)	**Cl** contains massive pure dolomite with some siliceous grading near the bed centers. 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.	Stromatolites are preserved within **Cl** exposures in the park.	None documented	Limestone, and to a lesser extent, dolomite are susceptible to dissolution. **Cl** hosts karst features within the park.	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. Bone Cave developed in **Cl.** **Cl** is lower unit of Cambrian-Triassic unconformity documented within park.

[1] Unit is of correct stratigraphic age and may be correlative, but not relevant to the Valley Forge area (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication 2010).

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Age	Map Unit (Symbol)	Features and Detailed Geologic Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Karst Issues	Mineral Resources	Habitat	Recreation	Geologic Significance
CAMBRIAN	Antietam and Harpers formations, undivided (Cah); Antietam Formation (Ca);[2] Hardyston Formation (Cha); Harpers Formation (Ch); Chickies Formation (Cch)	**Cah** includes **Ca** and **Ch**. **Ca** consists of gray quartzite that appears buff-colored 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.** *Skolithos* fossils within park exposures of **Cch.**	Quartzite historically provided building material regionally, including the restroom facilities near the visitor center and other structures within the park.	None documented	Quartzite	Units underlie ridgetop and well-drained habitat.	Resistant quartzite layers may attract rock climbers.	Erosion resistant units underlie topographic highs of Mount Joy and Mount Misery.
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-colored, 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 where slope and dominant foliation planes are parallel.	None	**Xpg** crystals may have provided prehistoric 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.
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, fine-grained greenish 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 suitable for most development unless heavily altered and/or fractured.	Rockfall hazard when unit is exposed on slope, especially where slope and dominant cleavage direction are parallel.	None	Marble may have provided quarry material historically.	Some dissolution of marble beds is 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.

[2] Although the Antietam Formation is shown to occur on some geologic maps, field evidence suggests that it may be the Chickies and/or Harpers formations (William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication 2010).

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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-colored, medium-grained gneiss of probable sedimentary origin. Unit **fgp** consists of light-colored, medium-grained silicic gneissic rocks. Unit **hg** is dark-colored, medium-grained gneiss of probable sedimentary origin. Units **mgh** and **mgp** are similar, consisting of dark, medium-grained gneiss of probable sedimentary origin. Unit **gn** is quartz- and feldspar-bearing gneiss with light color and medium-grained texture of probable 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.	Unit may pose rockfall hazard if undercut or exposed on a slope.	None	None documented	None	Gneiss	Mafic gneiss develops into iron-, magnesium-, and calcium-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.

Geologic History

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

Valley Forge National Historical Park is near the eastern edge of the Piedmont physiographic province. The Atlantic Coastal Plain province lies to the east, underlain by unconsolidated sediments. The landscape of the Valley Forge area contains features that are intimately tied with the long geologic history of the Appalachian Mountains and the evolution of the North American continent's eastern coast. A regional perspective is presented here to connect the landscape and geology of the park to its surroundings.

Precambrian and Early Paleozoic Era: Ancient Mountain Building and Iapetus Ocean Formation

The recorded history (reflected in exposed rocks) of the Appalachian Mountains begins in the Proterozoic (fig. 12). A supercontinent formed during the mid-Proterozoic Grenville orogeny (mountain-building event) that consisted of most of the continental crust in existence at that time. This included the crust of North America and Africa. Sedimentation, deformation, plutonism (intrusion of igneous rocks), and volcanism associated with this event are apparent in the metamorphic granites and gneisses in the core of the modern Blue Ridge Mountains, west of Valley Forge (Harris et al. 1997). These rocks formed over a 100-million–year period and are more than a billion years old, placing them among the oldest rocks known from this region. They were later uplifted and thereby exposed to erosion for hundreds of millions of years. Their leveled surface forms a basement upon which all other rocks of the Appalachian Mountains were deposited (Southworth et al. 2001). Rocks of this age in the vicinity of Valley Forge include mafic to felsic gneisses, marbles, and metadiabases (Berg et al. 1980).

The late Proterozoic, roughly 800–600 million years ago, brought extensional rifting to the area. The crustal extension created fissures through which massive volumes of basaltic magma were extruded (fig. 13A). This volcanism lasted tens of millions of years and alternated between flood basalt flows and ash falls. The volcanic rocks covered the Precambrian granitic/gneissic basement in southern Pennsylvania. Metamorphosed into greenstones, these rocks are exposed as the Catoctin Formation in central Maryland.

The tectonic tension caused the supercontinent to break up, and a sea basin formed that later became the Iapetus Ocean (approximately 600–400 million years ago). This basin subsided and collected many of the sediments that would eventually form the rock units of the Appalachian Mountains (fig. 13B). Some of these sediments were deposited as alluvial fans, large submarine landslides, and turbidity flows (Southworth et al. 2001). Subsequent deposits of sands, silts, and muds covered the earlier sediments in nearshore, deltaic, barrier island, and tidal flat areas along the eastern margin of the continent (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). Some of these sediments are present in the detrital sand, mud, and silt of the Cambrian-age Chickies and Harpers formations in the Valley Forge area (e.g., the western part of the park) (Berg et al. 1980; Wiswall 1993). 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, thicker to the east, provided the depositional setting for huge masses of carbonate, sandstone, and shale rocks during the Cambrian and Ordovician periods (545-480 million years ago) (Means 1995). Carbonate units such as the Elbrook and Ledger formations (underlying the area east and south of Mount Joy) and the Vintage Formation formed in this depositional environment (Means 1995; Bechtel et al. 2005). Cambrian to Ordovician units in the Valley Forge area, such as the Conestoga Formation (underlying the valley south of the park), record the locally intermittent transition from the carbonate platform to more nearshore terrestrial deposition associated with nascent uplift during the Taconic orogeny.

Paleozoic Era: Appalachian Mountain Building

Taconic Orogeny

After 50 million years spanning the Early Cambrian through Early Ordovician periods, orogenic activity along the eastern margin of the continent began again (Means 1995; Bechtel et al. 2005). The Taconic orogeny (approximately 440–420 million years ago in the central Appalachians) was a volcanic arc to continent convergence. Oceanic crust and the volcanic arc from the Iapetus Basin were thrust onto the eastern edge of the North American continent, resulting in the closing of the ocean, subduction of the oceanic crust, creation of volcanic arcs, and uplift of the continental crust (Means 1995). Initial metamorphism of the deeply buried igneous and nearshore sediments into metabasalts, quartzites, and phyllites occurred during this orogenic event. The collision compressed originally horizontal layers of sedimentary rocks into folds and thrust them inland along large faults (Wiswall 1993).

