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Richmond National Battlefield Park

Geologic Resources Inventory Report

Stars of the night sky over Cold Harbor battlefield. Richmond National Battlefield Park provides a green, rural oasis spread across 15 larger units and numerous sites within and around Richmond. The park commemorates two major periods of American Civil War history that played out here in 1862 and 1864.

NPS / RICHMOND BATTLEFIELD NATIONAL PARK

Richmond National Battlefield Park: Geologic resources inventory report

Science Report NPS/SR—2024/202

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Abstract

Geologic Resources Inventory reports provide information and resources to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in GRI reports may also be useful for interpretation. This report synthesizes discussions from a scoping meeting held in 2005 and a follow-up conference call in 2022. Chapters of this report discuss the geologic heritage, geologic history, geologic features and processes, and geologic resource management issues of Richmond National Battlefield Park. Guidance for resource management and information about the previously completed GRI GIS data and poster (separate products) are also provided.

Acknowledgments

The Geologic Resources Inventory (GRI) team thanks the participants of the 2005 scoping meeting and the 2022 follow-up meeting for their assistance in this inventory. The lists of participants reflect the names and affiliations at the time of the meeting and follow-up meeting. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the Virginia Division of Geology and Mineral Resources (now Virginia Department of Energy) for its maps of the area. This report and accompanying GIS data could not have been completed without them.

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Executive Summary

Comprehensive park management to fulfill the National Park Service (NPS) mission requires an accurate inventory of the geologic features of a park unit, but park managers may not have the needed information, geologic expertise, or means to complete such an undertaking; therefore, the Geologic Resources Inventory (GRI) provides information and resources to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in this GRI report may also be useful for interpretation.

Richmond, Virginia is a city of vast historical significance that also spans an important geologic boundary—the fall line. The fall line separates the Piedmont (west) from the Coastal Plain (east). For the eastern United States, the fall line is a zone of rapids and waterfalls on otherwise navigable rivers. At the head of the navigable James River, Richmond was the capital of the Confederacy during the American Civil War (1861–1865) and was the site of large-scale conflicts. The local geology not only influenced the location of Richmond but also the battle history there. The purpose of Richmond National Battlefield Park (referred to as the "park" throughout this report) is to preserve, protect, interpret, and commemorate Civil War battlefield landscapes. Though subtle, the park's landforms strongly influenced the human history of the area and helped determine military success or failure during the Civil War.

The geologic story of the park, as recorded by the rocks and sediments mapped therein, extends more than 300 million years. The oldest rocks in the area are part of the Piedmont province. These formed as a series of molten rock intrusions (granite plutons) that became part of North America during Appalachian mountain-building events. Much later, when the Atlantic Ocean began to form, sediments were weathered and eroded from the mountains, transported by rivers and streams downslope and eastward, and became part of the Coastal Plain province, building ever deeper and seaward. Sea level fluctuations caused a series of deposits, punctuated by periods of erosion, to accumulate in the park area. Modern Earth surface processes are reworking surficial sediments and continually reshaping landforms.

This report is supported by seven GRI-compiled maps of the surficial and bedrock geology of the park and consists of the following chapters:

Introduction— This chapter provides information about the establishment of the park and information about the GRI. It highlights the GRI process and products and recognizes GRI collaborators. A geologic map in geographic information system (GIS) format is the principal deliverable of the GRI. This chapter identifies the seven source maps used by the GRI team in compiling the GRI GIS data for the park and provides specific information about the use of these data. It also calls attention to the poster that illustrates these data.

Geologic Heritage—This chapter highlights the significant geologic features, landforms, landscapes, and stories of the park preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories.

Geologic History—This chapter describes the chronology of geologic events that formed the present landscape.

Geologic Features and Processes—This chapter describes the geologic features and processes of significance for the park and highlights them in a context of geologic time. The features and processes are discussed in order of relative geologic time, oldest to youngest.

Geologic Resource Management Issues—This chapter discusses management issues related to the park's geologic resources (features and processes).

