National Park Service
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Natural Resource Program Center

Monocacy National Battlefield

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/051

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Geologic Resources Division
Natural Resource Program Center
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COVER: Visitor Center Creek, Monocacy National Battlefield
INSIDE COVER: Thomas Farm Pond, Monocacy National Battlefield

NPS Photos by National Capital Region Network Staff

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Executive Summary

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

Monocacy National Battlefield is preserved to commemorate the men who fought on its soil in 1864 during the American Civil War. The landscape reflects a unique geologic history that spans from the ancient Precambrian through the formation of the Appalachian Mountains, and from the more recent Ice Age events to the modern day. Every landscape is determined by its past and present underlying geologic structure. The landscape begins with the geology, and the processes that shaped today's environments, history, and scenery.

Knowledge of geologic resources can directly support resource management decisions that address geologic issues, air and water quality, urbanization, flood risk, wildlife populations, invasive species, future scientific research projects, and interpretive needs associated with the park.

Geologic processes give rise to a landscape composed of rock formations, hills and valleys, waterfalls, and wetlands. This landscape played a prominent role in the movement of troops and battle locations during the Civil War. Local geology dictated the placement of bridges, fords, and railroads, which in turn informed military strategy. Today, geologic processes continue to develop a landscape that influences human use patterns. The connection between history and geology inspires visitors, and emphasis on geologic resources will enhance the visitor's experience.

The rocks of central Maryland reflect the powerful tectonic forces responsible for the Appalachian Mountains. Precambrian gneiss, metavolcanic rocks, and younger (Paleozoic) quartzite and phyllite underlie the hills visible to the west of Monocacy. The entire region was compressed during three separate tectonic events, the Taconic, Acadian, and Alleghenian orogenies. Following this compression, a series of fault-bounded extension basins, such as Frederick Valley, developed in the Triassic. These basins filled with sediment shed from the mountains.

Humans have significantly modified the landscape of Monocacy by developing dams, trails, buildings and farms, roads, bridges and streamworks, as well as polluting the air and water. Geologic processes continue to change the landscape. The need to balance historic and natural preservation and restoration with recreation makes resource management a challenge.

The following issues have geologic significance for management of the park:

- Erosion and slope processes

  The relatively wet climate of the eastern United States, combined with severe storms, loose soils along slopes, and active streams at Monocacy National Battlefield, creates a setting that is especially susceptible to slumping, slope creep, and erosion of stream banks. Increased runoff can dramatically alter the landscape, creating new hazardous areas in the process, and may also clog streams with excess sediment, which affects hydrologic systems and aquatic life.

- Sediment load and channel storage

  Erosion of the landscape at Monocacy leads to increases in the sediment carried by the rivers in the park. Sediment loads and distribution affect aquatic and riparian ecosystems (including drinking-water supplies). Sediment loading can result in changes to channel morphology and increased frequency of overbank flooding. Fine-grained sediments also serve to transport contaminants in a water system.

- Water issues

  Floods are a natural process along many rivers, creating fertile floodplains and washing away accumulated debris. However, seasonal flooding of the Monocacy River threatens the historic context of the battlefield and surrounding areas. Protecting these features and cultural resources along the banks of the river requires an understanding of the relationships between geology, the hydrologic system, and biology throughout the park.

Other geologic parameters and issues, such as recreational demands, water issues, agricultural pollution, and geologic education and research, have also been identified as critical management issues for Monocacy National Battlefield. These are described further in the Geologic Issues section of this report.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Monocacy National Battlefield.

Purpose of the Geologic Resource Evaluation Program

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

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

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

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

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

History of Monacacy National Battlefield

Monocacy National Battlefield is located in Frederick County, Maryland. It was established as a National Memorial Park on June 21, 1934, and redesignated a National Battlefield on October 21, 1976, by an act of Congress in order to preserve and commemorate the sacrifices made during the American Civil War.

The name Monocacy comes from the Shawnee name for the river "Monnockkesey" which means "river with many bends." This winding river set the stage for the battle fought there in 1864. The 1864 Battle of Monocacy Junction was fought on the east bank of the Monocacy River on July 9, 1864, along what is now Maryland Route 355. Union troops attempted to burn all bridges across the river, but the Confederates were able to cross late in the day.

The landscape of the park consists of rolling hills and river valleys. Brooks Hill provides a scenic view of much of the battlefield area (fig. 1). Over this hill the Confederate attacks proceeded towards Union troops at the Thomas Farm. The attack stretched from the Monocacy River almost to Baker Valley Road to the southeast. Fighting continued over to Georgetown Pike, and the Union retreat crossed the Baltimore and Ohio (B&O) Railroad towards Baltimore.

The boundaries of the park have changed several times since its beginning. Though created in the 1930s, land was not purchased until the 1980s and the park was not opened until 1991. The 1,647 acre park attracted 22,125 visitors in 2007. In addition to its rich historical context, the park provides recreational opportunities and a sanctuary for many species in the urbanized Frederick area.

Geologic Setting

The geology affected the 1864 Battle of Monocacy Junction on regional and local levels. Two large rivers, the Monocacy and the Potomac, shaped the course of military movements in the area before the battles. Safe river crossings were vital to military success during the Civil War.

The Monocacy River is the third largest tributary of the Potomac River. The free-flowing river is approximately 93 km (58 mi) long and is fed by a drainage area of 1,927 km^2 (744 mi^2). The river begins at the confluence of Marsh Creek and Rock Creek in Adams County, Pennsylvania, and ends at its confluence with the Potomac near Dickerson, Maryland. Tributaries of the river in the battlefield area include Furnace Branch, Double Pipe Creek, and Stony Creek in Maryland and Tom's Creek in Pennsylvania.

The area's smaller streams played a significant role in the actual fighting at Monocacy by creating important topographic differences and tactical targets such as railroad bridges, crossings, gaps, gulleys, and protective cover. On the gentle landscape of Monocacy, even the smallest swell or depression was utilized for tactical advantage.

Monocacy National Battlefield is located east of the Catoctin Mountains, part of the northern end of the Blue Ridge, a physiographic subprovince of the Appalachian Mountains (fig. 2). Forming the easternmost part of the Blue Ridge province of Maryland and northern Virginia, the Catoctin Mountains are a belt of Lower Cambrian sediments and older metavolcanic rocks. The mountain ridge extends 80 km (50 mi) along a discontinuous linear trend from Emmitsburg, Maryland to Leesburg, Virginia. The park is in the Frederick Valley and is underlain by thick Triassic sediments just east of the Blue Ridge. The downdropped Frederick Valley is bordered on the west by a large normal fault.

The following is a general description of several of the region's physiographic provinces.

Atlantic Coastal Plain Province

The Atlantic Coastal Plain province is primarily flat terrain with elevations ranging from sea level to about 100 m (300 ft) in northern Virginia. It extends from New York to Mexico. Sediments eroding from the Appalachian Highland areas to the west were intermittently deposited on the Atlantic Coastal Plain over the past 100 million years, forming a wedge-shaped sequence during periods of higher sea level. These deposits were then reworked by fluctuating sea levels and the continual erosive action of waves along the coastline.

The Atlantic Coastal Plain province stretches from the Fall Line east to the Chesapeake Bay and Atlantic Ocean. The province continues as the submerged Continental Shelf province for another 120 km (75 mi) to the east. Atlantic Coastal Plain surface soils are commonly sandy or sandy-loams that are well-drained. Large streams and rivers in the Atlantic Coastal Plain province, including the James, York, and Potomac Rivers, are often influenced by tidal fluctuations.

Piedmont Province

The "Fall Line," or "Fall Zone," marks a transitional zone where the softer, less-consolidated sedimentary rocks of the Coastal Plain to the east intersect the harder, more resilient metamorphic rocks to the west to form an area of ridges and waterfalls and rapids. This zone covers more than 27 km (17 mi) of the Potomac River from Little Falls Dam, near Washington, D.C., west to Seneca, Maryland. Examples of this transition are present in the Potomac Gorge of the Chesapeake and Ohio Canal National Historic Park. Encompassing the Fall Line, westward to the Blue Ridge Mountains, is the Piedmont physiographic province.

The eastward-sloping Piedmont Plateau was formed through a combination of folding, faulting, uplift and erosion. These processes resulted in an eastern landscape of gently rolling hills starting at 60 m (200 ft) in elevation that becomes gradually steeper towards the western edge of the province at 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.

Within the Piedmont are a series of Triassic extensional basins formed by normal faults during crustal extension. The faults opened basins (grabens) that were rapidly filled with roughly horizontal layers of sediment. Examples of these basins include the Frederick Valley, which hosts the park, and the Culpeper Valley of northern Virginia.

Blue Ridge Province

The Blue Ridge Province extends from Pennsylvania to Georgia along the eastern edge of the Appalachian Mountains. It contains the highest elevations in the Appalachian Mountain system in North Carolina, near Great Smoky Mountains National Park. Precambrian and Paleozoic igneous, sedimentary, 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 in Virginia (Nickelsen 1956). South Mountain and Catoctin Mountain, both anticlines, are two examples of the pervasive folding in the Blue Ridge province.

Eroding streams have caused the narrowing of the northern section of the Blue Ridge Mountains into a thin band of steep ridges, climbing to heights of approximately 1,230 m (4,000 ft). The Blue Ridge province is typified by steep terrain covered by thin, shallow soils, resulting in rapid runoff and low ground-water recharge rates.

Valley and Ridge Province

The landscape of the Ridge and Valley physiographic province is characterized by long, parallel ridges of resistant sandstone separated by valleys formed in more easily eroded shale and carbonate rocks. This province contains strongly folded and faulted sedimentary rocks in western Maryland.

Areas dominated by carbonate formations exhibit karst topography. "Karst" is a term used to describe a region of irregular topography characterized by sinks, underground streams, caves, and springs formed by water percolating through water-soluble rock.

The eastern part of the Ridge and Valley province is part of the Great Valley (Shenandoah Valley). It is connected to the Piedmont province by streams that cut through the Blue Ridge Mountains.

Figure 1. Map of Monocacy National Battlefield.