The crust bowed downward to the west of the rising mountains in response to the overriding plate thrusting westward onto the continental margin of North America. This process created a deep foreland basin that filled with mud and sand eroded from the highlands to the east (fig. 13C) (Harris et al. 1997). This Appalachian Basin was centered on what is now West Virginia.

The oceanic sediments of the shrinking Iapetus Ocean were thrust westward onto other deepwater sediments of the western Piedmont during the Late Ordovician. Sand, mud, silt, and carbonate sediment were then deposited in the shallow marine to deltaic environment of the Appalachian foreland basin. These rocks, now metamorphosed, currently underlie the Valley and Ridge physiographic province west of Valley Forge (Fisher 1976).

Acadian Orogeny

The Acadian orogeny (approximately 360 million years ago) continued the mountain building of the Taconic orogeny as the African continent drifted toward North America (Harris et al. 1997). Like the preceding orogeny, the Acadian event involved the collision of land masses, mountain building, and regional metamorphism (Means 1995). This event was focused north of eastern Pennsylvania.

Alleghanian Orogeny

During the Late Paleozoic and following the Acadian orogeny, the proto-Atlantic Iapetus Ocean closed as the North American and African continents collided. This event formed the Pangaea supercontinent and the Appalachian mountain belt we see today. This mountain-building episode is called the Alleghanian orogeny (325–265 million years ago), and was the last major orogeny to affect the Appalachians (fig. 13D) (Means 1995). The rocks deformed during as many as seven phases of folding and faulting, producing the numerous folds of the Valley and Ridge province west of Valley Forge (Nickelsen 1983; Southworth et al. 2001). The strata of the Appalachian Basin (now the Appalachian Plateau province) remained relatively undeformed.

During this orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were thrust inland along large faults and transported westward onto younger rocks of the Valley and Ridge province (Wiswall 1993). An estimated 20–50% (125–350 km, 80–220 mi) of crustal shortening took place (Harris et al. 1997).

Paleoelevations of the Alleghanian Mountains are estimated to have been approximately 6,100 m (20,000 ft) above sea level, analogous to the modern Himalaya Range in Asia. These mountains have been beveled by erosion to elevations less than 730 m (2,400 ft) above sea level west of Valley Forge (Means 1995). Erosion exposed the early Paleozoic formations, including the carbonates, following the Alleghanian orogeny (Bechtel et al. 2005).

Mesozoic Era: Rifting, Atlantic Ocean Formation, and Mountain Erosion

A period of rifting began during the late Triassic (230–200 million years ago), as the deformed rocks of the joined continents began to break apart. The supercontinent Pangaea was segmented into roughly the same continents that persist today. This rifting episode initiated the formation of the current Atlantic Ocean and caused many block-fault basins with accompanying volcanism to develop (fig. 13E) (Harris et al. 1997; Southworth et al. 2001). At this time, the uplifted Paleozoic units in the Valley Forge area, including the carbonate rocks, were lowered in the Gettysburg-Newark Rift Basin and reburied (Bechtel et al. 2005). Valley Forge National Historical Park is located near the southern edge of the Newark Basin (Wiswall 1993).

Extension and deposition were the dominant regional geologic processes during the Mesozoic Era. Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroding Alleghanian Mountains. These sediments were deposited atop the much older Cambrian rocks at the base of the mountains as alluvial fans, in thicknesses that occasionally exceeded 5 km (3 mi). Throughout the basin, Triassic sandstone and red shale beds rest unconformably on the Cambrian-age units (Bechtel et al. 2005). The Triassic-age Stockton Formation (underlying the northern and eastern parts of the park), Hammer Creek and Brunswick formations, and Jurassic sediments record this depositional environment in the Valley Forge area. The rapid lithologic changes within the Triassic rocks indicate shifting depositional regimes that included nearshore, fluvial, lacustrine, and alluvial fan depositional settings (Sloto and McManus 1996). Deposition spread eastward to form part of 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 record this environment (fig. 13F) (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). Only rare, scattered remnants of these units are present in the Valley Forge area. Exposed metamorphic rocks in the Blue Ridge province suggest that an immense amount of material was deposited. Many of the rocks exposed at the surface must have been at least 20 km (10 mi) below the surface prior to regional uplift and erosion.

Cenozoic Era: Karst Development and Ice Ages

The North American plate has continued to move westward since the breakup of Pangaea and the uplift of the Appalachian Mountains. The isostatic adjustments that uplifted the continent after the Alleghanian orogeny continued at a lesser rate throughout the Cenozoic Era (Harris et al. 1997). Over these millions of years, the still-buried carbonate rocks in the Valley Forge area underwent chemical weathering or dissolution along joints, cracks, fractures, or bedding planes. In some areas, these processes produced a subsurface network of interconnecting conduits and voids within the carbonate bedrock (Bechtel et al. 2005; William Kochanov, Pennsylvania Bureau of Topographic and Geologic Survey, Senior Geologic Scientist, written communication, February16, 2010). The network of solution cavities ranges in size from microscopic conduits to large, scenic caverns. Where dissolution approaches the surface, collapse of the overlying material may form sinkhole features such as Bone Cave (Port Kennedy Cave) (Bechtel et al. 2005).

Quaternary-period erosion continues to create the present landscape. The Schuylkill River and its tributaries, such as Valley Creek, erode sediments from the lowering hillslopes and deposit alluvial terraces along the rivers (fig. 13F).

The Pleistocene masses of continent-scale ice sheets never reached the Valley Forge area, but terminated at 365 to 610 m (1,200–2,000 ft) above sea level in northwestern and northeastern Pennsylvania. Upland surfaces have been glaciated to rounded ridges and sand- and gravel-filled valleys in northern Pennsylvania. However, the colder ice-age climates affected the formation of the landscape at Valley Forge National Historical Park. The periglacial conditions that must have existed in close proximity to the ice sheets intensified weathering and other erosional processes (Harris et al. 1997). Landforms and deposits such as the Trenton Gravel are probably late Tertiary to Quaternary in age. These features were formed when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into the ancestral river channels. This water flow enhanced downcutting and erosion by waterways and caused subsequent increases in downstream deposition (Means 1995; Zen 1997a, 1997b). Pleistocene fossil deposits, such as that in Bone Cave, record the climatic conditions and the impacts on local flora and fauna around 750,000 years ago (Bechtel et al. 2005).

