National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2010/229

THIS PAGE:
Stone wall along the modern day location of the Sunken Road, one of the bloodiest sites during the Civil War. Of the 12,600 Federal soldiers killed, wounded, or missing during the Battle of Fredericksburg, almost two-thirds fell in front of the stone wall.

ON THE COVER:
Cannons at Fairview, an important location during the Battle of Chancellorsville, May 2-3 1863.

National Park Service photographs Courtesy Gregg Kneipp (Fredericksburg and Spotsylvania County Memorial Battlefields National Military Park)

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
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The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Printed copies of this report are produced in a limited quantity and they are only available as long as the supply lasts. This report is available from the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

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NPS 326/105337, August 2010

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Executive Summary

This report accompanies the digital geologic map for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park in Virginia, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

The area surrounding Fredericksburg, Virginia, was the site of several major battles during the American Civil War, and is perhaps the most fought-for landscape in North America. The bloody fighting that took place here in 1862 and 1863, resulted in 85,000 wounded and 15,000 killed. Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park preserves the fading scars of battle, remnants of past land use, historic homesites of local families, and numerous monuments to the sacrifices made by Union and Confederate soldiers.

Many geologic factors contributed to the landscape at Fredericksburg and its position as a strategic point during the Civil War. The area's geology is more than just a landscape of rocks and mineral resources: geologic features and processes affect topography, the location of streams and rivers, the formation of soils, wetlands, and bogs, the patterns of vegetation, and the animal life that thrives in the environment. In addition to cultural resources, the park protects thousands of acres of woodland and riparian habitat.

The city of Fredericksburg is located at the Fall Line—the boundary between hard bedrock of the Piedmont physiographic province and the softer, sedimentary strata of the Atlantic Coastal Plain. The Fall Line influenced the location of the town when it was founded. Below this line, the Rappahannock River is navigable. Above it, waterfalls and rapids create a barrier to ocean-going vessels.

Fredericksburg's strategic military location between Washington, D.C., and Richmond, Virginia, focused Civil War activities here. Geologic features of the landscape were used to the Confederate army's advantage in the 1862 Battle of Fredericksburg. Furthermore, geologic resources contributed to the historic development of the area. Early mineral interest included mining for iron ore. Because smelting ore required a fuel source, the logging of local forests provided charcoal. Loss of trees resulted in the growth of heavy understory, which lent its name to the Battle of the Wilderness. Prospects within the gold-pyrite belt are also present in this region.

The following features, issues, and processes have a high level of geologic importance and management significance for the park:

- Disturbed Lands. There is a long history of mining in the park and surrounding area. Mineral resources include iron ore, gold, and sulfide minerals, as well as siltstone, gneiss, and basalt for crushed aggregate. Within park boundaries, abandoned mines, quarries, pits, and prospects create resource management issues. Acid mine drainage and heavy metal-laden sediments are issues for areas such as the brush covered pit on the recently aquired land in the Chancellorsville unit. Hazards to visitor and animal safety associated with mine features is also a management concern.
- Channel Morphology. The Rappahannock River has had a major influence on the landscape and history at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Here, the river is narrow and swift, and is bordered by riparian zones, floodplains, and higher terraces. The meandering river channel changes the riverbank types and position. These changes threaten visitor safety, existing park facilities, and the historical context of the landscape.
- Siting of Future Facilities. The historical features of the landscape are somewhat obscured at the park due to increased urban development, long-term agriculture, sedimentation, erosion, and vegetation. Park managers are discussing plans to restore battlefield-era conditions and expand facilities at the park. Ground penetrating radar (GPR) surveys along the suspected site of the Sunken Road, and on the heights west of Fredericksburg, helped to identify the locations of several historic features of the battlefield. Many geologic factors such as shrink-and-swell clays, springs, slope stability, and flood potential provide challenges for the appropriate placement of infrastructure.

The glossary contains explanations of many technical terms used in this report, including terms used in the Map Unit Properties Table. A geologic time scale is presented as figure 12.

Acknowledgements

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

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

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Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.

Purpose of the Geologic Resources Inventory

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

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

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

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps. The digital data sets provide geologic data for use in park GIS and facilitate the incorporation of geologic considerations into a wide range of resource management applications. The newest maps contain interactive help files. This geologic report assists park managers in the use of the map and provides an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information please refer to the Geologic Resources Inventory web site (http://www.nature.nps.gov/geology/inventory/).

History of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park

Established on February 14, 1927, during Herbert Hoover's administration, Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park commemorates the sacrifices endured by Civil War soldiers during the fierce fighting that took place near the town of Fredericksburg, Virginia (fig. 1). Originally administered by the War Department, the National Park Service became its steward on August 10, 1933. The park protects historic structures and Civil War battlefield sites, including Fredericksburg, Chancellorsville, the Wilderness, and Spotsylvania Court House. These battles occurred on December 11–13, 1862, April 27–May 6, 1863, May 5–6, 1864, and May 8–21, 1864, respectively. Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park covers 3,389 ha (8,374 ac). It is one of the largest military parks in the eastern United States.

Geologic Setting

Fredericksburg's strategic location between the Union capital of Washington, D.C., and the Confederate capital of Richmond, Virginia, was the reason for intense fighting in the surrounding countryside. The area's geography (affected by geology) influenced the battles that took place here. Three large regional rivers—the Rappahannock, the York, and the Rapidan—shaped the historical development of the Fredericksburg area and the course of military movements in the area before and during the battles. Safe river crossings and fords were vital to military success during the Civil War. Local streams such as Wilderness Run, Hazel Run, Ni River, Deep Run, Massaponax Creek, and other small-scale waterways created important topographic and tactical targets. On the relatively gentle landscape in the area, troops on both sides of the conflict used even the smallest swell or depression to strategic advantage.

Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park contains some of the most intriguing rocks of the Virginia Piedmont. The park's acreage lies within the Piedmont Plateau and Atlantic Coastal Plain physiographic provinces. The following is a general description of several of the different physiographic provinces that span from the Atlantic Coastal Plain to the Appalachian Mountains (fig. 2) and make up the region surrounding the park. This information is relevant to understanding the geologic history of the national military park.

Atlantic Coastal Plain Province

The Atlantic Coastal Plain physiographic province encompasses low, primarily flat terrain with elevations ranging from sea level to about 100 m (300 ft) in northern Virginia. The physiographic province extends from New York to Florida and stretches from the Fall Line east to the Chesapeake Bay and Atlantic Ocean. The province then continues as submerged Continental Shelf for another 120 km (75 mi) to the east. Over the past 100 million years, sediments eroding from the Appalachian Highlands to the west intermittently spread across the province in a wedge-shaped sedimentary package more than 2,400 m (8,000 ft) thick at the Atlantic coast. Fluctuating sea levels and the erosive action of waves along the coastline reworked these deposits. Soils of the Coastal Plain province are commonly well-drained, sandy loams. Large streams and rivers in the Coastal Plain province—including the James, York, Rappahannock, and Potomac—continue to transport sediment eastward, extending the coastal plain.

Piedmont Province

The "Fall Line" or "Fall Zone" marks a transitional zone where the softer, less consolidated sedimentary deposits of the Atlantic Coastal Plain intersect the harder, more resilient metamorphic rock to the west. This intersection forms a zone of waterfalls and rapids along the major rivers and lower-order tributaries. The Rappahannock River crosses this line at the city of Fredericksburg, creating a barrier to ocean vessel trade west of the city. Other examples of the Fall Line include the Potomac Gorge of the Chesapeake and Ohio Canal National Historical Park and at Great Falls Park just west of Washington, D.C. West of the Fall Line is the Piedmont physiographic province, which extends to the Blue Ridge Mountains.

The eastward-sloping Piedmont Plateau was formed primarily through uplift and erosion, which produced a landscape of gently rolling hills starting at 60 m (200 ft) above sea level. These hills become gradually steeper towards the western edge of the province at 300 m (1,000 ft) above sea level. The Piedmont Plateau is composed of folded and faulted igneous and metamorphic rocks, including schist, phyllite, slate, gneiss, and gabbro. Soils in the Piedmont Plateau are highly weathered and generally well drained.

A series of Triassic extensional basins occur within the Piedmont (fig. 3). During Mesozoic crustal extension (pulling apart), normal faulting produced basins (graben), which filled with nearly horizontal layers of sediment. Examples include the Frederick basin in Maryland and the Culpeper basin of northern Virginia.

Culpeper Basin

The Culpeper basin is one of a series of basins that fringe the boundary between the Blue Ridge and Piedmont along the length of the Appalachian Mountains. The basin formed as an intermontane basin during Mesozoic crustal extension. It trends northeast-southwest and is about 120 km (75 mi) long and 30 km (20 mi) wide. The rocks in the basin are mostly flat-lying sedimentary sandstone, siltstone, and shale, with some igneous diabase and basalt. Manassas National Battlefield Park contains rocks from the Culpeper basin.

The eastern boundary of the Culpeper basin is generally a depositional contact between Mesozoic sedimentary rocks and older igneous and metamorphic rocks of the Piedmont. A topographic change—from the rolling hills of the Piedmont to the relatively flat topography in the valley of the basin—marks the boundary. The western boundary of the basin is a system of faults collectively known as the Bull Run fault. West of the Culpeper basin is the Blue Ridge physiographic province.

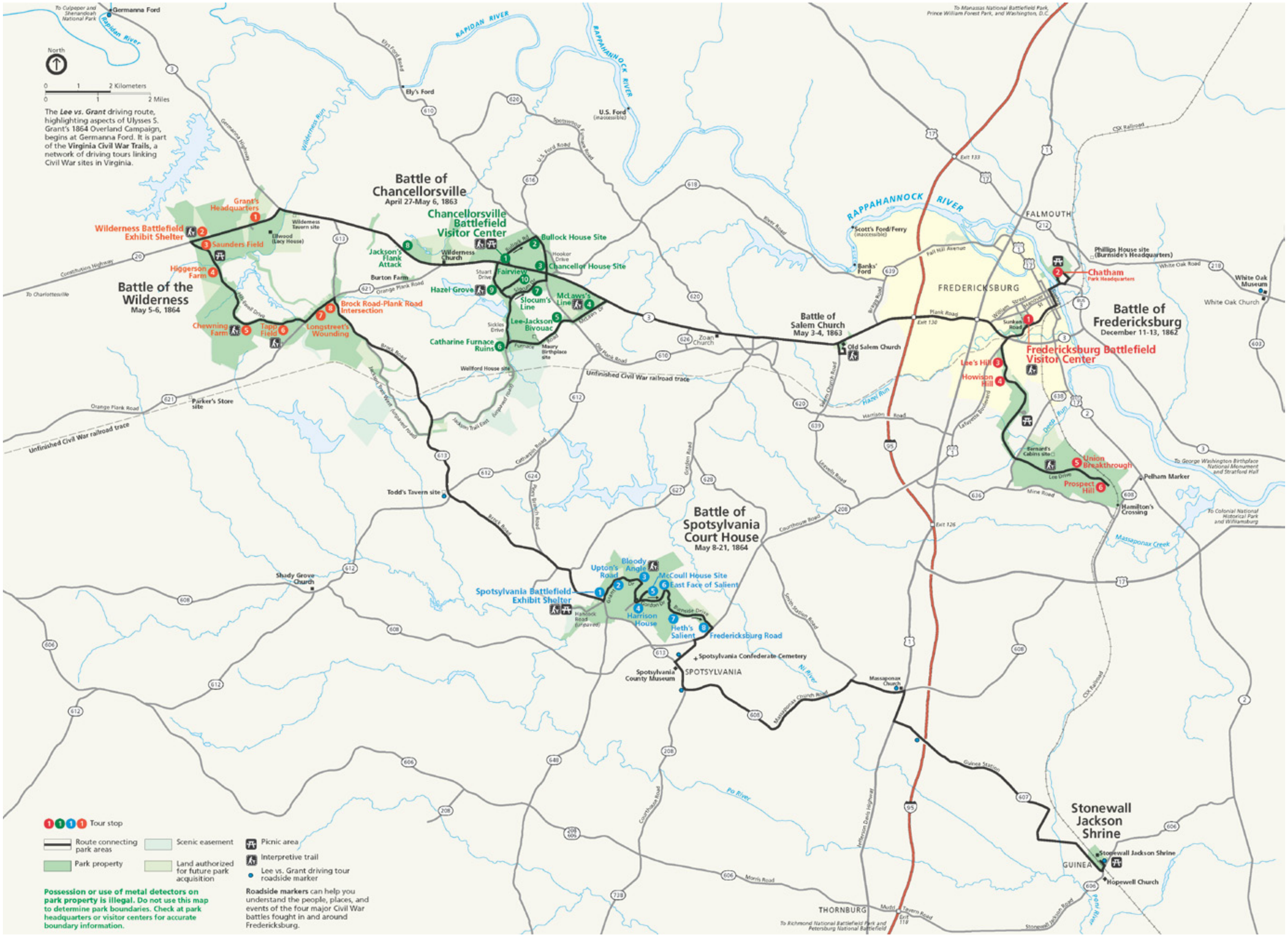

Figure 1. Map of Fredericksburg and Spotsylvania County Memorial Battlefields National Military Park. National Park Service map.

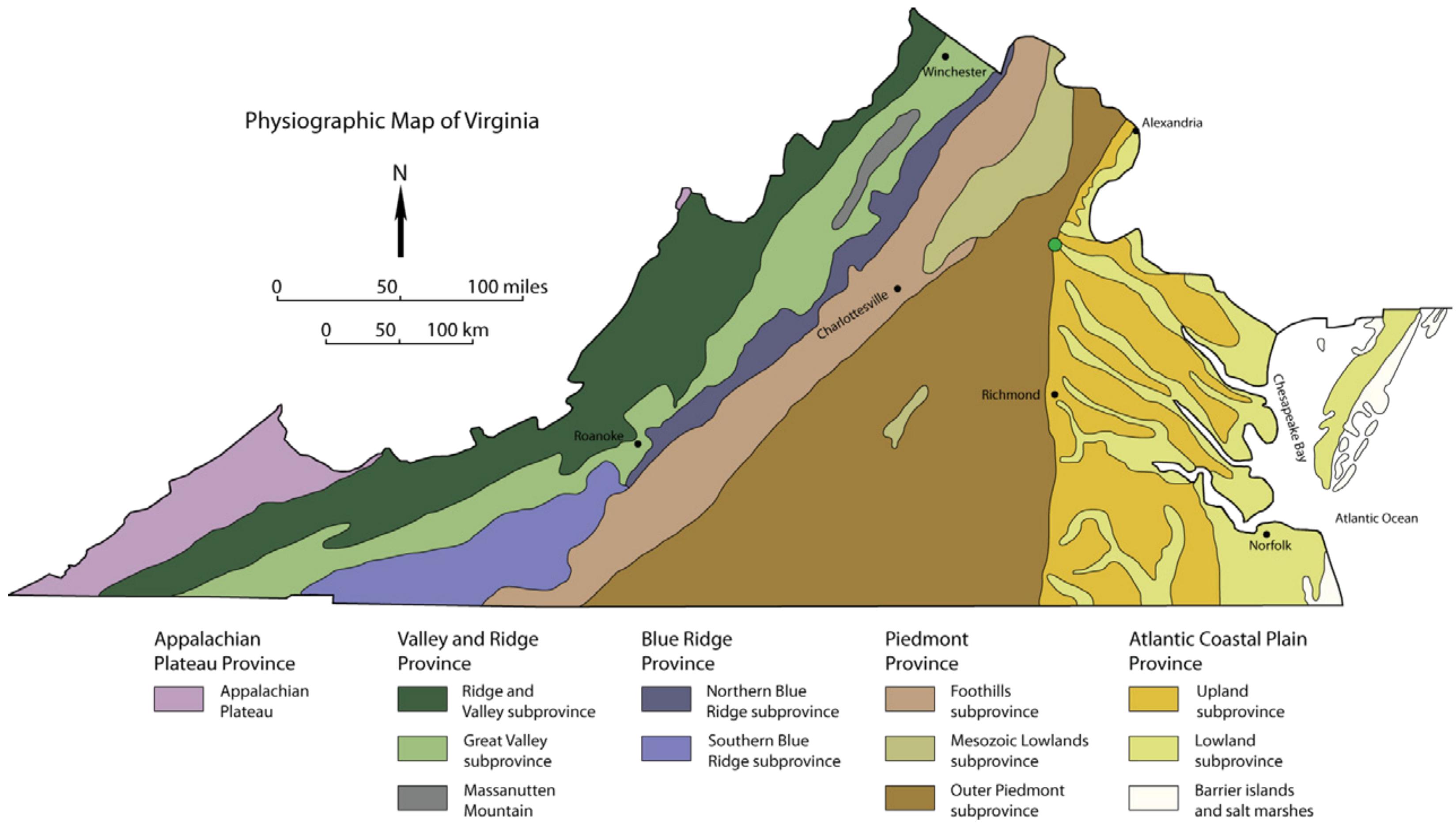

Figure 2. Physiographic map of Virginia. The figure shows the location of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park relative to the physiographic provinces of Virginia. The green dot on the figure represents the location of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Graphic modified from Bailey (1999) by Trista L. Thornberry-Ehrlich (Colorado State University).