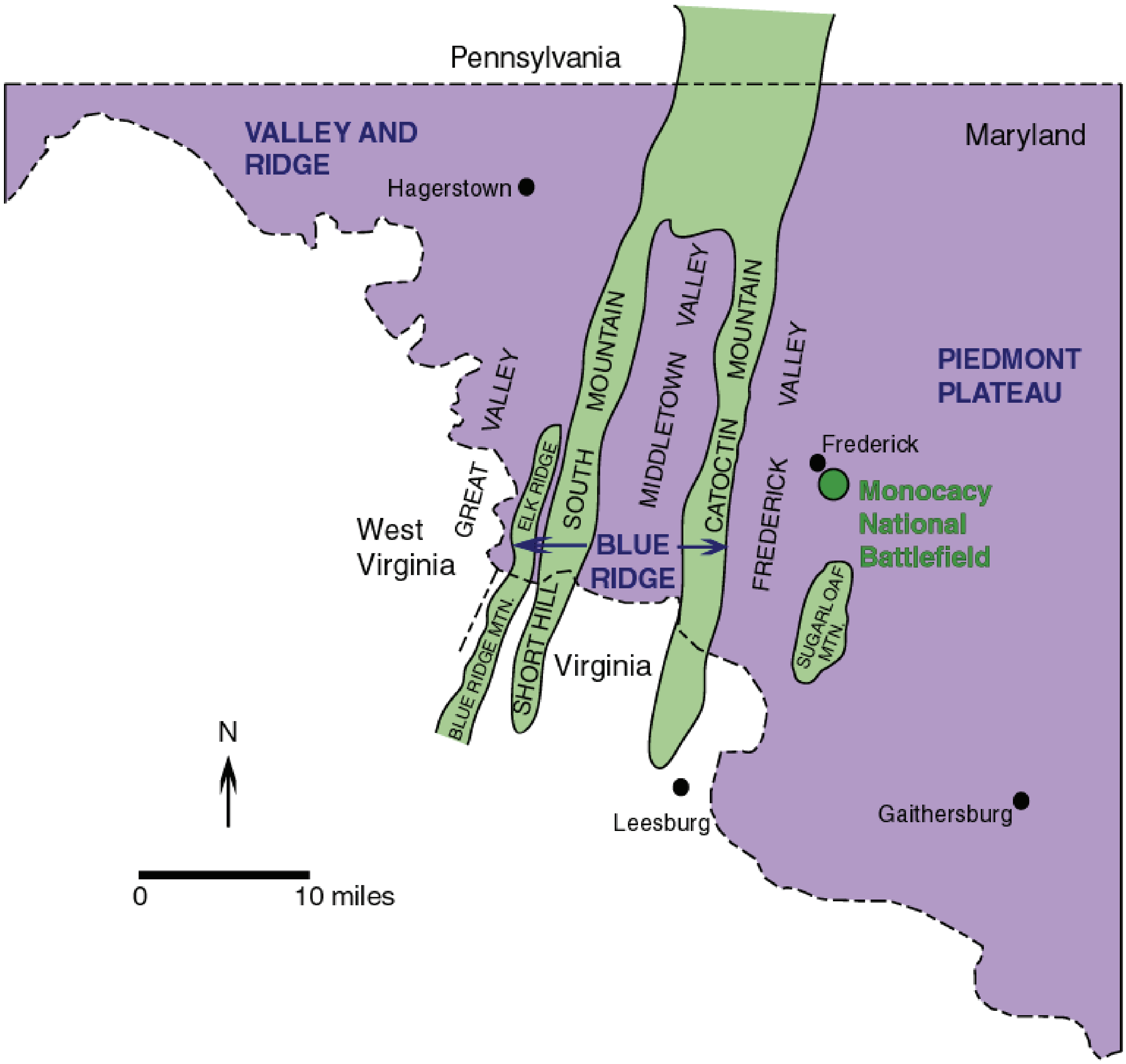


Figure 2. Location of Monocacy National Battlefield relative to geologic features of the Blue Ridge Province in Maryland. Note also the locations of the Piedmont and Valley and Ridge physiographic provinces. Graphic adapted from a figure in Whitaker (1955).

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Monocacy National Battlefield on April 30–May 2, 2001, 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.

Erosion and Slope Processes

The topographic relief within and surrounding the park is small. However, the likelihood of landslides and slumps increases with precipitation and undercutting of slopes by streams, roads, trails, and other development. Landslide hazard models and maps could help park managers assess specific areas relative risk for landslide occurance. These tools use information about geology, topology, and climate to identify hazardous areas.

Severe weather is difficult to predict. The Monocacy National Battlefield area of Maryland can receive large amounts of snow (e.g., 208 cm [82 in] in 1996) and is in a hurricane-affected zone. Periodic flooding of the Monocacy River results from sudden, large inputs of precipitation. Extreme weather combined with moderate slopes and loose, unconsolidated soils and substrate can lead to sudden, catastrophic slope failures. On slopes that lack stabilizing vegetation, rock and soil may mobilize and slide downhill, resulting in a massive slump or debris flow. In the vicinity of streams and rivers, this leads to shoreline erosion, increased sediment load, gullying, and the threat of destruction for trails, bridges, and other features of interest.

Increased erosion along the outer banks of bends in streambeds (where stream velocity is higher) causes the bank to retreat, leading to undercutting and washout. Trees, trails, and other features along these banks are undermined. Trees fall across the stream, and trails are washed out. Remedial structures such as cribbing, log frame deflectors, jack dams, stone riprap, and/or log dams can shore up the bank, deflect the flow, and help to slow erosion (Means 1995). However, these same structures may have deleterious effects when used at inappropriate sites causing eddying and further degradation of the banks beyond the margins of the structures.

Inventory, Monitoring, and Research Suggestions for Erosion and Slope Processes

- Monitor unstable slopes and streambanks for hazards to staff and visitors.
- Monitor erosion rates at key sites using repeated profile measurements.
- Develop a landslide hazard map or model for the park.

Sediment Load and Channel Storage

Erosion at Monocacy leads to increases in sediment carried by the park's rivers. Sediment loads and distribution affect aquatic and riparian ecosystems and can result in changes to channel morphology and increase overbank-flooding frequency.

High suspended sediment load continues to be a management problem at Monocacy National Battlefield. Seasonal floods and storms can increase sediment load to levels unsuitable for drinking-water suppliers, causing occasional closure of drinking water-supplies upstream and increasing the need for chemical treatment in drinking water from the lower reaches of the watershed. (http://www.acb-online.org/pubs/projects/deliverables-150-4-2003.pdf [Accessed August 2008]).

However, fine-grained sediments are vital in the overall fluvial transport of contaminants in a water system. Channel storage of fine sediment (and the contaminants contained therein) follows a seasonal cycle. This cycle is subject to hydrologic variability, with increased availability during the high stands of spring and decreased availability during the low stands of autumn. Fine-grained sediments do not travel downstream in a single pulse, but are often resuspended bottom material (Miller et al. 1984). This intermittent transport of contaminants and fine-grained sediment increases the affected area and could pose a threat to the park if focused, severe contamination were to occur within the Monocacy River Basin in Maryland.

Inventory, Monitoring, and Research Suggestions for Sediment Load and Channel Storage

- Study channel morphology of intense seasonal runoff. Consult professional geomorphologists about erosional processes.
- Inventory morphological characteristics of channels and monitor changes.
- Encourage reforestation along the Monocacy River to act as a buffer to erosion and to filter incoming nutrients and pollution.

Water Issues

In the humid eastern climate of Maryland, water seems present everywhere in streams, rivers, runoff, springs, and groundwater wells. Annual precipitation at Monocacy National Battlefield averages ≈97 cm (38 in) per year with almost half of the rain coming in the summer months during short intense storms. Because of the development of the surrounding areas, water resources are under constant threat of contamination and overuse. The most severe threats to park streams are from impacts of existing and future development in the rapidly growing Frederick area. The population of the

Monocacy watershed increased 55% between 1970 and 1990 alone (http://www.hood.edu/academic/biology/monocacy/Watershed/monocacy_watershed.htm [Accessed July 2005]).

Anthropogenic effects from road salts, runoff from impervious surfaces, septic systems, tilled fields, agricultural and residential fertilizers, pesticides, and herbicides, animal waste, overuse, and acid rain can considerably alter groundwater chemistry (Trombley and Zynjuk 1985; Dyer and Logan 1995). As suburbanization of the entire region increases, a decrease in agriculture and an increase in residential activites will lead to growth in landscaping-derived chemical input (L. McClelland 2005, personal communication).

The preservation of the integrity of the watershed is a major management objective at Monocacy and for the City of Frederick (the Monocacy is the principal water resource for the city) (www.cityoffrederick.com/departments/Planning [Accessed July 2005]). Local groups advocating a Riverbank Buffer Plan have stirred controversy among landowners (Kunkle 2004).

The integrity of the watershed is directly reflected in the quality of the river water. Differences in water quality stem from a variety of natural and non-natural sources. For instance, major geochemical differences exist between water sampled from areas underlain by different lithologic units as controlled by hydrolysis, or the process that controls the chemical composition of most natural waters (Bowser and Jones 2002). Studies stress the importance of knowing the mineral compositions of both the aqueous phase and the host rock.

Ground-water chemistry in silicate-dominated rocks seems particularly sensitive to compositions of plagioclase (albite), smectite (clay), and mafic minerals (mica, amphibole, and pyroxene), whereas the presence of quartz or potassium feldspar has very little effect (Logan and Kivimaki 1998; Bowser and Jones 2002). Similarly, it was determined that vein calcite and dolomite contribute calcium to the system and that chlorite contributes magnesium (Logan and Dyer 1996). Many of these minerals contributing to chemical variations of groundwater are present in the map units within and surrounding Monocacy.

The hydrogeologic system at Monocacy National Battlefield is dominated by a karst aquifer. Karst features are formed by the dissolution of carbonate rocks such as limestone and dolomite. Karst aquifers can be highly permeable. In tests of mass-balance models in the area, Field and Mose (1998) determined that the median conduit apertures ranged from 1.16–1.24 m (3.80–4.07ft). Median macrofissures (narrower than conduits) ranged from 5.53–5.88 cm (2.18–2.31 in.). This implies rapid flow of groundwater through the aquifer after rainstorms, reducing the capacity of the substrate to filter impurities from the groundwater.