Since the Pleistocene, the rivers and tributaries in the Valley Forge area continue to cut through thick layers of sedimentary deposits. Surface runoff erodes local slopes and is supplemented by mass wasting processes. Streams redistribute these sediments in riparian zones along the waterways and intermittently transport them toward the Atlantic Ocean. Natural erosion is augmented by human land disturbance activities such as agriculture, industrialization, drilling, quarrying, and widespread urban development throughout the area.

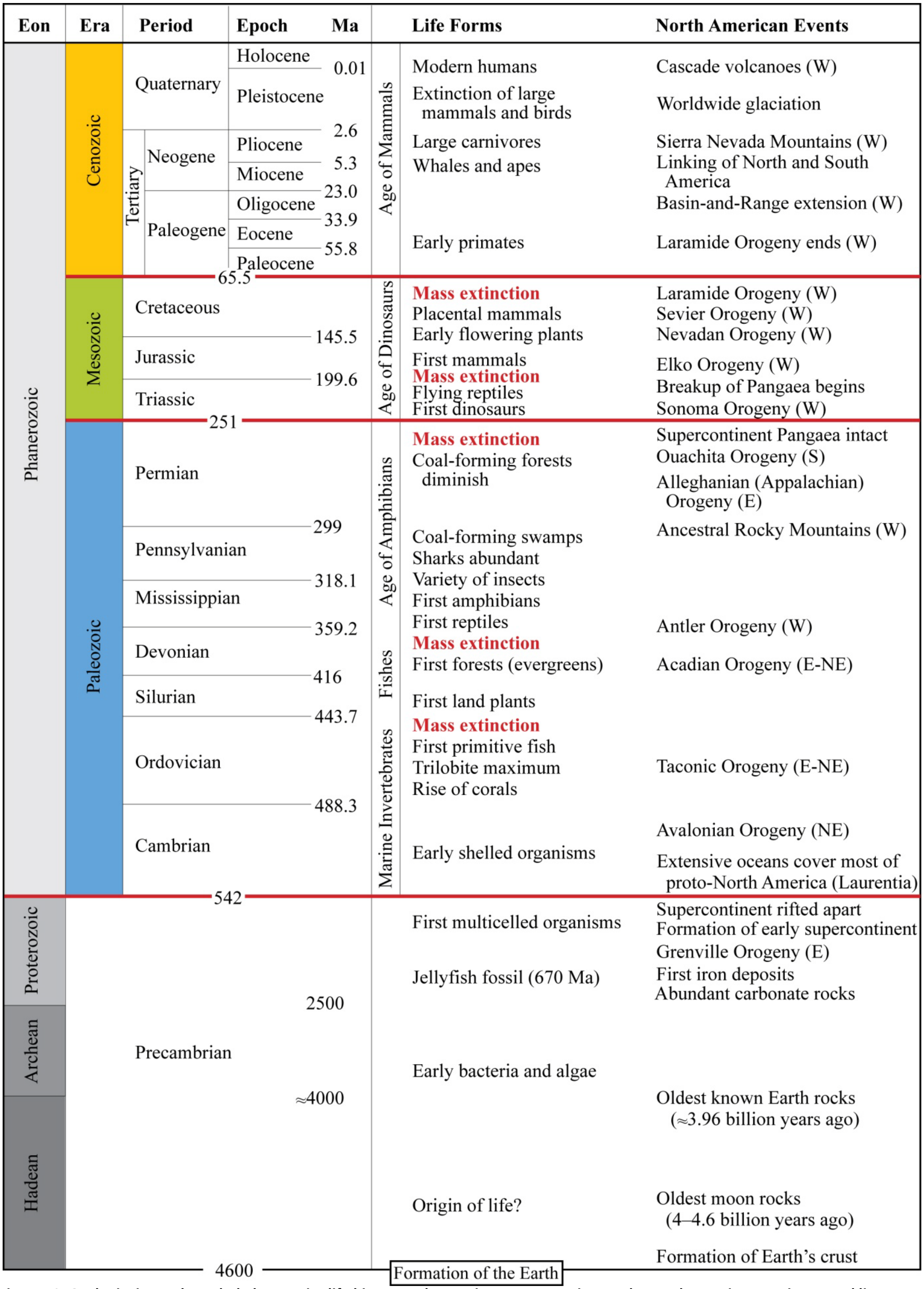
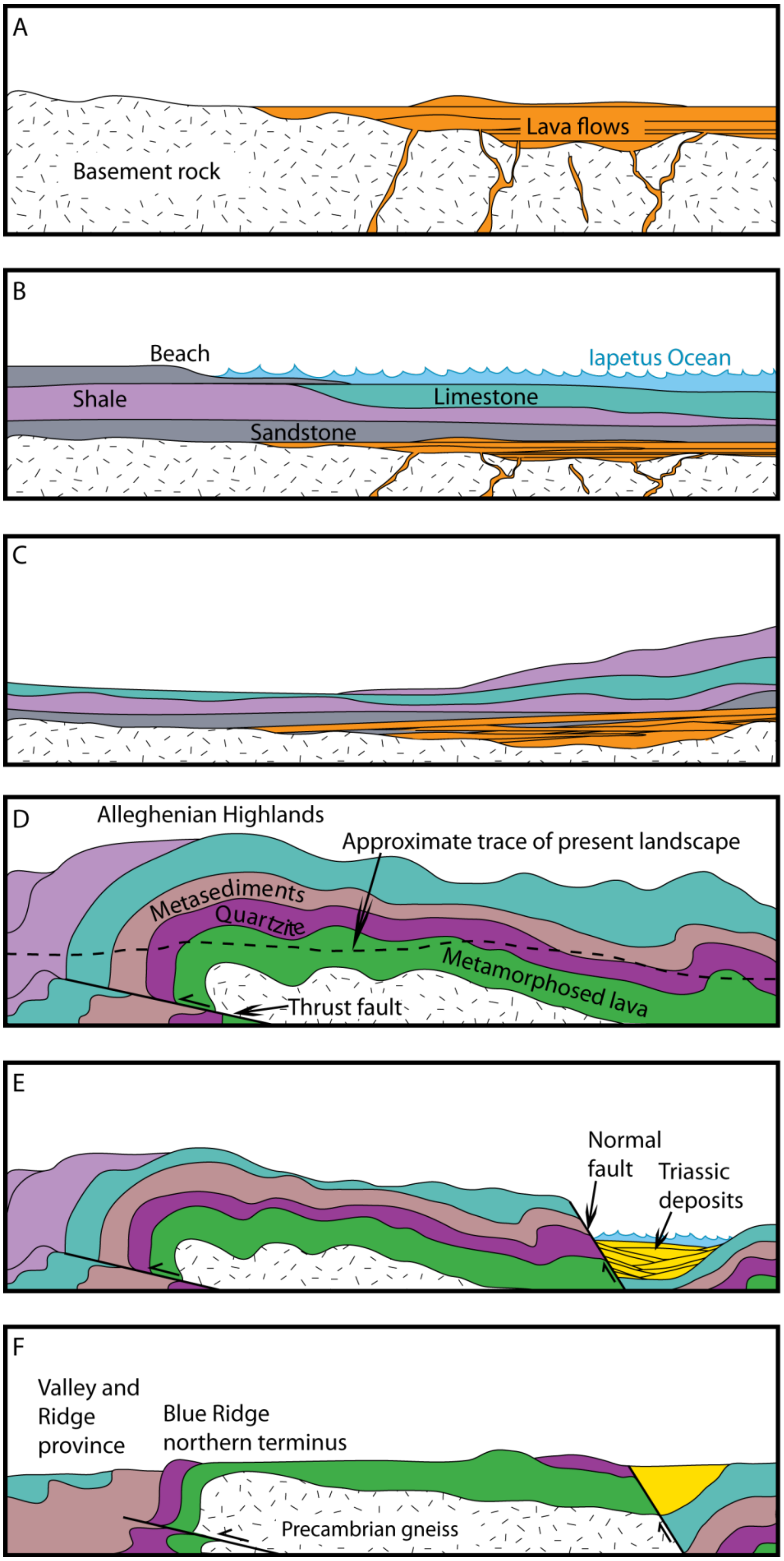