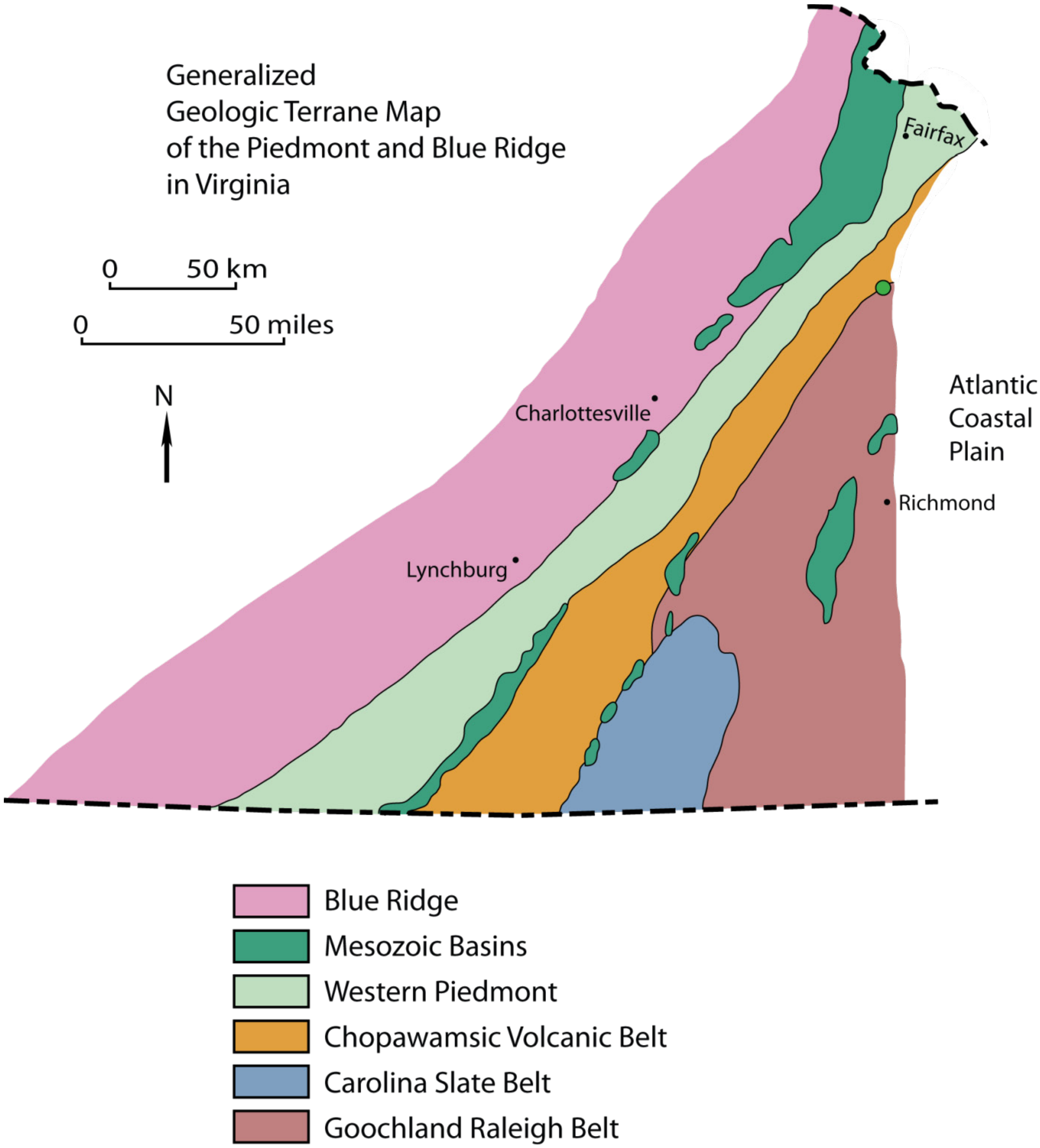

Figure 3. Geologic map of the Piedmont and Blue Ridge in central Virginia. Heavy dashed line indicates state boundaries. The green dot on the figure represents the location of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Graphic modified from Bailey (1999) by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park on April 13, 2005, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.

Introduction

Issues in this section are identified in relative order of resource management significance with the most critical listed first. Topics of general geologic interest and scientific research potential are presented towards the end of this section. Contact the NPS Geologic Resources Division for technical assistance.

Abandoned Mineral Lands

The history of mineral extraction from the rocks underlying Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park extends back to the 1600s. Small-scale abandoned mines, quarries, pits, and prospects dot the landscape within Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. This includes many pits and abandoned quarries that surround Catherine Furnace in the Chancellorsville unit. Iron ore was the first mineral commodity to be mined and processed in this area. Mining for iron started here around the Revolutionary War and resumed during the Civil War to provide munitions for the Confederate army (GRI scoping notes 2005).

While most of the abandoned mines in this area were probably iron ore mines, other mineral resources in the park area have fueled mining interest. For example, the Virginia gold-pyrite belt (described in the "Geologic Features and Processes" section) transects the park. Some small-scale mine features within the park boundary are probably gold or sulfide mineral prospects.

Other quarries in the region yield siltstone, sand and gravel (Rappahannock and Rapidan river deposits), granitic gneiss (quarry near Spotsylvania Court House in the Po River Metamorphic Suite), and basalt (quarry near Haymarket). These quarries provide crushed aggregate used in highway and building construction, roofing, erosion control, local landscaping, and leach fields (Culpeper Stone Company 1987).

There are more than 20 mineral extraction sites located within the park boundaries, many more than 6.1 m- (20 ft-) wide. A brush-covered pit on recently acquired land at the Chancellorsville unit is leaching arsenic into the groundwater and surface water.

According to the NPS Abandoned Mine Land (AML) inventory, the park contains two mine sites and three hazardous mine openings. The Virginia Department of Mines, Minerals, and Energy (VDMME) maintained an inventory of mine features, as well as descriptions of the different mineral resources in the area.

Mine-related features pose several concerns for resource management at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Visitor safety is a constant concern wherever open pits and loose tailings are associated with a mine feature. The potential for mine collapse of underground shafts within the park's boundaries is unknown. Most mine features that are accessible to the public have been blocked or filled, but for those that have not, retaining access for animals that inhabit the mines (e.g., bats), while addressing public safety, is a concern. Acid mine drainage, associated with the exposure of mine tailings to weathering, causes increased acidity in the pH of surface water and groundwater. Heavy metals leached from the rocks by acid drainage may precipitate in local soils, floodplain deposits, and alluvium.

Resource Management Suggestions for Abandoned Mineral Lands

- Continue to update the inventory of all mine-related features at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.
- Determine extent and nature of acid mine drainage from mine tailings and waste piles within the park.
- Determine use of mine features during the Civil War battles for protection or strategic advantage.
- Perform a slope stability survey, focusing on mine tailings within public zones. Where necessary, use slope stabilization techniques to ensure visitor safety.
- Prepare an interpretive program on historical prospecting, exploration, and extraction of mineral resources from Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.

Channel Morphology

The Rappahannock River is a major landscape-controlling feature at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Riparian zones, floodplains, and higher terraces, as well as small-scale tributaries, border the river. The bends of the river and local streams are constantly changing as part of a natural, meandering river system. Outer bends continue to erode as sediments are deposited on the inside bend. Changes in riverbank type and position (often changed due to bank failure and channel erosion) are resource management concerns at the park. These changes threaten existing park facilities and the historical context of the landscape.

The river is cutting into slopes near park headquarters. If the river undercuts this section of riverbank, a sudden collapse into the river could pose a threat to visitor safety and park infrastructure.

The river also played a vital role in the battles fought in this area. North of the Chatham Park headquarters, Union forces crossed the Rappahannock River on pontoon bridges (fig. 4). They were subjected to intense gunfire by Confederate sharpshooters while crossing. Erosion and seasonal flooding of the Rappahannock River threatens this historically relevant area along the eastern shore of the river.

Many open fields existed during the time of the battles fought at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Forests cover most of these areas now. In order to better interpret the cultural landscape and restore battlefield conditions, park managers are considering plans to clear these areas. However, soil erosion and subsequent sedimentation into nearby streams could result, degrading the river's water quality. The NPS Water Resources Division and Geologic Resources Division could provide technical assistance for addressing this concern.

Resource Management Suggestions for Channel Morphology

- Monitor fluvial changes using aerial photographs. Historic photographs may be useful in tracing the evolution of the channel and watershed since the Civil War.
- Research bank-stabilization methods for sections of the river that threaten historic features or encroach on potential pollution sources such as mine tailings.
- Relate channel dynamics to land-use evolution including agriculture, logging, and urban development.
- Consult Lord et al. (2009) for stream system monitoring techniques.

Siting of Future Facilities

Development, sedimentation, vegetation, and various land-use practices since the Civil War have obscured many historical features of the landscape. Park managers are discussing plans for restoring battlefield conditions and expanding facilities at the park (including the visitor center—possibly extending it underground beneath the existing parking lot). In 2003, ground penetrating radar (GPR) surveys along the suspected site of the Sunken Road (Telegraph Road) on the heights of Willis Hill (Marye's Heights) helped identify the locations of several historic features of the battlefield, including the sunken road, stone walls, trenches, farm building foundations, and artillery positions (Frangos and Geier 2003).

In addition to the potential for "obscured" cultural features, many geologic factors also affect park decision making regarding siting future facilities. The potential for regular flooding and slope failure are factors in selecting appropriate sites for facilities. Additionally, the presence of shrink-and-swell clays could undermine the longevity of any structure, road, or trail.

Understanding the nature of the substrate, locations of springs, and the hydrogeologic system would help avoid problems that could arise between groundwater flow and the siting of wastewater facilities.

Resource Management Suggestions for Siting of Future Facilities

- Consult local geologic experts when planning future facilities at the park.
- Perform GPR surveys to identify cultural and geologic features that may interfere with or influence the siting of future facilities and battlefield restoration (Frangos and Geier 2003).
- Locate areas of swelling clay, springs, groundwater flow, high slope, and unstable substrate to avoid for future facilities.
- Incorporate slope, geologic, vegetation, and hydrologic data into a GIS to compare with battle-era photographs to determine the best approach to restoration. Consult 2009 NPS vegetation map for additional data (http://biology.usgs.gov/npsveg/frsp/index.html).

Hydrogeology

Hydrogeology is the multidisciplinary study of the interaction between groundwater and subsurface geologic features such as structures, permeability, porosity, degree of fracturing, and rock composition. Visitor and park use, as well as surrounding development and agriculture, are increasing the levels of pollutants in both surface water and groundwater at the park. Nutrients from urban and agricultural waste are threatening the water quality of the region. Knowledge of the hydrogeologic system is critical to understanding the impacts of human-induced contaminants on the ecosystem and predicting ecosystem response.

Because municipal water and wells are the primary drinking water supplies for all the park units, an understanding of how the water table changes over time is significant for resource management and public safety. There are several wells throughout the park area that could be used for monitoring groundwater levels and quality. Monitoring groundwater flow via tracer studies in these wells would elucidate how quickly and in what direction water is moving through the system.

Another aspect of hydrogeology is wetlands. The National Park Service manages wetlands in compliance with mandates and requirements of Executive Order 11990 (Protection of Wetlands), the Clean Water Act, the Rivers and Harbors Appropriation Act of 1899, and the procedures described in Director's Order 77-1 (Wetland Protection) (National Park Service 2006). There are several seasonal wetlands within the park boundary. Some are adjacent to visitor trails and subject to degradation. Beaver activity likely formed a few of the larger wetland areas. Because wetlands are general indicators of overall ecosystem health, identifying, researching, and periodically monitoring wetlands in the park is a practical solution to assessing the system's condition.

Resource Management Suggestions for Hydrogeology

- Inventory, describe, and map any existing springs in the park.
- Contact the NPS Water Resources Division for additional information.

Slope Processes and Erosion

A major goal of park managers at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park is to present the historical context of the area, stemming from the pre-Revolutionary period through the Civil War. This process includes preserving and restoring earthworks, foundations, landscapes (fields, roads, and fences), and historic structures. Maintaining this historic context often means resisting natural geologic processes, which presents several management challenges.

Geologic slope processes such as landsliding, slumping, and slope creep can change the landscape at the park. Chemical weathering breaks down rock units causing instability in the rocks. Swelling soils, a product of the weathering of bedrock, occur throughout the park area. These soils contain clays that swell when saturated and shrink when dry. In extreme cases, this process can destroy roads, trails, visitor facilities, and building foundations.

Runoff erodes sediments from exposed soils and rock units (especially unvegetated and disturbed spots) and carries these sediments down to streams. Earthworks at the park are small, ranging in height from 1.0 to 1.5 m (3 to 5 ft) (fig. 5). These 140-year-old features are under constant threat of erosion. Geologic processes may also degrade bridge foundations, erode stream banks, and fill in low-lying areas such as battle-era trenches, railroad cuts, and gullies, distorting the historical context of the landscape.

Some slope failure is occurring in the westernmost park units. However, maximum relief for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park is only 91 m (300 ft). These gentle slopes seldom experience catastrophic failure. However, the Rappahannock River and many lower-order tributaries are undercutting riverbanks, posing potential hazards. Awareness of these processes is important for park decision making regarding the future locations of park facilities, restoration and preservation efforts, and visitor safety.

Resource Management Suggestions for Slope Processes and Erosion

- Monitor areas of higher slope for continuous slope creep.
- Map locations of swelling clays. Focus on areas with exposures of the Calvert Formation (Coastal Plain), Triassic units in the Culpeper basin, as well as amphibolites and other rock types in the Piedmont province.
- Identify areas prone to slope failure during intense storm events. Characteristics of such areas include undercut slopes, high clay content, high slopes, heterogeneous rock layers in close proximity, highly fractured units, and unvegetated slopes.
- Attempt to remediate slope processes that are threatening historic features on the landscape at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.
- Where appropriate, investigate restoration of earthworks damaged or obscured by extensive erosion.
- Wieczorek and Snyder (2009) suggest techniques for monitoring slope processes.

Urban Encroachment

Humans began settling the Fredericksburg and Spotsylvania area in the late 1600s to early 1700s. Their farming and homestead activities altered the natural landscape. Impacts from their activities persist today at the national military park. Minor irrigation features, removal of soil and rocks to create stone fences and rock-free pastures for livestock grazing, extensive logging operations, and other homestead features are scattered throughout the landscape.

Rapid population growth and development are affecting the area surrounding Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. As of 1995, office and commercial development has increased by more than 500% since the early 1970s and population increased by more than 50% along the Route-3 corridor through Fredericksburg. The area's urban population continues to grow; the Wilderness Battlefield is on the National Trust for Historic Preservation and the Civil War Preservation Trust included on their 2010 list of the "most endangered historic places" as the pending construction (currently under litigation) of a Wal-Mart threatens part of the battlefield. Development results in the creation of surfaces such as parking lots, roads, and large buildings that are impervious to rainwater infiltration, increasing flood hazards (McConnell and Ulrich 1995). Flash flooding associated with seasonal tropical storms and hurricanes has the potential to significantly alter the landscape (GRI scoping notes 2005).

As development continues, conservation of any existing forest-meadow community types surrounding parklands becomes a critical resource management concern (fig. 7). Understanding the nature of the geology beneath the biotic communities and their interrelationships becomes an integral part of their management. Park management of the landscape for historic preservation purposes complements the preservation of these forested areas.

Resource Management Suggestions for Urban Encroachment

- Using the geologic map, surficial maps, topographic maps, and hydrogeologic models, cooperate with local developers to minimize potential for geologic hazards, encroachment of contaminants, and invasive species near park areas.

Surface Water and Sediment Loading

Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park protects reaches of the Rappahannock River and other local streams. As such, the quality of the surface water at the park is very important to surrounding communities as well as park resources and visitors. However, surrounding development affects water quality and the hydrogeologic system.

Flooding and channel erosion are naturally occurring along most of the streams and rivers within the park. However, flooding and erosion exacerbated by development can threaten riparian zones and wetlands, as well as visitor facilities, cultural features, and park infrastructure. Compaction due to increased visitor use, as well as impervious surfaces, is increasing seasonal runoff as sheet flow. Engineering solutions such as culverts and bridges can help mitigate runoff. However, facilities maintenance and expansion has not kept pace with regional development, and runoff often overwhelms outdated structures.

Soils along rivers and in wetlands are important for filtering excess nutrients and contaminants such as phosphates from the surface and near-surface water flow. Deeper soils (more than 50 cm [20 in]) have the highest capacity to remove phosphate from near surface and groundwater (Axt and Walbridge 1999). Knowledge of these types of relationships helps predict ecosystem response to anthropogenic environmental inputs, and is, therefore, important to resource management at the park.

Alterations to vegetation along steep, exposed slopes lead to changes in the hydrologic regime in the park. For example, clearing of trees and their stabilizing roots for historical restoration can lead to increased erosion, gullying, and sediment loads in nearby streams, and could potentially contribute to slumps, slope creep, and landslides. Earthworks, hiking trails, and other high-use, sparsely vegetated areas are also at risk of intense erosion and sediment loading.

Resource Management Suggestions for Surface Water and Sediment Loading

- Quantitatively determine the contaminant-filtering and adsorption capacity of the soil/substrate at the park based on spatial relationships between soil/substrate type, composition, and depth by using GIS layers of geology, hydrogeology, biology, and soils in concert with monitoring cores and wells.
- Map park administrative roads and target streams and areas of erosion for remediation.
- Research planting new vegetation along vulnerable reaches of park streams to prevent excess erosion and sediment loading.

Connections between Geology and the Civil War History

Because geology forms the basis of the ecosystem and landscape, geologic features and processes are directly responsible for the unique history at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. In many military operations, familiarity with terrain is an advantage, and the proper utilization of the natural features of the area such as valleys, river crossings, gaps, ravines, cuts, hills, and ridges may decide the outcome of a conflict. For example, at the Battle of Fredericksburg in 1862, the Confederates used the floodplains, river terraces (figs. 6, 8), and north-south trending ridges around the Rappahannock River to their advantage, stalling Union advance on the Confederate capital of Richmond for several years.

