National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Booker T. Washington National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2010/234

THIS PAGE:
A spring box, used as an early refrigerator. Holes at each end of the box allow fresh, cool water to flow through, keeping perishables cool and fresh for several days at a time.

ON THE COVER:
The kitchen cabin (right) and smokehouse, historic buildings on the Burroughs Plantation where Booker T. Washington lived as a boy.

National Park Service photographs courtesy Timbo Sims (Booker T. Washington National Monument)

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, Colorado 80225

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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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.

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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.

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Executive Summary

This report accompanies the digital geologic map data for Booker T. Washington National Monument in Virginia, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

Established in 1956, Booker T. Washington National Monument covers 97 ha (239 ac) in Franklin County, Virginia, and preserves the tobacco plantation setting of the birthplace of Booker T. Washington. The purpose of the monument is to commemorate the achievements and legacy of Washington, who rose from slavery and poverty to be one of the most influential African Americans of the late 19th and early 20th centuries. The monument preserves many cultural resources, including replica slave cabins and plantation outbuildings, a 20th century segregated schoolhouse, and several cemeteries in an agrarian setting typical of the time in which Washington was born.

The monument lies near the western Piedmont-Blue Ridge transitional zone, which is underlain by hard crystalline metamorphic rocks such as schist, gneiss, and amphibolite. This area of Virginia contains numerous belts of rocks that accreted onto the North American continent during repeated continental collisions and mountain building (orogenic) events, culminating in the formation of the Appalachian Mountain chain. Large thrust sheets slid atop one another along major faults such as the Fries Fault, located just to the west of the monument. The regional geologic history spans more than 700 million years through the present regime of weathering, erosion, and anthropogenic land use patterns.

Geology forms the foundation of the ecosystem at Booker T. Washington National Monument and has influenced historical events, as well as surface water quality, water supply, sediment load, channel morphology, erosion, seismicity, adjacent development practices, seeps and springs, and shrink-and-swell clays. Geologic knowledge is essential in understanding landscape evolution and anthropogenic impacts, and for the siting of future facilities.

Resource managers should understand how water is moving through and under the monument; thus, hydrogeologic modeling is critical in determining the impacts of human-induced contaminants on the entire ecosystem as well as in predicting groundwater table changes. Several springs and seeps exist within monument boundaries and the nature of their formation is unknown.

Geologic processes such as erosion can impact the cultural landscape and natural systems in the park. Erosion can distort the landscape and increase sediment loads and meandering in local waterways, damaging the aquatic and riparian environments. Severe erosion in the past has created gulleys within the now forested slopes of the monument.

Adjacent land development has strongly impacted both the viewshed and hydrologic system at the monument. The mixed forest and agrarian landscape is rapidly being tranformed to housing developments and commercial centers, impacting the historic context of the area. Development practices have increased surface runoff following rain storms and increased erosion and sediment loading in Gills Creek and Jack-O-Lantern Branch.

Rocks in the Booker T. Washington National Monument area typically occur in elongated parallel belts trending northeast-southwest reflecting the orogenic processes that occurred during the accretion of terranes and the mountain building events of the Paleozoic Era. These large belts or thrust sheets of rocks are separated by major faults. The rocks of this area reflect a complex deformational and metamorphic history. The park sits atop Late Proterozoic- to early Cambrian-age bedrock that includes biotite gneiss and schist, metaconglomerate, amphibolite, mica schist, quartzite, marble, and actinolite schist. Cutting through these rocks are small-scale faults, fractures, mylonite zones, foliation, and minor folds; small-scale joints and fractures are ubiquitous. Most joints and fractures follow the northeast-southwest regional structural trend. Parallel thrust faults cut through the monument area, and may still be accommodating crustal stresses.

From the first settlers and farmers through modern development, geology has played a fundamental role in the evolution of Booker T. Washington National Monument. Geologic features and processes affect topographic expression, streams and rivers, soils, wetlands, vegetation patterns, and the animal life that thrives in the environment. Geographically, this transitional area is part of the tobacco belt. The “sweet” soil supported a cash crop for the Burroughs’ plantation where Washington was born in 1856. The geological landscape in south-central Virginia underscores the relationship between geology and history. Both the geologic resources and the natural history of the area should be emphasized and interpreted to enhance the visitor’s experience of Booker T. Washington National Monument.

Acknowledgements

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

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

Special thanks to: Timbo Sims (Booker T. Washington National Monument) for his enthusiasm for this project and for providing information and photographs for use in the report. William S. Henika (Booker T. Washington National Monument volunteer) provided additional information and photographs.

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Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Booker T. Washington National Monument.

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/).

Park Setting and Establishment

Booker T. Washington National Monument, located in Franklin County, western Virginia, is just east of the Blue Ridge Parkway and covers 97 ha (239 ac) (fig. 1). It is 35 km (22 mi) south of the major town of Roanoke, Virginia. The monument was authorized on April 2, 1956 to commemorate the birthplace of one of the most successful and influential African Americans of the late 1800s and early 1900s. The monument recreates an 1850s middle class farm, containing a tobacco barn, reconstructed plantation outbuildings (slave cabin, smoke house, blacksmith shop, privy, hog pen, duck lot, and chicken house), three small cemeteries, marked archaeological sites, and two walking trails. According to the monument's 2012 strategic plan, the purpose of the monument is, in part, to preserve and protect the birthplace, its cultural and natural landscape, and agrarian viewshed.

Booker T. Washington was born to a slave cook on April 5, 1856 on the Burroughs tobacco plantation. After gaining his freedom in 1865 at the end of the American Civil War, Washington went on to get an education at the Hampton Institute, and helped found the Tuskegee Normal and Industrial School in Alabama in 1881 (Tuskegee Institute National Historic Site). A noted educator, Washington held the position of first principal at Tuskegee Institute at age 26. He believed education was the true path to freedom and independence for himself and others. Later, as an adviser, author, and orator, his experiences with slavery strongly influenced his philosophies. He thought that the path to civil rights for African Americans would follow economic viability through skilled trades and education. Washington was very influential and powerful during a period of growing racial hostility and violence as the southern states struggled to recover from the Civil War.

Additional park information may be found at http://www.nps.gov/bowa, the Booker T. Washington National Monument web site. The glossary contains definitions of many geologic terms used in the report. Refer to figure 15 for a geologic time scale.

Geologic Setting

Booker T. Washington National Monument is located on the western border of the Piedmont physiographic province (Piedmont Upland or Foothills physiographic subprovince) near the eastern edge of the Blue Ridge physiographic province. The Piedmont surface descends gently eastward from the Blue Ridge Mountains to Smith Mountain Lake (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Gently rolling hills underlain by deeply weathered Precambrian metamorphic schist, granite, and gneiss characterize the geology of this area of the Eastern Blue Ridge geologic belt (Henika 1992; 1997; William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Most of the underlying Precambrian rocks formed in rift basins which opened approximately 750 million years ago as a result of the breakup of the megacontinent, Rodinia, and the opening of the Iapetus basin (Henika 1997; Dalziel 1995). Rift basin deposits (resting atop metamorphic and igneous basement rocks) formed during the Grenville Orogeny over one billion years ago. Rocks of the Greenville Orogeny are the fundamental geologic units of the Blue Ridge Province (Henika et al. 2000).

The landscape within the monument is gently sloping with rolling hills and valleys. In general, large terrace and alluvial fan deposits cap the interfluve highlands and active stream valleys are commonly filled with unconsolidated alluvium (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Elevations range from the low point of less than 260 m (840 ft) near the confluence of Gills Creek and Jack-O-Lantern Branch to just over 300 m (1,000 ft) near the monument entrance road (fig. 1). These two streams are the only perennial waterways at the monument and are part of the larger Roanoke River watershed. Two unnamed streams, and numerous seeps and springs also occur within the monument, some of which form the source of Jack-O-Lantern Branch (GRI scoping notes 2009).

Most of the Precambrian to early Cambrian rocks within this area are deeply weathered and overlain by thick rock debris and soil called regolith (Woodward 1932; Henika 1997). Regional streams dissect the highlands turning them into valleys and ridges. The Roanoke River is the southernmost stream that breaches the Blue Ridge Thrust Sheet (fig. 2) separating the single, narrow ridge to the northeast from the broader, dissected upland to the southwest (Dietrich 1990). The Blue Ridge province south of the Roanoke River gradually increases in breadth and generally increases in elevation (Dietrich 1990).

The major structural feature of the area is called the Blue Ridge anticlinorium, a regional assemblage of folded and deformed rocks. In this part of Virginia, rocks of the Blue Ridge anticlinorium are not confined to the Blue Ridge physiographic province, but include areas of the western Piedmont physiographic province as well (figs. 2 and 3) (Conley 1985). Complex stacks of folded and thrust-fault bounded rocks characterize the geologic framework of the area (Woodward 1932). There is a strong northeast to southwest trend to these features. Booker T. Washington National Monument contains rocks of the Fries thrust sheet, separated from the Blue Ridge thrust sheet to the west by the Fries Fault, and separated from the Smith River allochthon (mass of redeposited and transported rocks) to the east by the Ridgeway Fault (fig. 2) (Bartholomew 1981; Henika 1997). The Fries Fault, also known as the Fries thrust, locally occurs as a wide zone of deformed granitic gneiss juxtaposing the Ashe Formation in the southeast against the Unicoi Formation to the northwest (O'Hara 1990)(see Map Unit Properties section and Appendix A). Within the Fries thrust sheet are several large faults including the Bowens Creek Fault and many overturned or recumbent anticlines and synclines (Henika 1997). An anticlinal ("A"-shaped fold) structure trends northeast-southwest across the southern end of the monument.

Different rock units and their geologic structures' varying resistances to erosion control the topographic expression of the area. Relatively resistant rocks such as quartzites create topographic highs (Woodward 1932). Southeast of the monument, steep-sided ridges are upheld by resistant mica schist and quartzite layers (Smith Mountain) (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Local mountains include Thornton Mountain, Brier Mountain, Jacks Mountain, Cooks Knob, and Grassy Hill (Conley 1985). Three geologic units are exposed within the monument: laminated mica gneiss, the Ashe Formation (biotite gneiss and schist), and amphibolite (Henika 1997)(see Map Unit Properties section and Appendix A). These units are deeply weathered, buried by thick soil and regolith, and may only be visible along streambeds (GRI scoping notes 2009).

Physiographic and Tectonic Provinces near Booker T. Washington National Monument

Piedmont Province

The eastward-sloping Piedmont is located between the Blue Ridge province along the eastern edge of the Appalachian Mountains and the Atlantic Coastal Plain province to the east (fig. 3). The Fall Line (also known as the Fall Zone) marks a transitional zone where the softer, less consolidated sedimentary rock of the Atlantic Coastal Plain province to the east onlaps the harder, more resilient metamorphic rock to the west, forming an area of ridges, waterfalls, and rapids. The Piedmont physiographic province encompasses the Fall Line westward to the Blue Ridge Mountains. The Piedmont Plateau is composed of crystalline igneous and metamorphic rocks such as schists, phyllites, slates, gneisses, and gabbros. This province formed through a combination of folds, faults, uplifts, accretions, and erosion. The resulting landscape of gently rolling hills, starting at an elevation of 60 m (200 ft), becomes gradually steeper and higher in elevation toward the western edge where it reaches an elevation of 300 m (1,000 ft) above sea level. In the monument area, the Piedmont is subdivided into three subprovinces, from west to east: the western Piedmont (also called Foothills subprovince), containing numerous distinct belts; the Mesozoic lowlands subprovince; and the Outer Piedmont subprovince (fig. 3) (Bailey 1999). Several Mesozoic-age extensional basins (also called the Mesozoic lowlands subprovince) cut through the Piedmont locally, including the Danville and Farmville basins east of Booker T. Washington National Monument. They are on the eastern side of the Smith River allochthon (Goodwin et al. 1986).

Blue Ridge Province

The Blue Ridge province is located along the eastern edge of the Appalachian Mountains. It represents one of the most geologically complex regions in the world (Seaton and Burbey 2005). The highest elevations in the Appalachian Mountain system occur within the Black Mountain range, northeast of Asheville, North Carolina where Mount Mitchell rises to 2,037 (6,684 ft) above sea level (Mark Carter, geologist, U.S. Geological Survey, written communication 2009). Proterozoic and Paleozoic igneous, sedimentary, and metamorphic rocks were uplifted during several orogenic events (i.e., Taconic, Acadian, and Alleghanian) to form the steep rugged terrain. Resistant Cambrian quartzite forms most of the high ridges, whereas Proterozoic metamorphic rocks underlie the valleys (Woodward 1932). The elongated belt of the Blue Ridge stretches from Georgia to Pennsylvania. Eroding streams have caused narrowing in the northern section of the Blue Ridge Mountains into a thin band of steep ridges that rise to heights of approximately 1,200 m (3,900 ft). These streams link the adjacent Valley and Ridge and Piedmont provinces (fig. 3).

Valley and Ridge Province

Long parallel ridges separated by valleys (100 to 200 m [330 to 660 ft] deep) characterize the landscape of the Valley and Ridge physiographic province. The landforms are strongly representative of the lithology and structure of the deformed bedrock: valleys formed in easily eroded shale and carbonate formations among resistant sandstone ridges (Woodward 1932). The province contains strongly folded and faulted sedimentary rocks in western Virginia. The eastern portion is part of the Great Valley; this section is rolling lowland formed on folded carbonate rocks and shale. The city of Roanoke sits within this valley about 26 km (16 mi) northwest of Booker T. Washington National Monument.