Guidance for Resource Management—This chapter is a follow up to the "Geologic Resource Management Issues" chapter. It provides resource managers with a variety of ways to find and receive management assistance with geologic resources. A summary of laws, regulations, and policies which apply to geologic resources is also provided.

Additional References, Resources, and Websites—This chapter provides a thorough list of additional sources of information (e.g., websites, tools, publications, organizations) that may be useful to further explore the topics presented in this report.

In addition to these chapters, a "Literature Cited" section compiles all the references cited in this GRI report. It serves as a source of park-specific geologic information that is applicable to the protection, management, and interpretation of the historic site's geologic resources.

Introduction

The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division (GRD) of the National Park Service (NPS) Natural Resource Stewardship and Science Directorate, provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is funded by the NPS Inventory and Monitoring Program.

Park Background, Establishment, and Landscape

Only 176 km (110 mi) south of Washington, DC, at the head of the navigable James River, Richmond, Virginia was the capital of the Confederacy during the American Civil War, 1861–1865. The city was an important symbol and strategic objective throughout the war. Though under nearly constant threat, two large-scale conflicts in spring 1862 and summer 1864 centered on the area, including more than 30 battles. The second attempt resulted in the siege of Petersburg, which occurred over 10 months until the Union sent the Confederate forces in retreat to Appomattox, Virginia, where they surrendered at the end of the Civil War. Richmond National Battlefield Park (referred to as the "park" throughout the report) was created to preserve, protect, interpret, and commemorate Civil War battlefield landscapes, among other key elements of American military, social, and political history (National Park Service 2017a, b).

The 15 collective sites of the park and many other locations of historic events (not part of the park) occur within and around much of Richmond (Figure 1 and Figure 2). Renowned battlefields include Cold Harbor, Drewry's Bluff, Beaver Dam Creek, Gaines' Mill, Glendale, and Malvern Hill. The largest units include the Cold Harbor, Totopotomoy Creek, Glendale/Malvern Hill, and Fort Harrison units. A tour route connects the outlying units, sweeping in and out of the city. The park preserves more than 1,600 ha (4,000 ac) of cultural and natural resources (National Park Service 2015; GRI follow-up meeting participants, follow-up meeting, 31 May 2022). The entirety of the park's maximum authorized boundary encompasses more than 2,957 ha (7,307 ac) across five counties: Caroline, Hanover, Henrico, Richmond City, and Chesterfield. Regularly attracting close to 200,000 annual visitors, the park was established on 2 March 1936 and is among the largest military parks in the country (National Park Service 2023).