The underlying geology defines the rolling hills and gentle topography at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Along the southeastern side of the Rappahannock River valley at the foot of the bluffs sits the sunken road (fig. 8, inside cover). During the battle in 1862, Confederate forces positioned heavy artillery above the road along Marye's Heights and Willis Hill. This elevated position, proved insurmountable for Union General Burnside's forces, and the Union attacks were repeatedly repulsed (Sherwood and Flora 2002). According to the park web site, of the 12,600 Federal soldiers killed, wounded, or missing, in the Battle of Fredericksburg, almost two-thirds fell in front of the stone wall along the sunken road In addition to influencing battles, the landscape and topography affected the transport of troops and supplies during the Civil War.

Resource Management Suggestions for Connections between Geology and the Civil War History

- Create a general interest map with simple explanatory text on the geologic influences of battles for visitors to the park units.

Potential Fossil Resources

Fossils have not been formally documented from within the park; however, there is potential for future discovery (Kenworthy et al. 2006). While igneous and metamorphic rocks of the Piedmont rarely preserve fossils, rocks associated with the Coastal Plain province are more likely to preserve fossils. Regionally, all of the Cretaceous and Tertiary units mapped within the park contain fossilized plant debris, mollusks, marine vertebrate bones, and many other paleontological resources elsewhere. Investigation of exposures in the park may yield paleontological resources. Fossils would be an important resource at the park as they contribute stratigraphic information to the geologic history of the area. Fossils can also be targets of vandalism and theft.

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

Resource Management Suggestions for Potential Fossil Resources

- Perform a field-based inventory to assess and document fossils within park boundaries, possibly collecting and preparing samples for a park collection. Park managers may want to consider long-term monitoring of any significant localities.
- Create an interpretive exhibit highlighting the geologic story behind any paleontological resources at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.

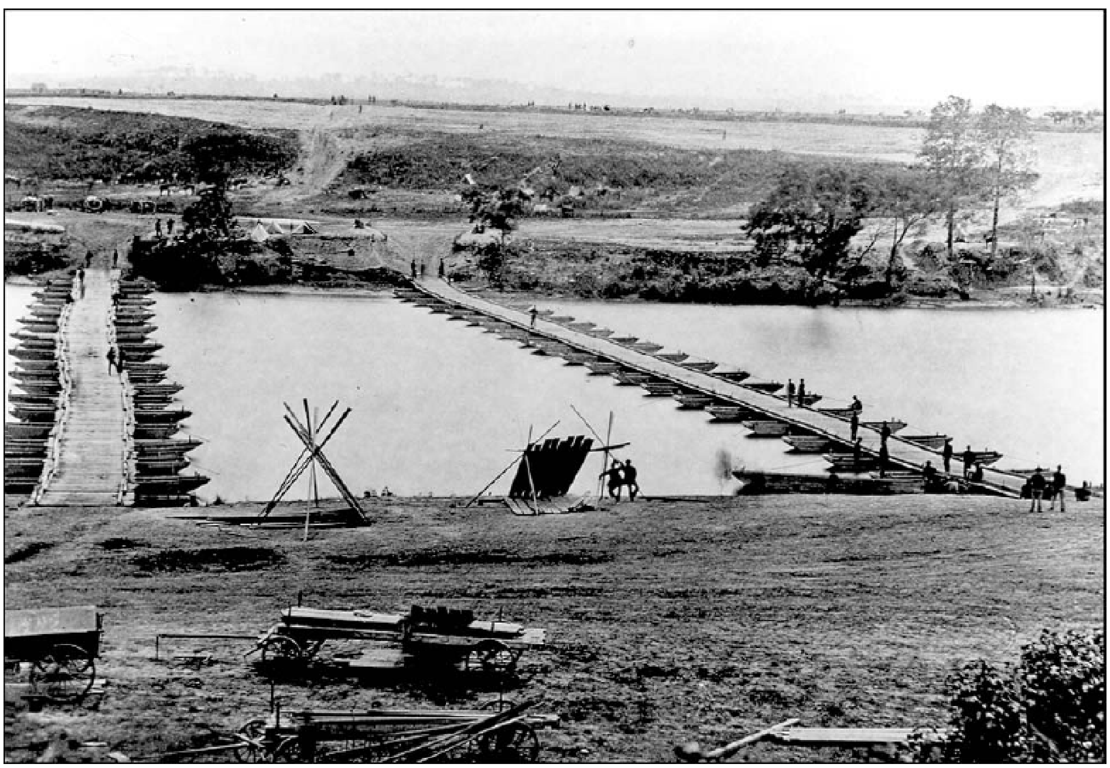

Figure 4. Union army pontoon bridges across the Rappahannock River. The photograph shows the pontoon bridges just below Stafford Heights looking east from the north end of Fredericksburg. Note the lack of trees. Photograph by Timothy O'Sullivan (date unknown). Courtesy of the National Archives Still Photo Unit, College Park, Maryland.

Figure 5. Confederate earthworks along visitor trail at the Chancellorsville unit. Signs discourage visitors from walking on the historic features; however, erosion is still beveling the historic battlefield. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 6. Terraces and River. View from Chatham towards Fredericksburg over the Rappahannock River. The Rappahanock and terrace topography associated with it were important influences in the outcome of the battles fought here during the Civil War. National Park Service photograph courtesy of Gregg Kneipp (Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park).

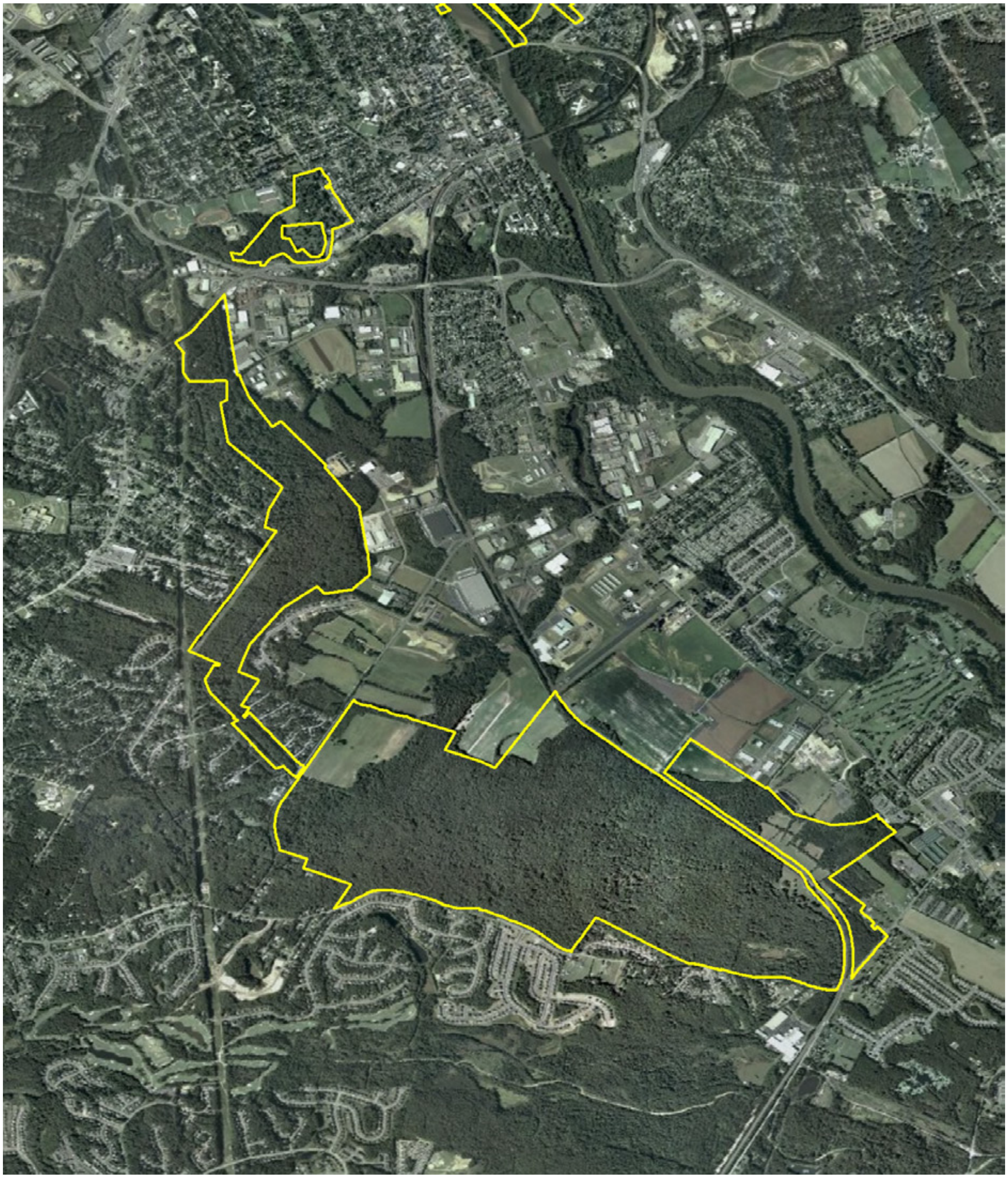

Figure 7. Urban development encroaching on the Fredericksburg Battlefield of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park (yellow outline). Aerial imagery compiled by Jason Kenworthy (NPS Geologic Resources Division) from ESRI ArcImage Service, USA Prime Imagery. Width of image is approximately 8 km (5 mi).

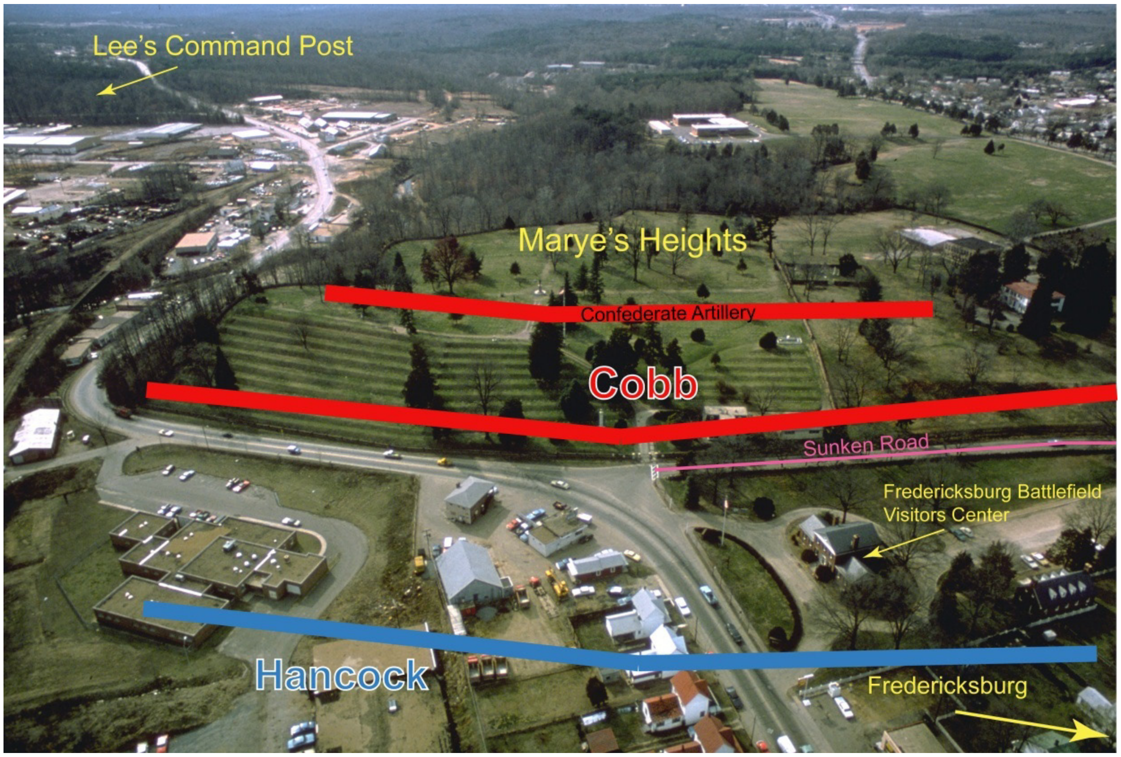

Figure 8. Battle Topography. Modern day aerial view of Marye's Heights, illustrating Union and Confederate positions during the Battle of Fredericksburg, December 13, 1862. The battle took place in a natural amphitheater, completely exposing advancing Federal troops to Confederate artillery fire from atop Marye's Heights. After crossing the plains, Union troops confronted fortified Confederate infantry at the Stone Wall above the Sunken Road, resulting in extremely high Union casualties. National Park Service photograph modified by Philip Reiker (NPS Geologic Resources Division).

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park.

Geology and History Connections

The geologic resources of the Fredericksburg and Spotsylvania area have provided benefits for people for centuries. The town of Fredericksburg is situated along the Fall Line, which blocks boat transport upriver, making this an important port area for the western reaches of the Virginia. Above the Fall Line, the river is narrow, with rocky rapids. Below the Fall Line, the river is tidal, and broadens downstream to more than 800 m (2,600 ft) wide at Port Royal (Ehlen and Abrahart 2002).

In addition to the regional transportation routes and river crossings, effective military leaders needed to understand the nuances of the landscape. Fredericksburg's strategic location between the Confederate capital of Richmond, Virginia, and the Union capital of Washington, D.C., made it an important area during the Civil War. At the time, the ranges and reliabilities of weapons and ammunition, the absence of adequate maps, supplies, and intelligence, as well as the poor physical conditions of the soldiers often made knowledge of the landscape decisive in major battles. Advantages such as line-of-sight, knowledge of state-of-the-ground, and the location and effectiveness of obstacles affected military decisions and the outcome of the battles (Ehlen and Abrahart 2002).

In 1862, during the battle of Fredericksburg, Confederate forces held off many Union advances on the town of Fredericksburg, postponing the eventual capture of Richmond for almost three years. Though outnumbered and undersupplied, the Confederates were able to make strategic use of the local topographic landforms. Their knowledge of the area's terrain, including high-level terraces(figs. 6, 9) along the Rappahannock River and gentle slopes below parallel north-south ridges, gave them a strong advantage (Ehlen and Abrahart 2002; Ehlen 2004).

The Confederates set up defensive positions on the western north-south trending ridge at Marye's Heights, Willis Hill, Telegraph Hill, and Prospect Hill. East of the Rappahannock River is Stafford Heights, where Union forces installed heavy artillery (figs. 8, 9). The river flows between two topographic highs (fig. 4)—Marye's Heights to the west, and Stafford Heights to the east. The two ridges form an amphitheatre, sloping down to the banks of the river.

Stafford Heights is composed of river terrace material (see Map Unit Properties Table). Cretaceous and Tertiary sands and gravels underlie Marye's Heights and the other hills along the western ridge (Ehlen 2004). Piedmont rocks underlie higher ridges to the west.

East of the Fall Line, the Rappahannock and other local rivers incised through the softer, unconsolidated to loosely consolidated deposits of the Atlantic Coastal Plain. This created narrow stream valleys with steep slopes floored by wetlands such as Massaponax Creek. Ehlen and Abrahart (2002) detailed the course of the battle over these subtle topographic differences in the Fredericksburg landscape; readers are encouraged to use this resource for interpretation.

Tactical advantages were also derived from anthropogenic obstacles, including major roads, stone walls, fences, buildings, agricultural ditches and irrigation canals, a railroad embankment (Richmond, Fredericksburg & Potomac Railroad), and the streets of Fredericksburg (Ehlen and Abrahart 2002). The famous stone wall along Sunken Road (Telegraph Road) (See inside cover photo). It is composed primarily of coarse sandstone known as the Aquia Freestone, derived from the Potomac Formation, as well as some igneous and metamorphic rocks. The sandstone contains quartz grains in a finer grained, feldspar-rich matrix. Mined from local quarries, gouges and grooves on these rocks are evidence of mechanical quarrying (Flora and Sherwood 2001).

Mineral Resources

Smelting operations started in the area, including the Catherine Furnace, because of the nearby iron ore deposits. Smelting of iron ore requires lime (obtained from oyster shells). Smelting also requires vast amounts of fuel for heat, traditionally produced from burning coal or charcoal. Before the Civil War, smelting operators cleared the entire Wilderness unit of the park of heavy timber, which allowed a thick understory to thrive in the clear-cut areas. This understory lent its name to the Battle of the Wilderness and forced fighting between Union and Confederate troops into the close quarters of bushy woods. Later, smelting operations were resurrected to supply Confederate forces with arms, including Catherine Furnace that had been shut down in the 1840s (GRI, scoping notes 2005; Rokus 2009).

Massive sulfide deposits (more than 13.5 million tons) occur in a volcanic-plutonic metamorphic belt (known as the Virginia gold-pyrite belt) (fig 10) that extends 175 km (110 mi) in the central Virginia Piedmont. The deposits occur in two parallel lenses that strike N40E and dip southeast at angles ranging from 60° to 70° (Seal et al. 2002). Minerals include pyrite (iron sulfide; FeS_2), sphalerite (zinc sulfide; ZnS), galena (lead sulfide; PbS), chalcopyrite (copper-iron sulfide; $CuFeS_2$), and pyrrhotite (iron sulfide; $Fe_{1-x}S$) with some zinc (Zn) and lead (Pb) minerals in smaller deposits (Pavlides et al.

1982; Seal et al. 2002). These minerals are likely associated with submarine volcanic exhalation, much like the white and black smokers (submarine vents) that occur along active plate boundaries such as the Atlantic mid-ocean ridge. The host rocks are predominantly low-potassium granitoid rocks of the Piedmont.