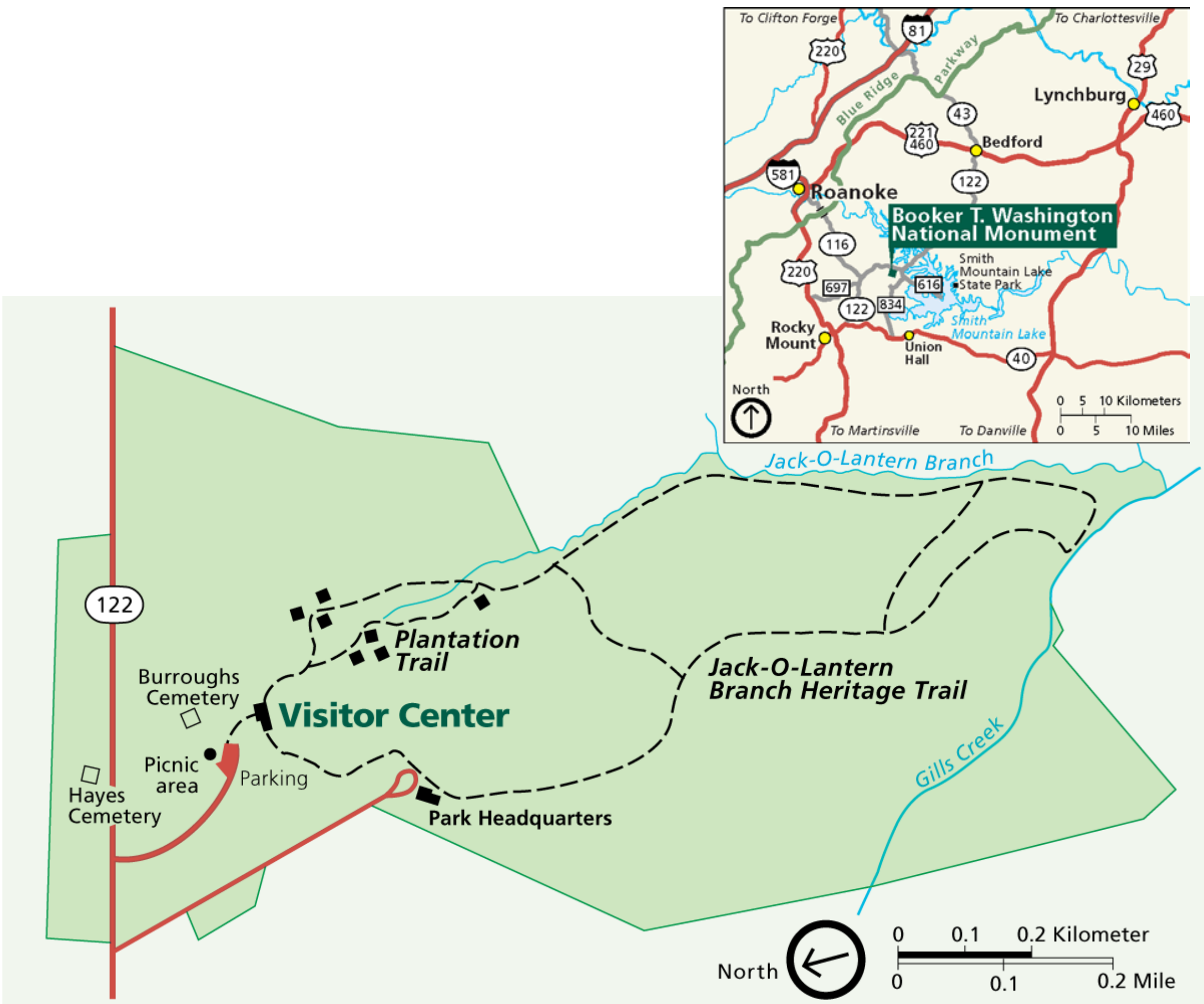

Figure 1. Map of Booker T. Washington National Monument in Hardy, Virginia. Note orientation of park map (north is to the left). National Park Service graphics.

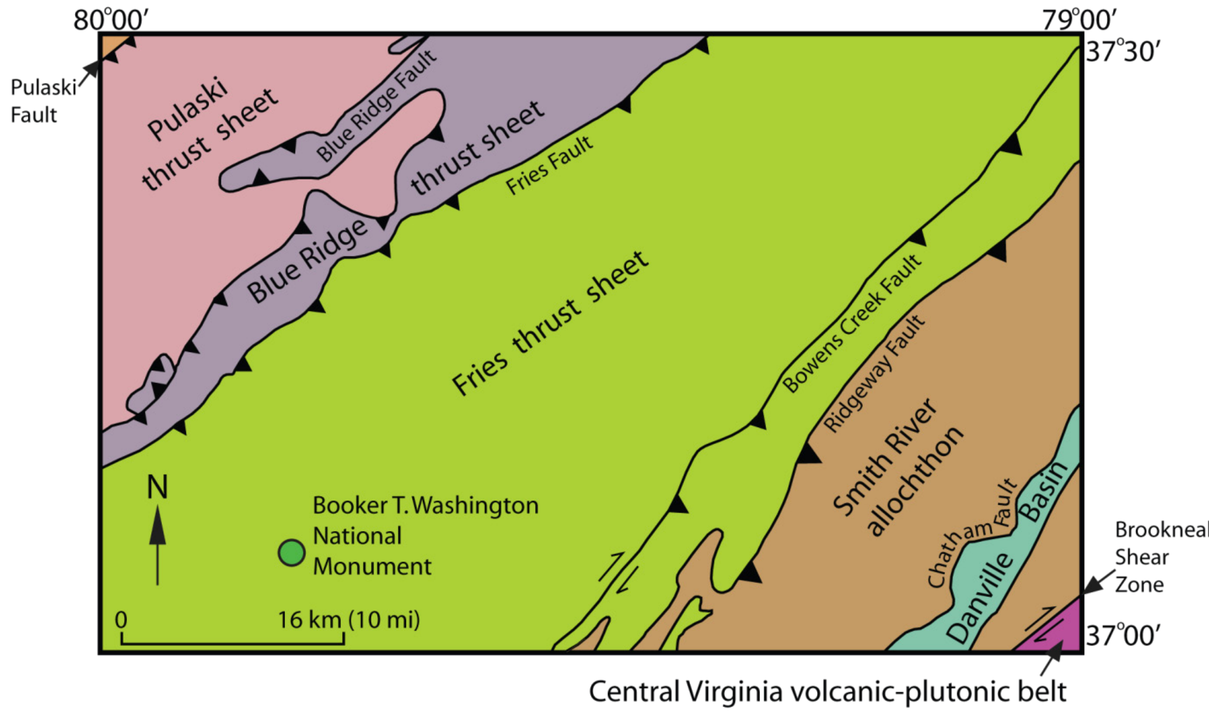

Figure 2: Location of Booker T. Washington National Monument relative to the tectonic provinces and major faults of west-central Virginia. The "Geologic History" section describes the history and relationships between these different groups of rocks. Graphic is adapted from Henika (1997).

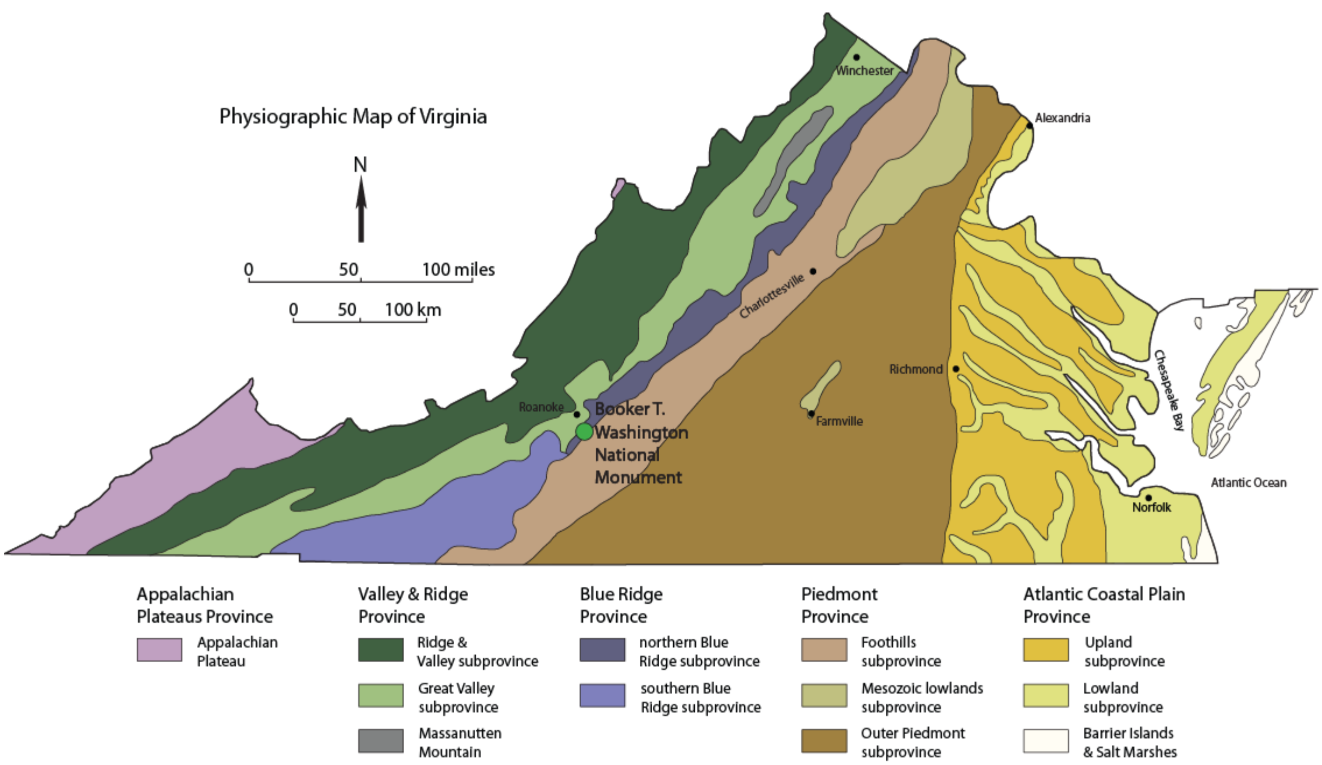

Figure 3: Location of Booker T. Washington National Monument relative to the physiographic provinces and subprovinces of Virginia. Graphic is adapted from Bailey (1999).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Booker T. Washington National Monument on August 27, 2009, 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. Potential research projects and topics of scientific interest are presented at the end of each section.

Water Issues

Several secondary, non-navigable streams traverse the landscape at Booker T. Washington National Monument. Jack-O-Lantern Branch is a tributary of Gills Creek which is the largest stream in the monument (figs. 4 and 5). The tributaries originate at springs located inside and outside of park boundaries. Streams within the park mostly have bedrock channels with wide patches of sand and gravel accumulated in meanders (figs. 6 and 7). Some gravel deposits near the southwestern boundary of the monument may be up to 6 m (20 ft) thick (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009).

High flow events and continued development around the park may impact fluvial ecosystems within the monument (fig. 8). Park staff have noted increased stream flow caused by more localized precipitation from severe seasonal storms (possibly influenced by climate change) as well as runoff over impervious surfaces from adjacent developments such as parking lots, roads, and buildings (GRI scoping notes 2009). According to Karl et al. (2009), climate change in this part of the country will produce increases in severe, seasonal storms. During high flow events, erosion causes degradation of the aquatic and riparian environments in the monument because of increased sediment load (GRI scoping notes 2009). A group affiliated with the University of Virginia and Virginia Polytechnic Institute and State University (Virginia Tech) are taking monthly sediment load readings and looking at water chemistry as part of a natural resource assessment in the monument. John Karish (NPS Northeast Region) and Jim Comiskey (NPS Mid-Atlantic Inventory and Monitoring Network) are contacts for this project.

A major goal of the monument is to maintain the high water quality that typically exists in the park streams (GRI scoping notes 2009). Chemical and biological factors are monitored in the monument. To best manage this resource an understanding of the hydrogeologic system is crucial. Resource managers should understand how water is flowing through the park both above and below the ground surface. Hydrogeologic models specific to the monument area could provide invaluable tools for resource managers (Seaton and Burbey 2005). These kinds of data are needed to monitor future influences of increasing urban development surrounding the monument (GRI scoping notes 2009) as well as potential impacts from climate change.

Groundwater is generally stored in fractures within the crystalline bedrock of the Blue Ridge and Piedmont provinces and flows in the direction of the lowest outlet, in this case, Gills Creek (Gilliam and Henika 1999). The hydrogeologic system and groundwater resources underlying the monument are greatly influenced by fractures, depth to bedrock, soil and regolith thickness and mineralogy (the composition of soils and regolith reflects the original chemistry and lithology of the bedrock), and northeast-southwest trending geologic structures such as faults (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009).

Regional studies indicate that high-permeability zones occur in brittle crystalline rocks above regional thrust faults occurring at depths of 300 m (1,000 ft) or more (Seaton and Burbey 2005). These faults may compartmentalize the deep aquifer system. Southeast of the monument, Smith Mountain Lake is a large hydropower reservoir held against a narrow, northeast-trending mica schist ridge along the Brevard-Bowens Creek fault zone which acts as a confining zone (Conley 1985; Henika 1997; Hibbard et al. 2001; William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). If such faults are present in the vicinity of the monument, they could and yield significant quantities to local wells (Seaton and Burbey 2005). However, the unconsolidated regolith, including saprolite that occurs on top of the bedrock, can hold ten to one hundred times more groundwater than the crystalline rocks (Sethi et al. 2000). Recharge of crystalline aquifers can take thousands of years unless a localized breached zone or heavily fractured quartzose confining layer is present. Recharge is more rapid for shallower, unconfined, surficial aquifers (Sethi et al. 2000; Seaton and Burbey 2005). Shallower aquifers may also be susceptible to threats from pollution sources like leaking underground storage tanks, septic systems, landfills, agricultural fertilizers and pesticides, and mining operations (Sethi et al. 2000). Thus the depth of the regolith would be a valuable dataset for resource managers.