The hydrogeologic system changes in response to increased surface runoff as well. This increase is a result of the further development of impervious surfaces, such as parking lots, roads, and buildings. Sedimentation also increases due to clearing land for development and water temperature increases because of the insulating nature of impervious surfaces. However, base flows of streams decrease because impervious surfaces prevent infiltration into the aquifer. Thus, the difference between base and peak streamflows typically increases as a consequence of development in the absence of runoff mitigation measures, such as detention ponds.

Where agricultural runoff, construction materials, and other human pollutants are present, nitrogen (and other contaminant) levels in the water may reach dangerous levels. Runoff from roadways commonly contains high levels of oil and other car emissions that are carried into park waterways and seep into the soil. Salt used to keep roads clear of snow and ice in winter contaminates soil along ditches. Knowledge of the chemicals used in regional agriculture and development, combined with an understanding of the hydrogeologic system, including groundwater flow patterns, is essential to protect the ecosystem of the watershed for the park.

The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow. Other input sources include wind, surface runoff, ground-water transport, sewage outfalls, landfills, and fill dirt. Streams in effect integrate the surface runoff and ground-water flow of their watersheds. Thus, they provide a measure of the status forthe watershed's hydrologic system. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Flooding Issues

Much of Monocacy National Battlefield comprises floodplains along the Monocacy River. The visitor center and surrounding fields are often flooded during sudden and seasonal high stands. This flooding has damaged foundations of buildings and electrical wiring and has affected crops in surrounding fields. The floodplain of the Monocacy River is described in greater detail in the following Features and Processes section.

Agricultural Pollution

The Monocacy River is categorized as a Maryland Wild and Scenic River (passed by the Maryland General Assembly in 1968, Monocacy River inclusion April 30, 1974). However, it has one of the greatest non-point source pollution problems in the region, largely due to agricultural runoff. Agriculture combined with easily eroded soil has the potential to degrade both surface and groundwater.

By increasing nutrient levels such as nitrogen and phosphorous, introducing other agrichemicals, and increasing suspended sediment, agricultural practices pose a serious threat to the Monocacy watershed and by extension the Potomac River and Chesapeake Bay systems.

The Environmental Protection Agency rated the Monocacy watershed (Hydrologic Unit Code 2070009) a

3 overall on a scale of 1–6 for water quality. This score indicates moderately serious water-quality problems with aquatic conditions below state goals (http://www.hood.edu/academic/biology/monocacy/Watershed/monocacy_watershed.htm [Accessed July 2005]).

As much as 60% of the watershed is dedicated to agricultural use on the fertile soils of the Frederick Valley, including large areas of Monocacy National Battlefield. About 33% remains forested (mixed-oak deciduous forest). Urban areas such as Frederick, Maryland, complete the watershed. More than 3,500 farms, dairies, and livestock operations contribute polluting runoff and eroded sediment to the system (http://www.acb-online.org/pubs/projects/deliverables-150-4-2003.pdf [Accessed August 2008]).

The U.S. Department of Agriculture, as well as the Maryland Department of Agriculture, is addressing this problem in a water-quality demonstration project designed to help reduce degradation from agricultural operations. Improved water quality depends upon better farming techniques, termed Best Management Practices (BMPs), which should address nutrient and agrichemical use as well as soil conservation in the area.

Across the watershed, soil erosion from open fields ranges from 2–35 tons of soil per acre per year. This affects the land surrounding Monocacy National Battlefield as well as the river flowing through it. The T-value (a measure of how much soil can be eroded and still maintain agricultural productivity) is a mere 3 tons per acre per year throughout the watershed. Erosion control is needed to improve productivity as well as preserve the watershed (http://www.acb-online.org/pubs/projects/deliverables-150-4-2003.pdf [Accessed August 2008]).

Runoff from nearby farms combined with all septic systems enrich nutrients in the Monocacy watershed. Livestock operations produce nearly 1,119,400 tons of manure containing the equivalent of 4,400 tons of nitrogen and 900 tons of phosphorous. Inorganic nitrogen fertilizer use has increased more than four-fold since 1960. Pesticide use has tripled since 1964. Fecal coliform, an indicator of disease-causing organisms in water, has been a persistent problem for the section of river below the Frederick Sewage Treatment plant, very close to Monocacy National Battlefield (http://www.acb-online.org/pubs/projects/deliverables-150-4-2003.pdf [Accessed August 2008]).

Geologic and climatic factors play a significant role in the overall condition and health of the watershed. Precipitation, slope, soil type, soil permeability, and water-recharge rates all significantly affect the amount of nitrogen and other pollutants leached below plant root zones. The overall pollution problem is complicated by properties such as solubility and absorption rate. Once the contaminant moves below the soil and into the underlying karst aquifer, little chance for filtering exists in the highly permeable substrate. Karst terrane commonly has interconnected conduits, and water typically moves rapidly through the system.

Pilot programs in which farmers utilized BMPs have produced promising results for the Monocacy conservation projects. In 1991, 42 demonstration plots resulted in reduced soil erosion on land covering 3,500 acres. Erosion was reduced by an average of 6 tons of soil per acre per year. This early work prevented nearly 5,600 tons of sediment from flowing into the targeted streams (Israel Creek, Piney/Alloway Creeks, and Linganore Creek). More farmers are being invited to join the incentives program.

In 2007 the NPS Water Resources Division (WRD) completed a Water Resources Stewardship Report for Monocacy National Battlefield. The goal of this report is to develop comprehensive strategies for water resources that help the park achieve or maintain desired conditions using measurable and objective indicators. The report is available on the Web (http://www.nature.nps.gov/water/planning/Stewardship_Reports/MONO_WRSR_final_pdf.pdf) (Accessed September 2008).

Inventory, Monitoring, and Research Suggestions for Water Issues

- Work with the NPS WRD, the U.S. Geological Survey, and the Maryland Geological Survey to design and implement appropriate monitoring programs in the watershed.
- Map and quantify subterranean recharge zones, focusing specifically on karst-related conduits.
- Work with local officials to encourage development and maintenance of a buffer zone along the river to help protect the watershed by facilitating natural river processes.
- Prepare educational exhibits explaining the natural processes of floods, including the benefits to soil fertility.
- Reference - the Water Quality Inventory for Watershed Monocacy at the following EPA site: http://yosemite.epa.gov/water/adopt.nsf/c2e500503531739e85256a71005550c8/4a7150b0ee01226e85256f9c006c838c!OpenDocument (Accessed August 2008).
- Reference - the Maryland Department of the Environment's (MDE) list of documents regarding various conservation, restoration, and monitoring projects, as well as water quality, physical habitat condition, and other biological measures in the Lower Monocacy River watershed: http://mddnr.chesapeakebay.net/wsprofiles/surf/prof/wsprof.cfm?watershed=02140302 (Accessed August 2008).

Recreational Demands

Monocacy National Battlefield provides numerous recreational possibilities, including Civil War study, hiking, fishing, bicycling, picnicking, and photography. The park promotes activities that do not damage the park's resources or endanger other visitors.

The park receives many visitors, especially during the summer months; visitors totaled 22,125 in 2007. Visitors are placing increasing demands on the resources of the park. Management concerns vary from trail erosion to streambank erosion.

Many trails wind through preserved biological, historical, and geologic environments at the park. Many of these are especially fragile, and off-trail hiking promotes their degradation. The park encourages recreation within designated trails and picnic areas. Prohibited use in non-designated areas increases the area of impact and places delicate ecosystems at risk.

The Monocacy River enhances the natural beauty of the park. As with hiking, overuse of certain areas can lead to contamination and degradation of the ecosystem and increased erosion of stream banks. The Works Progress Administration (WPA) built stone walls in the 1930s to combat flooding along the Monocacy River. These and other efforts by the park have attempted to protect certain sensitive reaches of the river and locations near visitor areas. These supports are meant to reduce stream-bank erosion, but such measures are temporary. In addition to the large river and local streams (Bush Creek, Harding's Run, among other unnamed tributaries), there are two manmade ponds in the park (on the Gambrill and Thomas Farms) intended to provide water for livestock.

Inventory, Monitoring, and Research Suggestions for Recreational Demands

- Design wayside exhibits to encourage responsible use of park resources.
- Promote stabilizing vegetation along slopes at risk for slumping and erosion.
- Promote topographic and geologic mapping in the park linked to recreational use patterns to determine areas at high risk for resource degradation.

Soil

The Soil Resources Inventory (SRI) Program of the NPS Geologic Resources Division partnered with the Natural Resources Conservation Service (NRCS) to complete a soil survey for Monocacy National Battlefield in 2005. The SRI Program provides user-friendly products to park managers to facilitate effective resource management, as well as baseline information on soil resources for the Vital Signs Monitoring Program. Soil resource inventories equip parks with maps showing the locations and extent of soils; data about the physical, chemical, and biological properties of those soils; as well as information regarding potential uses and limitations of each kind of soil type. The products also can be used for park interpretive programs and to identify emerging Soil Program needs.

Paleontology

Monocacy National Battlefield has not had a formal paleontological inventory and no paleontological material has been collected within the park. However, there may be potential for future fossil discoveries within the fossiliferous geologic formations exposed within the park (Kenworthy and Santucci 2004).

The Araby Formation of early to mid Cambrian age, has yielded fragments of trilobite fossils from a location northeast of Monocacy National Battlefield. These are considered significant because they are among the oldest Piedmont fossils found in Maryland. The Rocky Springs Station Member of the Fredrick Formation (late Cambrian in age) has also produced trilobite fossils from a location northwest of the park (Kenworthy and Santucci 2004).

Fossils are non-renewable resources that bring geologic history to life from an interpretive perspective and would require park protection if discovered. Scientific interest in the paleontology of Monocacy National Battlefield may afford the park an opportunity to partner with researchers and develop interpretive programs and materials explaining this aspect of the parks geologic history.

Inventory, Monitoring, and Research Suggestions for Paleontology

- Collaborate with the scientific community to investigate potential paleontological sites.
- Be aware of formations containing potential fossil resources when planning infrastructure projects in the park.