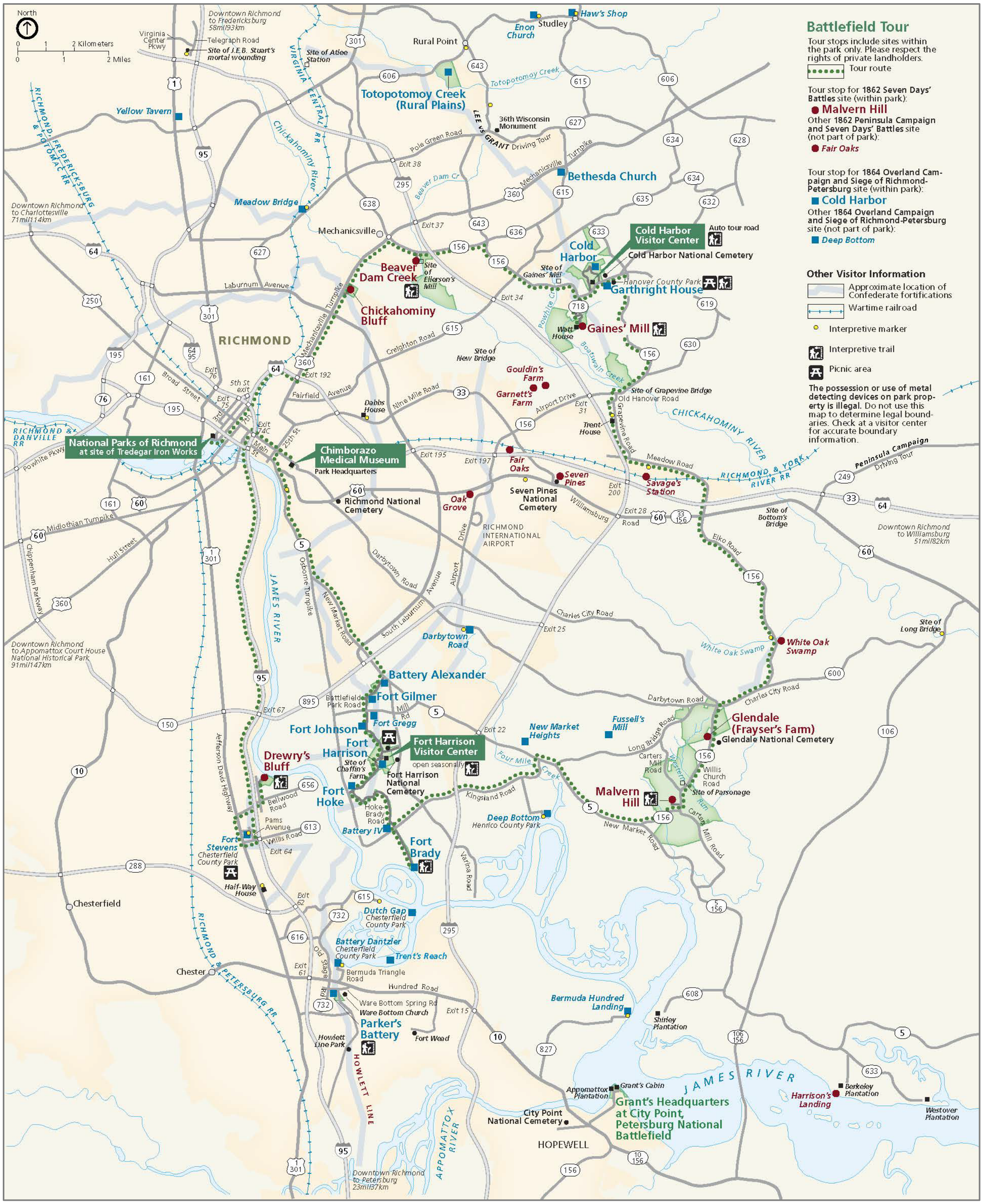

Figure 1. Park map. The units of the park stretch from north of the city, around the eastern side in an arc, to south of the city. In 1862 and 1864, Civil War battles were fought along this trend in attempts by the Union to capture the Confederate capital. Geology strongly influenced strategies and outcomes. Extensive defensive forts and lines were built in areas underlain by the Coastal Plain. National Park Service map, available online: https://www.nps.gov/rich/planyourvisit/maps.htm