Within the monument, groundwater resources can vary greatly with the composition of the underlying bedrock. In general, the more massive mica gneiss units in the Lynchburg Group (geologic map units Zam, CZmy; see Map Unit Properties section and Appendix A) have deeper soil profiles and would provide better well locations where they occur along fractured zones. This capacity is due to soil profile characteristics over weathered gneissic bedrock have more storage capacity than the harder granitic rocks in the Blue Ridge. Similarly, the mica-gneiss tends to yield more groundwater than the more mica-rich schist, slate, phyllite, and the dense amphibole-rich mafic volcanic complexes, which form relatively thin, clay-rich soils underlying ridges in the area (Conley 1985; DeVore 1998; William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Certain layers of pyrite-rich or graphic-rich schist and some of the mafic schist units of the Moneta Gneiss (unit Zmg) may contain highly mineralized zones that tend to produce groundwater enriched in iron sulfates and, hypothetically, asbestos from mafic igneous complexes (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009).

In neighboring Pittsylvania and Halifax counties, Legrand (1960) demonstrated how the topographic situation of 282 wells in the Piedmont is among the most important factors to consider in the location of water wells. By subdividing the topography into hillcrests, slopes, flats, and draws or saddles, Legrand determined that draws and saddles had the highest average yields (42 gallons per minute [gpm]) whereas hillcrests had the lowest at 7 gpm and 70% of wells on flats and 81% of wells in draws had sustained yields of greater than 20 gpm. Geophysical studies since this work have conclusively shown a strong relationship between bedrock fracture zones and low-lying topographic features (flats, draws, and saddles) along linear fracture traces (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Understanding the bedrock geology of the park is a critical resource management concern and can impact the understanding and management of groundwater and other resources.

Contact the NPS Water Resources Division (Ft. Collins, Colorado) for technical assistance with water quality issues. The Water Resources Division produced a baseline water quality data inventory and analysis report (National Park Service 1997).

Erosion

When Booker T. Washington was born on James Burroughs's tobacco farm, little was recorded about the family's agricultural practices. Historically, the agricultural areas of western Virginia were not developed in a sustainable manner (GRI scoping notes 2009). Fields were cleared and farmed with little regard for soil conservation. Farmers would simply move on to clear another patch of ground when the soil was depleted. The sloping nature of the landscape and these farming and development practices led to severe erosion throughout the region. At Booker T. Washington National Monument, deep gulleys pointing toward streams present on forested slopes record erosion from fields left fallow some 80 or more years ago. Vegetation has gradually reclaimed the eroded slopes (fig. 9) (GRI scoping notes 2009).

Soil erosion continues in western Virginia today, especially in agricultural areas. With the exception of riparian areas along streams, much of the landscape is sloped and local creeks are orange with eroded soil following rainfall events (GRI scoping notes 2009). Soil types such as the clay-rich sandy loams present at the monument present moderate to severe erosion hazards and limitations on the types of motorized land-use practices they will support as defined by soil conservationists (Hendrick 1978). A Soils Resources Inventory was completed for the park in 2007 (National Park Service 2007). According to the monument's 1999 General Management Plan (GMP), pastures within park boundaries are managed to minimize soil erosion. Education and cooperation with surrounding landowners in sustainable land-use practices could help mitigate the problem of soil erosion in the area.

As mentioned anecdotally in the fluvial section, park staff noticed increased stream flow in recent years; either due to climate change-induced severe storm events, increased runoff from surrounding development, or more likely a combination of the two (GRI scoping notes 2009). This is causing severe erosion along the stream banks within the monument. A few trails run along creeks within the monument; there is a potential threat to visitor safety if a trail becomes compromised by undercutting or washes away during a high flow event (fig. 10). In the 1980s and 1990s, the monument performed some buttressing and restoration along the Jack-O-Lantern Branch to mitigate streambank erosion (GRI scoping notes 2009). According to the monument's 1999 GMP, erosion forced the relocation of portions of the Jack-O-Lantern Branch Trail away from Gills Creek and nearby wetlands.

As flow and erosion increase along the monument's streams, channel morphology will naturally change as well. Meanders will continue to cut into the banks and deposition will increase riparian areas along the opposite bank. So far, this change appears to be minor. For some stretches, the centerlines of Gills Creek and Jack-O-Lantern Branch are the legal, surveyed monument boundaries. Recent rezoning of some adjacent property resulted in a small buffer around Jack-O-Lantern Branch (GRI scoping notes 2009).

The formation of social (unofficial) trails and other off-trail activities can strip the landscape of stabilizing vegetation causing increases in erosion. A foot trail that originated as a fire trail in the late 1970s runs along the Jack-O-Lantern Branch. At this time, visitor use of this trail does not contribute to local erosion (GRI scoping notes 2009).

Adjacent Development

The areas surrounding Booker T. Washington National Monument is experiencing significant population growth. This influx of people is causing the value of farm land to increase as urban developers continue to purchase large tracts of land for housing and commercial centers (GRI scoping notes 2009). As of 2009, offers were made to purchase cow pastures on the other side of Gills Creek from the monument (GRI scoping notes 2009). The increase in land value makes acquisition of additional land for the park more difficult. However, more problematic are the changes to the landscape outside the monument that affect ecosystems within the monument.

Neighboring developers are installing stormwater drain systems and retention ponds with overflow channels that flow directly into the area's creeks (GRI scoping notes 2009). Park staff have noted pulses of sediment load increases in monument streams during the construction phases of neighboring development (GRI scoping notes 2009). These increases may be due to heavy flow events caused by severe storms, increased impervious surfaces associated with development, or a combination of the two. Increased sediment load may also be indicative of the potential for increased contamination from chemicals used in landscaping, associated with automobiles, and other human uses.

Increased demand for groundwater supplies from adjacent development may also impact the groundwater supply and spring flow within the monument. In 2003-2004, a neighboring farm was developed into a town center. This development involved the drilling of a deep well that connected to a water tower system. When this system went online, there was a noticeable decrease in stream and spring flow within the monument (GRI scoping notes 2009).

According to the 2012 strategic plan report, the monument has partnerships with three Chambers of Commerce, Eastern National, the Blue Ridge Parkway, and the National Park Foundation-African American Experience Fund for promoting regional tourism, interpretive items, law enforcement support, and special events volunteerism, respectively. These and potential future partnerships may provide tools and resources necessary to mitigate issues concerning surrounding development. Educating the public is an invaluable tool to increase awareness of the potential problems associated with surrounding development.

Seismicity

Active seismicity is not commonly characteristic of the Piedmont or Blue Ridge of Virginia; however, several minor, but noticeable earthquakes occur in the region every few years (GRI scoping notes 2009). In 1924, earth tremors in Roanoke, Virginia were severe enough to cut water pipes (Woodward 1932). Several years ago an earthquake near Amherst, Virginia (some 100 km [60 mi] away) caused noticeable ground shaking at the monument. At this time, no cultural resources are considered threatened by seismicity within the monument (GRI scoping notes 2009). Visitor use facilities and park infrastructure, such as foundations, could be cracked or shifted during earthquakes.

The effects of earthquakes in the Blue Ridge and Piedmont are felt over relatively broad areas because the hard, crystalline basement rocks transmit seismic waves effectively (Sethi et al. 2000). Even moderate seismic shaking can trigger mass wasting (Gilliam and Henika 1999). Debris flows, or mixtures of soil, rocks, and water that move downhill as fast-moving landslides, are not uncommon in west-central Virginia following intense storms and can be triggered by an earthquake. In Virginia, debris flows can be thick enough to carry away trees, cars, and buildings. They typically start on steep slopes of about 30 degrees or more, accelerate to 56 km/hr (35 mi/hr) or more, and deposit thick lobes of unsorted material on flatter ground, burying whatever lies in its path (Sethi et al. 2000). Areas with thick, loose soils (such as those developed on granitic gneisses that are rich in quartz sand and mud) may be likely to move downhill during heavy rainfall events and slides may be acerbated during seismic shaking.

Seeps and Springs

Seeps and springs occur throughout the monument (fig. 11). In the monument, springs emerge out of the ground, often as wet, swampy areas. One spring emerges at a big, flat rock, possibly hinting at the geologic structure controlling its location. Park staff have not noted immediate increases in spring flow following precipitation events, which may indicate that the springs are deep-sourced. Recent drilling associated with a 2009 addition to the monument visitor center (circa 1965) went down approximately 11 m (35 ft) before it hit the water table (GRI scoping notes 2009). In the monument, surface water percolates down through deep regolith to recharge the underlying aquifer.

Shrink-and-Swell Clays

The clay-rich soil within the monument may contain shrink-and-swell clays that could undermine building, road, trail, and other infrastructure foundations. Similarly, these slippery clays can affect visitor trails, causing them to be unsafe in wet conditions. These clays swell when saturated with water and shrink when dry causing moderate to extreme volume changes.

Regionally, shrink-and-swell clays arise from weathering of amphibolite units (Mark Carter, geologist, U.S. Geological Survey, written communication 2009). Amphibolite (geologic map unit CZmi) occurs within Booker T. Washington National Monument. Knowledge of the extent of this unit correlated with park infrastructure and visitor use areas could help mitgate potential problems associated with shrink-and-swell clays.

Figure 4: Rocks within Gills Creek, which is part of the monument's west boundary and flows through the monument. The stream bottom varies from a bedrock channel to gravel and other sediment. Within the monument, Gills Creek primarily crosses rocks mapped as Ashe Formation (geologic map unit Zam). View is from the east. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 5: Jack-O-Lantern Branch originates within the monument and forms the east and south boundary. The right side of the stream bank faces east at the bottom of an east-facing wooded slope. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 6: The bedrock channel of Jack-O-Lantern Branch at Booker T. Washington National Monument. Jack-O-Lantern Branch crosses rocks mapped as amphibolite (geologic map unit CZmi) and Ashe Formation (Zam). Photograph has the same viewpoint as figure 5. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 7: Gravel and finer sediments within a meander along Jack-O-Lantern Branch. The sediments form a mini point-bar and are on the inside of the meander loop. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 8: Jack-O-Lantern Branch flowing west with increased flow and volume after being joined by two unnamed tributaries. Anthropogenic features including a fence, have created a temporary dam, artificial pool, and small waterfall. View is from the northern side of the stream. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 9: Weathered outcrop on eroded, reforested landscape within Booker T. Washington National Monument. Such bedrock exposures are rare in the monument area and contain important information about the local geologic history and structures. Photograph is from an area southwest of monument headquarters and courtesy of Booker T. Washington National Monument staff.

Figure 10: Undercut slope along a small, unnamed tributary that originates from a spring in the wooded area of the monument southwest of headquarters. Stream flows southwest to Gills Creek. Note the deep red soil color. View is toward the northwest. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 11: Jack-O-Lantern Branch within 100 m (300 ft) of its confluence with Gills Creek. Note the presence of a smaller, spring-fed tributary in the middle of the image. In this stretch the stream has a wide flood plain with eroded areas and sediments within the channel. View is from the north. Photograph courtesy of Booker T. Washington National Monument staff.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Booker T. Washington National Monument.

Geologic Influences on History

The Blue Ridge Mountains had an impact on settlement patterns in Virginia. Early English colonists preferred the gentler terrain of the Piedmont and Coastal Plain whereas Scotch-Irish settlers felt more comfortable in the highlands (Sethi et al. 2000). Their settlement patterns in combination with natural geologic processes of weathering and erosion shaped the lands in the monument region (De Vore 1998).

Discoveries of minerals often spur population surges as people, eager to take advantage of quick economic gain, move to boom towns. Iron deposits (red hematite, and iron-rich clays) were among the first mineral resources developed in the region. Iron mineralization in quartzite breccias and as limonite nodules in deep orange residual clay soils provided the primary source of ore (Gilliam and Henika 1999). The old Back Creek furnace, located about 10 km (6 mi) south of Roanoke; the old Catawba furnace (ca. 1820) operated near Haymakertown; and the Cloverdale furnace (active between 1830 and 1849) reflected the local accessibility of ores (Woodward 1932). These types of small-scale operations may have provided tool material to rural farmers such as the Burroughs.

According to Woodward (1932), the Precambrian rocks of the greater Roanoke area contain nelsonite (a source of ilmenite and apatite), barite (mined near Thaxton in Bedford County), quartz veins with small amounts of placer gold, and residual clays (source of kaolin). Prospects for silver, nickel, cobalt, arsenic, copper, graphite, and talc yielded little of commercial value (Woodward 1932). Iron mining and the railroad were the primary drivers of the population boom of the late 19th century.

Access to an abundant, reliable source of water strongly influenced the selection and development of farmland. Gills Creek and Jack-O-Lantern Branch played major roles in the farming practices of the Burroughs family. In 2000, investigators recognized at least one old dam along a colonial road bed located just upstream from the southwestern monument boundary (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Springs occur where groundwater is controlled by the structure of the underlying rocks. Geologic features such as faults, folds, and resistant layers often focus the location of springs. Several springs and seeps occur at Booker T. Washington National Monument. These likely supplied some water to the farming efforts of the Burroughs family.

Booker T. Washington National Monument sits near the transition between the western Piedmont and the Blue Ridge. It is on the fringe of the tobacco growing area (southern tobacco belt) and the mix of flora and fauna at the monument reflect this transition (De Vore 1998; GRI scoping notes 2009). In the mid-1850s, tobacco was the cash crop at the Burroughs' farm. In the interest of being self-sufficient, sustenance crops were also raised. Regionally, red and yellow podzolic soils are developed on rocks of the region characterized by a deep saprolite forming the C soil horizon (Hunt 1972; Conley 1985). Locally, the depth to bedrock is variable from 2 to 18 m (6 to 60 ft) (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). The soils at Booker T. Washington National Monument are well-drained, bright red in color, enriched with iron, and high in clay content (clayey-sandy loam soils) (fig. 10) (De Vore 1998; GRI scoping notes 2009). For more information regarding soils in the monument refer to the National Park Service Soil Survey database (2007). This type of soil can arise from deep weathering of amphibolite rocks such as those beneath the monument (geologic map unit CZmi). Amphibolites are unstable under surface chemical weathering conditions and tend to form thin soils which protect the unstable rocks from further weathering. Soils underlain by quartz- and feldspar-bearing gneisses and gabbro-type rocks readily develop thick (as much as 45 m [150 ft]) saprolite layers (Conley 1985). Some of the soils within the monument are very deep, however, formed as residuum weathered from felsic crystalline rocks such as mica schists and gneisses (De Vore 1998).