Figure 12. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual 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.



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

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

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

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

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

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

Figure 13. Evolution of the landscape in the area of the Valley Forge National Historical Park from the Precambrian through the present. Ma, millions of years (mega-annum). Drawings not to scale. Graphic adapted from Means (1995) by Trista Thornberry-Ehrlich (Colorado State University).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://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.

abyssal plain. A flat region of the deep ocean floor, usually at the base of the continental rise.

active margin. A tectonically active margin where lithospheric plates come together (convergent boundary), pull apart (divergent boundary) or slide past one another (transform boundary). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism. Compare to "passive margin."

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.

angular unconformity. An unconformity where the rock layers above and below are oriented differently. Also see "unconformity."

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

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.

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

asthenosphere. Earth's relatively weak layer or shell below the rigid lithosphere.

axis (fold). A straight line approximation of the trend of a fold which divides the two limbs of the fold. "Hinge line" is a preferred term.

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

base flow. Stream flow supported by groundwater; flow not attributed to direct runoff from precipitation or snow melt.

base level. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

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.

basinite. A very fine-grained basalt.

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

beach. A gently sloping shoreline covered with sediment, commonly formed by the action of waves and tides.

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

bedding. Depositional layering or stratification of sediments.

bedrock. A general term for the rock that underlies soil or other unconsolidated, surficial material.

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

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

carbonaceous. Describes a rock or sediment with considerable carbon content, especially organics, hydrocarbons, or coal.

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]).

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

concretion. A hard, compact aggregate of mineral matter, subspherical to irregular in shape; formed by precipitation from water solution around a nucleus such as shell or bone in a sedimentary or pyroclastic rock. Concretions are generally different in composition from the rocks in which they occur.

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.

continental rise. Gently sloping region from the foot of the continental slope to the deep ocean abyssal plain; it generally has smooth topography but may have submarine canyons.

continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths less than 200 m (660 ft).

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

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

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

core. The central part of Earth, beginning at a depth of about 2,900 km (1,800 mi), probably consisting of iron-nickel alloy.

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").

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.

crystal structure. The orderly and repeated arrangement of atoms in a crystal.

debris flow. A moving mass of rock fragments, soil, and mud, in which more than half the particles of which are larger than sand size.

deformation. A general term for the processes 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.

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

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

discordant. Describes contacts between strata that cut across or are set at an angle to the orientation of adjacent rocks.

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

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

ductile. Describes a rock that is able to sustain deformation (folding, bending, or shearing) before fracturing.

eolian. Describes materials formed, eroded, or deposited by or related to the action of the wind. Also spelled "Aeolian."

eustatic. Relates to simultaneous worldwide rise or fall of sea level.

evaporite. A sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent (usually water).

exfoliation. The breakup, spalling, peeling, or flaking of layers or concentric sheets from an exposed rock mass caused by differential stresses due to thermal changes or a reduction in pressure when overlying rocks erode away.

extrusive. Describes molten (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.

fan delta. An alluvial fan that builds into a standing body of water. This landform differs from a delta in that a fan delta is next to a highland and typically forms at an active margin.

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

felsic. Describes an igneous rock having abundant light-colored minerals such as quartz, feldspars, or muscovite. Compare to "mafic."

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.

levee. Raised ridge lining the banks of a stream. May be natural or artificial.

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

lithification. The conversion of sediment into solid rock.

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

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

loess. Windblown silt-sized sediment, generally of glacial origin.

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.

marine terrace. A narrow coastal strip of deposited material, sloping gently seaward.

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

matrix. The fine grained material between coarse (larger) grains in igneous rocks or poorly sorted clastic sediments or rocks. Also refers to rock or sediment in which a fossil is embedded.

meander. Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

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

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

meta–. A prefix used with the name of a sedimentary or igneous rock, indicating that the rock has been metamorphosed.

metamorphic. Describes the process of metamorphism or its results. One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

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

meteoric water. Pertaining to water of recent atmospheric origin.

mid-ocean ridge. The continuous, generally submarine and volcanically active mountain range that marks the divergent tectonic margin(s) in Earth's oceans.

migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

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

monocline. A one-limbed fold in strata that is otherwise flat-lying.

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.

outwash. Glacial sediment transported and deposited by meltwater streams.

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

overburden. Rock and sediment, not of economic value, and often unconsolidated, that overlies an ore, fuel, or sedimentary deposit.

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

palustrine. Pertaining to material growing or deposited in marsh or marsh-like environment.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

parent material. Geologic material from which soils form.

parent rock. Rock from which soil, sediments, or other rocks are derived.

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 (compare to "active margin").

pediment. A gently sloping, erosional bedrock surface at the foot of mountains or plateau escarpments.

peneplain. A geomorphic term for a broad area of low topographic relief resulting from long-term, extensive erosion.

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

plastic. Capable of being deformed permanently without rupture.