Geology Education and Research

Monocacy National Battlefield has the opportunity to improve geologic interpretation by educating park visitors about role of geology in the environment and history. A detailed geologic map and a road or trail log, along with a guidebook linking Monocacy National Battlefield to the other parks in the Central Appalachian region would enhance a visitor's appreciation of the geologic history and dynamic processes that created the natural landscape and played a role in the Civil War battle showcased at the park. Strategically placed wayside exhibits would also help explain the geology and the role that geology played in park history to visitors.

Inventory, Monitoring, and Research Suggestions for Geology Education and Research

- Research the surficial geologic story at Monocacy and develop an interpretive program to relate the current landscape, ecosystem, history, and biology to the geology.

Geologic Features and Processes

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

Geologic Setting and Military History of Monocacy National Battlefield

The Confederate army's 2nd Corps, under the command of Lieutenant General Jubal A. Early, set out with 10,000 men, 4,000 cavalry, and 40 guns towards Washington, D.C., from the Shenandoah Valley, crossing the Potomac at Shepherdstown, in June of 1864 (fig. 3). They were attempting to divert Union forces from the quagmire at Petersburg. Union Major General Lewis Wallace traveled west with a small force (≈5,000 men) to meet the Confederates. His defensive position was east of the Monocacy River, directly facing three bridges spanning the river (http://usa-civil-war.com/Monocacy/monocacy.html [Accessed August 2008]).

On July 9, the Confederates began crossing the river at a downstream ford to advance on the Union left flank (fig. 4). The Battle of Monocacy Junction had begun. Approximately 2,400 men fell in the struggle also known as the "Battle that Saved Washington." In the end, the Confederates won the day, diverting Union attention away from General Robert E. Lee's forces at Petersburg, Virginia. However, the battle delayed the Confederate advance on Washington, D.C. Although they reached Fort Stevens within the city's boundaries by July 12, Early's troops were forced to retreat by the arrival of Union reinforcements to defenses around the capital city (www.nps.gov/mono).

Geology played a vital role in military success and failure in the Battle of Monocacy Junction. In the area around Monocacy, the parallel valleys and ridges of the Piedmont, Blue Ridge, and Valley and Ridge physiographic provinces directed troop and supply movement along predictable routes. Gaps such as Thoroughfare Gap and Harper's Ferry through the Blue Ridge were often the only means of crossing the mountains from east to west. These were strategic points to defend. Many early railroads and roads followed the trends of these natural geologic features. The confluence of several major roads and railroads at Monocacy Junction made it a focal point of defense from a southern approach towards Washington, D.C., or Baltimore.

The Monocacy River, the third largest tributary of the Potomac River, was another obstacle to Confederate advancement. Union Major General Lew Wallace chose Monocacy Junction as the site of a battle to halt Confederate troops. The Georgetown Pike to Washington, the National Road to Baltimore, and the Baltimore and Ohio (B&O) Railroad all crossed the river in the area. These, in addition to the natural Worthington McKinney Ford, were strategic targets for the Union army to defend.

During the battle, troops used natural features such as ridges, low valleys and depressions, shallow fords, undercut banks, and other subtle topographic expressions to their advantage and for defense. Interpretive materials could emphasize geologic controls during troop movements as a way of educating the public about the interconnectedness between history and science. A deeper understanding of the landscape would also result from such information.

In cooperation with the Chesapeake & Ohio Canal Association, visitors may also be directed to the neighboring Monocacy Aqueduct, in nearby Chesapeake & Ohio Canal National Historical Park (fig. 5). The aqueduct is one of eleven along the canal. It is more than 157 m (515 ft) in length and has seven arches constructed of white and pink quartz sandstone quarried nearby at Sugarloaf Mountain. Construction began in 1829 and ended in 1833. This feature is threatened by floods and large storms such as Hurricane Agnes in 1972 (http://www.geocities.com/Yosemite/3524/monocacy.html [Accessed August 2008]).

Flooding of the Monocacy River

Floods bring to mind terrible disasters, lost property, and lost resources. However, floods are a natural process and are vital to soil formation in fertile floodplain areas. Floodplains are defined as areas of land adjacent to rivers that are covered in water on a regular basis during river high stands. Much of the Monocacy Battle was fought on the floodplain. In the 1800s most of the riverbank was cleared of buffering trees for agriculture. Encourageing native plant life along the river will help buffer the erosive nature of floods as well as absorb (in part) potentially harmful nutrients, waste, and sediments from nearby developments and fields.

The U.S. Geological Survey measures the streamflow of the Monocacy at several locations. Hydrographs are available at the following website: http://md.water.usgs.gov/surfacewater/streamflow/ (Accessed August 2008). These hydrographs detail the location, drainage area, gage, station type, peak streamflow, daily streamflow, and contact information.

According to the National Oceanic and Atmospheric Administration (NOAA), from 1929–2001 there were 86 floods that reached a flood stage of 5 m (16 ft). This is almost one per year with the potential to cause serious damage to low-lying areas along the river's edge (http://www.erh.noaa.gov/marfc/Rivers/FloodClimo/Months/pot/FrederickPOT.pdf [Accessed August 2008]). A minor flood was defined as a crest from 5–5.2 m (16–17 ft), a moderate flood as 5.2–6 m (17–20 ft), and a major flood as greater than 6 m (20 ft) above normal flow.

Near the park, the floodplain of the Monocacy River was the site of the original Moravian settlement in Bethlehem. Many historic buildings are located on the floodplain. As part of the New Deal program in the 1930s the Works Progress Administration program erected stonewalls along the Monocacy to prevent further flood damage (http://home.moravian.edu/users/phys/mejjg01/geology/images/Flood_1955/bethlehem_flood_of_1955.htm [Accessed August 2008]). In addition to the park area, the City of Frederick maintains areas of parkland along the floodplain itself, but the entire area is poorly drained and prone to seasonal flooding.

The Blue Ridge Anticlinorium and Frederick Valley

The northern terminous of the Blue Ridge is north of Monocacy, in southern Pennsylvania. At this northern end, the Blue Ridge consists of a northeast-plunging, asymmetric anticlinorium, locally referred to as the South Mountain anticlinorium (trending N20E) (Logan and Dyer 1996). It extends southwestward nearly 400 km (250 mi) to the Roanoke, Virginia, area (Mitra 1989). Monocacy National Battlefield is east of the eastern, upright limb of the anticlinorium, also known as the Catoctin Mountains. The normal, eastern limb of the anticline at the Catoctin Mountains exhibits open folds that show uniform strains (Mitra 1976).

The entire anticlinorium is locally overturned to the northwest. The west limb dips steeply southeast, the crest is broad and flat, and the east limb dips approximately 50 degrees southeast. The anticlinorium exposes Grenville granodiorite and granitic gneiss in its core and is flanked on each side by Precambrian and Lower Paleozoic metasedimentary and metavolcanic rocks (Mitra 1989). The Swift Run (phyllite and quartzite), Fauquier and Mechum River (metamorphosed clastic sedimentary rocks), and Catoctin (greenstone, metarhyolite, and metasediments) Formations unconformably overlie the Precambrian gneissic rocks in central Maryland and northern Virginia. The structural style of the anticlinorium is continuous across the Great Valley and into the Valley and Ridge province. The anticlinorium is associated with Alleghenian thrusting above a detachment that extends eastward into the Piedmont province (Onasch 1986).

The anticlinorium marks the easternmost extent of the Blue Ridge province in Maryland. The structure at Catoctin Mountain is truncated on the east by a Triassic border fault. The fault separates the early Paleozoic rocks to the west from the thick Triassic rocks filling the Frederick Valley. The fault is largely covered by debris and sediments shed from the Catoctin Mountains highlands (Whitaker 1955). The fault was likely active during the Triassic extension that was responsible for many large, narrow, northeast-trending, down-faulted basins along the foothills of the Appalachians following the Alleghenian orogeny. The Culpeper Basin, south of Catoctin Mountain in Virginia, is another example of a Triassic extensional basin.

Caves and Karst Formation

Large carbonate deposits, including the Frederick Limestone, underlie the Frederick Valley. Carbonate rock dissolves in acidic meteoric water to form fissures. With increased water flow and subsequent dissolution, these fissures can expand into passages and ultimately hollow caverns and rooms. Outside the park, north of Frederick, the Monocacy River Cave is developed in thin-bedded Frederick Limestone. The cave is small, having an entrance 1.2 m (4 ft) wide and extending for another 8 m (26 ft). The cave is located above the east bank of the Monocacy River, east of Harrisonville. River alluvium that covers the floor of the cave demonstrates the role of the river in cave formation (http://www.mgs.md.gov/esic/features/cave/monoc.html [Accessed August 2008]).

The presence of even a small cave in nearby areas is evidence of karst development in the geologic units beneath Monocacy National Battlefield. The dissolution of carbonate rocks by ground water flowing through fissures, cracks, or joints creates karst terrain. The presence of karst has had a dramatic effect on the hydrogeology of the area. Because Frederick Limestone underlies the Monocacy River basin almost entirely, its hydrogeologic regime has probably been altered by the dissolution of the carbonate below. Karst terrain can include underground streams, springs, caves, sinkholes, and pinnacles. Sinkholes are developed throughout most of the carbonate rock formations in the area. The karst features around Monocacy National Battlefield have not yet been inventoried.

Karst landforms, like sinkholes and caves, occur elsewhere in the Frederick Valley area, including in the Great Valley, the Valley and Ridge, the Culpeper basin, and Westminster terrane in the western Piedmont province. These areas have abundant limestone, dolomite, and marble rock units (Southworth et al. 2001). Karst is rare in the Blue Ridge province to the west because marble occurs only as small bodies.

Karst occurs in three different sections of the Piedmont province. Kanawha Spring, just east of Point of Rocks, flows from the limestone of the Frederick Formation, which underlies the flood plain. Limestone cobbles within the conglomerate of the Leesburg Member of the Balls Bluff Siltstone dissolve to form hummocky topography with abundant sinkholes and springs just southeast of Point of Rocks. In addition, marble and limestone rock units of the Westminster terrane (exposed along Monocacy River north of Indian Flats) underlie linear valleys. These form abundant sinkholes to the north.