Bedrock outcrops are not common in the monument. Where present they occur as ledges in streams (fig. 12). Rocks derived from weathering and mass wasting litter the landscape (fig. 13). Early settlers piled larger rocks into irregular mounds and straight lines that run through the woods of the monument (fig. 14). The purpose of these stone lines is unknown, but may have been to delineate different fields, property lines, or to act as fences. Local rocks also likely formed the source for building foundations and chimneys and were probably reused and recycled during the long history at the monument. An old stone foundation for a barn or tobacco building exists within the monument. Evidence from old stonewalls in a dam structure near the monument boundary suggests the rock was mined; however, no local quarry sites have been identified (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Local stones probably were also used for roadbeds. Gravel from local stream deposits in meanders along tributaries to Gills Creek would have provided gravel sources for roadways across the farm site (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Stream bottom outcrops of talc-tremolite schist within 200 m (650 ft) of the southeastern monument boundary corner may have provided quarry stones for hearths (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Most park buildings have dry rubble foundations of large, flat gray rocks installed in the 1970s. Split rail fences within the monument have joints atop rocks to keep the wood from rotting on the ground. Old cemeteries (one dates back to the 1820s), surveyed with remote sensing in 1998, are marked with fieldstones as headstones and footstones (De Vore 1998). The source of these rocks is unknown (GRI scoping notes 2009).

Weathered Regolith

Knowledge of the composition, thickness, and extent of surficial deposits is important for planning, construction, restoration, and groundwater development throughout the Booker T. Washington National Monument (Arnato 1973). More than 95% of the local bedrock is covered by interrelated deposits of residual soil, alluvium, and colluvium ranging in thickness from a few centimeters to more than 30 m (100 ft) (Arnato 1973). The bedrock underlying the monument is deeply weathered producing a thick overburden of saprolite, soil, and other residual regolith. As mentioned under "Geologic Influences on History", the soils at the monument are clay rich atop a thick layer of saprolite, reflecting the residual nature of their formation. Certain resistant minerals such as quartz and staurolite persist in the soils as the final unweathered portion of the bedrock. Quartz is present as rounded clasts and angular chunks locally. The well-rounded clasts are likely derived from the Blue Ridge rocks to the northwest that were deposited along ancient fluvial terraces (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). The angular quartz rock and lenticular veins (injected into the gneissic bedrock during deformation and metamorphism from 200 to 460 million years ago) form resistant ledges cutting deeply weathered bedrock (saprolite) throughout the map area (Henika 1997; William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). At the monument, quartz rocks occur at the surface. Nearby Fairy Stone State Park is famous for the accumulation of the cross-shaped metamorphic mineral staurolite crystals ("fairy stones") (GRI scoping notes 2009). Staurolite only forms in the relatively high temperature and pressure environments associated with regional metamorphism from ancient orogenies.

Soil conservation plans prepared by the U.S. Department of Agriculture Soil Conservation Service identified and mapped, nine different soil types: Toccoa Fine Sandy Loam, Wilkes Pine Sandy Loam (two slope ranges), Madison Fine Sandy Loam (three slope ranges), Cullen clay loam, and Poindexter Pine Sandy Loam (Hendrick 1978). Many of these soils have firm clay subsoil layers and are moderately drained. Remnant clasts include micas and quartz (Hendrick 1978). A thorough review of soil patterns and development at Booker T. Washington National Monument is beyond the scope of this report. Resource managers are encouraged to consult the Soil Resources Inventory Program of the NPS Geologic Resources Division; a soil database was produced by the Soil Resources Inventory Program (National Park Service 2007).

Figure 12: Bedrock ledges along Jack-O-Lantern Branch. The view is toward the east. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 13: "Whale Rock" along the western-flowing Jack-O-Lantern Branch. Many large boulders exist along streams within the monument area. Photograph courtesy of Booker T. Washington National Monument staff.

Figure 14: Rock piles on west-facing slopes in the forested area southwest of the monument headquarters. Rocks were piled as they were cleared from areas previously used for agricultural purposes. Many such piles are linear and oriented to one another all along the slope of the woods. Photograph courtesy of Booker T. Washington National Monument staff.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Booker T. Washington National Monument. 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 Booker T. Washington National Monument 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. 15) for the age associated with each time period. The table highlights characteristics of map units such as: susceptibility to erosion and hazards; the occurrence of paleontological resources (fossils), cultural resources, mineral resources, and caves or karst; and suitability as habitat or for recreational use. Some information on the table is conjectural and meant to serve as suggestions for further investigation.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following references are the sources for the GRI digital geologic data for Booker T. Washington National Monument:

Henika, W.S. 1997. Geologic map of the Roanoke 30 x 60 minute quadrangle. Scale 1:100,000. Publication 148. Richmond, VA: Virginia Division of Mineral Resources.

Elizabeth V. M. C., D. Sheres, and C. R. Berquist, Jr. 2001. Digital spatial data for a portion of the Roanoke, VA 1:100,000 30x60 minute quadrangle - Hardy, Goodview, Redwood, Moneta SW 7.5-minute quadrangles. Scale 1:100,000. Unpublished. Richmond, VA: Virginia Division of Mineral Resources.

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

Map Unit Properties Table: Booker T. Washington National Monument

Colored rows indicate geologic units mapped within Booker T. Washington National Monument

Age	Unit Name (Symbol)	Features and Detailed Geologic Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Cultural Resources	Karst	Mineral Occurrence	Habitat	Geologic Significance and Miscellaneous Notes
JURASSIC	Igneous dikes and sills (Jd)	Unit contains fine- to coarse-grained extrusive basalt, and intrusive diabase and gabbro with dark-greenish-black to black appearance and outcrops. Degree of visible crystallization ranges from aphanitic (indistinguishable), intergranular, subophitic to hypidiomorphic-granular. Chilled margins are common in outcrop exposures.	High	Unit is limited in extent, but could weather to produce shrink-and-swell clays.	Where unit is more resistant that surrounding rock and exposed on a slope, rockfall potential exists.	Glassy pieces of unit may have provided tool material.	None.	Plagioclase, olivine.	Unit may weather to produce iron- and magnesium-rich soils.	Unit records the extensional tectonic environment of the eastern margin of North American throughout the mid-Mesozoic.
PALEOZOIC	Mylonite gneiss (PZZmy)	Unit is part of the Blue Ridge thrust sheet and contains dark-gray to dark-grayish-green protomylonite (least deformed) and mylonite as well as light-gray, siliceous ultramylonite (most deformed) and micaceous phyllonite. Zones of this unit are 3-6 m (10-20 ft) wide and may be poorly- to well-foliated.	Moderate	Unit is associated with deformation zones and will act as zones of anisotropy within country rock exposures.	Heterogeneous nature of unit may render it unstable on exposed, weathered slopes.	None documented.	None.	Unit is highly disseminated, recrystallized country rock.	None documented.	Unit developed during Paleozoic deformation of Middle to Late Proterozoic country (basement) rock units.
CAMBRIAN	Unicoi Formation (Cu)	Unit is part of the Blue Ridge thrust sheet and the Chilhowee Group. Total thickness ranges from 300 to 425 m (1,000 to 1,400 ft). The upper portion of this unit contains quartz pebble conglomerate that appears greenish-gray, purple, and white in outcrops of three to five thick-bedded ledges. Some coarse-grained, purplish-gray ferruginous sandstones present locally. The lower portion of the unit contains metasiltstone and meta-arkose that appears pinkish gray to dark-greenish-gray. Lower beds are fine- to coarse-grained, locally contain conglomerate and exhibits spheroidal weathering.	High	Unit would form a strong foundational base unless highly fractured, weathered, and/or exposed on a steep slope.	Unit may be prone to rockfall and topple where undercut by erosion and exposed on ledges and slopes.	Where unit forms ledges and overhangs, American Indians may have taken advantage of natural shelters.	None.	Ferruginous sandstones were locally prospected for iron; conglomerate.	Unit forms prominent ledges that may provide nesting habitat.	Unit is part of the Lovingston massif and has gradational contacts with metamorphosed regolith formed on older, Middle Proterozoic gneiss. Unit contains igneous stratigraphy that indicates several volcanic centers active during the Cambrian.
CAMBRIAN-LATE PROTEROZOIC	Amphibolite (CZmi)	Unit is part of the Lynchburg Group and the Fries thrust sheet. Amphibolite appears dark-greenish to black with coarse granoblastic textures. Amphibolite grades into greenish-gray, fine-grained, chlorite-amphibole schist, ultramafic schist, or soapstone in metamorphosed plutons. Unit crops out in Booker T. Washington National Monument.	Moderate	Heavily altered zones may be points of weakness in units. Due to high shrink and swell clay potential, avoid development of buildings and septic fields on this unit.	Lenses of resistant rocks in schistose layers may be susceptible to block and rockfall. Abundant shrink and swell clay potential exists for weathered portions of this unit.	Soapstone may have provided trade material.	None.	Soapstone, chlorite, amphibole.	Unit may weather to produce calcium-, iron-, and magnesium-rich soils.	Unit is part of the Lovingston massif and contains a record of deformation within the Fries thrust sheet; igneous intrusions; and regional metamorphism.
	Laminated mica gneiss (metagraywacke) (CZmy);	Unit is part of the Alligator Back Formation, Lynchburg Group, and Fries thrust sheet and contains medium- to light-gray mica schist, quartzite, calc-gneiss, graphitic phyllite, marble, blue-quartz-granule and metaconglomerate beds. Textures range from fine- to medium-grained. Dark-greenish-gray actinolite schist occurs in thin partings throughout the unit. Unit crops out in Booker T. Washington National Monument.	Moderate to high for quartzite	Heterogeneous nature of unit may render it unstable on slopes.	Unit may be prone to landsliding where undercut on steep slopes and heavily fractured.	None documented.	Marble may be prone to dissolution, but too localized to be problematic.	Marble, quartzite, actinolite.	None documented.	Unit is part of the Lovingston massif and represents a mixed depositional environment and contains record of regional metamorphism of the Fries thrust sheet. The Alligator Back Formation contains an ophiolite-bearing metasedimentary suite.
	Actinolite schist (CZas)	Unit is part of the Lynchburg Group and consists of dark-greenish-gray to light-yellowish-green, quartz-epidote granofels layered with tuffaceous metasandstone and thin quartz-mica phyllite, quartzite, metagraywacke, talc-silicate beds, and local lens-shaped pods of white and pink marble.	Moderate to high for quartzite	Schistose nature of portions of this unit may be unstable for heavy development. Avoid especially micaceous and/or weathered areas.	If unit is highly weathered and exposed on a slope, landslide potential exists. Radon gas can develop from this unit.	Residual clay from this unit may have been used in local brick making operations.	Marble may be prone to dissolution, but too localized to be problematic.	Marble, talc.	Unit may weather to produce calcium-rich soils	Unit is part of the Lovingston massif and is correlative to off-shore equivalents of metabasalt, metarhyolite, and arkose of the Catoctin Formation to the northeast, deposited after the Grenville Orogeny.

Colored rows indicate geologic units mapped within Booker T. Washington National Monument