The Virginia Lead and Zinc Company opened the Valzinco mine in 1914. However, exploration in the 1940s discovered profitable sulfide-gold deposits in the area. This mine, as well as the Valzinco Halladay (or Holloday) and the Mitchell mine are all located within the Virginia gold-pyrite belt. There are also numerous other gold mines throughout Spotsylvania County that include features such as pits, shafts, and covered dumps and tailings. Acid mine drainage and remobilization of heavy elements from dumps and tailings affects the entire watershed downstream from these mines (Seal et al. 2002)

Diamonds occur in Spotsylvania County. Local mines, including the Vaucluse and Whitehall mines, hold potential for diamond exploration in this area. These diamonds are likely associated with scattered kimberlite dikes emplaced during regional extension in the Jurassic Period (Sweet 1996). The diamonds could also be from previously unrecognized and unmapped Eocene volcanic rocks. These rocks would look very similar to the older Mesozoic volcanics and might go unnoticed without age dating (M. Carter, U.S. Geological Survey, written communication, 2010).

Faults and Folds

Underlying geologic structures such as faults and folds within the Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park area have had a pronounced influence on landform development. They reflect the tectonic forces that crumpled, fractured, or sheared deep underlying rocks as the Appalachian Mountains were forming (see “Geologic History”). The Rappahannock anticlinorium (a large-scale anticline, or convex upward fold, onto which smaller folds are superimposed) dominates the structural grain in the region surrounding the Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. The anticlinorium extends from the Stafford, Virginia, area southwards beyond the James River (fig. 11). The anticlinorium roughly trends and plunges to the northeast. The eastern portions of the anticlinorium are composed of island-arc deposits and some felsic plutons. Associated with the western side of the anticlinorium is the parallel trending Quantico synclinorium. (Pavlides et al. 1982). The Spotsylvania thrust fault bounds the feature on the east, and the Long Branch fault bounds the feature on the west. Northwest of Fredericksburg, the right-lateral (strike-slip) Accokeek fault truncates the northern nose of the anticlinorium. Structures along the limbs of the anticlinorium suggest multiple phases of folding and at least two metamorphic events. (Onasch 1986; Mixon et al. 2000).

Several large, parallel, low- to high-angle thrust faults trend northeast-southwest through the region and dip to the southeast. From east to west, these are the Spotsylvania, Long Branch, Chopawamsic, and Lake of the Woods thrust faults. East of the Lake of the Woods thrust fault lies the Mountain Run fault zone, a 1.6-km-(1-mi-) wide sheared zone (Mixon et al. 2000). These thrust faults moved large masses of Piedmont rocks and associated plutons atop younger rocks to the west. At the surface, most of these faults are not well exposed. The Spotsylvania thrust fault, referred to as the Central Piedmont/Spotsylvania high-strain zone, locally separates schist and gneiss from island-arc rocks of the eastern limb of the Rappahannock anticlinorium. It separates the Goochland and Chopawamsic terranes (Spears et al. 2004; Bailey et al. 2004). It may be the northern extension of the Lakeside fault zone in the central Virginia Piedmont and the Hyco shear zone, which is traceable for over 500 km (300 mi) in the southern Appalachians (Francis et al. 2001; Spears et al. 2004). Closer to the park are several high-angle reverse faults, including the Dumfries, Hazel Run, Brooke, and Fall Hill faults. These are part of the Stafford fault system within the inner Coastal Plain of Virginia. The Stafford fault system extends along the Fall Line 68 km (42 mi) from Spotsylvania northeastward to southern Fairfax County. These features are en echelon, or step-like in map pattern, and trend to the northeast. Vertical displacement along these features is minor, only 10–60 m (33–197 ft), but this amount of offset significantly affects the thickness and distribution of Coastal Plain sediments (Mixon et al. 2000). Sediments present on the western, upthrown blocks are thinner than their counterparts on the eastern, downthrown blocks across these high-angle reverse faults.

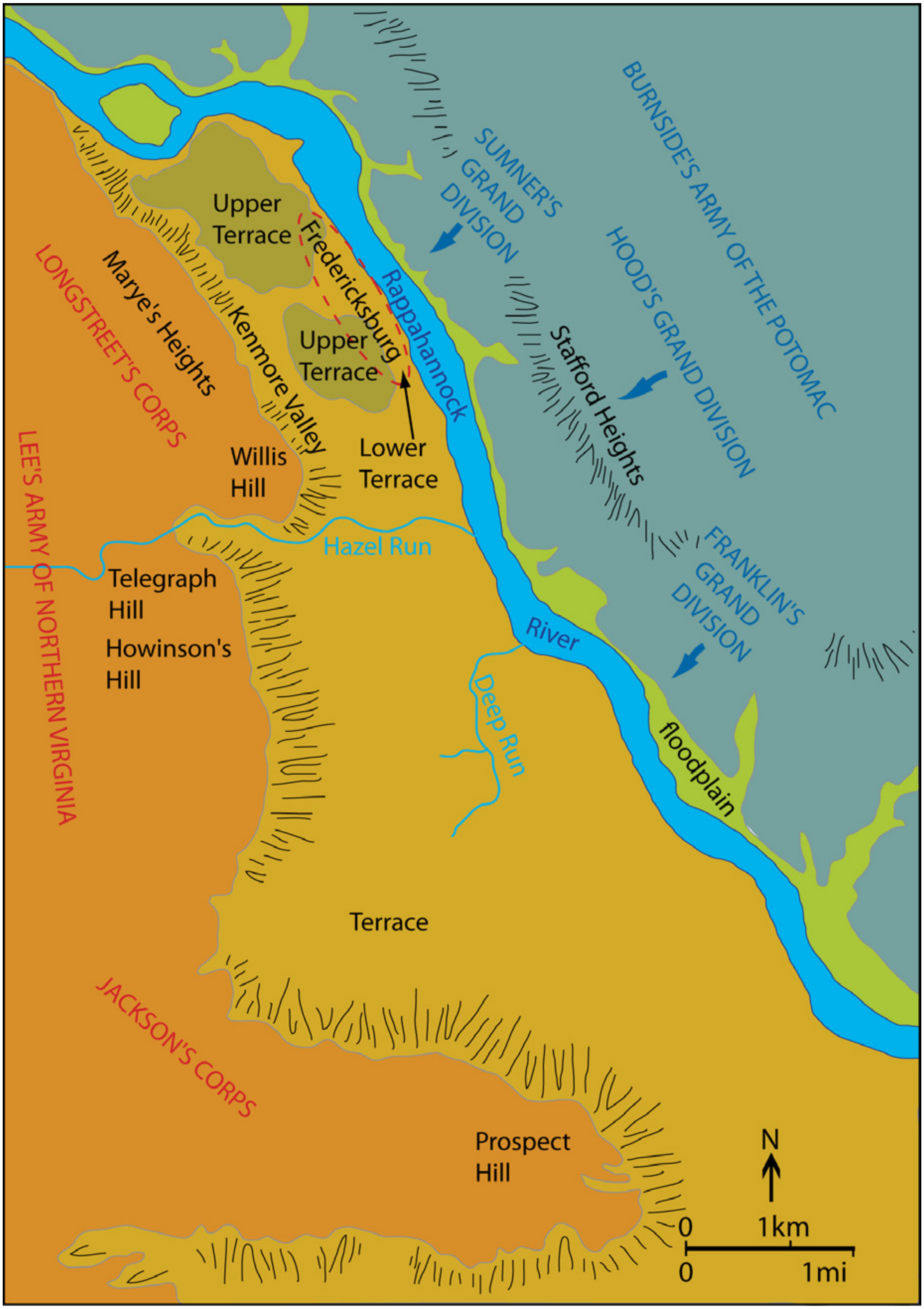

Figure 9. Map of the historic Fredericksburg landscape. The figure illustrates locations of military installments, topographic highs, river terraces, and floodplains relative to the river and the town of Fredericksburg during the 1862 Battle of Fredericksburg. Graphic adapted from Ehlen (2004) by Trista L. Thornberry-Ehrlich (Colorado State University).

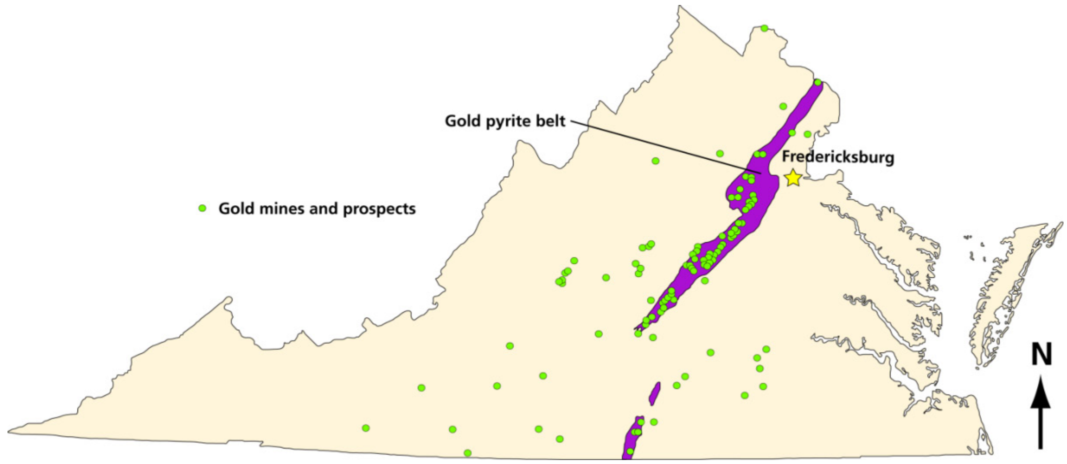

Figure 10. Map of gold mines and prospects in Virginia. The gold pyrite belt is also illustrated in purple. Fredericksburg is identified as a gold star. Graphic adapted by Philip Reiker (NPS Geologic Resources Division) from Sweet (2007).

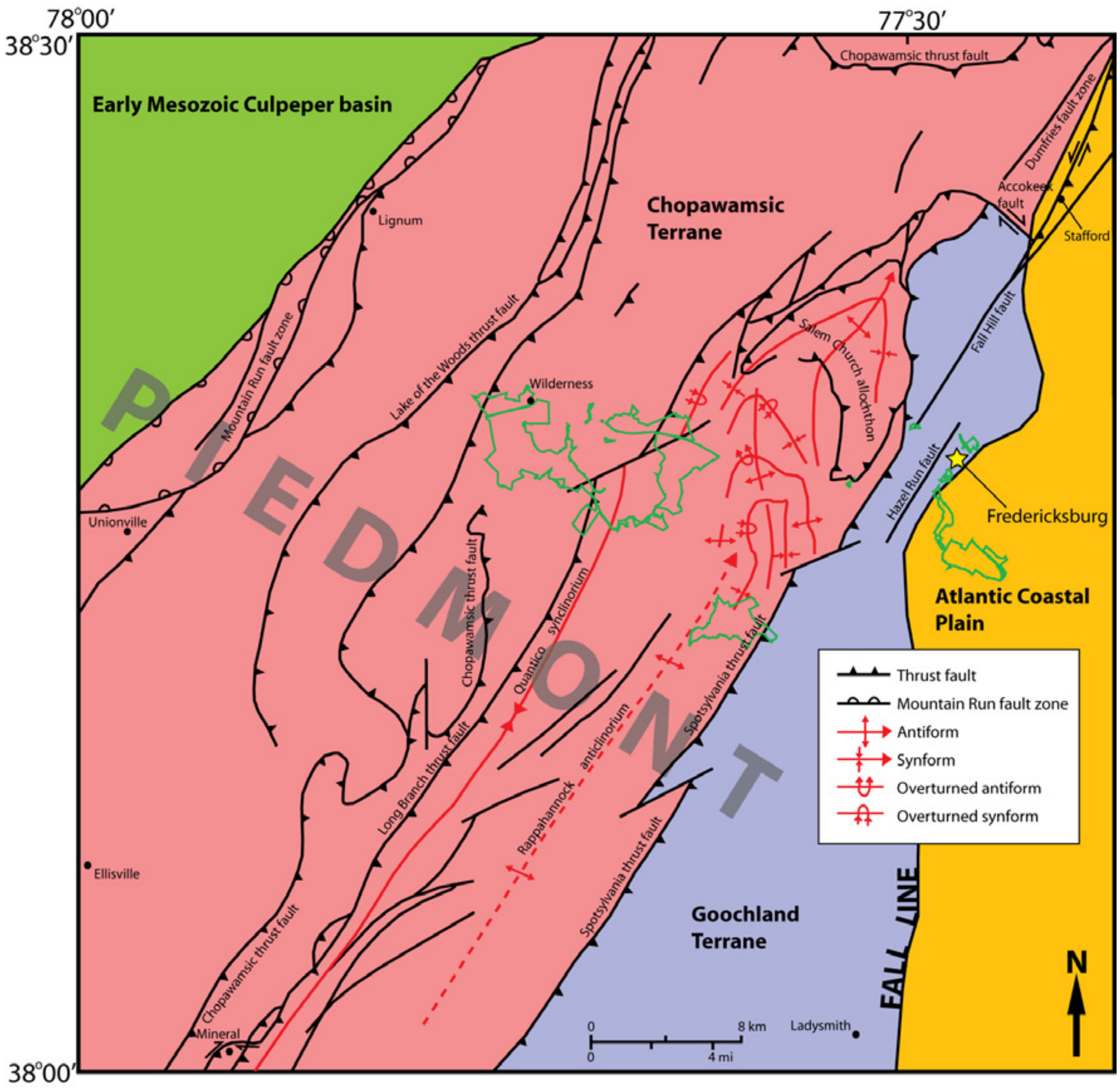

Figure 11. Simplified map of geologic structures around Fredericksburg. Note the complexity of the structures at the nose of the anticlinorium, just west of Fredericksburg. The location of the Rappahannock anticlinorium axis and the Fall Line between the Piedmont and Atlantic Coastal Plain are estimates. Green outline shows the boundary of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), based on information from figure 1 of Mixon et al. (2000).

Map Unit Properties

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

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park provided information for the Geologic Issues, Geologic Features and Processes, and Geologic History sections of this report. Geologic maps are two-dimensional representations of complex three-dimensional relationships; their color coding illustrates the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

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

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Similarly, map units show areas that have been susceptible to hazards such as landslides, rockfalls, and volcanic eruptions. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by depicted geomorphic features. For example, alluvial terraces may have been preferred use areas and formerly inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 12) for the age associated with each time period. The table highlights characteristics of map units such as: susceptibility to erosion and hazards; the occurrence of paleontological resources (fossils), cultural resources, mineral resources, and caves or karst; and suitability as habitat or for recreational use. Some information on the table is conjectural and meant to serve as suggestions for further investigation.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following reference is the source for the GRI digital geologic data for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park:

Mixon, R. B., L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards and L. W. Ward. 2000. Geologic map of the Fredericksburg 30' × 60' quadrangle, Virginia and Maryland (scale 1:100,000). Miscellaneous Investigations Series I-2607. U.S. Geological Survey, Reston, Virginia, USA.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, and increases the overall utility of the data. GRI digital geologic map products include data in ESRI personal geodatabase, shapefile, and coverage GIS formats, layer files with feature symbology, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map.

GRI digital geologic data are included on the attached CD and are available through the NPS Data Store at http://science.nature.nps.gov/nrdata/ (accessed June 2, 2010).

Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park Map Units

The map for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park by Mixon et al. (2000) covers parts of three physiographic provinces and one geologic basin: the Atlantic Coastal Plain, Piedmont, and Blue Ridge provinces, and the Culpeper basin. The oldest rocks in the area are altered greenstones (basalts) of the Catoctin Formation, and the metasiltstones and schists of the Charlottesville Formation of the Lynchburg Group. These units are Proterozoic in age and are located west of the park area on the map. Granitic gneiss and diorite gneiss of the Potomac Creek pluton are Late Proterozoic to Early Paleozoic in age. Of similar age is the Po River Metamorphic Suite; it contains biotite and gneisses and schists, as well as amphibolite. This is a prominent unit in the southeastern park area. Within the Po River Metamorphic Suite are lenticular granitoid layers that may be the metamorphosed remnants of earlier intrusive plutons.

Latest Proterozoic to earliest Cambrian rocks include amphibolites, serpentinites, talcs, and other ultramafic rocks. These rocks occur as small xenoliths within Cambrian to Ordovician units, which dominate the bedrock underlying the park.

Cambrian units include metagabbros, amphibolite-biotite gneisses of the Ta River Metamorphic Suite, altered tonalites and granites, and metavolcanic and metasedimentary rocks of the Chopawamsic Formation. The Chopawamsic contains lenses and tongues of feldspathic schist, phyllites, meta-arenites, amphibolite greenstones, and gneisses.

Spanning the Cambrian to Ordovician is the plagiogranite of the Richland Run pluton, in the northeast corner of the park area, as well as the highly variable mélange zones of the Mine-Run Complex. These zones include metasedimentary and metavolcanic blocks in a phyllitic to schistose matrix. Ordovician metasedimentary rocks, and phyllite and staurolite schists of the Quantico Formation, contain discontinuous lenses of quartzite in the eastern portions of the park.

The Fall Line between the easternmost Piedmont and the western Atlantic Coastal Plain crosses the Rappahannock River at Fredericksburg. The rock units to the east of this line include the Lower Cretaceous Potomac Formation, which erosion has exposed along many of the rivers and streams in the area. This formation is composed of sandstone, silty channel-bar deposits, and lignitic sandy silt and clay layers. Atop the Potomac Formation is the upper Paleocene Aquia Formation, consisting of glauconitic sands, silts, clays, and containing some scant fossil layers. Deposits of Eocene Nanjemoy Formation overlie the Aquia Formation. These are glauconitic sands, clays, and silts. Miocene sands and gravels overlie the Aquia and Nanjemoy formations in the park area.