Geology and Archaeology

Long before Confederate and Union troops converged on the Monocacy area during the Civil War, people had been using the area’s abundant natural resources for hunting and farming. Hunting tools and animal (mastodon) teeth in Frederick County record local ancient Native American activity. Early settlers, in the mid 1600’s, reported an Indian hunting camp northwest of Frederick (Means 1995). The area provided the Native Americans with materials for tools, animals for food and clothing, and a variety of nuts, berries and other plants for gathering.

The thick, rich soils shed from the highlands to the west and deposited in the floodplains, as well as an abundant annual water supply, attracted settlers and farmers to the area. This interest continues today with local agricultural comprising the bulk of the Monocacy watershed.

Historical Preservation

One of the major goals of the park is to preserve the historical context of the area; this includes preserving and restoring old buildings and the landscape around them. Maintaining this landscape often means resisting natural geologic changes, which presents several management challenges. For example, a proposal for restoration of a historic building may consist of removing surrounding natural materials. The streams in the park are also sometimes engineered to preserve fishing habitat and protect trails, buildings, and streambanks from being undercut. These efforts attempt to reverse many natural geologic changes.

Geologic slope processes such as landsliding, slumping, chemical weathering, and slope creep are constantly changing the landscape at the park. Runoff erodes sediments from any open areas and carries them down streams and gullies. Historic structures and subtle topographic features are all vulnerable to change due to the geologic processes of weathering and erosion. Erosion naturally diminishes higher areas and fills in the lower areas and in the process distorts the historical context of the landscape. The park's goal of preserving both the natural and historical context of the area is constantly compromised by the continuous natural processes of erosion and weathering as well as local urban development.

Intense storms such as Hurricane Isabel in September 2003 damaged many local historical features, including the Beatty-Kramer House, Derr House, the Visitor Center at Monocacy National Battlefield, cabins at Catoctin Mountain Park, and the Chesapeake and Ohio Canal National Historical Park (www.marylandhistoricaltrust.net/isabel_event_FR.html [Accessed July 2005]).

The history of the area is heavily influenced by its geology. The geology determined the local river crossings and fords, and localized construction of railroad grades (fig. 6).

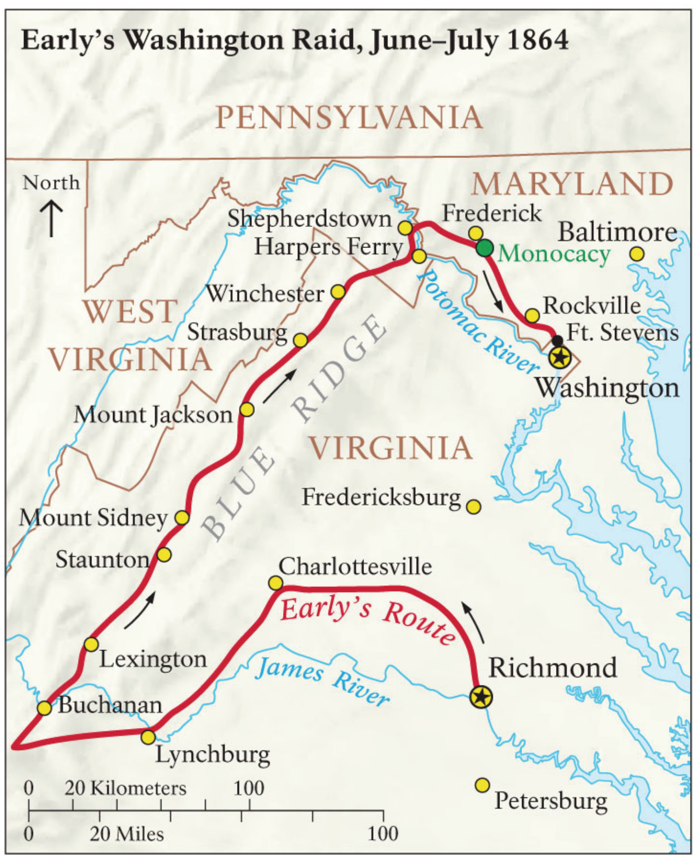


Figure 3. Regional map showing the path that Lieutenant General Jubal A. Early's troops followed towards Washington, D.C. in the summer of 1864.

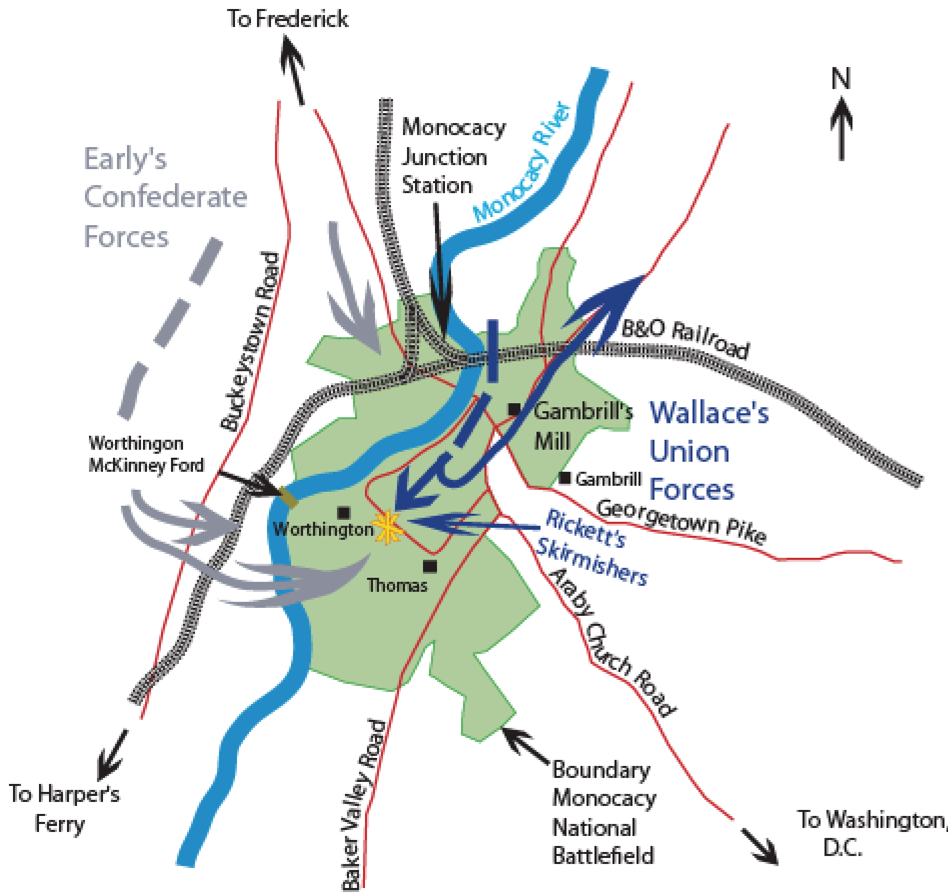


Figure 4. Map of Monocacy area showing troop movement during 1864 battle. Gray arrows indicate Confederate forces. Blue arrows indicate Union forces. Note location of Monocacy Junction, the Worthington McKinney Ford, and Gambrill's Mill (modern Visitor Center).

Figure 5. The Monocacy Aqueduct, which carries the Chesapeake and Ohio Canal over the Monocacy River. Photograph by Robert Kroll (1964).

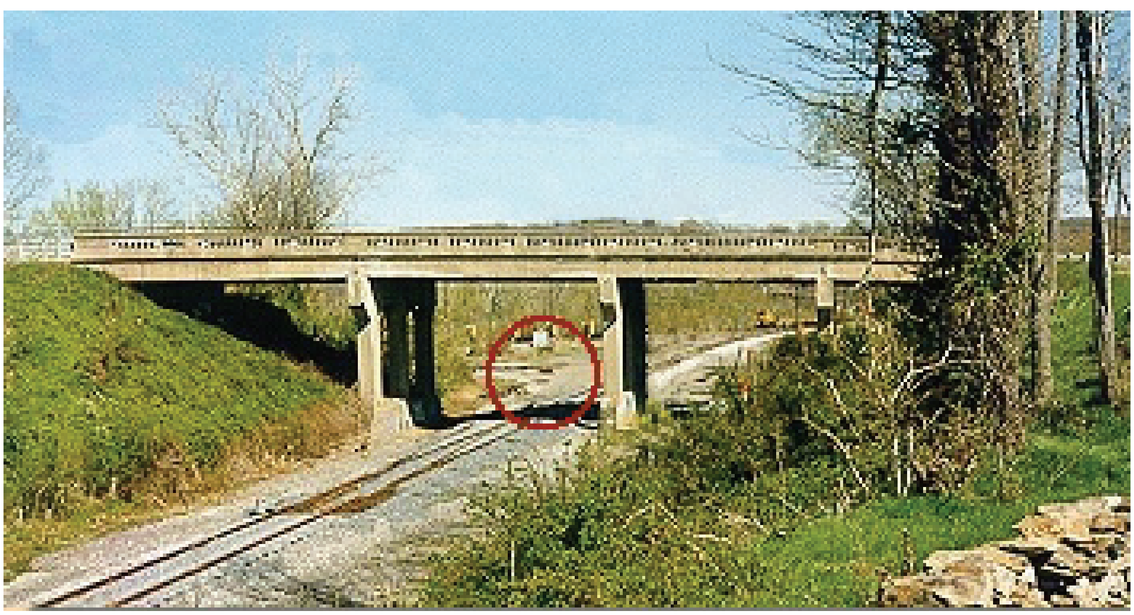


Figure 6. Monocacy Junction (circle). This was the center of the Union infantry skirmish line. Photograph courtesy of: http://usa-civil-war.com/Monocacy/monocacy.html.

Map Unit Properties

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

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

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

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

The features and properties of the geologic units in the following table correspond to the accompanying digital geologic data. Map units are listed from youngest to oldest. Please refer to the geologic time scale (fig. 7) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use. The following are source data for the GRE digital geologic map:

Southworth, S., and D. Denenny. 2006. *Geologic map of the national parks in the National Capital Region, Washington D.C., Virginia, Maryland and West Virginia*. Scale 1:24,000. Open-File Report OF 2005-1331. Reston, VA: U.S. Geological Survey.