Age	Unit Name (Symbol)	Features and Detailed Geologic Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Cultural Resources	Karst	Mineral Occurrence	Habitat	Geologic Significance and Miscellaneous Notes
LATE PROTEROZOIC	Ashe Formation (Zam)	Unit is part of the Lynchburg Group and contains biotite gneiss and schist with medium- to light-gray appearance in outcrop and coarse- to very coarse-grained textures. Unit is nearly structureless. Conglomeratic layers contain feldspar, quartz, and granitic clasts, and grades upward into medium- to fine-grained, two-mica plagioclase gneiss interbedded with mica schist. Unit crops out in Booker T. Washington National Monument.	Moderately high	Foliation and schistosity of unit may render it susceptible to mass wasting processes of exposed on slope parallel to regional fabric.	Unit may be prone to blockfall and topple where resistant conglomerates are undercut on slopes. Metavolcanic rocks can be a source of radon gas.	None documented.	None.	'Salt and pepper' gneiss, feldspar, quartz, mica.	None documented.	Unit is part of the Lovingston massif. Conglomeratic layers may correlate with Rockfish Conglomerate to the northeast. Unit is intergradational along strike with metavolcanic rocks of an Iapetan rift basin (Zmg).
LATE PROTEROZOIC	Granitic gneiss (Zgd)	Unit is part of the Lynchburg Group and contains medium-gray or pinkish-gray, medium- to coarse-grained biotite or hornblende granitoid. Granitoid is poorly foliated to massive and is gradational with medium-gray, fine- to medium-grained mylonite gneiss at sheared pluton contacts.	Moderately high	Suitable for most forms of development unless highly weathered and/or fractured.	Unit may pose blockfall or topple hazard on slopes. Radon gas can develop from this unit.	None documented.	None.	Biotite, hornblende.	None documented.	Unit is part of the Lovingston massif. Unit records deformation accompanying igneous intrusions.
LATE PROTEROZOIC	Moneta Gneiss (Zmg)	Unit is part of the Lynchburg Group and consists of black and white banded gneiss with medium- to fine-grained textures. Weathered outcrops appear olive-brown to yellowish-green. Locally, dark-greenish-gray to black and white amphibolite; light-gray quartz-feldspar gneiss; feldspathic metaconglomerate; and mica schist are interlayered with the gneiss. Abundant granitic dikes and sills present locally.	Moderately high	Schistose, and highly foliated units should be avoided for heavy development due to inherent weakness. Heavily deformed and/or weathered areas are also unsuitable and unstable in deep excavated cuts.	May be susceptible to mass wasting if exposed on slope. Weathered material (saprolite) is susceptible to severe erosion and sedimentation problems if exposed.	Pegmatites were mined in the Moneta-Bells feldspar mining district of Bedford County.	None.	Mica, pegmatite minerals, feldspar.	Unit may weather to produce clay-rich soils.	Unit is part of the Lovingston massif. Unit correlates gradationally with conglomeratic biotite gneiss and schist of the Ashe Formation.
MIDDLE PROTEROZOIC	Layered gneiss and granulite (Ypg)	Unit is part of the Blue Ridge thrust sheet and Lynchburg Group. Unit is composed of massive granofels that appear medium- to dark-greenish-gray in outcrop with fine- to medium-grained textures. Unit also contains layered, garnet-pyroxene-quartz-feldspar rock surrounding plutons and as xenoliths in large intrusive suites. Near deformed areas, unit grades into greenish-gray mylonite and mylonite gneiss.	Moderate	Heterogeneous nature of unit may render it unstable on slopes.	Unit may be prone to landsliding where undercut on steep slopes and heavily fractured.	Garnets may have been source for abrasives or trade material.	None.	Garnet, pyroxene.	Unit may weather to iron-, magnesium-, and calcium-rich soils.	Unit is part of the Pedlar massif. Unit occurs as xenoliths in Grenville and Iapetan intrusive suites. Unit is correlative with the Lady Slipper granulite gneiss unit, with zircon age of 1130 Ma.
MIDDLE PROTEROZOIC	Augen and flaser gneiss (Yma)	Unit is part of the Lynchburg Group and the Fries thrust sheet. Unit is light- to medium-gray, with mesoscopic layers and medium- to coarse grained textures. Dominant rock type is muscovite-biotite gneiss with lesser amounts of polycrystalline quartz-feldspar augen with mica-rich, schistose matrix.	Moderate	Schistose layers may weather preferentially causing instability for heavy development.	Weathering along schistose layers may render portions of this unit unstable and prone to rockfall.	None documented.	None.	Mica, augen.	Unit may weather to produce clay-rich soils.	Unit is part of the Lovingston massif. Unit contains record of deformation and metamorphism within the Fries thrust sheet.
MIDDLE PROTEROZOIC	Biotite-granitoid gneiss (Ybg)	Unit is part of the Lynchburg and Fries thrust sheet and consists of medium- to dark-gray, medium- to coarse-grained gneiss with prominent relict subhedral to augen-shaped monocrystalline alkali feldspar crystals.	Moderately high	Suitable for most development unless highly weathered and/or fractured.	Preferential weathering of less resistant layers may increase likelihood of spalling when unit is exposed on a slope.	Phenocrysts may have provided trade material.	None.	Alkali feldspar phenocrysts.	Unit may weather to produce clay-rich soils.	Unit is part of the Lovingston massif.

Colored rows indicate geologic units mapped within Booker T. Washington National Monument

Age	Unit Name (Symbol)	Features and Detailed Geologic Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Cultural Resources	Karst	Mineral Occurrence	Habitat	Geologic Significance and Miscellaneous Notes
MIDDLE PROTEROZOIC	Charnockite (Yc)	Unit is part of the Lynchburg and Fries thrust sheet and consists of dusky-green, medium- to coarse-grained granitoid rock. In outcrop, this unit may appear massive to foliated and may be granular to porphyritic.	Moderately high	Suitable for most development unless highly weathered and/or fractured. Avoid weathered areas for basements and foundations due to potential radon problems.	May be susceptible to mass wasting if exposed on slope.	None documented.	None.	Orthopyroxene.	None documented.	Unit is part of the Lovingston massif. Unit includes the southeastern part of the Peaks of Otter Charnockite Suite and charnockite of the Turkey Mountain Suite.
MIDDLE PROTEROZOIC	Biotite granitoid (Yhm)	Unit is part of the Lynchburg and Fries thrust sheet and contains medium- to dark-gray, coarse-grained to porphyritic gneiss that grades into dark-gray, well-foliated biotite-granitoid gneiss, protomylonite (less deformed) and mylonite (more deformed) gneiss.	Moderately high	Unit is locally associated with deformation zones and will act as zones of anisotropy within country rock exposures.	Weathered and fractured portions of this unit pose blockfall hazard especially if exposed on a slope.	None documented.	None.	Biotite.	None documented.	Unit is part of the Lovingston massif. Unit includes the Horsepen Mountain Suite and the biotite granitoid of the Turkey Mountain Suite.
MIDDLE PROTEROZOIC	Biotite granofels and gneiss (Ygb)	Unit is part of the Lynchburg and Fries thrust sheet and consists of light-gray to dark-grayish-green amphibolite with medium- to coarse-grained, banded textures. Unit locally grades into relict granulite assemblages. Green mylonite is common within this unit along major shear zones.	Moderate	Unit is locally associated with major shear zones and will act as zones of anisotropy within country rock exposures.	Weathered and fractured portions of this unit pose blockfall hazard.	Garnets may have been source for abrasives or trade material.	None.	Garnet, hornblende, uralitic amphibole, opaque minerals.	None documented.	Unit is part of the Lovingston massif. Unit contains record of early metamorphic conditions overprinted by later, lower grade metamorphism. Shear zones within this unit contain record of deformation events.

Geologic History

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

The geologic history of any region is interpreted from all the geologic features present in the landscape. In the area of Booker T. Washington National Monument, the succession of ancient events is recorded primarily in the rocks and topographic expression. Each rock formation, soil, and feature of the landscape provide evidence which may be interpreted in terms of the sequence of processes which produced the features. This must all be taken into account to decipher the successive stages of geologic history.

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

The recorded geologic history of the Appalachian Mountains begins in the Mesoproterozoic Era (figs. 15, 16, and 17A), during the Grenville Orogeny about one billion years ago. At that time, Rodinia, a supercontinent, formed and incorporated most of the continental crust in existence, including the craton of North America and Africa. The supercontinent separated into several pieces one of which is known as Laurentia or ancestral North America. The sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism are manifested in the metamorphic gneisses in the core of the modern Blue Ridge Mountains just west of Booker T. Washington National Monument (Harris et al. 1997). Geologic units of the Blue Ridge thrust sheet include charnockites, nelsonite, layered gneiss and granulite (Henika 1997). These and other rocks were deposited over a period of 100 million years and are more than a billion years old, making them among the oldest rocks from this region. They form a basement upon which all other rocks of the Appalachians were deposited (Sethi et al. 2000; Southworth et al. 2001). Rocks from this time in the vicinity of the monument include augen and flaser gneiss, as well as biotite-granitoid gneiss (geologic map units Yma and Ybg) (Henika 1997).

In the late Proterozoic (fig. 17B), roughly 750 to 600 million years ago, rifting started in the area. The supercontinent broke up intermittently and a sea basin formed that eventually became the Iapetus Ocean. The Iapetus (named for Iapetus; in Greek mythology the father of Atlas, namesake of the Atlantic Ocean) was one of several proto-Atlantic ocean basins that closed episodically during the Paleozoic. Other basins included the Theic and Rheic oceans (named for other Titans in Greek mythology) (Horton and Zullo 1991; Nance and Linnemann 2008). The Iapetus basin collected many of the sediments and volcanic rocks that would eventually form the Appalachian Mountains and Piedmont Plateau. Mixed sedimentary and volcanic rocks (now metamorphosed) such as laminated mica gneiss of the Alligator Back Formation, biotite gneiss and schist of the Ashe Formation, and amphibolite that occur in both units in the vicinity of Booker T. Washington National Monument, accumulated during this time (units CZmy and Zam) (Conley 1978; Henika 1997). The Ashe Formation has coarse-grained, conglomeratic beds that accumulated along the margin of the Iapetan rift basin intergrading along strike with metavolcanic rocks (Moneta gneiss) (Henika 1997). Pebbly greywacke and conglomerates were covered by turbidite deposits eastward, and then mud and limestone as the basin continued to subside (Conley 1978).

As a result of rifting flood basalts and other igneous rocks such as diabase and rhyolite accumulated on the North American continent. These igneous rocks were intruded through cracks in the granitic gneisses of the Blue Ridge core and extruded onto the land surface during the breakup of the Rodinian continental land mass (Southworth et al. 2001). The weathered and altered remains of the early flood basalts are preserved in the Catoctin Formation, located to the north of Booker T. Washington National Monument (Mixon et al. 2000). The Alligator Back Formation (laminated mica gneiss, actinolite schist [metabasalt], and metagraywacke) is likely the offshore equivalent of the metabasalt, metarhyolite, and arksose of the Catoctin Formation (Henika 1997). The garnet-bearing hornblende gneiss, mica gneiss, and schist with coarse-grained amphibolite layers exposed as ledges along creeks within the monument were possibly part of a complex igneous volcanic and plutonic suite intruded into mixed strata within the rift (Henika 1997; William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). In general, rocks of the Lynchburg Group overlie the basement on the southeastern limb of the Blue Ridge anticlinorium at Booker T. Washington National Monument (Conley 1978).

Large deposits of sand, silt, and mud were deposited in near-shore deltaic, barrier island, and tidal flat environments along the eastern continental margin of the Iapetus basin (fig. 17C) (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). As the Iapetus opened, spreading center volcanism (similar to the modern Atlantic spreading ridge) mixed basaltic lavas with marine sediments resulting in complex, heterogeneous stacks of rock. The erosionally resistant Cambrian Unicoi Formation (unit Cu, quartz pebble conglomerate; Chilhowee Group within the Blue Ridge thrust sheet) was deposited in near-shore environments on attenuated continental crust (Henika 1997; Henika 2004). Rocks derived from volcanic processes in the Unicoi Formation indicate numerous volcanic centers active to the southeast of the Blue Ridge (Henika 2004).

A large carbonate platform—similar to the Bahamas today—that existed during the Cambrian and Ordovician periods (545 to 480 million years ago) resulted in extensive deposits of carbonate rocks exposed in the Valley and Ridge province. The carbonate deposits thicken to the east (fig. 18D). Carbonate rocks deposited in passive margin sequences, foreland basins, intrashelf basins, and ramp to basin sequences form much of the Valley and Ridge Province in the Roanoke area of Virginia, west of the monument (Read 1983). Major formations include the Beekmantown Formation, Stonehenge Limestone, Conococheague Formation, Elbrook Formation, Waynesboro Formation, and Shady Dolomite (Henika 1997).

Paleozoic Era: Appalachian Mountain Building

Taconic Orogeny

Several orogenies are responsible for the Appalachian Mountains, deforming and metamorphosing sediments and volcanics turning them into schists, gneisses, marbles, slates, and migmatites (Southworth et al. 2001). The repeated episodes resulted in a system of rocks characterized by northeast-striking thrust faults that are stacked vertically and shingled laterally. Many of the older thrust sheets (e.g. the Fries thrust sheet) have undergone multiple periods of deformation and have been crosscut in a variety of orientations by younger faulting (Pratt et al. 1988; Seaton and Burbey 2005). Many of these rocks are preserved in the greater Booker T. Washington National Monument area. Southeast of the Fries Fault, the thrust sheets of this part of the western Piedmont are increasingly deformed and have undergone metamorphism (Henika and Fokin 2006).

From Early Cambrian through Early Ordovician time, orogenic activity along the eastern margin of the North American continent was active. This included the closing of the Iapetus Ocean, subduction of oceanic crust, creation of volcanic arcs, and uplift of continental crust (fig. 18E) (Means 1995). The Taconic Orogeny (about 440 to 420 million years ago in the central Appalachians) was a convergence between a volcanic arc and the North American continent. Oceanic crust, basin sediments, and the volcanic arc that formed during subduction (within the Iapetus basin) were thrust onto the eastern edge of the North American continent (Sethi et al. 2000; Hibbard et al. 2001). Some geologists suggest that the fault separating the Ashe Metamorphic Suite (Ashe Formation of this report) from basement to the west (in North Carolina, south of Booker T. Washington National Monument) corresponds to a suture zone between the Piedmont and ancient continent of Laurentia (Stewart et al. 1999).

In response to the overriding plate thrusting westward onto the continental margin of North America, the crust bowed downward, creating a deep basin that filled with mud and sand eroded from the highlands to the east (Harris et al. 1997).
This Appalachian basin was centered on what is now West Virginia (fig. 18F). Sandstones, shales, siltstones, quartzites, and limestones were continuously deposited in fluvial deltaic to shallow marine environments of the Appalachian basin for a period of about 200 million years during the Ordovician to the Permian periods. This deposition resulted in thick piles of sediments. The source of these sediments was from the highlands that were rising to the east during the Paleozoic orogenic events.

The Taconic Orogeny caused the initial metamorphism of the widespread Catoctin Formation, Alligator Back Formation, and other basalts into greenstones, metabasalts, and metarhyolites, as well as the basin sediments (graywackes) into quartzites, schists, gneisses, and phyllites (Conley 1985; Trupe et al. 2004). Deformation patterns occur throughout the region's rocks on many scales ranging from broad, open regional folds, to microscopic recrystallization textures. Fold patterns within the amphibolites of the Lynchburg Group delineate the primary structures of the Blue Ridge anticlinorium in the monument area (Conley 1985). Deformation during subsequent orogenic events created a series of overprinted folds in complex regional patterns. Later stage folds, such as the northeast-trending Cooper Creek anticline (located southeast of the monument), are evidence of further regional deformation (Conley 1985).