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

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

point bar. A low ridge of sand and gravel deposited in a stream channel on the inside of a meander where flow velocity slows.

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

prodelta. The part of a delta below the level of wave erosion.

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

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

pyroclastic. Describes clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also pertaining to rock texture of explosive origin. In the plural, the term is used as a noun.

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.

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

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

relative dating. Determining the chronological placement of rocks, events, 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.

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

sapping. The undercutting of a cliff by erosion of softer underlying rock layers.

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

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

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.

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

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

sill. An igneous intrusion that is of the same orientation as the surrounding rock.

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.

sinkhole. A circular depression in a karst area with subterranean drainage and is commonly funnel-shaped.

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

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.

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

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

suture. The linear zone where two continental landmasses become joined via obduction.
syncline. A downward curving (concave up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.
system (stratigraphy). The group of rocks formed during a period of geologic time.
tectonic. Relating to large-scale movement and deformation of Earth's crust.
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.
transmissivity. A measure of the rate at which water travels through an aquifer.
trend. The direction or azimuth of elongation of a linear geologic feature.
tuff. Generally fine-grained, igneous rock formed of consolidated volcanic ash.
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. An unconformity 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).
volcanic arc. A commonly curved, linear, zone of volcanoes above a subduction zone.
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.

Literature Cited

This section lists references cited in this report. A more complete geologic bibliography is available from the National Park Service Geologic Resources Division.

Anonymous. 2002. Pennsylvanian coal mine drainage projects. Coal International 250(6):254–260.

Baughman, S. H., T. D. Bechtel, T. DeMayo, and J. L. Hojdila. 2006. Port Kennedy Bone Cave; rediscovered with geophysics. Geological Society of America Abstracts with Programs 38(2):82.

Bechtel, T. D., J. L. Hojdila, S. H. Baughman II, T. DeMayo, and E. Doheny. 2005. Relost and refound; detection of a paleontologically, historically, cinematically(?), and environmentally important solution feature in the carbonate belt of southeastern Pennsylvania. Leading Edge Tulsa, OK 24(5):537–540.

Bell, C. J., E. L. Lundelius Jr., A. D. Barnosky, R. W. Graham, E. H. Lindsay, D. R. Ruez Jr., H. A. Semken Jr., S. D. Webb, and R. J. Zakrzewski. 2004. The Blancan, Irvingtonian, and Rancholabrean mammal ages. Pages 232-314 in Woodburne, M. O., editor. Late Cretaceous and Cenozoic mammals of North America. Columbia University Press, New York, NY.

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

Candon, M. R. 1986. Applied geophysics; a conceptual approach of geophysics to real-world applications. Eos, Transactions, American Geophysical Union 67(16):276–277.

Cannon, J. G. 1999. An earth science curriculum guide based on the geology of Valley Forge National Historical Park. Geological Society of America Abstracts with Programs31(2):8.

Daeschler, E., E. E. Spamer, and D. C. Parris. 1993. Review and new data on the Port Kennedy local fauna and flora (late Irvingtonian), Valley Forge National Historical Park, Montgomery County, Pennsylvania. Mosasaur 5:23–41.

Daeschler, E. B., M. C. Lamanna, and M. Carfioli. 2005. On the trail of an important ice age fossil deposit. Park Science 23(2):31–34. (http://www.nature.nps.gov/ParkScience/archive/PDF/ParkScience23(2)Fall2005.pdf) Accessed 28 February 2010.

Doering, F., N. Doering, and D. Hill. 2001. Electrochemical remediation technologies for groundwater, soil and sediments. Pages 195–204 *in* R. E. Hinchee, A. Porta, and M. Pellei, editors. Remediation and beneficial reuse of contaminated sediments. Battelle Press, Columbus, Ohio, USA.

Drumheller, J. C. 1985. Exploration and repair of limestone sinkholes by impact densification. Proceedings of the Annual Highway Geology Symposium 36:46. Highway Geology Symposium, Atlanta, Georgia, USA.

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

Ellsworth, A., and K. Noon. 2009. Report for travel to Valley Forge National Historical Park, August 25 and September 28, 2009. Memorandum (L54[2380])to Valley Forge NHP superintendent, October 6, 2009. On file at Water Resources Division (Lakewood, Colorado).

Emrich, G. H. 1984. Groundwater. Journal - Water Pollution Control Federation 56(6):707–708.

Emrich, G. H., and W. Beck, Jr. 1981. Methods of containing contaminated ground water. Pages 19–46 *in* Proceedings; AWWA seminar on organic chemical contaminants in ground water; transport and removal. American Water Works Association, Denver, CO.

Ervin, E. M. 1985. A preliminary investigation of Holocene river dynamics on the Schuylkill River, Montgomery County, Pennsylvania in relation to prehistoric archeologic site 36 MG 156. Geological Society of America Abstracts with Programs 17(1):18.

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

Fraley, L. M., A. J. Miller, C. Welty, and A. C. Gellis. 2005. Determination of spatial patterns of sediment storage and transport in Valley Creek, Valley Forge National Historical Park. Geological Society of America Abstracts with Programs 37(7):489.

Goncalves, J. N., R. L. Forman, and J. Ferry. 1988. SW-846 soil sampling and analytical techniques for volatile organic compounds. Pages 465–473 *in* Proceedings of the petroleum hydrocarbons and organic chemicals in ground water: prevention, detection and remediation conference 1998. Ground Water Publishing Company, Westerville, Ohio, USA.

Good, S. C. 1998. A teacher-scholar model for earth science teachers to do scientific inquiry. Geological Society of America Abstracts with Programs30(7):392.

Harris, A. G., Tuttle, E., and Tuttle, S. D. 1997. Geology of national parks. Kendall/Hunt Publishing Company, Dubuque, Iowa, USA.

Hojdila, J., T. DeMayo, S. Baughman, T. Bechtel, and M. Carfioli. 2005. The long-lost cave has been found! Park Science 23(2):35–36. (http://www.nature.nps.gov/ParkScience/archive/PDF/ParkScience23(2)Fall2005.pdf) Accessed 28 February 2010.

Johnson, S. E., G. H. Emrich, and M. Apgar. 1986. On-site removal of volatile organic contaminants from soils; two case studies. Pages 685–599 *in* Proceedings of the third annual eastern regional ground water conference. National Water Well Association, Dublin, Ohio, USA.

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

Kenworthy, J. P., C. C. Visaggi, and V. L. Santucci. 2006. paleontological resource inventory and monitoring, mid-Atlantic network. TIC #D-800, National Park Service, Geologic Resources Division, Denver, CO.