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

GRE digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/). The surficial map units in the Monocacy National Battlefield area include and overlie rocks of the western Piedmont province. These rocks include late Proterozoic and Lower Cambrian metasedimentary rocks of the Chilhowee Group (Loudoun, Weverton, Harpers, and Antietam Formations), which consist of metaconglomerate, phyllite, quartzite, shale, and slate. Other map units in the area are Lower and Middle Cambrian metasedimentary rocks and Upper Cambrian to Lower Ordovician carbonate rocks of the Frederick Valley synclinorium, including the Tomstown Dolomite and the Frederick and Grove Limestones (Southworth and Brezinski 2003).

The area is part of the Triassic extensional basin formed by down-dropped block faulting to the west. Upper Triassic sedimentary rocks of the Newark Group and early Jurassic diabase sills and dikes fill the basin. The Gettysburg Shale and New Oxford Formation lie within several Triassic extensional basins as part of the Newark Group. The scant diabase sills and dikes are late remnants of tectonic extension and renewed igneous activity in the area.

Lining river and stream valleys are unconsolidated high- and low-level alluvial terrace gravels, alluvial gravel, sand, and silt, and residual gravel. Other recent deposits include colluvial slope deposits such as talus and slump deposits (Southworth and Brezinski 2003). These Quaternary units cover the landscape at Monocacy National Battlefield.

Map Unit Properties Table

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Specimens	Karst Issues	Mineral Resources	Habitat	Recreation	Global Significance
QUATERNARY (HOLOCENE)	Alluvium (Qa); Sinkhole (Qs).	Unit Qa contains broad deposits flanking active stream channels of sand, gravel, clay, and silt layers. Unit Qs consists of local depressions commonly filled with rubble from the collapse of areas undermined by dissolution of underlying carbonate rocks.	Very low	Avoid stream edge/riparian areas for heavy development; avoid both units for waste-water treatment facilities due to proximity to water and high permeability.	Unit Qa is associated with stream banks and riparian zones and may be unstable if exposed on a slope or saturated with water. Unit Qs is associated with collapse, and surrounding areas may be prone to further failure, endangering buildings and infrastructure.	Modern remains	May contain artifacts and/or settlement sites along major waterways.	None documented.	Unit Qs shows extreme dissolution of underlying carbonate rocks to form sinkholes (collapse) and caves.	Sand, gravel, silt, clay.	Riparian zones and burrow habitat.	Avoid for heavy recreation, especially areas underlain by unit Qs. Unit Qa is suitable for some trail development.	Unit Qs reflects karst processes throughout the region, and unit Qa reflects modern stream valley development throughout the Quaternary.
QUATERNARY (HOLOCENE AND PLEISTOCENE)	Terrace deposits, low level (Qt); colluvium (Qc).	Deposits of unit Qt are concentrated near stream confluences and contain reworked alluvial sand, gravel, silt, and clay, as well as larger colluvium clasts. Unit Qc commonly fills broad hollows in meadows and contains relatively unsorted, fine-grained fragments in layers of variable thickness.	Very low	Avoid most terrace and colluvium deposits for heavy development due to instability of slopes and high permeability.	Units are associated with stream bank slopes, and with mass wasting driven by gravity, water, and debris-flow processes.	May contain modern remains, plant fragments, and pollen(?); may contain fossiliferous fragments.	May contain artifacts and/or settlement sites along major waterways.	None documented.	None	Cobbles, gravel, sand.	Forms upland areas supporting larger trees and bushes with more soil development along waterways.	Suitable for most recreation unless unstable slopes are present.	Terrace units record the evolution of local waterways and changes in channel morphology.
CAMBRIAN	Frederick Formation, Lime Kiln Member (Cfl); Frederick Formation, Adamstown Member (Cfa); Frederick Formation, Rocky Springs Station Member (Cfr); Frederick Formation, Rocky Springs Station Member (shale) (Cfrs).	The Frederick Formation is a regionally extensive, thick interval of thin- to medium-bedded limestone and dolostone with thinner layers of shale and sandstone. Unit Cfl contains thin beds of limestone with algal limestone near the top of the formation. Unit Cfa consists of thin beds of limestone and shale intervals. Unit Cfr is composed of polymictic limestone breccia whereas unit Cfrs is locally interbedded as gray to black shale layers within the breccia.	Moderate	Suitable for most development unless carbonate layers are highly dissolved and/or the units are highly fractured, rendering them unstable on slopes and too permeable for septic systems.	Unit is found along creek beds and stream embankments and is subject to slope-failure processes.	May contain trace fossils, burrows, and algal mats.	May contain battlefield relics; unit may have provided lime for early iron-smelting operations.	None documented.	Dissolution is likely within this unit.	Limestone, dolostone for building material.	Unit supports a wide variety of habitats.	Unit is suitable for most recreation unless carbonate dissolution has rendered areas too unstable and/or friable for trails.	Units record the evolution of a shallow marine basin with off-shelf submarine slides, deeper water sedimentation, basin enlargement, and basin filling.
CAMBRIAN	Araby Formation (Car).	Unit Car contains sandy metasiltstone and graphitic metashale that appear light brownish gray in outcrop. Both rock types have been burrowed extensively and show marked cleavage development that obscures bedding structures.	Moderate	Unit has marked level of cleavage development that may render it unstable and/or too permeable for heavy development.	Unit is exposed in road cuts and along rivers and may be prone to erosion and mass-wasting processes.	Algal mats, bioturbation, trace fossils, trilobite *Olenellus*, possiblly crinoids, brachiopods, bivalves, and bryozoans.	Unit Car forms low ridges at Monocacy.	None documented.	Not enough carbonate present to form karst.	Slate?	Unit supports a wide variety of habitats.	Unit may be too friable and fractured for heavy recreation.	Unit Car reflects a deep-water slope facies environment within a starved clastic basin.
CAMBRIAN AND NEOPROTEROZOIC	Ijamsville Phyllite (CZi).	Unit consists of blue, purple, and green phyllite, slate, and phyllonite that contain pods and stringers of folded white vein quartz.	Moderate	Highly deformed nature of unit may render it weak for foundations; associated with a shear zone.	Unit has strong cleavage that renders it weak if exposed on slopes; may fail as large sheets.	None	None documented.	White vein quartz.	None	Hematite	Unit supports a wide variety of habitats.	Unit may be too friable and fractured for heavy recreation.	Unit reflects deep-water depositional environment of the Iapetus Ocean and marked deformation along the Martic fault.

Geologic History

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

Monocacy National Battlefield is located in the Frederick extensional valley just east of the ridge that forms the boundary between the Blue Ridge and Piedmont physiographic provinces in central Maryland. As such, it contains features that are intimately tied with the long geologic history of the Appalachian Mountains and the evolution of the eastern coast of the North American Continent. A regional perspective is presented here to connect the landscape and geology of the park to its surroundings.

The recorded history of the Appalachian Mountains begins in the Proterozoic (fig. 7). In the mid-Proterozoic, during the Grenville orogeny, a supercontinent formed that consisted of most of the continental crust in existence at that time, including North America and Africa. Sedimentation, deformation, plutonism, and volcanism are all manifested in the metamorphic granite and gneiss in the core of the modern Blue Ridge Mountains (Harris et al. 1997).

These rocks formed over a period of a 100 million years and are more than a billion years old, making them among the oldest rocks known in this region. They were later uplifed and thus exposed to erosive forces for hundreds of millions of years. Their leveled surface forms a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001). At Monocacy National Battlefield, these ancient rocks are buried beneath the Catoctin Mountains to the west, but they are exposed in the Blue Ridge south of the park (Means 1995).

The late Proterozoic, roughly 800–600 million years ago (Ma), brought extensional rifting to the area. The crustal extension created fissures through which massive volumes of basaltic magma were extruded (fig. 8A). This volcanic activity lasted tens of millions of years and alternated between flood-basalt flows and ash falls. The volcanic rocks covered the granitic and gneissic basement in the Catoctin Mountains area.

Because of the tensional tectonic forces, the supercontinent broke up and a sea basin formed that eventually became the Iapetus Ocean. This basin subsided and collected many of the sediments that later formed the Appalachian Mountains (fig. 8B).

Some of the sediments were deposited as alluvial fans, large submarine landslides and turbidity flows, which today preserve their depositional features. These early sediments are exposed on Catoctin Mountain, Short Hill–South Mountain, the Blue Ridge–Elk Ridge, and in areas within and surrounding Monocacy as the Chilhowee Group (Loudoun Formation, Weverton Formation, Harpers Formation, and Antietam Formation) (Southworth et al. 2001).

Associated with the shallow marine setting along the eastern continental margin of the Iapetus were large deposits of sand, silt, and mud in near-shore, deltaic, barrier-island, and tidal-flat areas. Some of these are present in the Chilhowee Group in Central Maryland, including the Harpers Formation and the Antietam Formation (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). In addition, huge masses of carbonate rocks, such as the Cambrian Tomstown Dolomite and Frederick Limestone, as well as the Upper Cambrian to Lower Ordovician Grove Limestone, were deposited atop the Chilhowee Group. They record a grand platform thickening to the east that persisted during the Cambrian and Ordovician Periods (545-480 Ma) and that forms the floors of Frederick and Hagerstown Valleys (Means 1995).

Somewhat later, 540, 470, and 360 Ma, igneous granodiorite, pegmatite, and lamprophyre, respectively, intruded the sedimentary rocks. During several episodes of mountain building and continental collision (described below) the entire sequence of sediments, intrusive rocks, and basalt were deformed and metamorphosed into schist, gneiss, marble, slate, and migmatite (Southworth et al. 2000).

Taconic Orogeny

From Early Cambrian through Early Ordovician time orogenic activity along the eastern margin of the continent began again. The Taconic orogeny (≈440–420 Ma in the central Appalachians) was a volcanic arc–continent convergence. Oceanic crust and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of the North American continent. The Taconic orogeny resulted in the closing of the ocean, subduction of oceanic crust during the creation of volcanic arcs within the disappearing basin, and the uplift of continental crust (Means 1995).

Initial metamorphism of the igneous rocks of the Catoctin Mountains (Catoctin Formation) into metabasalt and metarhyolite, as well as the Chilhowee Group Rocks into quartzite and phyllite, occurred during this orogenic event.