The Piedmont Province contains large groupings of rocks that accreted onto North America during these intermittent collision events. Some were portions of island arcs or oceanic crust and others were fragments of other continents. These terranes typically form alternating, fault-bounded sequences of metamorphic rocks that have Late Paleozoic intrusions (Sacks 1999). East of Booker T. Washington National Monument, the Neoproterozoic to early Paleozoic Smith River allochthon is one example. The Sauratown Mountains anticlinorium is east of the Smith River allochthon (Conley 1978). Rocks within this body include the Cambrian Melrose Granite, Leatherwood Granite, Interlayered felsic and mafic metavolcanic and metasedimentary rocks, the Fork Mountain Formation (gneiss, schist, amphibolite, quartzite, and granofels), and the Bassett Formation (amphibolite, gneiss, and granofels) (Conley et al. 1981; Henika 1997). Rocks within this allochthon underwent a higher grade of metamorphism than the surrounding rocks (Sethi et al. 2000). By contrast, rocks of the Lynchburg Formation are at greenschist grade and lower and locally contain some recognizable sedimentary structures (Conley and Henika 1973; Henika 2006).

Acadian Orogeny

The Acadian Orogeny (approximately 360 million years ago) continued the mountain building of the Taconic Orogeny, as the African continent approached North America, pushing ocean basin sediments and volcanic rocks westward (Harris et al. 1997). Similar to the preceding Taconic Orogeny, the Acadian Orogeny involved land mass collision, mountain building, and regional metamorphism (Means 1995). This event was focused farther north than south-central Virginia.

Piedmont metasediments record the Ordovician transition from passive margin sedimentation not associated with an orogeny to clastic sedimentation associated with an orogeny. (Fisher 1976). East of Booker T. Washington National Monument, these metasediments include schists, metagraywackes, phyllites, gneiss, and metasiltstones. Oceanic crust caught up in the orogenic events now exists in the Piedmont Plateau as peridotites, metagabbros, serpentinite, and pyroxenites, among other metamorphosed mafic rocks (Drake et al. 1994; Mixon et al. 2000).

Alleghany Orogeny

The Iapetus Ocean was completely destroyed during the Late Paleozoic following the Acadian Orogeny, as the North American continent collided with the African continent during the formation of the supercontinent Pangaea. This mountain building episode, called the Alleghany Orogeny (about 325 to 265 million years ago) formed the overall trend of the current Appalachian mountain belt, and was the last major orogeny in the evolution of the Appalachian mountains (fig. 19G) (Means 1995). Deformation produced large Appalachian structures like the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont and the Blue Ridge-South Mountain anticlinorium in the Valley and Ridge province (Southworth et al. 2001). Deformation along the regional thrust faults near Booker T. Washington National Monument (Blue Ridge and Fries Faults) culminated during this event (Tracy et al. 1995; Nelson et al. 1999; Trupe et al. 2004).

During the Alleghany Orogeny, rocks of the Great Valley (Shenandoah), Blue Ridge, and Piedmont provinces were transported, as a massive block (the Blue Ridge–Piedmont thrust sheet), westward onto the younger rocks of the Valley and Ridge Province. Estimates of the horizontal shortening range from 20 to 50 percent which correlates to 125 to 350 km (75 to 125 mi) across the area (Harris et al. 1997). Shortening of just the Pulaski thrust sheet, one of a series of stacked thrust sheets west of Booker T. Washington National Monument is on the order of 80% with estimated westward displacements of approximately 100-110 km (62-68 mi) (Bartholomew 1987).

Metamorphism during the Alleghany Orogeny locally overprinted, but did not completely obliterate earlier metamorphic facies from the Taconic Orogeny (Nelson et al. 1999; Trupe et al. 2004). The thrust sheets of the western Piedmont were folded and faulted, and existing thrust faults were reactivated as both strike slip and thrust faults during the Alleghanian orogenic events (Southworth et al. 2001). Mylonites and migmatites, indicating strong shearing, are characteristic of the terranes found in the thrust sheets of the Piedmont and Blue Ridge provinces (Simpson and Kalaghan 1987; Horton et al. 1999). These rocks form under intense heat and pressure during a deformation event. The Fries thrust zone contains mylonites with textures indicating right-lateral strike-slip motion in addition to thrust movement (Conley 1978; Simpson and Kalaghan 1987). Deformed plutons (i.e. the Striped Rock pluton) along the northwest edge of the Fries thrust sheet (to the southwest of the monument) indicate brittle deformation that both pre- and post-dates the primary phase of ductile deformation (Simpson and Kalaghan 1987).

Millions of years of erosion exposed the metamorphic core of the Appalachian Mountains. Paleoelevations of the Alleghanian Appalachian Mountains are estimated at approximately 6,100 m (20,000 ft), analogous to the modern day Himalaya range in Asia.

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

During the late Triassic, following the Alleghany Orogeny, a period of rifting began from about 230 to 200 million years ago (fig. 19H). The supercontinent Pangaea was pulled apart into roughly the continents that exist today. This episode of rifting initiated the formation of the current Atlantic Ocean, and caused many block-fault basins to develop with accompanying volcanism (Goodwin et al. 1986; Harris et al. 1997). Mesozoic rift-block basins in the monument area include the Danville, Farmville, and Taylorsville basins which are buried beneath a thick cover of younger deposits (Conley 1985; Mixon et al. 2000).

The Triassic-age Newark Supergroup includes all of the Triassic-Jurassic sedimentary rocks deposited in a system of rift basins that trend roughly northeast-southwest exposed from Nova Scotia to South Carolina (Goodwin et al. 1986). Streams carried sediments from the recently uplifted Blue Ridge and Piedmont provinces depositing large alluvial fans as they entered grabens. These deposits were lacustrine shales, siltstones, and sandstones.

The large faults that formed the western boundaries of the basins created escarpments that were quickly covered with sediment. Igneous rocks, such as diabase, intruded into the newly deposited sediments as sills and dikes that extend beyond the basins into adjacent rocks. Diabase in the west-central Virginia area tends to be rich in iron (Gottfried et al. 1991). Swarms of diabase dikes trend in north and northwesterly directions often with en echelon patterns (Conley 1985). Jurassic dikes and sills occur in the Booker T. Washington National Monument area (Henika 1997) and appear on the digital geologic map (unit Jd).

After these dikes and sills intruded during the Jurassic the region underwent a period of slow uplift and erosion.

The uplift was in response to isostatic adjustments within the crust, which pushed the continental crust upward and exposed it to further erosion (fig. 19I). Erosionally resistant diabase caps some of the higher ridges, hills, and slopes within each basin. Weathering of diabase tends to focus along joints and produce spheroidal boulders and ocherous (brown, yellow, or red) saprolite (Conley 1985). These boulders may be a component of the field stones at Booker T. Washington National Monument.

Following continental rifting, stream terrace gravels and deep residual soils developed on the gneissic rocks of the eastern Blue Ridge through nearly 200 million years of erosion (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009). Recent dating near Martinsville, Virginia (Bank et al. 2001) indicates the weathered surface of the Piedmont, southeast of the Bowens Creek-Brevard Fault, is 90-100 million years old whereas the surface developed across the fault on the eastern Blue Ridge is 149-197 million years old. Weathered surfaces throughout the area developed as southeastward flowing streams dissected the eastern flanks of the Blue Ridge uplift creating the eastern Atlantic margin (William S. Henika, geologist, Virginia Department of Natural Resources, written communication 2009).

Throughout the Mesozoic Era, gravel, sand, and silt eroded from the mountains and were deposited at the base of the mountains as alluvial fans spreading eastward, covering metamorphic and igneous rocks and becoming part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The Roanoke River cuts the Cretaceous-age Potomac Formation, which is a widespread example of a clastic wedge deposited in this manner. The amount of material inferred for these deposits from exposed metamorphic equivalents of these sediments is immense. Many of the rocks exposed at the surface today were buried some 20 km (about 10 mi) below the surface prior to regional uplift and erosion. This burial is primarily due to continued deposition of sediment on the clastic wedge growing from the eroding mountains and crustal downwarping creating a dynamic accommodation space. The burial depth is inferred via geobarometry as indicated by the presence of certain combinations of metamorphic minerals.

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, creating an eastern passive margin. Isostatic adjustments after the Alleghanian Orogeny continued at a subdued rate throughout the Cenozoic period (Harris et al. 1997). These adjustments may be responsible for occasional seismic events felt throughout the region. Weathering and erosion continued throughout the Cenozoic era with early rivers cutting gaps through the mountains along zones of weakness such as faults. Rivers, like the Roanoke River and its tributaries (including Gills Creek), continue to carve their channels, stripping the surficial deposits, lowering the mountains, and depositing alluvial terraces along the rivers, contributing to the present landscape (fig. 19J).

Cenozoic Era: Shaping the Modern Landscape

The geomorphology of the greater Booker T. Washington National Monument area was altered by weathering, erosion and localized deposition over the past 5 million years. The erosion continues today along regional drainage patterns developed throughout the Cenozoic Era. Large rivers and tributaries such as Gills Creek and Jack-O-Lantern Branch are stripping sediments, lowering the mountains, and depositing alluvial terraces and alluvium and contributing to the present landscape. Rain, frost, rooted plants, rivers and streams, chemical dissolution, and mass wasting are all wearing away the once-craggy highlands. Layers of resistant rocks, such as quartzite and metaconglomerate underlie local ridges and mountains.

Although not included on the 1:100,000 scale digital geologic map (Appendix A), many surficial deposits of alluvium cover the landscape of Booker T. Washington National Monument. The position, distribution, thickness, and elevation of alluvium and low-lying alluvial terraces vary by province, age, and rock type. The elevations of terraces along the larger regional rivers show that the slope of the ancient and modern river valleys are similar, which suggests that the terraces formed as the result of either global sea level drop or regional uplift or both (Zen 1997a, 1997b).

From about 2.6 million years ago to 11,000 years ago, the intermittent colder climates of the ice ages played a role in the formation of the landscape at Booker T. Washington National Monument. Continental glacial ice sheets of the Pleistocene Ice Ages never reached the south-central Virginia area (the southern terminus was in northeastern Pennsylvania). However, freeze and thaw cycles at higher elevations in the Blue Ridge led to increased erosion by ice wedging, freeze thaw and other cold weather mechanical weathering mechanisms. Many of the concentrations of boulders, block fields, and fine-textured colluvium on the forested mountainsides of western Virginia record the process of frost-wedging. Sea level fluctuations during the Pleistocene caused the base level of many of the area's rivers to change. During lowstands (sea level drops), the rivers would erode their channels, exposing the deformed bedrock of the Piedmont Plateau. During oceanic highstands, the river basins flooded and deposition resulted in beach sediments far west of current shorelines.

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 15: 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.

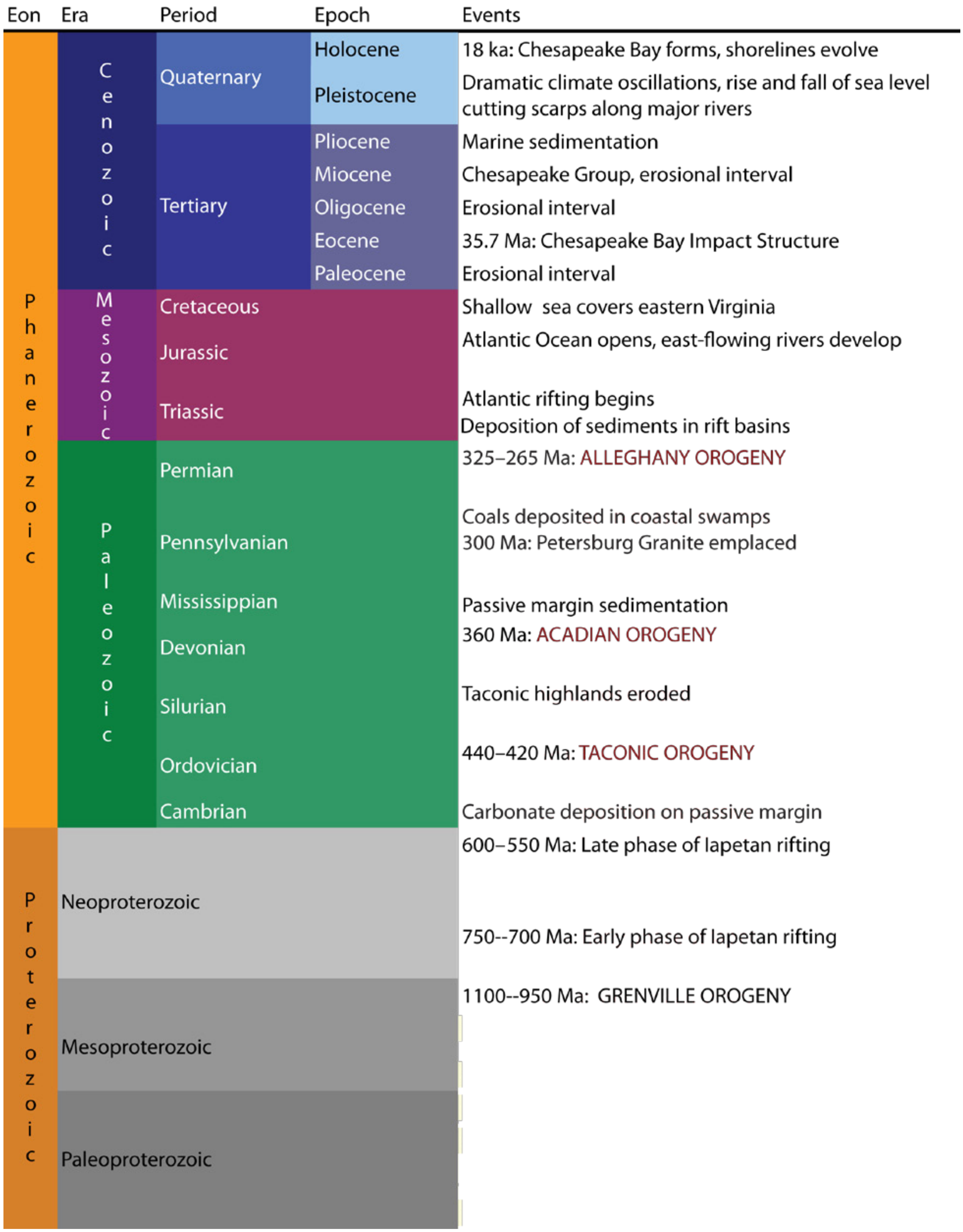

Figure 16: Geologic time scale specific to Virginia. Dates are approximate. Graphic is adapted from Bailey and Roberts 1997-2003.