Kochanov, W. E. 1993. Sinkholes and karst-related features of Montgomery County, Pennsylvania (scale 1:24,000). Open-File Report 93-02, 4th Series. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA.

Kochanov, W. E. 1999. Sinkholes in Pennsylvania. Educational Series 11. Bureau of Topographic and Geologic Survey. Middletown, Pennsylvania, USA. (http://www.dcnr.state.pa.us/topogeo/hazards/es11.pdf) Accessed 28 February 2010.

Kochanov, W. E. in prep. Bedrock geologic map of the Chester Valley, Chester, Delaware, Montgomery, and Philadelphia Counties, Pennsylvania (scale 1:50,000). Open-File Report. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA.

Kochanov, W. E., and S. O. Reese. 2003. Density of mapped karst features in south-central and southeastern Pennsylvania (scale 1:300,000). Map 68, 4th Series. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA. (http://www.dcnr.state.pa.us/topogeo/map68/index.aspx). Accessed 28 February 2010

Kraus, D. L., and A. L. Dunn. 1983. Trichloroethylene occurrence and ground-water restoration in highly antisotropic bedrock; a case study. Proceedings of the National Symposium on Aquifer Restoration and Ground-Water Monitoring 3:16–81.

Layton, E., D. Lehmann, W. Mader, E. Teeters, and D. McKee. 2006. Characterization of an Appalachian colluvial deposit and its impact upon groundwater flow, Centre County, Pennsylvania. Geological Society of America Abstracts with Programs 38(2):87.

Lord, M. L., D. Germanoski, and N. E. Allmendinger. 2009. Fluvial geomorphology: Monitoring stream systems in response to a changing environment. Pages 69–104 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado, USA.

McCarthy, C. 1994. The case of the disappearing cave. Lapidary Journal 47(10):55–56, 58, 60, 126–129.

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

Mercer, H.C., 1899. The Bone Cave at Port Kennedy, Pennsylvania and its Partial Excavation in 1894, 1895, and 1896. Journal of the Academy of Natural Sciences of Philadelphia 11(2):268–286.

Miles, C. E., and T. G. Whitfield (compilers). 2001. Bedrock geology of Pennsylvania (scale 1:250,000). Digital dataset extracted from Geologic map of Pennsylvania (scale 1:250,000). 4th ser., Pennsylvania Department of Conservation and Natural Resources (PA DCNR): Map 1. Bureau of Topographic and Geologic Survey, Middletown, PA.

Nickelsen, R. P. 1983. Aspects of Alleghanian deformation. Pages 29–39 *in* R. P. Nickelson and E. Cotter, editors. Silurian depositional history and Alleghanian deformation in the Pennsylvania Valley and Ridge. Guidebook for the annual field conference of Pennsylvania geologists 48. The Field Conference of Pennsylvania Geologists, Inc., Middletown, Pennsylvania, USA.

Nikitina, D. L. 2003. Geology of western Pennsylvania in the classroom and in the field. Geological Society of America Abstracts with Programs 35(6):275.

National Park Service. 2010. Geologic Formations. Valley Forge National Historical Park. http://www.nps.gov/vafo/naturescience/geologicformations.htm. Accessed 5 August 2010.

Ozdemir, T., S. Roy, and R. S. Berkowitz. 1992. Imaging of shallow subsurface objects; an experimental investigation. IEEE Transactions on Geoscience and Remote Sensing 30(3):472–481.

Palmer, A. N. 1981. A geological guide to Mammoth Cave National Park. Zephyrus Press, Teaneck, New Jersey, USA.

Palmer, A. N. 1984. Geomorphic interpretation of karst features. Pages 173–209 *in* R. G. LaFleur, editor.

Groundwater as a geomorphic agent. International Series 13. The Binghamton symposia in geomorphology. Elsevier, Amsterdam, Netherlands.

Palmer, A. N. 1990. Groundwater processes in karst terranes. Pages 177–209 *in* C. G. Higgins and D. R. Coates, editors. Groundwater geomorphology; the role of subsurface water in earth-surface processes and landforms. Special Paper 252. Geological Society of America, Boulder, Colorado, USA.

Parrish, J. B., M. Cohen, and F. Holzel. 1987. Geophysical, biogeochemical, and remote sensing study of an archaeological site, Valley Forge National Historic Site, Valley Forge, PA. Geological Society of America Abstracts with Programs 19(7):800.

Parrish, J. B., and M. Cohen. 1987. Geophysical, biogeochemical and remote sensing study of an archaeological site, Valley Forge National Historic Site, Valley Forge, Pennsylvania. Proceedings of the International Symposium on Remote Sensing of Environment 21:1143.

Qubain, B. S., and E. J. Seksinsky. 1998. An innovative foundation in difficult ground through detailed site characterization. Pages 269–274 *in* P. K. Robertson and P. W. Mayne, editors. Proceedings of the first international conference on site characterization. A. A. Balkema, Rotterdam, The Netherlands.

Qubain, B. S., E. J. Seksinsky, and E. G. Aldin. 1995. Techniques to investigate and remedy sinkholes. Proceedings - Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst 5: 341–347. A. A. Balkema, Rotterdam, The Netherlands and Boston, Massachusetts, USA.

Rader, H. L. 1951. Geology of Valley Forge Park and vicinity, Valley Forge, Pennsylvania. Master's thesis, Lehigh University, Bethlehem, Pennsylvania, USA.

Reif, A. G., and R. A. Sloto. 1997. Metals, pesticides, and semivolatile organic compounds in sediment in Valley Forge National Historical Park, Montgomery County, Pennsylvania. Water-Resources Investigations WRI 97-4120. U. S. Geological Survey, Reston, Virginia, USA. (http://pa.water.usgs.gov/reports/wrir97-4120.pdf). Accessed February 2009.

Reifsnyder, R. H., R. A. Brennan, and J. F. Peters. 1988. Sodium silicate grout technology for effective stabilization of abandoned flooded mines. Bureau of Mines Information Circular 9184:390–398. U. S. Bureau of Mines, Washington, D.C., USA

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. Geologic Resources Division Technical Report NPS/NRGRD/GRDTR-01/02. National Park Service, Lakewood, Colorado, USA. (http://nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf). Accessed February 2009.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA.

Schenck, H. 1978. Archaeological prospecting at Valley Forge. MASCA Journal 1(1):16–17.