Younger deposits include the Miocene Calvert Formation and the Pliocene Yorktown Formation. The Calvert Formation consists of silty sand and clay. The Yorktown Formation contains quartz and feldspar sands, mixed with lesser clays and silts. The upper Pliocene Bacons Castle Formation includes gravelly sand and sandy-silty-clayey upper layers. Sediments of the Bacons Castle Formation crop out in high-level terrace areas. Younger deposits within the park include various Quaternary units. Fine to coarse sand, gravel, silt, and clay of the Windsor Formation is of upper Pliocene to lower Pleistocene age. The gravelly Charles City Formation, sands and silts of the Chuckatuck Formation, as well as coarse sands, gravels, pebbles and occasional boulders of the Shirley Formation are of middle Pleistocene age. The upper Pleistocene Tabb Formation contains sands, gravels, silts, and clays and underlies low terraces in the area.

The youngest deposits at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park include thick alluvial floodplain deposits of sand, gravel, silt and clays; marsh and swamp deposits along the rivers; and artificial fill from construction of roads, dams, bridges, landfills, and highways.

Map Unit Properties Table: Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park

Gray-shaded rows indicate map units in the accompanying GIS data but not mapped within the park.

Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
QUATERNARY - RECENT	Artificial fill (af)	Mostly sand and gravel materials of varying thickness. Local to construction areas such as highways, bridges, roads, dams, and other facilities.	Low	Material is used in development projects	Prone to rockfall, slumps, slides, and other mass wasting if positioned on steep slopes, or undercut by additional construction or natural erosion	Same as source material	May be useful to land-use evolution studies	Same as source material	Habitat for opportunistic plants and animals, including invasive plants along roadways	Used at recreation areas and along roadways	Eventual use for land-use evolution studies
QUATERNARY - HOLOCENE	Sand (**Qs**) Swamp deposits (**Qsw**)	**Qs**—pale gray to light yellowish gray, fine to coarse grained, poorly to well sorted sand, 2–8 m (7–26 ft) thick. Present as low natural levees along the primary channel of the tidal Rappahannock River. Some beaches, sand bars, spits, and deltas developed along tributaries. **Qsw**—mud, muddy sand, muck, and organic material; brownish gray to grayish black color, depending on the amount of decaying material; less than 3 m (10 ft) thick. Typically overlies alluvium.	Very low to low	Unsuitable for most development due to presence of marshy wetlands and saturated, unconsolidated sediments	Prone to erosion and flooding	None documented	May contain historic artifacts and battleground relics	Heavy minerals, peat, and sand	Modern riparian habitat with wetland species. Modern shell fragments and mollusk valves locally present. Leaf, stem material, tree trunks, and pollen.	Unsuitable for most trails and other recreation due to water saturation and proximity to delicate wetland areas	Natural levees. Riparian zone along Rappahannock River is vital natural buffer.
HOLOCENE - PLEISTOCENE	Alluvium (**Qal**)	Fine to coarse gravelly sand, sandy gravel, silt, and clay; mostly medium gray and yellowish gray; grains of vein quartz, quartzite, and other metamorphic rocks; maximum thickness 15 m (49 ft). Present as channel, point-bar, terrace, and floodplain deposits; grades into colluvium along steep slopes	Low	Unsuitable for most development due to presence of saturated, unconsolidated sediments in floodplain areas	Prone to mass wasting. Flood hazard associated with this unit.	None documented	May contain historic artifacts and battleground relics	Metamorphic and other heavy minerals, clay, silt, gravel, sand, and quartzite pebbles	Riverine and floodplain habitats, modern/recent plant debris	Suitable for some stream edge recreation if not regularly flooded	Records Pleistocene to Holocene transition along valley walls
PLEISTOCENE	Tabb Formation, undivided (**Qtu**) Alluvial terrace deposits, undivided (**Qatu**) Shirley Formation, unit 1 (**Qsh**) Chuckatuck Formation (**Qc**) Charles City Formation (**Qcc**)	**Qtu**—sand, gravel, silt, and clay, underlying low terraces along the area's larger rivers **Qatu**—fine- to coarse-grained gravelly sand, sandy gravel, silt and clay lenses in surficial deposits along rivers and tributaries **Qsh**—coarse sand, interbedded with pebbly and bouldery layers, with some light to medium grayish yellow silty fine sand and pinkish sandy silt; 10–20 m (33–66 ft) thick **Qc**—cross-bedded gravelly sand, sandy silt, and light to medium yellowish gray clay; 5–15 m (16–49 ft) thick. Sediments often weather reddish brown. Present in surficial deposits of mid-level estuarine terraces. **Qcc**—fining upward sequences of basal coarse gravelly sand to moderately sorted medium to fine sand, silt, and clay; oxidizes to a brownish color; maximum thickness 18 m (59 ft). Present along high-level terraces.	Low to moderately low for gravel-rich layers	Suitable for most development unless highly permeable and porous. Avoid steep margins of terraces, which may be undercut by rivers.	Prone to mass wasting, especially where steep slopes near waterways are present. Slumping of large blocks is possible.	Coral (*Astrangia*), peat, organic matter, pollen, and trace fossils (i.e., invertebrate burrows)	Cap rock (high ground in the area). Strategic points during battles.	Heavy minerals, gravel, boulders, sand, silt, and clay. Borrow pits along Rappahannock River.	High-level terraces may provide habitat for burrowing animals.	Suitable for most recreation unless undercut or near a cliff face or steep slope	Correlative throughout the region. **Qsh** contains dateable U-Th coral (184±20 ka).
PLEISTOCENE AND (OR) PLIOCENE	Terrace deposits (**QTt**)	Well-bedded, gently sloping deposits of gravel, sand, silt, and clay along large rivers; <1 to 3 m (3.3 to 10 ft) thick and 60 m (197 ft) wide. Present above modern floodplain.	Low	Avoid for most development due to location along rivers and steep valley slopes	Prone to sliding especially if water saturated along valley slopes	None documented	None documented	Greenstone, vein quartz, quartzite, phyllite, hornfels, and diabase cobbles, heavy minerals, gravel, pebbles, sand, silt, and clay	Habitat along major rivers	Good for most recreation unless undercut or water saturated	Records river migration along major waterways during sea-level highstands

Gray-shaded rows indicate map units in the accompanying GIS data but not mapped within the park.

Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
PLEISTOCENE AND PLIOCENE	Colluvium (**QTc**) Windsor Formation (**QTw**) Windsor Formation and (or) Moorings Unit of Oaks and Coch (1973) (**QTmw**)	**QTc**—gravel, sand, and silt, interbedded in lenticular deposits on slopes; clasts are typically subangular and occur in a yellowish-orange to greenish-gray silty sand and clayey silt matrix; up to 6 m (20 ft) thick **QTw**—fine to coarse sand, gravel, silt, and clay in yellowish brown to reddish colored matrix; up to 12 m (39 ft) thick in upper Rappahannock area. Present on terraces. **QTmw**—sand and gravel on high-level terraces	Low to moderately low for gravel- and clast-rich layers	Heterogeneous nature of unit may prove unstable on slopes and when undercut or water saturated.	Prone to mass wasting (e.g., rockfall)	Pleistocene-Pliocene estuarine floral and faunal remains	Chert within units may have been used for early tool material	Greenstone, quartzite, vein quartz, schist, chert and phyllite clasts, and amygdaloidal basalt, diabase, and gneiss cobbles, heavy minerals, sand, silt.	High-level terraces may provide habitat for burrowing animals.	Good for most recreation unless undercut or water saturated	Records migration of Mattaponi River. **QTw** is correlative throughout the region.
TERTIARY - PLIOCENE	Moorings Unit of Oaks and Coch (1973) (**Tm**) Bacons Castle Formation (**Tb**) Sand and gravel (**Tps**) Yorktown Formation (**Ty**)	**Tm**—white, light gray, and grayish yellow quartzose sand and sandy gravel, with clasts of well-rounded pebbles, cobbles, and boulders; 3 to 9 m (10 to 30 ft) thick. Occurs as surficial deposits in high-level terraces along the Rappahannock River. **Tb**—yellowish orange in outcrop; fining upward sequence composed of two primary sediment types: the lower 3 to 6 m (10 to 20 ft) contains medium to coarse gravelly sand and sandy gravel, poorly sorted, with thick cross-beds; upper beds contain gray to pink, poorly sorted, sandy and clayey silt and silt clay, interbedded with fine sand, sandy silt, and clay; as much as 18 m (59 ft) thick. **Tps**—yellowish to brownish gravelly sand, sandy gravel, and fine to coarse grained sand; some clay and silt lenses occur in trough cross-bedded layers; up to 18 m (59 ft) thick. Caps drainage divides. **Ty**—yellowish to orangish gray, fine to coarse grained, poorly to well-sorted quartz and feldspar sands and gravels in planar and cross-bedded, thin to thick beds; some clay and silt occurs as matrix material; 3 m (10 ft) to as much as 25 m (82 ft) thick with several fining upward sequences	Low to moderately low for coarser grained beds	High permeability of units may prove unsuitable for waste-treatment facility development. Heterogeneity of layers may render them unstable along slopes, especially if undercut.	Prone to rockfalls from high-level terraces along the Rappahannock River. Mass movements are likely for units when water saturated.	Trace fossils (*Ophiomorpha nodosa*)	Chert within units may have been used for early tool material. Iron-oxide cements may have been mined in colonial period as "bog iron."	Chert, weathered basalt, metamorphic rock pebbles, ilmenite, and magnetite grains, heavy minerals, gravel, sand, silt, clay, pebbles, and cobbles	High-level terraces may provide habitat for burrowing animals. Present as cliffs along waterways.	Good for most recreation unless undercut or water saturated	Overlapping terraces record migration of several rivers channels. Record Pliocene depositional environments that are correlative throughout the region.
TERITARY - MIOCENE	Sand and gravel (**Tms**) Calvert Formation, undivided (**Tc**)	**Tms**—yellowish orange and brown, fine to coarse gravelly sand, sandy gravel, silt, and kaolinitic clay in beds as much as 10 m (33 ft)thick. Occurs on higher topography throughout the region **Tc**—mostly fine to very fine quartzose sand with some silt and clay layers; thickly bedded, with mappable sand-silt-clay sequences; appears light gray to white, pinkish gray and pale yellowish orange in outcrop. Members of this unit include (from bottom to top): Fairhaven (**Tcf**), Plum Point Marl (**Tcp**), and Calvert Beach (**Tcc**).	Moderately low	Suitable for most development. Avoid pebbly layers for waste-treatment facilities. Avoid expandable clay-rich layers for road and trail development. Avoid **Tc** during construction; it is rich in disseminated pyrite and other iron-sulfide minerals, and quickly produce acid drainage when exposed.	Massive bedding may be prone to large block slides when unit is undercut along rivers and gullies.	Diatoms (including *Rhaphoneis diamantella*), fish teeth, scales, shell fragments, lignitized wood, marine vertebrate bones, silicoflagellates, and dinocysts	Kaolinite may have been used for painting and dyes.	Kaolinite, quartzite, and crystalline etched pebbles, heavy minerals, gravel, sand, kaolinitic clay (diatomaceous and expandable), pebbles (including phosphate), and cobbles	Support ridge-top forests	Good for most recreation	Record Miocene marine depositional environments

Gray-shaded rows indicate map units in the accompanying GIS data but not mapped within the park.

Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
TERTIARY - EOCENE	Nanjemoy Formation, undivided (**Tn**)	Yellowish brown (weathered) to dark olive gray, greenish gray, and olive black glauconitic quartz sand; also fine to coarse, clayey and silty, micaceous and shelly interbeds of silty and sandy clay; lowermost beds are the highly glauconitic Potapaco Member (**Tnp**); upper Woodstock Member (**Tnw**) beds are more micaceous; **up** to 64 m (210 ft) thick	Low	Generally suitable for most forms of development, but locally rich in disseminated pyrite and other iron-sulfide minerals, which quickly produces acid drainage when exposed during construction. Iron-rich nature of sediment generally produces poor groundwater quality.	Glauconite-cemented sand may slide off slopes in large blocks or sheets, especially if water saturated	Trace fossils (bioturbation), shell fragments, and mollusks including *Venericardia poapacoensis*, *Venericardia ascia*, *Macrocallista sumimpressa*, *Corbula aldrichi*, *Lucina dartoni*, *Lunatia* sp., and *Cadulus* sp.	Iron sulfide concretions may have provided fire making materials.	Iron sulfide nodules, sand, gravel, silt, clay, and glauconite	None documented	Suitable for most forms of recreation	Records Eocene marine depositional environments
TERTIARY - PALEOCENE	Aquia Formation (**Ta**)	Nearly massive glauconitic quartz sand; thickly bedded, fine to medium sands are interlayered with some clay and silt rich beds, as well as lenses of sandy and shelly limestone; **up to** 35 m (115 ft) thick. Fresh surfaces are dark olive gray and greenish black, whereas weathered exposures are yellowish gray to orange.	Low	Supports an important freshwater aquifer. Suitable for most development unless highly permeable layers are present, or significant heterogeneity exists locally, which may cause unit to be unstable.	Glauconite-cemented sand may slide off slopes in large blocks or sheets, especially if water saturated or undercut along a poorly consolidated shelly layer.	Mollusks (*Cucullaea gigantea*, *Ostrea alepidota*, *Crassatellites* sp., and *Dosiniopsis* sp), ophiomorpha-type burrows, gastropod (*Turitella mortoni*), bivalves (*Ostrea sinuosa*, *Crassatellites alaeformis*, and *Cucullaea* sp.), foraminifera, dinocysts, nannofossils, and pollen	Stone wall along Sunken Road	Sand, glauconite, silt, and clay	Poor cementation may provide burrowing habitat.	Suitable for most forms of recreation	Records marine to terrestrial depositional environment during the Tertiary-Quaternary transition (Thanetian age)
CRETACEOUS	Potomac Formation (**Kp**)	Composed of three main sediment types: (1) fine to coarse feldspathic quartz sand and sandstone, thickly bedded, with some trough cross-beds, in a poorly sorted clay-silt matrix; conglomerate beds present locally; (2) greenish gray to reddish brown silt and sandy clay, clayey silt, and clayey fine sand; some illite and smectite clay-silt plugs are present locally; (3) dark yellowish brown to olive gray lignitic sandy silt, clay, and silty fine sand and sandstone. Thickness <1 m (3.3 ft) to the west, to more than 500 m (1,640 ft) in the subsurface in the eastern part of the region.	Low to moderately low for conglomerate layers	Supports an important freshwater aquifer in sandy layers. Generally suitable for most development, but variations in bedding, sediment, and degree of cementation may render unit unstable on slopes.	Susceptible to slumps and slides. Clay-rich, massive bedded layers may spall in large blocks when unit is exposed on slopes.	Plant stems; silicified coniferous tree trunks; leaf and stem impressions of ferns, cycads, and other gymnosperms; pollen. Barremian?, Aptian, and Albian pollen and leaves	May preserve ancient campsites and relics	Vein quartz, quartzite, illite, smectite clays, sand, gravel, metamorphic rock cobbles and pebbles, silt, boulders (some >1 m [3.3 ft] in diameter)	Supports eastern hardwood forests throughout region	Suitable for most forms of recreation unless present in bluffs along major waterways	Very widespread unit. Records Cretaceous environment along the Atlantic coast.
JURASSIC	Diabase and diabase dikes (**Jd**) Diabase, low-titanium (**Jdql**) Diabase, high-titanium (**Jdqh**) Diabase, late-stage granophyric differentiates (**Jdqhg**)	Crystalline, fine- to medium-grained, dark gray to black diabase rocks; textures are generally intergranular to ophitic; primary minerals include bytownite-augite feldspar, minor biotite, with rare fayalitic olivine. Occur as narrow dikes with chilled aphanitic margins. **Jdql** and **Jdqh**—light to dark gray, crystalline to porphyritic diabase **Jdqhg**—sodic plagioclase, K-feldspar, quartz, and other minerals in small diabase pods	High	Suitable for most development unless highly fractured or weathered (friable). Require blasting for excavation.	Rockfall potential if exposed on slope	None	None documented	Sodium plagioclase, potassium feldspar, quartz, hornblende, biotite, pyroxene, calcic plagioclase, gabbro, granophyre, syenite, aplite, and olivine. Crystalline rocks may provide building material and crushed fill material for construction	May support localized plant species	Suitable for most recreation unless exposed on a slope	Represents Jurassic volcanic activity accompanying Mesozoic extension throughout the region. Radiometric age dates.

Gray-shaded rows indicate map units in the accompanying GIS data but not mapped within the park.

Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
TRIASSIC	Mountain Run Member of the Tibbstown Formation (**TRtmr**) Balls Bluff Siltstone, lacustrine member (**TRbl**) Balls Bluff Siltstone, fluvial member (**TRbf**) Manassas Sandstone, upper unnamed member (**TRmu**) Manassas Sandstone, Rapidan Member (**TRmr**) Hornfels, metagraywacke and metaconglomerate (**TRtm**)	**TRtmr**—conglomerate containing pebble- to boulder-sized greenstones, interbedded with pebbly sandstone and upward-fining sequences; as much as 640 m (2,100 ft) thick. Lower portions contain metavolcanic rocks in a red to pale green clayey sandstone and siltstone matrix. **TRbl** and **TRmu**—siltstone, mudstone, and shale, interbedded as fining-upward sequences. Color varies from reddish brown to dark gray to black and light purple. Mudstone is massive to laminated. **TRbl** is more than 1,000 m (3,280 ft) thick. **TRfl** is 100 to 200 m (328 to 656 ft) thick. **Trmr**—greenish gray to reddish arenitic sandstone, pebbly sandstone, siltstone, and minor shale, in fining-upward sequences. Lower beds consist of conglomerates containing rounded boulders, cobbles, and pebbles of metabasalt and other Piedmont rocks. **TRtm**—dark gray to bluish mauve, fine to coarse grained metasedimentary rocks present as contact aureoles around Jurassic diabase intrusions. Hornfels contains cordierite, epidote, and chlorite in a cooling-outward assemblage. Aureole is 60 to 120 m (197 to 393 ft) thick.	Moderate to moderately high for metamorphic rocks	Suitable for most development unless highly heterogeneous layers are present, or beds are heavily fractured. Avoid areas with high friability (due to weathering of carbonate cements). Swelling clays are locally abundant.	Large boulders and cobbles in **TRtmr** are susceptible to rockfall and mass wasting when exposed on slopes and undercut by local rivers. Clay- and shale-rich layers are susceptible to slumping and sliding, especially when water saturated.	Triassic palynomorphs; **TRbl** contains sporomorphs, root tubes, dinosaur and reptile trackways, stromatolitic limestone, shelly fossils, and paleosols.	Nodules of sulfides may have provided useful materials.	Greenstone pebbles, vein quartz clasts, caliche (carbonate nodules), chlorite, epidote, fragments of quartzite, meta-arkose, marble, and phyllitic schist. Hornfels (cordierite, chlorite, and epidote). Sulfides (iron, copper, zinc, and lead). Hard rock for building materials. Attractive red stones for crushed aggregate and dimension stone.	Support eastern hardwood forests	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Type sections of the Mountain Run Member of the Tibbstown Formation and the Rapidan Member of the Manassas Formation. Manassas Sandstone records fluvial environment following Alleghanian Orogeny.
CARBONIFEROUS	Falmouth Intrusive Suite (**PMfi**)	Masses of fine-grained monzogranite and pegmatitic (coarse-grained) granite, fine-grained granodiorite, and tonalite locally	High	Suitable for most development unless highly weathered or fractured	Susceptible to rockfall if exposed on slope	None	Large crystals may have provided trade material.	Tonalite and coarsely crystalline pegmatite. Attractive building stone material	None documented	May be friable, and unsuitable for climbing. Also may prove to be an unstable base for trails and other visitor facilities if highly weathered.	Dateable material
SILURIAN	Falls Run Granite (**Sf**)	Pale pink to nearly white hornblende and biotite granite gneiss. Composition ranges from monzogranite to granite and is strongly foliated.	High	Suitable for most development unless highly weathered or fractured. Avoid areas of intense preferential compositional weathering (along foliation).	Susceptible to rockfall if exposed on slope	None	None documented	Hornblende and plagioclase. Attractive building stone material	None documented	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Dateable material. Records deformation and metamorphic conditions.
ORDOVICIAN	Quantico Formation (**Oq**) Quantico Formation, quartzite (**Oqq**) Metasedimentary rocks, undivided (**Ou**) Metamonzogranite of Goldvein pluton (**Og**) Phyllite (**Op**) Phyllite with mylonitic rock (**Opm**)	**Oq**—dark gray phyllite and fine- to medium-grained staurolite schist and biotite-muscovite schist. Some calc-silicate interbeds and quartzite lenses present locally. **Ou**—green silty phyllite and gray to white metasiltstone and fine-grained quartzite, fine-grained mica schist, green slate and phyllite with scant quartzite and metagraywacke layers. **Og**—coarse- to medium-grained, mesocratic, foliated metamonzogranite. Green phyllites (Op) may be highly sheared locally to mylonitic textures (**Opm**).	Moderate for highly deformed layers, high for undeformed units	Heterogeneity of units may render them unstable locally for foundation, road, and facilities development.	Susceptible to spalling, rockfall, and other forms of mass wasting if undercut on slopes	None	Mineral inclusions may have provided trade material	Staurolite, garnets, kyanite, quartzite lenses, and altered pink and green feldspar grains. Attractive building stone material (e.g., slate and granite)	Support large tracts of eastern hardwood forests	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Accreted terranes within the Piedmont province

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Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
ORDOVICIAN AND (OR) CAMBRIAN	True Blue Formation (**Oct**) True Blue Formation, Everona Limestone Member (**OCte**) Mine-Run Complex, Melange Zone IV (**OCmIV**) Mine-Run Complex, Melange Zone IV, metasedimentary (**OCmIVq**) Mine-Run Complex, Melange Zone IV, metavolcanics (**OCmIVv**) Mine-Run Complex, Melange Zone III (**OCmIII**) Mine-Run Complex, Melange Zone II (**OCmII**) Mine-Run Complex, Melange Zone I (**OCmI**) Lunga Reservoir Formation (**OCl**) Trondhjemite of the Horsepen Run pluton (**OCtj**) Plagiogranite of the Richland Run pluton (**OCpg**)	**Oct**—calcareous and noncalcareous slate, siltstone, and some argillite; contains bodies of **OCte** as blue gray, fine-grained, metalimestone, which is about 160 m (525 ft) thick. **OCm**—contains four (I–IV) thrust slices of block-in-phyllite mélange. Rocks are gray to green. Zones are commonly phyllite, metasandstone and metasiltstone with some metavolcanic and phyllitic lenticular bodies. Zone III contains Proterozoic amphibolite, ultramafic rocks, biotite gneiss, granite gneiss, serpentinite, and foliated talc. Zones I and II contain Cambrian, felsic and mafic metavolcanic blocks. Mylonites are present locally. **OCl**—mélange consisting of nonstratified graywacke, surrounding blocks of greenstone and metamafic rocks. **OCtj**—granular, fine-grained, granophyric rock with intergrown albite and quartz. **OCpg**—plagiogranites and tonalites, present as metaintrusives, with intense deformation ranging from brittle cataclasis to ductile mylonitization.	Moderate for sedimentary and deformed rocks, high for crystalline intrusions	Suitable for most development unless calcareous layers are weathered, or the mylonites and cataclasites are highly deformed. Mafic rocks weather to clayey soils with high shrink-swell potential.	Contain large blocks separated by deformed zones of rock, which are susceptible to spalling and rockfall hazards on slopes. Carbonate minerals may weather preferentially, increasing the likelihood of failure and mass wasting. Clay (weathered rocks) layers may fail when water saturated.	Some marine fossil remnants possible in sedimentary units	Chert and ironstone may have provided material for tools.	Chert, ironstone, phyllite, mylonite, euhedral magnetite, talc, serpentinite, blue green amphibole, and garnets. Limestone, slate, chips and pebbles of gneiss and schist, and quartz boulders	Widespread and support many habitats	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Accreted, exotic terranes
CAMBRIAN	Chopawamsic Formation (**Cc**) Ta River Metamorphic Suite (**Ct**) Metasedimentary rocks, undivided (**Cm**)	**Cc**—lenses and tongues of metavolcanic and metasedimentary rocks including silicic, intermediate, and mafic varieties, with some breccia and tuff layers present locally. Metasedimentary rock types include schist, meta-arenite, and some gneiss. **Ct**—primarily dark gray to black, foliated amphibolitic gneisses. Some biotite rich areas present locally. **Cm**—mixture of tan, gray and light brown pebbly feldspathic quartzite, layered with purplish metasiltstone and phyllite. Quartzite is fine to coarse grained, with few preserved cross-beds, and deformed by slaty cleavage.	Moderate to high depending on degree of deformation	Foliation and variability of rock types may render the units unstable for heavy development. Mafic rocks weather to clayey soils with high shrink-swell potential.	Slaty cleavage and deformation between large blocks may cause them to be susceptible mass wasting on slopes, especially if undercut by erosion of weathered underlying units.	May contain traces of early life. Some metamorphosed burrows possible.	Caps ridges	Keratophyres, albitic plagioclase, prismatic amphibole, greenstones, pyroxene, biotite, pyrite, sphalerite, and chalcopyrite. Lead and zinc ores, gold, and massive sulfide deposits mined near Mineral, Virginia.	Widespread and support many kinds of habitat	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Accreted, exotic terranes

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Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
CAMBRIAN (?)	Amphibole metagabbro (**Cg**) Felsic metavolcanic rocks (**Cvf**) Mafic metavolcanic rocks (**Cvm**) Altered tonalite and granodiorite granitoid blocks (**Ctg**)	**Cg**—massive, coarse to medium grained, and melanocratic. Some coarse-grained amphibole and epidote are abundant locally. **Cvf**—rare olistoliths **Cvm**—similar to **Cc** (described above) **Ctg**—igneous intrusions of intermediate compositions (tonalites and granodiorites). Feldpsar minerals are preferentially weathered in these blocks.	High unless weathered, then moderate	Suitable for most development unless local blocks or plagioclase groundmass are altered and weathered, rendering the unit friable. Mafic rocks weather to clayey soils with high shrink-swell potential.	Susceptible to spalling, rockfall, and other forms of mass wasting hazards	None	None documented	Olistoliths, coarse grained amphibole, epidote, and quartz	None documented	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Oceanic crust and volcanic-arc material, as part of accreted terranes
CAMBRIAN AND (OR) PROTEROZOIC	Blastomylonitic tonalite and granodiorite gneiss (**CZg**) Amphibolitic xenoliths (**CZa**) Ultramafic rocks (**CZu**) Serpentinite (**Czs**) Massive as well as foliated talc (**CZt**) Biotite gneiss (**CZbg**) Serpentinite and talc (**CZst**) Amphibolite and serpentinite (**CZas**) Amphibolite and talc (**CZat**) Serpentinite and mafic rock (**CZsm**)	Rock types include altered basalts, greenstones (serpentinite), and talc-rich layers. **CZa** contains muscovite-biotite granites. Present in pods and lenses locally throughout the western portions of the park area.	Moderate to high for crystalline blocks	Highly heterogeneous and typically heavily weathered, rendering units rather weak for heavy development. Mafic rocks weather to clayey soils with high shrink-swell potential.	Unstable on slopes. Prone to mass wasting.	Records Precambrian-Cambrian transition	None documented	Talc, serpentinite, amphibole, plagioclase, quartz, epidote, chlorite, and xenoliths	Support species that prefer high iron, magnesium, and calcium soils	Friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Accreted, exotic terranes
CAMBRIAN OR PROTEROZOIC	Holly Corner Gneiss (**CZh**) Garrisonville Mafic Complex (**CZgn**)	**CZh**—foliated hornblende and biotite rich gneiss, dark gray to black, fine to medium grained **CZgn**—fine to coarse grained, massive to foliated amphibolite and hornblendite. Some metapyroxenite, metawebsterite, and metanorite are present locally. Talc-amphibole schist is present near boundaries.	High to moderately low for talc-rich units	Not suitable for development. Typically weather to very clay-rich soils with very high shrink-swell potential. Avoid areas of intense preferential compositional weathering (along foliation).	May be susceptible to rockfall if exposed on slope. Talc and weathered areas may increase likelihood of sliding.	Records Precambrian-Cambrian transition	Mineral inclusions may have provided early trade material.	Andesine, quartz, epidote, diopside, amphibole, talc, and enstatite. Talc. Landscaping material. Attractive building stone.	None documented	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Accreted, exotic terranes

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Age	Map Unit (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Resources	Habitat	Recreation	Geologic Significance
PALEOZOIC AND (OR) PROTEROZOIC	Po River Metamorphic Suite, biotite gneiss and schist (**PZZp**) Po River Metamorphic Suite, quartzofeldspathic gneiss (**PZZpm**) Po River Metamorphic Suite, amphibolite and amphibole gneiss (**PZZpa**) Po River Metamorphic Suite, magnetite-bearing biotite gneiss (**PZZpmb**)	**PZZp**—primarily biotite gneiss and schist. Gneiss is dark-colored, layered and foliated, with micaceous materials concentrated in the dark layers, and quartz and feldspar concentrated in the lighter layers. Feldspar augens and hornblende gneiss present locally. Garnetiferous two-mica schist occurs locally. Many pegmatoids occur in tabular bodies forming concordant, sill-like layers that range from less than 2.5 cm (1 in) to as much as 7.6 m (25 ft) thick. **PZZpm**—fine- to coarse-grained, strongly foliated, garnet-muscovite quartzofeldspathic gneiss **PZZpa**—fine- to coarse-grained, weakly to strongly foliated, irregularly layered amphibolite and amphibole gneiss **PZZmb**—quartz-rich, magnetite-bearing biotite gneiss	High to moderate where deformed	Avoid highly schistose layers as well as areas of intense preferential compositional weathering (along foliation). Mafic rocks weather to clayey soils with high shrink-swell potential.	Lenses of resistant rocks in schistose layers susceptible to block and rockfall	None	None documented	Garnets, muscovite, amphiboles, magnetite, and feldspar augens. Landscaping material. Attractive building stone. Garnets for abrasives.	May weather into soils that attract species preferring high sodium, calcium, and aluminum soils	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Po River accreted terrane
PALEOZOIC OR PROTEROZOIC	Diorite gneiss of the Potomac Creek pluton (**PZZd**) Granite gneiss (**PZZpg**)	**PZZd**—gray quartz-plagioclase-biotite-rich diorite gneiss, with strong foliations and lineations; fine to medium grained and contains numerous cross-cutting dikes. **PZZpg**—fine- to medium-grained granite gneiss, ranging in composition to tonalite. Numerous biotite gneiss, biotite schist, and amphibolite layers exist within this tabular to lenticular shaped unit.	High	Highly heterogeneous and interlayered with younger units. Strong foliation creates zones of preferential jointing, which should be avoided for heavy development. May require blasting to excavate. Mafic rocks weather to clayey soils with high shrink-swell potential.	Lenses of resistant rocks in schistose layers may be susceptible to block and rockfall.	None	None documented	Epidote, garnet, and muscovite. Landscaping material. Attractive building stone. Garnet for abrasives.	Present near Fall Line; may correlate with specific species	Suitable for most forms of recreation, unless rocks are friable and weathered (i.e., an unstable base for trails and other visitor facilities)	Part of accreted terrane on the eastern edge of the Piedmont. Record later accretions onto the North American continent.
PROTEROZOIC	Catoctin Formation (**Zc**) Charlottesville Formation of the Lynchburg Group (**Zch**)	**Zc**—dark green metabasalt, ranging in texture from aphanitic to medium-grained and massive. Local interbeds of phyllite and quartzite are present, with concordant slaty cleavage. **Zch**—primarily of miceaceous metasiltstone and massive quartz-muscovite-sericite schist with thin quartzite and brown meta-arkose interbeds; typically very weathered, producing a light brownish gray sandy clay soil.	Moderately high to moderate where unit is highly weathered	Avoid for most heavy development. **Zc** (metabasalts) typically weather to a clay-rich soil with moderately high shrink-swell potential.	Susceptible to failure if exposed on slope or undercut . Rockfall hazard.	None	Greenstone may have been valued as trade material.	Quartz, muscovite, sericite, greenstone, chlorite, and epidote. Clay. Quartzite may provide flagstone material.	Support species that prefer high iron, magnesium, and calcium soils	Friable and weathered (i.e., an unstable base for trails and other visitor facilities)	**Zc** represents portions of ancient flood basalts that are correlative over a wide area. Rocks predate Paleozoic orogenic events and thus contain record of deformation throughout the Paleozoic orogenic cycle.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park, the environment in which those units were deposited, and the timing of geologic events that created the present landscape

Precambrian (prior to 542 million years ago)

The geologic history recorded in the Appalachian Mountains begins in the Mesoproterozoic Era (figs. 12, 13, and 14A). The igneous rocks from this era crystallized over a period of 100 million years, and are more than a billion years old, making them among the oldest known rocks known from this region. They form a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001). At this time, the Grenville Orogeny (mountain-building event) was changing the landscape, raising and concentrating the continental crust of North America and Africa. Plutonism, volcanism, sedimentation, and deformation that resulted from the orogeny are manifest in the metamorphic gneisses and granite-like rocks in the core of the present-day Blue Ridge Mountains west of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park (Harris et al. 1997).

The Neoproterozoic Era (fig. 14B), roughly 700 million years ago, is marked by extensional tectonism in this region, as the existing mass of continental crust broke apart and a sea basin formed, eventually becoming the Iapetus Ocean. This basin was a catchment for many of the sediments that now underlie the Blue Ridge Mountains and Piedmont Plateau. In this continental rifting environment, flood basalts extruded onto the surface through cracks in the granitic gneisses of the Blue Ridge core, and other igneous rocks such as diabase and rhyolite crystallized within the North-American crust (Southworth et al. 2001). The Catoctin Formation—located in the western edges of the map for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park—preserves the altered remains of the early flood basalts (Mixon et al. 2000).

Paleozoic Era (542 to 251 million years ago)

During the Cambrian, deposition of significant deposits of sand, silt, and mud in nearshore, deltaic, barrier-island and tidal-flat areas was associated with the shallow marine setting along the eastern continental margin (fig. 14C) (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). As the Iapetus Ocean continued to expand, mid-ocean rift volcanism mixed basaltic lavas with marine sediments. Eventually, a grand carbonate platform, similar to present day Bahamas, developed in this region. This platform existed as an eastward-thickening wedge that persisted through the Cambrian and Ordovician periods (545–480 million years ago) (fig. 14D). Meanwhile, episodes of mountain building and continental collision during the Paleozoic contributed the heat and pressure needed to deform and metamorphose the entire package of intrusive rocks, basalts, and sediments into schists, gneisses, marbles, slates, and migmatites (Southworth et al. 2001). Many of these rocks occur in the Fredericksburg area.

By Early Ordovician time, orogenic activity along the eastern margin of the North American continent had begun again, this time involving the closing and eventual destruction of the Iapetus Ocean through subduction of oceanic crust. The process created volcanic arcs (like the Aleutian Islands in Alaska today) and uplifted the eastern margin of the North American continental crust (fig. 14E) (Means 1995). The Taconic Orogeny (approximately 440 to 420 million years ago in the central Appalachians) involved volcanic arc–continental margin convergence. During convergence in the Iapetus Ocean basin, tectonic forces thrust oceanic crust, marine sediments, and a volcanic arc onto the eastern edge of the North American continent. This mountain-building episode caused initial metamorphism of the Catoctin Formation into metabasalts and metarhyolites, and sedimentary rocks of the ocean basin into quartzites and phyllites.