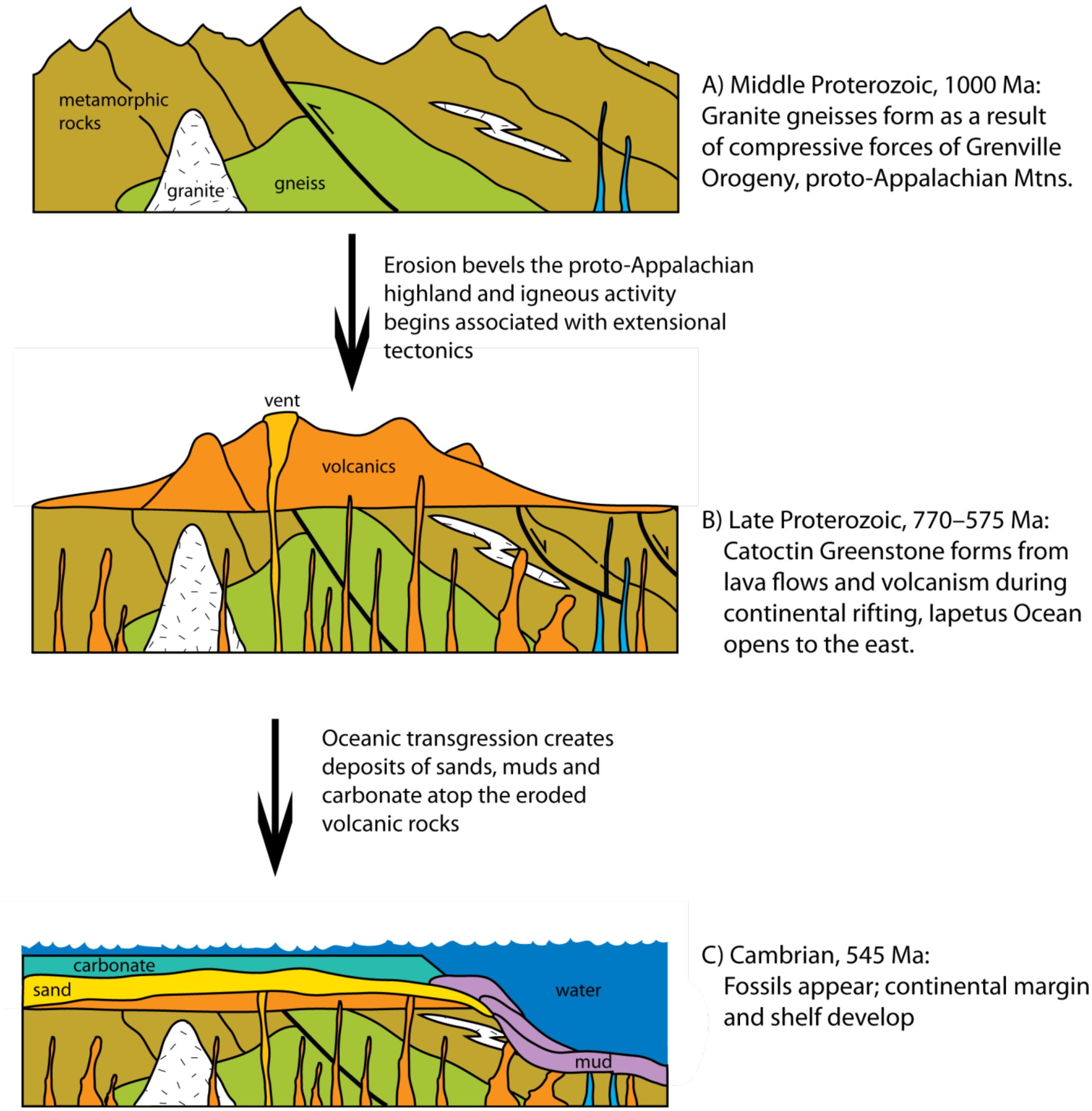

Figure 17: Geologic evolution of the Appalachian Mountains in the Booker T. Washington National Monument area, west to east cross-sectional view. A) First, intrusions of granite, metamorphism, and deformation related to the Grenville Orogeny lasted 60 million years, from 1.1 billion to 950 million years ago; these rocks are found in the Blue Ridge province. B) Continental rifting and volcanic activity occurred in the Grenville terrane and turbidites were deposited in the deep water basin to the east; this activity continued for about 200 million years, from about 770 to 575 million years ago. C) The margin of the continent became stable with carbonate rocks deposited in quiet water (rocks of the current Great Valley). Shelly fossils appeared about 545 million years ago; then deep-water rocks were deposited into a basin east of the shelf margin for about 65 million years. Adapted from Southworth et al. (2001).

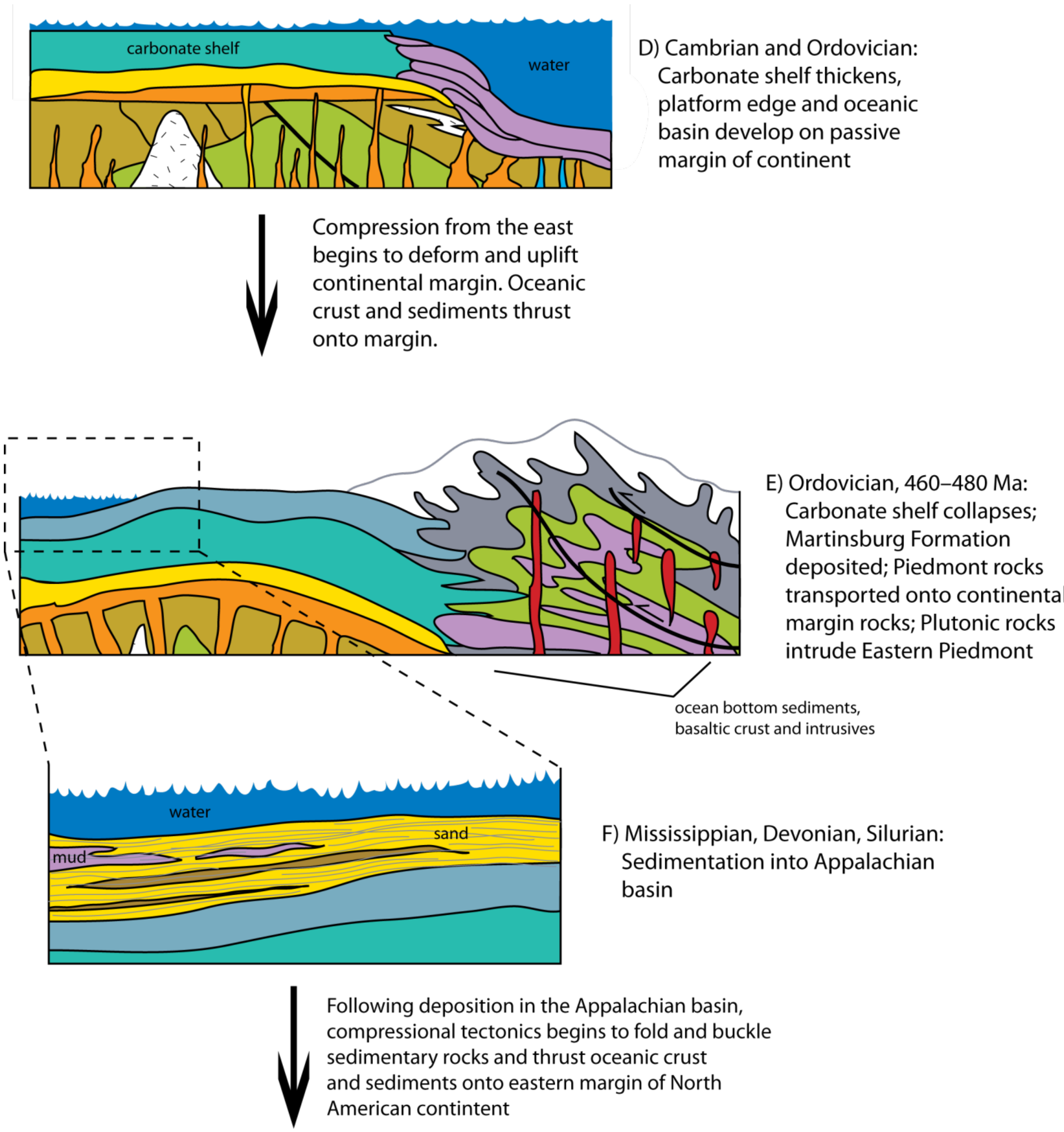

Figure 18: Geologic evolution of the Appalachian Mountains in the Booker T. Washington National Monument area, west to east cross-sectional view. D and E) Following deposition, the stable shelf foundered as the Taconic Orogeny (480-460 million years ago) elevated the rocks to the east and provided a source for the clastic materials in Ordovician shales. Rocks in the Piedmont province were intruded by plutonic rocks. F) Then, a thick sequence of sedimentary rocks were deposited in a deepening Appalachian basin for 120 million years. Most of these rocks are now found in the Valley and Ridge province. Adapted from Southworth et al. (2001).

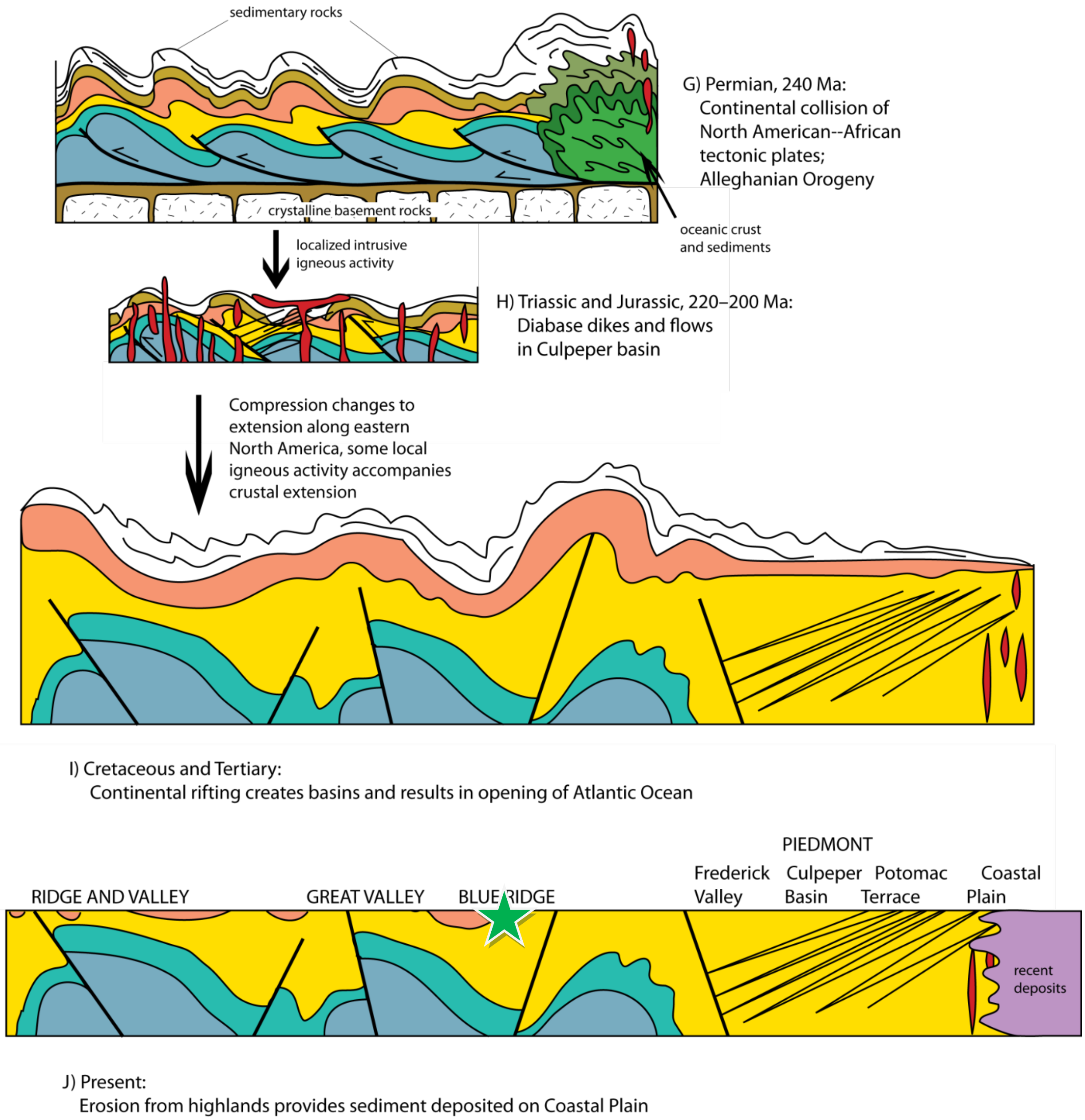

Figure 19: Geologic evolution of the Appalachian Mountains in the Booker T. Washington National Monument area, west to east cross-sectional view. G) About 240 million years ago, the continental plates of North America and Africa collided, resulting in the Alleghanian Orogeny. Many of the folds and faults in rocks west of the Piedmont province are related to this event. H) Continental rifting began and lasted for about 20 million years (220 to 200 million years ago). I) Thick sequences of sedimentary rock were deposited in fault-bounded basins while volcanic activity occurred. Rifting ultimately resulted in the creation of the Atlantic Ocean. The Culpeper and Farmville basins in the western Piedmont are the result of this event. J) For the past 200 million years, the landscape has eroded, and rivers have carried the sediment eastward to deposit the thick strata of the Atlantic Coastal Plain. The green star represents the approximate location of Booker T. Washington National Monument in the Blue Ridge. Diagrams are not to scale and are broadly representative of the tectonic settings. Adapted from Southworth et al. (2001).