Schuller, R. M., W. W. Beck, Jr., and D. R. Price. 1982. Case study of contaminant reversal and groundwater restoration in a fractured bedrock. Pages 94–96 *in* H. Bernard, B. Bixler, D. Lamont, H. Masters, J. Rollo, D. Sanning, H. Snyder, Jr., and W. K. Tusa, compilers. Management of uncontrolled hazardous waste sites. Hazard Mater Control Research Institute, Silver Spring, Maryland, USA.

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

Scott, J. A., and S. K. Ofenstein. 2008. Maurice Stephens House (site of Huntington's Quarters) – Historic structure report. Valley Forge National Historical Park. National Park Service, Valley Forge, Pennsylvania, USA. (http://www.nps.gov/history/history/online_books/vafo/maurice_hsr.pdf). Accessed February 2009.

Sevon, W. D. 2000. Physiographic provinces of Pennsylvania (scale 1:2,000,000). Map 13. 4th edition. Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania, USA.

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

Sloto, R. A., and B. C. McManus. 1996. Hydrology and ground-water quality of Valley Forge National Historical Park, Montgomery County, Pennsylvania. Water-Resources Investigations WRI 96-4120. U. S. Geological Survey, Reston, Virginia, USA. (http://pa.water.usgs.gov/reports/wrir96-4120.pdf). Accessed February 2009.

Southworth, S., D. K. Brezinski, R. C. Orndorff, P. G. Chirico, and K. M. Lagueux. 2001. Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia. A, Geologic map and GIS files (disc 1); B, Geologic report and figures (disc 2). Open-File Report: OF 01-0188. U. S. Geological Survey, Reston, Virginia, USA. (http://pubs.usgs.gov/of/2001/of01-188/). Accessed February 2009.

Symms, K. G., K. G. Lawrence, D. H. Wardrop, and R. J. Vitale. 1995. Modeling VOC migration and vapor intrusion into building indoor air from subsurface soil sources. Soil & Environment(5):551–556.

Thornberry-Ehrlich, T. 2010. Hopewell Furnace National Historic Site: geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2010/214. National Park Service, Ft. Collins, Colorado. (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm#H) Accessed 24 August 2010.

Toomey, R. S, III. 2009. Geological monitoring of caves and associated landscapes. Pages 27–46 *in* R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA.

Vitale, R. J., O. Braids, and R. Schuller. 1991. Ground water sample analysis. Pages 501–539 *in* D. M. Nielson, editor. Practical handbook of ground-water monitoring. Lewis Publishing, Chelsea, Michigan, USA.

Vitale, R. J., O. C. Braids, and R. Schuller. 2006. Ground-water sample analysis. Pages 1113–1134 *in* D. M. Nielson, editor. Practical handbook of environmental site characterization and ground-water monitoring. CRC Press Taylor and Francis Group, Boca Raton, Florida, USA.

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

Wieczorek, G. F., and J. B. Snyder. 2009. Monitoring slope movements. Pages 245–272 *in* R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA.

Wiswall, C. G. 1993. Valley Forge National Historical Park, Montgomery and Chester Counties–The geologic history. Park Guide 8, 4th series. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA. (www.dcnr.state.pa.us/topogeo/parkguides/pg08.pdf). Accessed 28 February 2010.

Zen, E-an. 1997a. The seven-storey river: Geomorphology of the Potomac River channel between Blockhouse Point, Maryland, and Georgetown, District of Columbia, with emphasis on The Gorge complex below Great Falls. Open-File Report OF 97-60. U.S. Geological Survey, Reston, Virginia, USA. (http://onlinepubs.er.usgs.gov/djvu/OFR/1997/ofr_97_60.djvu). Accessed February 2009.

Zen, E-an. 1997b. Channel geometry and strath levels of the Potomac River between Great Falls, Maryland, and Hampshire, West Virginia. Open-File Report OF 97-480. U.S. Geological Survey, Reston, Virginia, USA. (http://onlinepubs.er.usgs.gov/djvu/OFR/1997/ofr_97_480.djvu). Accessed February 2009.

Additional References

This section lists additional references, resources, and web sites that may be of use to resource managers. Web addresses are current as of May 2010

Pennsylvania Karst

Berg, T. M., and C. M. Dodge, compilers. 1981. Atlas of preliminary geologic quadrangle maps of Pennsylvania. Map 61, 4th Series. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA. (http://www.dcnr.state.pa.us/topogeo/map61/61intro.aspx).

Bosbyshell, H. 2006. Bedrock geologic map of the Chester Valley and Piedmont portion of the Germantown, Malvern, Norristown, and Valley Forge quadrangles, Chester, Delaware, Montgomery, and Philadelphia counties, Pennsylvania. Open-File Report OFBM 06-04.0, 4th Series. Bureau of Topographic and Geologic Survey, Middletown, Pennsylvania, USA. (http://www.dcnr.state.pa.us/topogeo/openfile/chester.aspx).

Ford, D., and Williams, P. 1992. Karst geomorphology and hydrology. Chapman & Hall, London, England, UK.

MacLachlan, D. B. 1994. Some aspects of the Lower Paleozoic Laurentian margin and slope in southeastern Pennsylvania. Pages 3-23 *in* R. T. Faill and W. D. Sevon, editors. Various aspects of Piedmont geology in Lancaster and Chester Counties, Pennsylvania. Guidebook 59. Annual Field Conference of Pennsylvania Geologists, Lancaster, Pennsylvania, USA.

White, W. B. 1988. Geomorphology and hydrology of karst terrains. Oxford University Press, New York, New York USA.

Geology of National Park Service Areas

National Park Service Geologic Resources Division (Lakewood, Colorado). http://nature.nps.gov/geology/

NPS Geologic Resources Inventory. 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/

Harris, A. G., E. Tuttle, and S. D. Tuttle. 2003. Geology of National Parks. Sixth edition. Kendall/Hunt Publishing Co., Dubuque, Iowa, USA.

Kiver, E. P., and D. V. Harris. 1999. Geology of U.S. parklands. John Wiley and Sons, Inc., New York, New York, USA.

Lillie, R. J. 2005. Parks and plates: The geology of our national parks, monuments, and seashores. W.W. Norton and Co., New York, New York, USA. [Geared for interpreters].

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. 2009. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA.

[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/

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. 1984. American Geological Institute dictionary of geological terms. 3rd edition. Bantam Doubleday Dell Publishing Group, New York, New York, USA.

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").