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 (Harris et al. 1997). Present-day West Virginia was the center of the “Appalachian Basin” (fig. 14F). Sediments—which eventually turned into sandstones, shales, siltstones, quartzites, and limestones—were deposited continuously in this shallow marine basin for about 200 million years during the Ordovician to Permian periods.

During the Upper Ordovician, more oceanic sediments of the Iapetus Ocean were thrust westward onto other deepwater sediments of the western Piedmont along the Pleasant Grove fault. These rocks, now metamorphosed, currently underlie the Valley and Ridge province located west of the Blue Ridge (Fisher 1976).

The Acadian Orogeny (approximately 360 million years ago) continued the mountain building and regional metamorphism as the African Plate converged with the North American Plate, thrusting ocean sediments and volcanic rocks westward (Harris et al. 1997). Metamorphosed sedimentary rocks of the Piedmont record the transition from passive margin (“nonorogenic”) sedimentation to extensive, “synorogenic” sedimentation during Ordovician time (Fisher 1976). In the Fredericksburg area, these metasedimentary rocks include schists, metagraywackes, phyllonites, mélanges, and metasiltstones. Oceanic crust caught up in these orogenic events now exists on the Piedmont Plateau as peridotites, metagabbros, serpentinites, and pyroxenites, along with other metamorphic and igneous rocks (Drake et al. 1994; Mixon et al. 2000).

The Iapetus Ocean basin completely closed during the Late Paleozoic Alleghany Orogeny (325–265 million years ago) as the North American continent collided with the African continent, forming the supercontinent Pangaea. This event also formed the present-day Appalachian mountain belt and was the last major collisional orogenic event in the evolution of the Appalachian mountains (fig. 14G) (Means 1995). This collision deformed rocks by folding and faulting, producing large-scale Appalachian structures. Present-day representatives of these structures are the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, as well as the Blue Ridge–South Mountain anticlinorium and numerous folds and faults of the Valley and Ridge province (Southworth et al. 2001).

Regionally deformed and metamorphosed rocks in the Fredericksburg and Spotsylvania area, are composed of a number of terranes with different origins and geologic histories (Spears et al. 2004). For example, the Chopawamsic terrane (not the Chopawamsic Formation) is an Ordovician volcanic and plutonic, island-arc complex containing sedimentary rocks.

East of the Chopawamsic volcanic arc is another exotic terrane, the Goochland terrane. This body of rock is a Meso- to Neoproterozoic basement massif. It contains gneiss, amphibolite, granite, and anorthosite. The rocks in this terrane underwent multiple stages of deformation and granulite-facies (high-pressure and temperature) metamorphism. Separating these two terranes is a highly deformed band of rocks known as the Spotsylvania high-strain zone (Spears et al. 2004).

Tectonic forces during the Alleghany Orogeny folded and faulted the Chopawamsic, Goochland, and other terranes south of the Fredericksburg area, reactivating pre-existing thrust faults as both strike-slip and thrust faults (Southworth et al. 2001). Rocks of the Shenandoah Valley, Blue Ridge, and Piedmont provinces were transported as a massive block (Blue Ridge–Piedmont thrust sheet) westward onto younger rocks of the Valley and Ridge along the North Mountain fault. The amount of compression was extreme, shortening the landscape by 20% to 50%, or approximately 125–350 km (75–125 mi) (Harris et al. 1997). The Alleghany-aged Appalachian Mountains were analogous to the modern day Himalaya Range in Asia. Now, erosion has exposed the metamorphosed core of the mountain range.

Mesozoic Era (251 to 65.5 million years ago)

Following the Alleghany Orogeny, during the Upper Triassic (228–200 million years ago), an episode of continental rifting began (fig. 14H). At this time, Pangaea broke into the continents that exist today. This episode of rifting initiated the formation of the present Atlantic Ocean producing many block-fault basins along the continental margin of North America and was accompanied by volcanism. (Harris et al. 1997; Southworth et al. 2001). These Mesozoic basins lie to the west and south of the park, including the Culpeper and Taylorsville basins (Mixon et al. 2000). Igneous rocks such as diabase accompanied rifting and intruded the new strata as sub-horizontal sheets, or sills, and near-vertical dikes that extend beyond the basins into adjacent rocks. Collectively, these Mesozoic basins make up the Newark Basin system. This system of rift basins extends along the length of the Appalachians in a nearly linear trend from Massachusetts to South Carolina.

In Triassic time, streams feeding large alluvial fans carried sediments and debris from the recently uplifted Blue Ridge and Piedmont provinces, depositing them into these fault-bounded basins. These shallow-water, lacustrine deposits eventually became shales and sandstones. The Manassas Sandstone and the Balls Bluff Siltstone (named for exposures within and near Manassas National Battlefield Park) are part of these Newark Basin sedimentary rocks in the Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park area.

After emplacement of igneous rocks during the Jurassic Period (200 million years ago), 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 further erosion (fig. 14I). The igneous rocks, being harder than the surrounding sedimentary rocks, were more resistant to erosion and now cap many of the higher ridges, hills, and slopes in the region. Rocks exposed at the surface today in the Piedmont must have been at least 20 km (12 mi) below the surface prior to regional uplift and erosion.

Throughout the Mesozoic Era, thick deposits of unconsolidated gravel, sand, and silt shed from eroding mountains became alluvial fans. These fans spread eastward from the mountain front and covered the metamorphic and igneous rocks of the Piedmont, eventually forming the lowermost strata of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The Cretaceous Potomac Formation is an example of a widespread clastic wedge of sediment.

Since the regional uplift of the Appalachian Mountains and the subsequent breakup of Pangaea, the North American plate has continued to drift toward the west, concentrating tectonic activity on the western edge and creating an eastern passive margin. The isostatic uplift that occurred after the Alleghany Orogeny continued throughout the Cenozoic Era (Harris et al. 1997). This uplift and adjustment may be responsible for occasional seismic events felt throughout the region.

Cenozoic Era (the past 65.5 million years)

Weathering and erosion has also continued throughout the Cenozoic Era lowering the height of the mountains to west, and depositing alluvial terraces along major rivers (fig. 14J). The geomorphology of the Potomac, Rappahannock, and other large river valleys is the result of erosion and deposition from the mid-Cenozoic to the present (or at least the last 5 million years). The distribution of floodplain alluvium and ancient fluvial terraces along the rivers and adjacent tributaries record the historical development of these drainage systems. There is little evidence that the rivers migrated laterally across the broad, relatively flat regions of the Piedmont Plateau and upper Coastal Plain; these rivers may have simply cut downward through very old, resistant rocks, washing away their earlier courses as the landscape rose beneath them (Southworth et al. 2001).

Many terrace deposits occur in the Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park, along the Rappahannock River. The position, distribution, thickness, and elevation of these terraces and their sediments vary by province, age, and rock type. The elevations of terraces along the rivers show that the slope values of the ancient and modern river valleys are similar, which suggests that the terraces formed as the result of either eustatic sea level drop or uplift (Zen 1997a,b).

Though glaciers of the Pleistocene ice ages never reached the central Virginia area (the southern terminus was in northeastern Pennsylvania), the intermittent colder climates played a role in the formation of the landscape at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Freeze-and-thaw cycles at higher elevations led to increased erosion of large boulders and rocks by ice wedging. Sea level fluctuations throughout the Pleistocene caused the base level of many of the area's rivers to change. During regressions (sea level drops), the rivers eroded their channels, exposing the deformed bedrock of the Piedmont Plateau. During oceanic transgressions, the river basins flooded, which resulted in beach-sediment deposition of younger Coastal Plain strata.

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

Figure 12. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, http://pubs.usgs.gov/fs/2007/3015/ with additional information from the International Commission on Stratigraphy. http://www.stratigraphy.org/view.php?id=25.

Eon	Era	Period	Epoch	Events
Phanerozoic	Cenozoic	Quaternary	Holocene	18 ka: Chesapeake Bay forms, shorelines evolve
			Pleistocene	Dramatic climate oscillations, rise and fall of sea level cutting scarps along major rivers
		Tertiary	Pliocene	Marine sedimentation
			Miocene	Chesapeake Group, erosional interval
			Oligocene	Erosional interval
			Eocene	35.7 Ma: Chesapeake Bay Impact Structure
			Paleocene	Erosional interval
	Mesozoic	Cretaceous		Shallow sea covers eastern Virginia
		Jurassic		Atlantic Ocean opens, east-flowing rivers develop
		Triassic		Atlantic rifting begins Deposition of sediments in rift basins
	Paleozoic	Permian		325–265 Ma: ALLEGHANY OROGENY
		Pennsylvanian		Coals deposited in coastal swamps 300 Ma: Petersburg Granite emplaced
		Mississippian		Passive margin sedimentation
		Devonian		360 Ma: ACADIAN OROGENY
		Silurian		Taconic highlands eroded
		Ordovician		440–420 Ma: TACONIC OROGENY
		Cambrian		Carbonate deposition on passive margin
Proterozoic	Neoproterozoic			600–550 Ma: Late phase of Iapetan rifting 750--700 Ma: Early phase of Iapetan rifting
	Mesoproterozoic			1100--950 Ma: GRENVILLE OROGENY
	Paleoproterozoic			

Figure 13. Geologic timescale specific to Virginia. Dates are approximate and presented in thousands (ka) and millions of years (Ma) before present. Modified from Bailey (1997–2003) by Trista L. Thornberry-Ehrlich (Colorado State University).

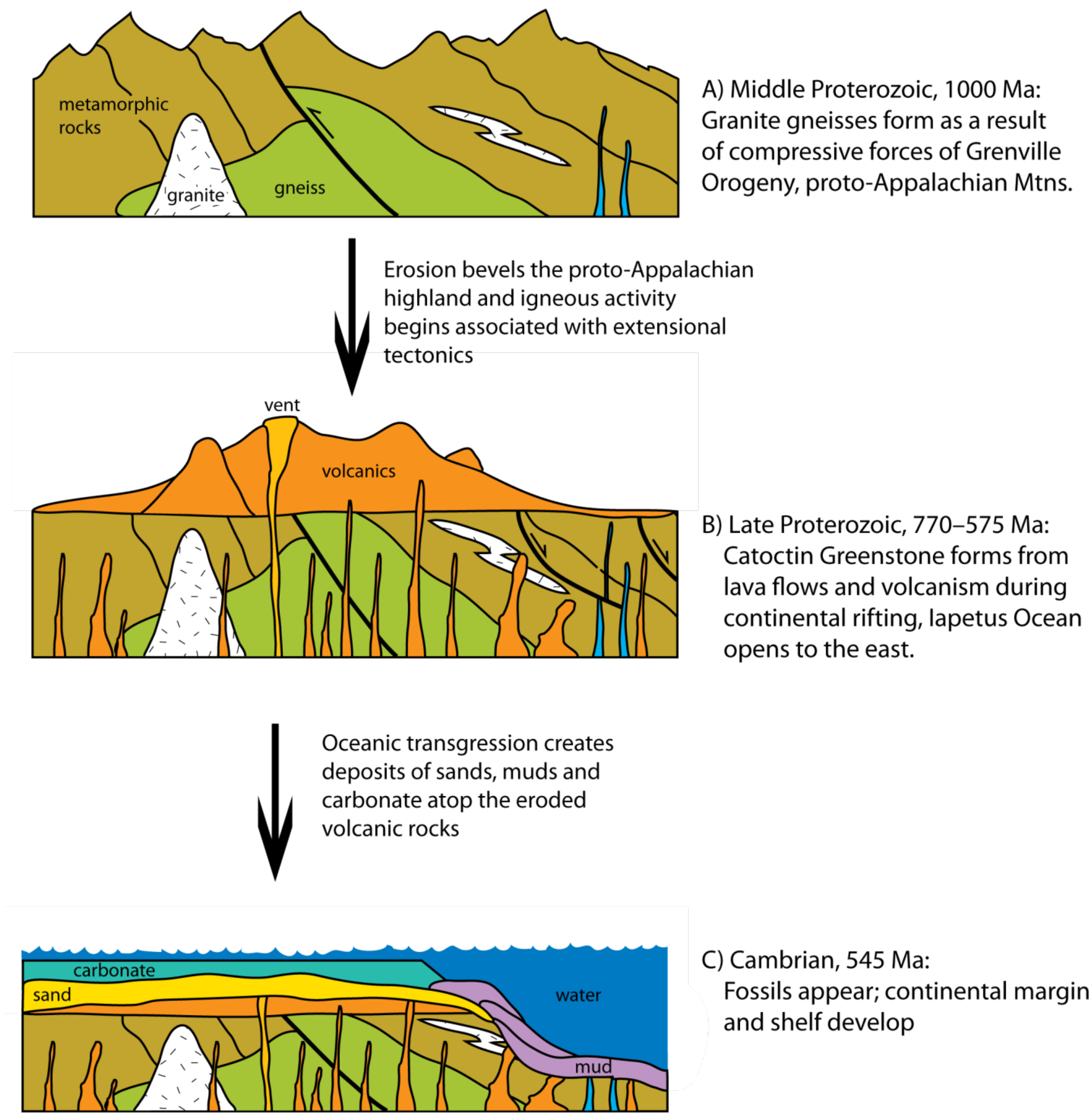

Figure 14 Geologic evolution of the Appalachian Mountains in the Fredericksburg area. Cross-sectional view is west to east. (*A*) Intrusions of granitic gneiss, metamorphism, and deformation related to the Grenville Orogeny lasted 60 million years, from 1.1 billion to 950 million years ago. These rocks occur in the Blue Ridge province. (*B*) Continental rifting and volcanic activity in the Grenville terrane (current Blue Ridge province) and deposition of turbidites in deepwater basin to the east (current Piedmont province) lasted about 200 million years, from about 770 to 575 million years ago. (*C*) The margin of the continent became stable with quiet waters filling with carbonate sediments (rocks of the current Great Valley and Frederick Valley). Shelled organisms appeared about 545 million years ago. Deepwater sediments filled a basin east of the shelf margin for about 65 million years.

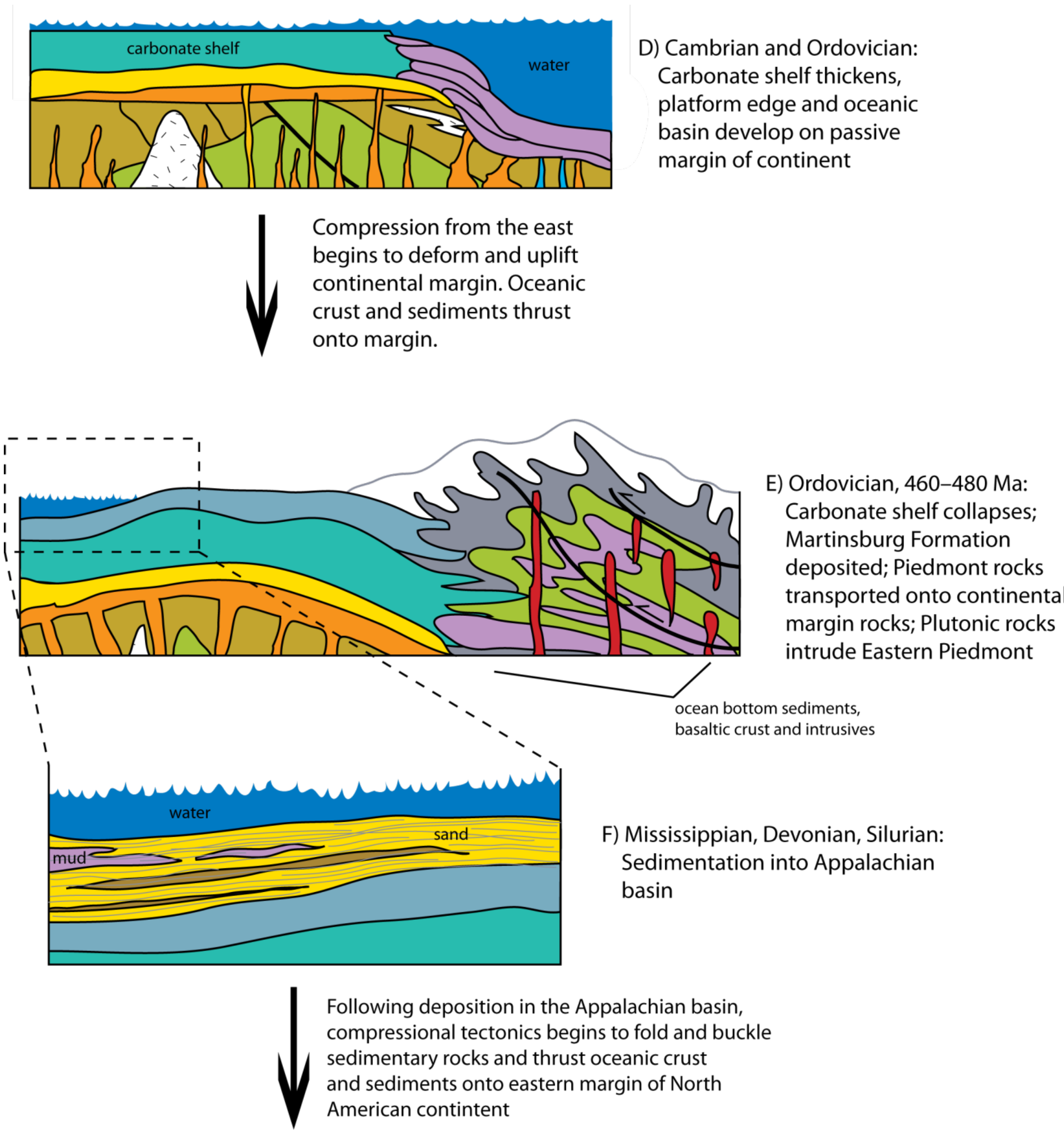

Figure 14, continued. (*D*) Following deposition, the stable shelf foundered as the Taconic Orogeny (*E*) elevated the rocks to the east and provided a source for the clastic materials that make up the shale of the Martinsburg Formation. Plutonic rocks intruded the rocks in the Piedmont province. (*F*) A thick sequence of sediments began filling a deepening Appalachian basin over a span of 120 million years. Most of these rocks now occur in the Valley and Ridge province. About 370 million years ago, magma (igneous rock) intruded the rocks near Great Falls.