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."

allochton. A mass of rock formed elsewhere and redeposited or transported to its present location.

allochthonous. Describes rocks or materials formed elsewhere and subsequently transported to their present location. Accreted terranes are one example.

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.

amphibole. A common group of rock-forming silicate minerals. Hornblende is the most abundant type.

amphibolite. A metamorphic rock consisting mostly of the minerals amphibole and plagioclase with little or no quartz.

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.

apatite. A group of variously colored phosphate minerals. Tooth enamel and bones contain minerals from the apatite group.

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.

arc. See "volcanic arc" and "magmatic arc."

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

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

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

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

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

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

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

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

bedding. Depositional layering or stratification of sediments.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

cleavage (mineral). The tendency of a mineral to break preferentially in certain directions along planes of weaknesses in the crystal structure.

cleavage. The tendency of a rock to split along parallel, closely spaced planar surfaces. It is independent of bedding.

colluvium. A general term applied to any loose, heterogeneous, and incoherent mass of rock fragments deposited by unconcentrated surface runoff or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

epicenter. The point on Earth's surface that is directly above the focus (location) of an earthquake.

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."

fold. A curve or bend of an originally flat or planar structure such as rock strata, bedding planes, or foliation that is usually a product of deformation.

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, or fault).

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

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

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

granoblastic. Describes the texture of a metamorphic rock in which recrystallization formed crystals of nearly the same size in all directions.

granodiorite. A group of intrusive igneous (plutonic) rocks containing quartz, plagioclase, and potassium feldspar minerals with biotite, hornblende, or, more rarely, pyroxene, as the mafic components.

graywacke. A term commonly used in the field for a dark gray to dark green, very hard, dense sandstone of any composition but with a chlorite-rich matrix; these rocks have undergone deep burial.

greenschist. A metamorphic rock, whose green color is due to the presence of the minerals chlorite, epidote, or actinolite, corresponds with metamorphism at temperatures in the 300–500°C (570–930°F) range.

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

hinge line. A line or boundary between a stable region and one undergoing upward or downward movement.

hoodoo. A pillar of rock developed by erosion of horizontal strata of varying hardness. Typically found in climatic zones where most rainfall is concentrated during a short period of the year.

hornblende. The most common mineral of the amphibole group. Hornblende is commonly black and occurs in distinct crystals or in columnar, fibrous, or granular forms.

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

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

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

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

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

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

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

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

lamination. Very thin, parallel layers.

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

lapilli. Pyroclastics in the general size range of 2 to 64 mm (0.08 to 2.5 in.).

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

limb. Either side of a structural fold.

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

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

lithic. A sedimentary rock or pyroclastic deposit that contains abundant fragments of previously formed rocks.

lithification. The conversion of sediment into solid rock.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

ophiolite. An assemblage of ultramafic and mafic intrusive and extrusive igneous rock, probably representing oceanic crust.

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 deposit. Alluvium deposited outside a stream channel during flooding.

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

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

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

parabolic dune. Crescent-shaped dune with horns or arms that point upwind.

parent material. Geologic material from which soils form.

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

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

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

phenocryst. A coarse (large) crystal in a porphyritic igneous rock.

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").

plastic. Capable of being deformed permanently without rupture.

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

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

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

podzolic soil. soil usually forming in a broadleaf forest and characterized by moderate leaching, which produces an accumulation of clay and, to some degree, iron that have been transported (eluviated) from another area by water.

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

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

porphyry. An igneous rock consisting of abundant coarse crystals in a fine-grained matrix.

protolith. The parent or unweathered and/or unmetamorphosed rock from which regolith or metamorphosed rock is formed.

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

recharge. Infiltration processes that replenish groundwater.

regolith. General term for the layer of rock debris, organic matter, and soil that commonly forms the land surface and overlies most bedrock.

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

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

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

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

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

rilles. A trench-like or crack-like valley, commonly occurring on planetary surfaces subjected to plains volcanism; they may be irregular with meandering courses (sinuous rilles) or relatively straight (normal rilles).

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

rock fall. Mass wasting process where rocks are dislodged and move downslope rapidly; it is the fastest mass wasting process.

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

saprolite. A soft, earthy, typically clay-rich, thoroughly decomposed rock, formed in place by chemical weathering of igneous, sedimentary, and metamorphic rocks.

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.

schistose. A rock displaying schistosity, or foliation.

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

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

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

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

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

silicate. A compound whose crystal structure contains the SiO_4 tetrahedra.

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

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

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

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

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

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

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

stratification. The accumulation, or layering of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

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

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

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

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

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

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

structural geology. The branch of geology that deals with the description, representation, and analysis of structures, chiefly on a moderate to small scale. The subject is similar to tectonics, but the latter is generally used for the broader regional or historical phases.

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

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

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

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

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

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

system (stratigraphy). The group of rocks formed during a period of geologic time.

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

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

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

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

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

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

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

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

tuff. Generally fine-grained, igneous rock formed of consolidated volcanic ash.

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

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

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

undercutting. The removal of material at the base of a steep slope or cliff or other exposed rock by the erosive action of falling or running water (such as a meandering stream), of sand-laden wind in the desert, or of waves along the coast.

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

vent. An opening at Earth's surface where volcanic materials emerge.

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

volcanic arc. A commonly curved, linear, zone of volcanoes above a subduction zone.

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

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

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Additional References

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

Geology of National Park Service Areas

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

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

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

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

Resource Management/Legislation Documents

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

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

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

Geologic Monitoring Manual
R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado.

[Website under development]. Contact the Geologic Resources Division to obtain a copy.

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

Geological Survey Websites

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

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

American Geological Institute: http://www.agiweb.org/

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

Other Geology/Resource Management Tools

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

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

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

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

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

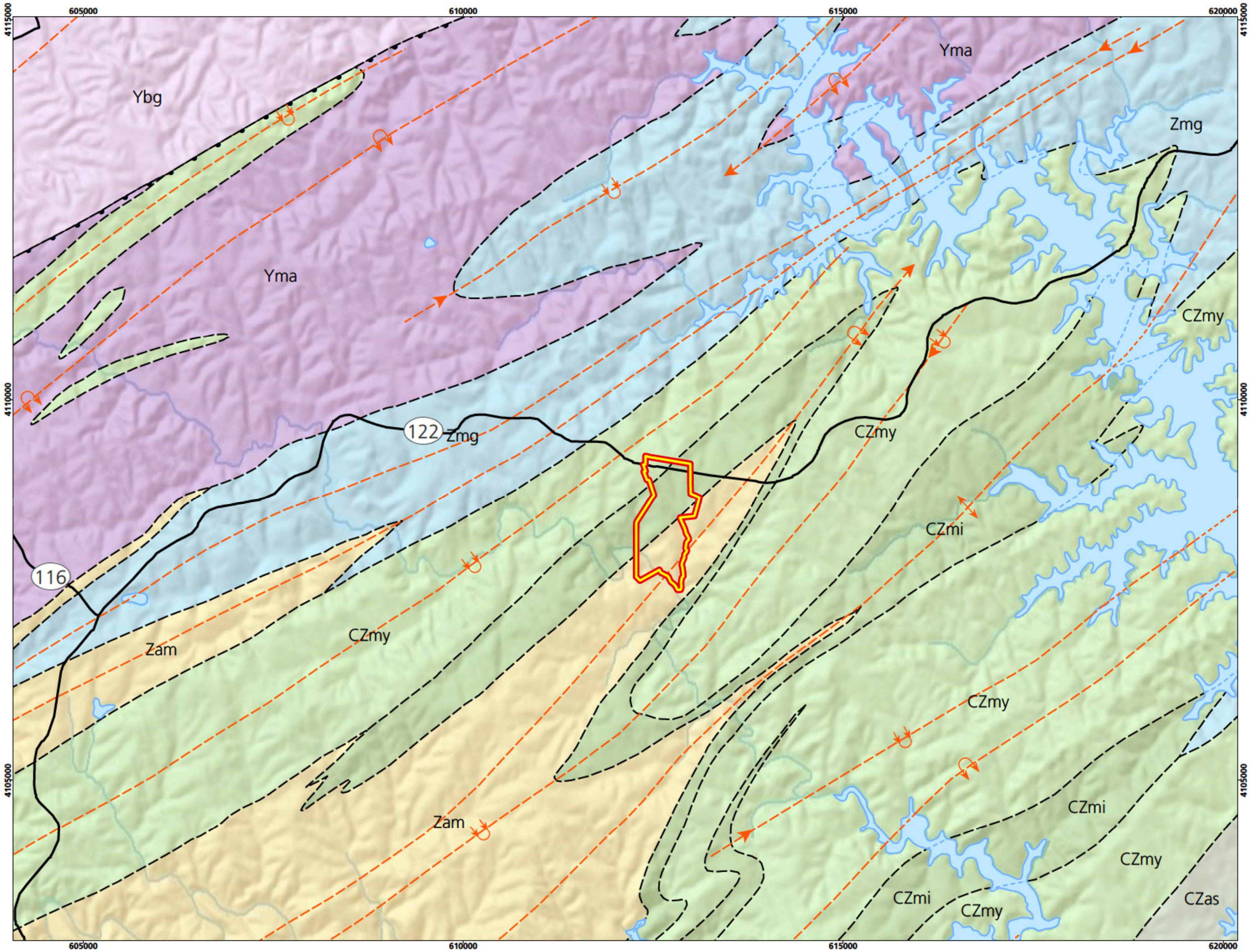
U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

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

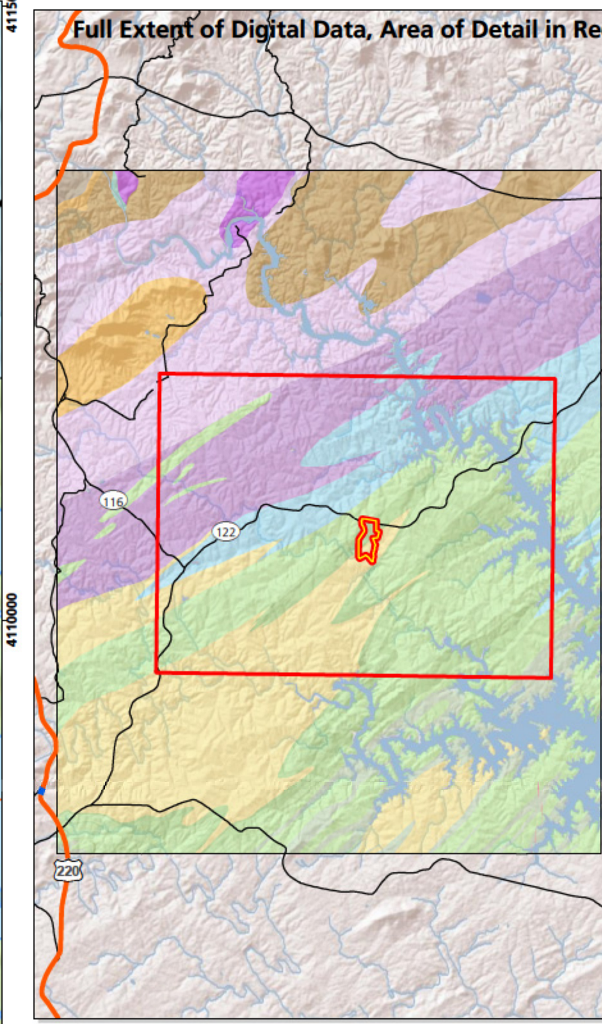
Appendix A: Overview of Digital Geologic Data

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

Overview of Digital Geologic Data for Booker T. Washington NM



Full Extent of Digital Data, Area of Detail in Red



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

Henika, W.S. 1997. *Geologic map of the Roanoke 30 x 60 minute quadrangle*. Scale 1:100,000. Publication 148. Virginia Division of Mineral Resources.

Elizabeth V. M. Campbell, Daniel Sheres, and C. R. Berquist, Jr, 2001. Digital spatial data for a portion of the Roanoke, VA 1:100,000 30x60 minute quadrangle - Hardy, Goodview, Redwood, Moneta SW 7.5-minute quadrangles. 1:100,000 scale. unpublished. Commonwealth of Virginia Department of Mines, Minerals and Energy - Division of Mineral Resources.

Digital geologic data and cross sections for Booker T. Washington National Monument, 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/

UTM Zone 17N NAD 83

Scale greater than source data

0 1 2 3 4 Kilometers

0 1 2 3 4 Miles

N

NPS Boundary

Faults

ductile fault, approximate

Folds

synform, approximate
antiform, approximate
overturned anticline, approximate
overturned syncline, approximate
antiform, inferred
synform, inferred
overturned syncline, inferred
overturned anticline, inferred

Geologic Contacts

approximate
subaqueous (inferred)
water or shoreline

Geologic Units

water
CZmi - amphibolite
CZmy - laminated mica gneiss
CZas - actinolite schist
Zam - Ashe Formation
Zmg - Moneta Gneiss
Yma - augen and flaser gneiss
Ybg - biotite-granitoid gneiss

Produced by the Geologic Resources Inventory

September 2010

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National Park Service
U.S. Department of the Interior

Natural Resource Program Center
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Fort Collins, CO 80525

www.nature.nps.gov