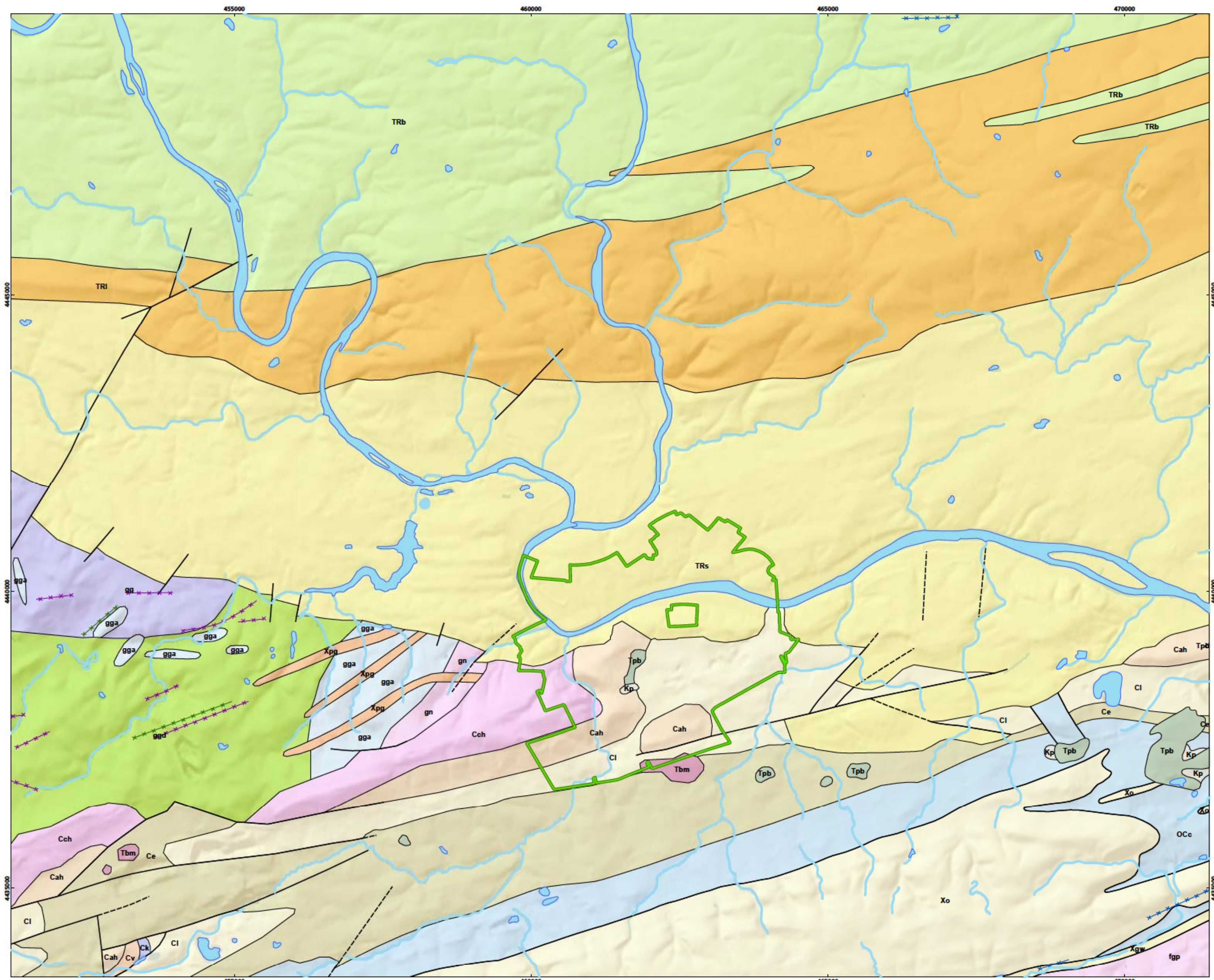
U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

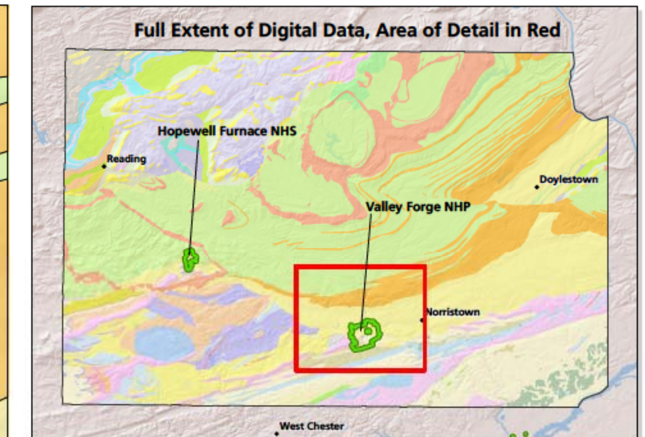
U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

Appendix A: Overview of Digital Geologic Data

The following page is an overview of the digital geologic data for Valley Forge National Historical Park. 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.

Overview of Digital Geologic Data for Valley Forge NHP





NPS Boundary

Dikes

Jd, known or certain

Xpg, known or certain

md, known or certain

Faults

unknown offset/displacement, known or certain

unknown offset/displacement, approximate

Geologic Contacts

known or certain

approximate

Geologic Units

Tpb - Pensauken and Bridgeton Formations, undifferentiated

Tbm - Bryn Mawr Formation

Kp - Patapsco(?) Formation

Trb - Brunswick Formation

Trl - Lockatong Formation

Trs - Stockton Formation

OCc - Conestoga Formation

Ce - Elbrook Formation

Cl - Ledger Formation

Ck - Kinzers Formation

Cv - Vintage Formation

Cah - Antietam and Harpers Formations, undivided

Cch - Chickies Formation

Xpg - Pegmatite

Xo - Octoraro Formation

Xgw - "Glenarm Wissahickon" formation

ggd - Felsic and intermediate gneiss

gga - Banded mafic gneiss

gg - Graphitic felsic gneiss

fgp - Felsic gneiss

gn - Felsic to mafic gneiss

0 2 4 6 8 Kilometers

0 1 2 3 4 Miles

UTM Zone 18N NAD 83

scale greater than source data

N

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 Valley Forge National Historical Park, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

Produced by the Geologic Resources Inventory

August 2010

Appendix B: Scoping Meeting Participants

The following is a list of participants from the GRI scoping session for Valley Forge National Historical Park, held on June 22–24, 2004. The contact information and email addresses in this appendix may be outdated; please contact the Geologic Resources Division for current information. The scoping meeting was the foundation for this GRI report.

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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 464/105493, September 2010

National Park Service
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