In response to the overriding plate thrusting westward onto the continental margin of North America, the crust bowed downwards creating a deep basin that filled with mud and sand eroded from the highlands to the east (fig. 8C) (Harris et al. 1997). This so-called Appalachian basin was centered on what is now West Virginia. These infilling sediments covered the grand carbonate platform and are today recorded by the shale of the Ordovician Martinsburg Formation (Southworth et al. 2001).

During the Late Ordovician, the oceanic sediments of the shrinking Iapetus Ocean were thrust westward onto other deep-water sediments of the western Piedmont along the Pleasant Grove fault. Sediments that later became sandstone, shale, siltstone, quartzite, and limestone were then deposited in the shallow marine to deltaic environment of the Appalachian basin. These rocks, now metamorphosed, currently underlie the Valley and Ridge province west of Monocacy National Battlefield (Fisher 1976).

Shallow marine to fluvial sedimentation continued for a period of about 200 million years during the Ordovician through Permian Periods, resulting in thick layers of sediments. Their source was the highlands that were rising to the east during the Taconian orogeny (Ordovician) and the Acadian orogeny (Devonian).

Acadian Orogeny

The Acadian orogeny (≈360 Ma) continued the mountain building of the Taconic orogeny as the African continent drifted toward North America (Harris et al. 1997). Similar to the preceding Taconic orogeny, the Acadian event involved collision of land masses, mountain building, and regional metamorphism (Means 1995). This event was focused north of central Maryland.

Alleghenian Orogeny

Following the Acadian orogeny, the proto-Atlantic Iapetus Ocean closed during the Late Paleozoic as the North American and African continents collided. This collision formed the Pangaea supercontinent and the Appalachian mountain belt still evident today. This mountain-building episode, termed the Alleghenian orogeny (≈325–265 Ma), is the last major orogeny that affected the Appalachians (fig. 8D) (Means 1995). The rocks were deformed by folds and faults producing the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge–South Mountain anticlinorium (including the Catoctin Mountains), and the numerous folds of the Valley and Ridge province (Southworth et al. 2001).

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

Deformed rocks in the eastern Piedmont were also folded and faulted, and existing thrust faults were reactivated as both strike-slip and thrust faults during the Alleghenian orogeny (Southworth et al. 2001). Paleoelevations of the Alleghenian Mountains are estimated at approximately 6,000 m (20,000 ft), analogous to the modern-day Himalaya Range in Asia. These mountains have been beveled by erosion to elevations of less than 600 m (2,000 ft) west of Monocacy National Battlefield (Means 1995).

Triassic Extension to the Present

Following the Alleghenian orogeny, during the late Triassic, a period of rifting began as the deformed rocks of the joined continents broke apart from about 230–200 Ma. The supercontinent Pangaea was segmented into roughly the same continents that persist today. This episode of rifting, or crustal fracturing, initiated the formation of the current Atlantic Ocean and created many block-fault basins with accompanying volcanism (fig. 8E) (Harris et al. 1997; Southworth et al. 2001).

The Newark Basin system is a large component of this tectonic setting. Large streams carried debris shed from the uplifted Blue Ridge and Piedmont provinces creating alluvial fans at their mouths. These were deposited as non-marine mud and sand in fault-created troughs, such as the Frederick Valley in central Maryland and the Culpeper basin in the western Piedmont of central Virginia. Many of these rift openings became lacustrine basins and were filled with thick deposits of silt and sand.

Large faults, such as the border fault west of Monocacy National Battlefield, running beneath Thurmont and Catoctin Furnace, Maryland, formed the western boundaries of the basins and provided an escarpment that was quickly covered with eroded debris. Magma was intruded into the new sandstone and shale strata as sills (sub-horizontal sheets) and nearly vertical dikes that extend beyond the basins into adjacent rocks.

After this magma was emplaced approximately 200 Ma, the region underwent a period of slow uplift and erosion. The uplift was in response to isostatic adjustments within the crust, which forced the continental crust upwards and exposed it to erosion.

Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroded mountains. These were deposited at the base of the mountains as alluvial fans and spread eastward becoming part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The amount of material that was deposited has been inferred from the now-exposed metamorphic rocks to have been immense. Many of the rocks exposed at the surface must have been at least 20 km (≈10 mi) below the surface prior to regional uplift and erosion. Today, the Potomac, Rappahannock, Rapidan, and Shenandoah Rivers and tributaries continue to erode the Coastal Plain sediments, lowering the mountains, and depositing alluvial terraces along the rivers, as they sculpt the present landscape.

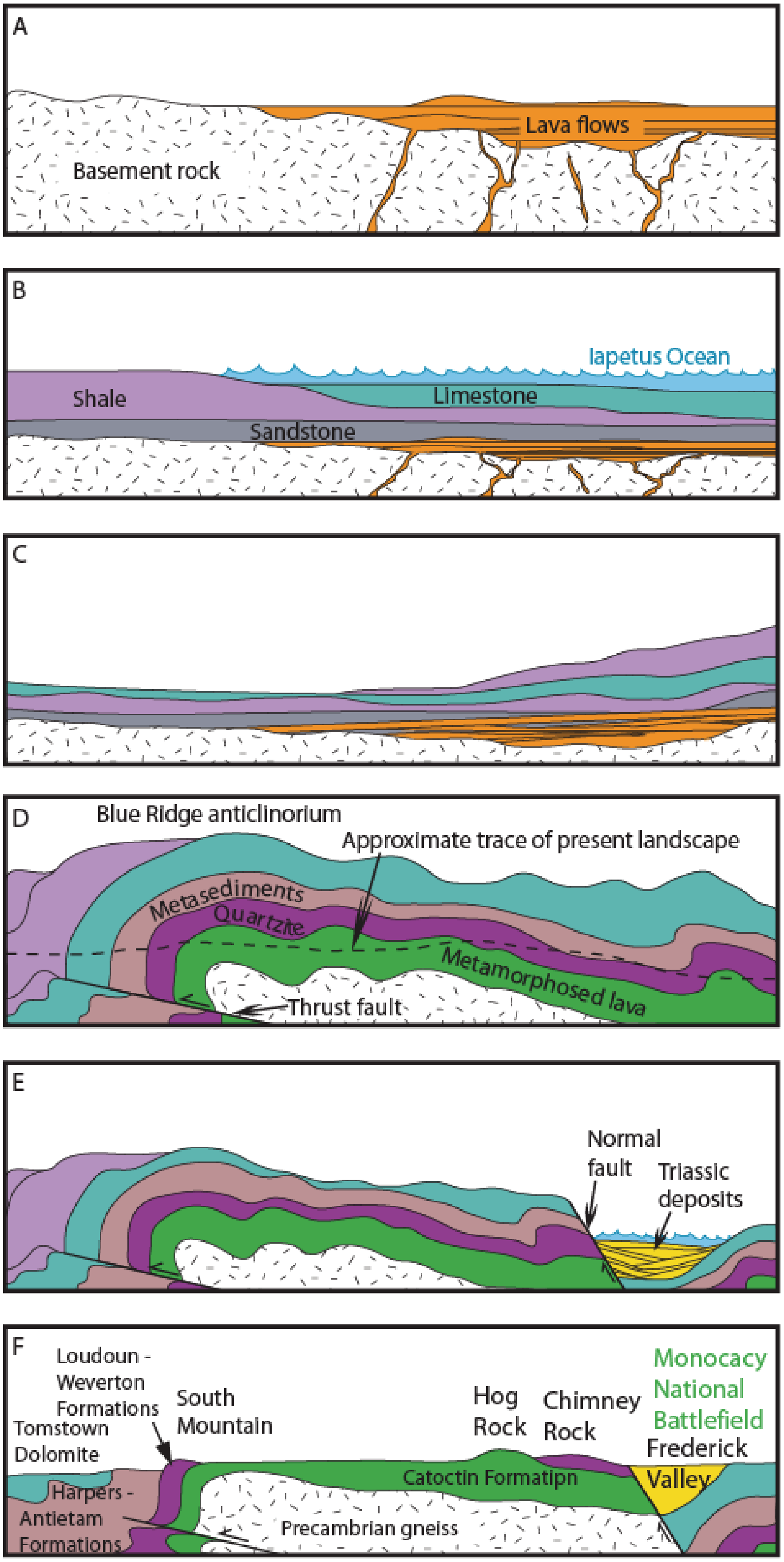
Since the breakup of Pangaea and the uplift of the Appalachian Mountains, the North American plate has continued to drift toward the west. Isostatic adjustments that uplifted the continent after the Alleghanian orogeny continued at a lesser rate throughout the Cenozoic Period (Harris et al. 1997).

The landscape and geomorphology of the greater Potomac and Rappahannock River valleys are the result of erosion and deposition from about the middle of the Cenozoic Period (≈5Ma) to the present. The distribution of flood plain alluvium and ancient fluvial terraces of the rivers and adjacent tributaries reflect the historical development of both drainage systems. There is little or no evidence that the rivers migrated laterally across a broad, relatively flat region. It seems the rivers have cut downward through very old, resistant rocks, overprinting their early courses (Southworth et al. 2001).

Though glaciers from the Pleistocene Ice Ages never reached the central Maryland area (the southern terminus was in northeastern Pennsylvania), the colder climates of the Ice Ages played a role in the formation of the landscape at Monocacy National Battlefield. The periglacial conditions that must have existed near the glaciers intensified weathering and other erosional processes (Harris et al. 1997). Glacially influenced landforms and deposits are probably late Tertiary to Quaternary, when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into the ancestral river channels, enhancing downcutting and erosion by waterways (Means 1995; Zen 1997a and 1997b).

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

Figure 7: Geologic time scale; adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years(Ma, or mega-annum).



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

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

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

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

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

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

Figure 8. Evolution of the landscape in the area of Monocacy National Battlefield from the Precambrian through the present. Graphic adapted from Means (1995). Drawings not to scale.

Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

bedding. Depositional layering or stratification of sediments.