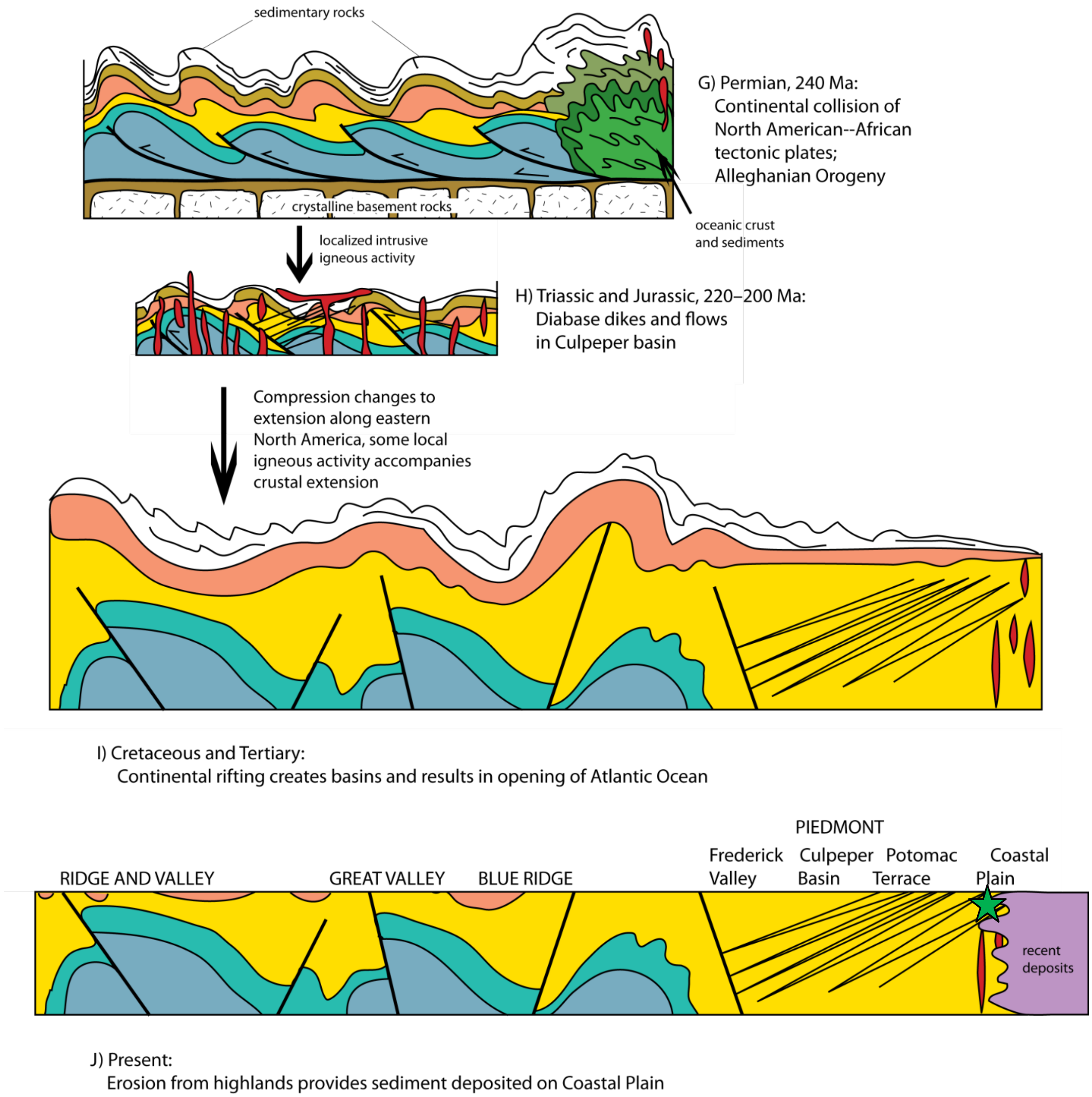

Figure 14, continued. (*G*) About 240 million years ago, the continental tectonic plates of North America and Africa collided, resulting in the Alleghany Orogeny. Many of the folds and faults in rocks west of the Piedmont province record this event. (*H*) About 20 million years later, continental rifting began and lasted for about 20 million years (220–200 million years ago). (*I*) Thick sequences of sediments filled fault-bounded basins; volcanic activity (continental rifting) created the Atlantic Ocean. The Culpeper and Gettysburg basins in the western Piedmont are the result of this event. (*J*) For the last 200 million years, erosion has denuded the landscape and rivers have carried the sediment eastward to deposit the thick strata of the Atlantic Coastal Plain. The green star on the figure represents the location of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park. Diagrams are not to scale and are broadly representative of the tectonic settings. Adapted from Southworth et al. (2001) by Trista L. Thornberry-Ehrlich (Colorado State University).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).

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

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

alluvium. Stream-deposited sediment.

amygdule. A gas cavity or vesicle in an igneous rock, which is filled with secondary minerals. ("amygdaloidal" describes rocks with amygdules).

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

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

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

arenite. A general term for sedimentary rocks composed of sand-sized fragments with a pure or nearly pure chemical cement and little or no matrix material between the fragments.

augen. Describes large lenticular mineral grains or mineral aggregates that have the shape of an eye in cross-section. Found in metamorphic rocks such as schists and gneisses.

aureole. A zone surrounding an igneous intrusion in which the country rock shows the effects of contact metamorphism from the high temperature, molten material.

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

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

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

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

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

bedding. Depositional layering or stratification of sediments.

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

bog iron ore. A general term for a soft, spongy, and porous deposit of impure hydrous iron oxides formed in bogs, marshes, swamps, peat mosses, and shallow lakes by precipitation from iron-bearing waters and by the oxidizing action of algae, iron bacteria, or the atmosphere.

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

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

channel bar. An elongate deposit of sand and gravel located in the course of a stream. Common in braided streams.

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

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

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

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

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

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

craton. The relatively old and geologically stable interior of a continent.

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

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

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

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

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

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

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

diabase. An intrusive igneous rock consisting primarily of the minerals labradorite and pyroxene.

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

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

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

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

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.

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

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

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

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

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

foliation. A preferred arrangement of crystal planes in minerals. In metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas.

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

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

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

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

gabbro. A group of dark-colored, intrusive igneous rocks. The intrusive equivalent of basalt.

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

glauconite. A green mineral, closely related to the micas. It is an indicator of very slow sedimentation.

gneiss. A foliated rock formed by regional metamorphism with alternating bands of dark and light minerals.

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

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

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

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

joint. A 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.

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

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

lens. A sedimentary deposit characterized by converging surfaces, thick in the middle and thinning out toward the edges, resembling a convex lens.

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

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

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

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

mantle. T The zone of Earth's interior between the crust and core.

massif. A massive topographic and structural feature, especially in an orogenic belt, commonly formed of rocks more rigid than those of its surroundings. These rocks may be protruding bodies of basement rocks, consolidated during earlier orogenies, or younger plutonic bodies.

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

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

mélange. A mappable body of jumbled rock that includes fragments and blocks of all sizes, both formed in place and those formed elsewhere, embedded in a fragmented and generally sheared matrix.

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

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

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

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

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

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

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during dehydration at Earth's surface.

mylonite. A fine-grained, foliated rock typically found in localized zones of ductile deformation, often formed at great depths under high temperature and pressure.

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

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

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

olistolith. A large block or other rock mass (usually greater than 10 m or 33 ft) transported by submarine gravity sliding or slumping and included within a debris-flow deposit called an olistostrome.

orogeny. A mountain-building event.

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.

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

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

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

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

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

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

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

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

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

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

quartzite. Metamorphosed quartz sandstone.

recharge. Infiltration processes that replenish groundwater.

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

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

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

rhyolite. A group of extrusive volcanic rocks, typically porphyritic and commonly exhibiting flow texture, with phenocrysts of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass. The fine-grained extrusive equivalent of granite.

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

roundness. The relative amount of curvature of the "corners" of a sediment grain.

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

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

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

schist. A strongly foliated metamorphic rock that can be readily be split into thick flakes or slabs. Micas are arranged in parallel, imparting a distinctive sheen, or "schistosity" to the rock.

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 rock and mineral fragments.

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

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

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

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

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

slate. A compact, fine-grained metamorphic rock that can be split into slabs and thin plates. Most slate was formed from shale.

slope. The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."

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

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

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

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

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

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

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

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

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

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

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

synorogenic. Describes a geologic process or event occurring during a period of orogenic activity; also describes a rock or feature formed by those processes or event.

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

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

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

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

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

tongue (stratigraphy). A member of a formation that extends and wedges out away from the main body of a formation.

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. Tracks, trails, burrows, coprolites (dung), 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.

ultramafic. Describes rock composed chiefly of mafic (dark-colored, iron and magnesium rich) minerals.

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

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

volcanic exhalation. An emission of gas or ash from a vent in a relatively short burst.

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

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

xenolith. A rock particle, formed elsewhere, entrained in magma as an inclusion.

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

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

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

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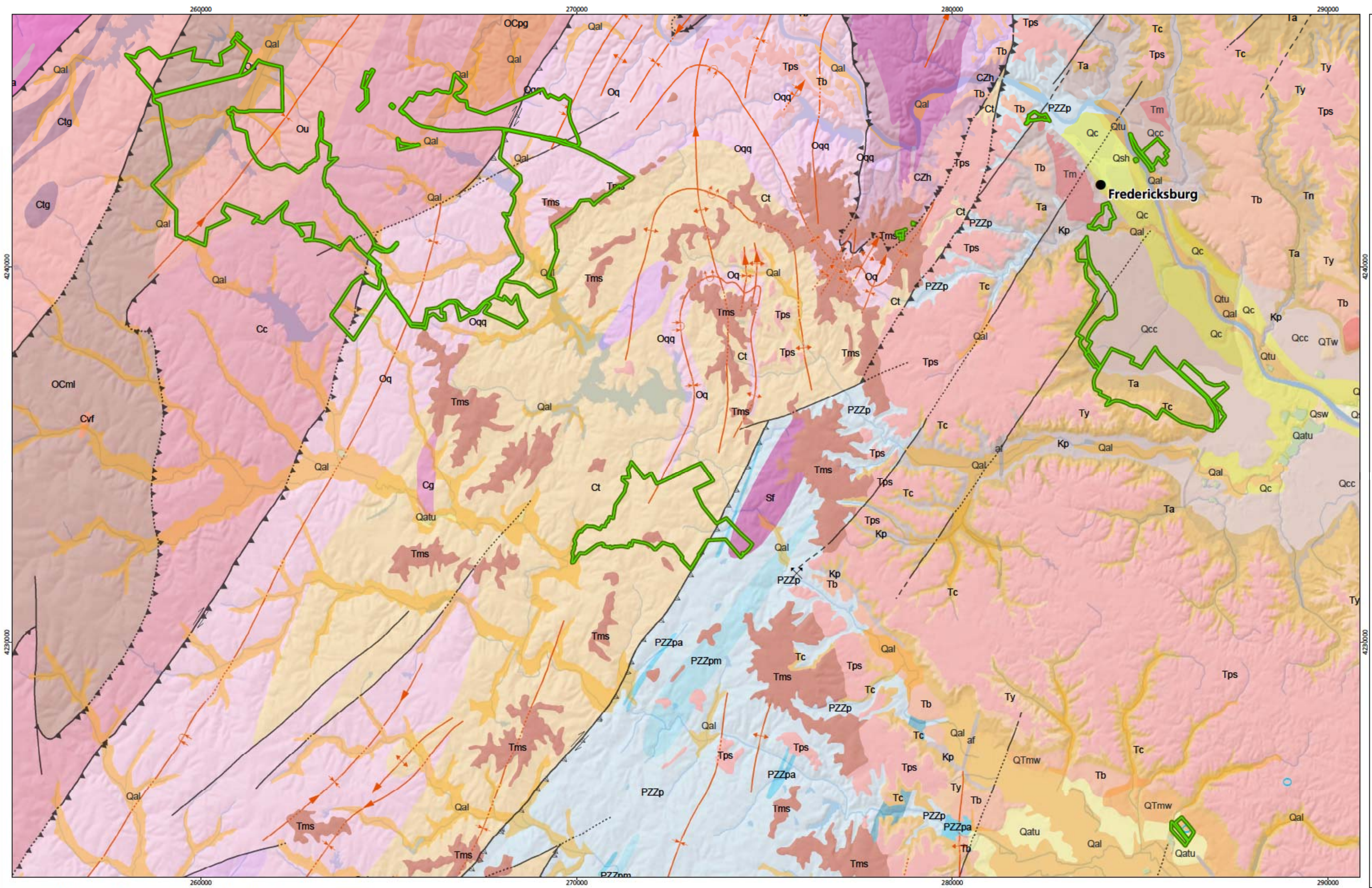
Appendix A: Overview of Digital Geologic Data

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

National Park Service
U.S. Department of the Interior

Overview of Digital Geologic Data for Fredericksburg and Spotsylvania County Battlefields Memorial NMP



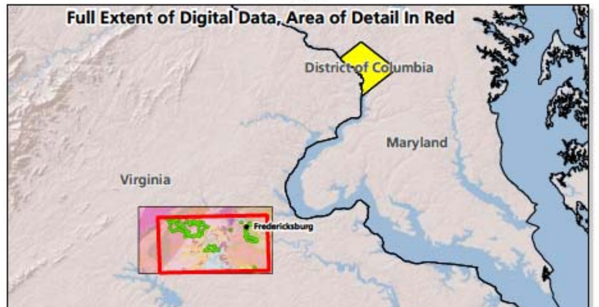
Surficial Units

- Qaf - Artificial fill
- Qs - Sand
- Qsw - Swamp deposits
- Qa - Alluvium
- Qtu - Tab Formation, undivided
- Qt - Alluvial terrace deposits, undivided
- Qsh - Shirley Formation
- Qc - Chuckatuck Formation
- Qcc - Charles City Formation
- QTw - Windsor Formation
- QTmw - Windsor Formation and (or) Moorings Unit
- Tm - Moorings Unit

Geologic Units

- Tb - Bacons Castle Formation
- Tps - Sand and gravel
- Ty - Yorktown Formation
- Tms - Sand and gravel
- Tc - Calvert Formation, undivided
- Tn - Nanjemoy Formation, undivided
- Ta - Aquia Formation
- Kp - Potomac Formation
- PMfi - Falmouth Intrusive Suite
- Sf - Falls Run Granite
- Oq - Quantico Formation
- Oqq - Quantico Formation, quartzite
- Ou - Metasedimentary rocks, undiviided
- OCmIII - Mine-Run Complex, Melange Zone III
- OCmII - Mine-Run Complex, Melange Zone II
- OCmI - Mine-Run Complex, Melange Zone I
- OCpg - Plagiogranite of the Richland Run pluton
- Cc - Chopawamsic Formation
- Ct - Ta River Metamorphic Suite
- Cg - Amphibole metagrabbro
- Cvf - Felsic metavolcanic rocks
- Ctg - Altered tonalite and granodiorite granatoid blocks
- CZ - Metamorphic rocks
- PZZp - Po River Metamorphic Suite, biotite gneiss and schist
- PZZpm - Po River Metamorphic Suite, garnet-muscovite quartzofeldspathic gneiss
- PZZpa - Po River Metamorphic Suite, amphibolite and amphibole gneiss
- PZZpmb - Po River Metamorphic Suite, magnetite-bearing biotite gneiss

Full Extent of Digital Data, Area of Detail In Red



UTM Zone 18N NAD 83

scale greater than source data

0 1 2 3 4 5 6 Miles

0 2 4 6 8 10 Kilometers

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

Mixon, Robert B., Louis Pavlides, David S. Powars, Albert J. Froelich, Robert E. Weems, J. Stephen Schindler, Wayne L. Newell, Lucy E. Edwards and Lauck W. Ward. 2000. *Geologic Map of the Fredericksburg 30' x 60' Quadrangle, Virginia and Maryland.* Scale 1:100,000. USGS, I-2607.

Digital geologic data and cross sections for Geologic Map of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

NPS Boundary

Mine Point Features
- quarry
- well

Fault and Fold Symbology
- antiform
- fold plunge arrow head
- overturned antiform
- overturned synform
- right-lateral fault block movement arrow
- syncline
- synform

Folds
- synform, known or certain
- synform, concealed
- syncline, known or certain
- overturned synform, known or certain
- overturned synform, concealed
- overturned antiform, known or certain
- overturned antiform, concealed
- antiform, known or certain
- antiform, concealed

Faults
- unknown offset/displacement, known or certain
- unknown offset/displacement, inferred
- unknown offset/displacement, concealed
- thrust right-lateral strike-slip fault, known or certain
- thrust right-lateral strike-slip fault, concealed
- thrust fault, known or certain
- thrust fault, concealed

Produced by the Geologic Resources Inventory

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Appendix B: Scoping Meeting Participants

The following is a list of participants from the GRI scoping session for Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park, held on April 13, 2005. The contact information and e-mail addresses in this appendix may be outdated; please contact the Geologic Resources Division for current information. The scoping meeting summary was used as the foundation for this GRI report. The original scoping summary document is available on the GRI website at http://www.nature.nps.gov/geology/inventory/gre_publications.cfm (accessed May 27, 2010).

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