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

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

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

calcareous. A rock or sediment containing calcium carbonate.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

dike. A tabular, discordant igneous intrusion.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

lithification. The conversion of sediment into solid rock.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.
oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–mi) thick and generally of basaltic composition.
orogeny. A mountain-building event, particularly a well-recognized event in the geological past (e.g., the Laramide orogeny).
outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.
overbank deposits. Alluvium deposited outside a stream channel during flooding.
paleogeography. The study, description, and reconstruction of the physical geography from past geologic periods.
paleontology. The study of the life and chronology of Earth's geologic past based on the phylogeny of fossil organisms.
Pangaea. A theoretica, single supercontinent that existed during the Permian and Triassic Periods (also see "Laurasia" and "Gondwana").
parent (rock). The original rock from which a metamorphic rock or soil was formed.
passive margin. A tectonically quiet continental margin indicated by little volcanic or seismic activity.
pebble. Generally, small, rounded rock particles from 4 to 64 mm in diameter.
permeability. A measure of the ease or rate that fluids move through rocks or sediments.
plateau. A broad, flat-topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).
plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.
pluton. A body of intrusive igneous rock.
plutonic. Describes igneous rock intruded and crystallized at some depth in the Earth.
porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.
Principal of Original Horizontality. The concept that sediments are originally deposited in horizontal layers and that deviations from the horizontal indicate post-depositional deformation.
Principle of Superposition. The concept that sediments are deposited in layers, one atop another, i.e., the rocks on the bottom are oldest with the overlying rocks progressively younger toward the top.
progradation. The seaward building of land area due to sedimentary deposition.
provenance. A place of origin. The area from which the constituent materials of a sedimentary rock were derived.
radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.
radiometric age. An age in years determined from radioisotopes and their decay products.
recharge. Infiltration processes that replenish groundwater.
red beds. Sedimentary strata composed largely of sandstone, siltstone, and shale that are predominantly red due to the presence of ferric oxide (hematite) coating individual grains.
regression. A long-term seaward retreat of the shoreline or relative fall of sea level.
relative dating. Determining the chronological placement of rocks, events, fossils, etc. from geological evidence.
reverse fault. A contractional, high-angle (>45°), dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").
rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.
ripple marks. The undulating, subparallel, usually small-scale ridge pattern formed on sediment by the flow of wind or water.
rock. A solid, cohesive aggregate of one or more minerals or mineraloids.
roundness. The relative amount of curvature of the "corners" of a sediment grain, especially with respect to the maximum radius of curvature of the particle.
sandstone. Clastic sedimentary rock of predominantly sand-sized grains.
scarp. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement.
seafloor spreading. The process by which tectonic plates diverge and new lithosphere is created at oceanic ridges.
sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.
sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).
sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a major sea level transgression-regression sediment package.
shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.
silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256–1/16 mm).
siltstone. A variably lithified sedimentary rock composed of silt-sized grains.
slickenside. A smoothly polished and commonly striated surface representing deformation of a fault plane.
slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).
slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.
soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and commonly overlying the parent rock from which it formed.
spring. A site where water flows out at the surface due to the water table intersecting the ground surface.
strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).
stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, age, etc. of rock layers, especially sedimentary rocks.
stream. Any body of water moving under gravity flow and confined within a channel.
strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.
strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Appendix A: Geologic Map Graphic

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

Geologic Map of Monocacy National Battlefield

Cross Section Line

Faults

- unknown offset/displacement, known or certain
- unknown offset/displacement, concealed

Contacts

- known or certain
- concealed
- map boundary

Surficial Units

- Qa - Alluvium
- Qs - Sinkhole
- Qt - Terrace deposit, low level
- Qc - Colluvium

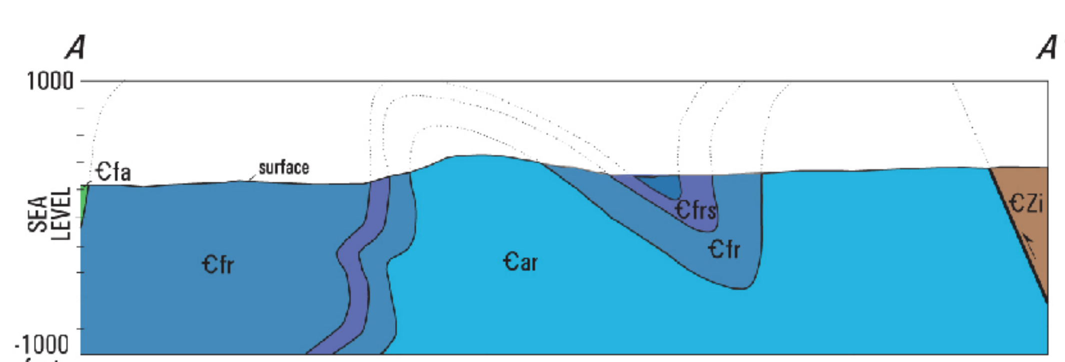
Bedrock Units

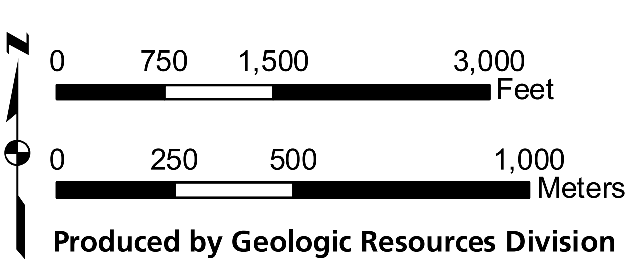
- Cfl - Frederick Fm, Lime Kiln Member
- Cfa - Frederick Fm, Adamstown Member
- Cfr - Frederick Fm, Rocky Springs Station Member 1
- Cfrs - Frederick Fm, Rocky Springs Station Member 2 (shale)
- Car - Araby Formation
- CZi - Ijamsville Phyllite

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

Southworth, S., and D. Denenny. 2006. *Geologic map of the national parks in the National Capital Region, Washington D.C., Virginia, Maryland and West Virginia.* Scale 1:24,000. Open-File Report OF 2005-1331. Reston, VA: U.S. Geological Survey.

Digital geologic data and cross sections for Monocacy National Battlefield in Maryland and all other digital geologic data prepared as part of the Geologic Resource Evaluation Program, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/





Produced by Geologic Resources Division

September 2008

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Monocacy National Battlefield. The scoping meeting was on April 30–May 2, 2001; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

Geologic Resource Evaluation (GRE) workshops were held for National Park Service (NPS) Units in the National Capital Region (NCR) over April 30-May 2, 2001. The purpose was to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Natural Resources Information Division (NRID), individual NPS units in the region, and the United States Geological Survey (USGS) were present for the workshop.

This involved half-day field trips to view the geology of Catoctin Mountain Park, Harpers Ferry NHP, Prince William Forest Park, and Great Falls Park, as well as another full-day scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the GRD, and the ongoing GRE. Round-table discussions involving geologic issues for all parks in the National Capital Region included the status of geologic mapping efforts, interpretation, paleontologic resources, sources of available data, and action items generated from this meeting.

Geologic Mapping

- Existing Geologic Maps and Publications

After the bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for the National Capital Region parks. The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverages were developed based on scales (1:24,000, 1:100,000, etc.) available for the specific park. Numerous geologic maps at varying scales and vintages cover the area. Index maps were distributed to each workshop participant during the scoping session.

- Status

The index of published geologic maps is a useful reference for the NCR. However, some of these maps are dated and are in need of refinement, and in other places, there is no existing large-scale coverages available. The USGS began a project to map the Baltimore-Washington, D.C., area at 1:100,000 scale, and as a result it was brought to their attention that modern, large-scale geologic mapping for the NCR NPS areas would be beneficial to NPS resource management.

Because of this, the USGS developed a proposal to re-map the NCR at large scale (1:24,000 or greater) and to supply digital geologic databases to accompany this mapping. Scott Southworth (USGS-Reston, VA) is the project leader and main contact. The original PMIS (Project Management Information Systems) statement is available as number 60900; of note is that portions of it need to be changed to reflect that the source of funding will be Inventory and Monitoring funds and not NRPP.

-Desired Enhancements

To better facilitate the geologic mapping, Scott Southworth would like to obtain better topographic coverage for each of the NCR units. Tammy Stidham knows that some of these coverages are already available and will supply them to Scott and the USGS. In general, anything in Washington, D.C., proper has 1-meter topographic coverage, and Prince George's county has 1:24,000 coverage.

Notes on Monocacy National Battlefield

Monocacy (MONO) is lumped with Antietam; should have topographic coverage soon. Have occasional flood problems.

Digital Geologic Map Coverage

The USGS will supply digital geology in ArcInfo format for all of the NCR parks. GRE staff will take this data and add the Windows help file and NPS theme manager capability to the digital geology and will supply to the region to distribute to each park in NCR.

Other Desired Data Sets for NCR

Soils

Pete Biggam (GRD Soil Scientist) supplied the following information in reference to soils for parks:

National Capitol Parks - Central is covered by the "District of Columbia" Soil Survey (State Soil Survey Area ID MD099). It has been mapped, and is currently being refined to match new imagery. An interim digital product is available to us via NRCS, but the "final certified" dataset most likely will not be available until FY03.

National Capitol Parks - Eastern is covered by portions of three soil survey areas; "District of Columbia (MD099)," "Charles County, Maryland (MD017)," and "Prince George's County, Maryland (MD033)." Both Charles County and Prince George's County are currently being updated, with Charles County scheduled to be available sometime in calendar year 2002, and Prince George's County sometime within calendar year 2003.

Paleontology

Greg McDonald (GRD Paleontologist) would like to see an encompassing, systematic paleontological inventory for the NCR describing the known resources in all parks with suggestions on how to best manage these resources. In addition to the parks containing paleo resources in NACE, according to his current database, the following are considered "paleo parks" in the NCR:

- Chesapeake & Ohio Canal NHP
- George Washington Memorial Parkway
- Manassas NBP
- Prince William Forest Park
- Harpers Ferry NHP

Geologic Report

A stand-alone encompassing report on each park's geology is a major focus of the GRE. As part of the USGS proposal to map the NCR, they will be summarizing the major geologic features of each park in a report to accompany their database.

It was suggested hoped that after the individual reports are finished a regional physiographic report will be completed for the entire NCR.

List of Attendees for NPS National Capital Region Workshop

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Monocacy National Battlefield

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/051
NPS D-78, September 2008

National Park Service

Director • Mary A. Bomar

Natural Resource Stewardship and Science

Associate Director • Bert Frost

Natural Resource Program Center

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

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