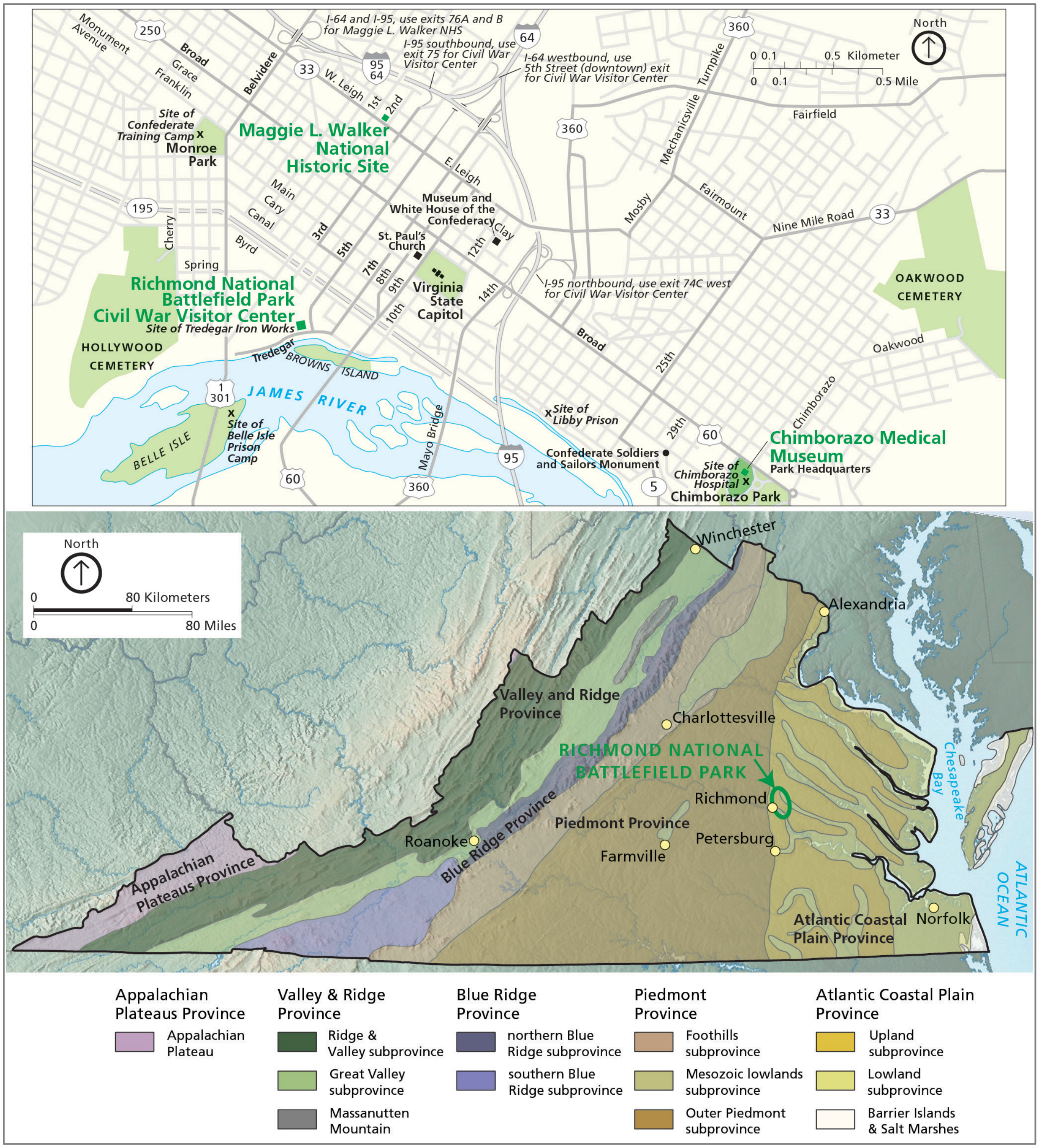

Figure 2. A close-up view of the Richmond city center park map and physiographic provinces of Virginia diagram. Richmond was founded along the fall line, where a sharp drop in elevation caused a high-energy setting for mills and factories such as the Tredegar Iron Works. In the city, this boundary is notable for islands of resistant Petersburg Granite (PNMpg, PNMpgu, PNMpp, PNMpf, PNMpl, and PNMpm) and other resistant metamorphic rocks (e.g., Pocoshock Gneiss [not delineated in the GRI GIS data]) in the river channel. Graphic is adapted from Bailey (1999) by Trista L. Thornberry-Ehrlich (Colorado State University). Base map by Tom Patterson (National Park Service), available online: http://www.shadedrelief.com/physical/index.html (accessed 31 March 2021). National Park Service map from the Harpers Ferry Center available online: https://www.nps.gov/carto/app/#!/parks/state/va

The regional landscape consists of rolling gentle hills between steeper ravines and valleys, with highest elevations of about 90 m (300 ft) in the west and lowest elevations near sea level along the lower (tidal) James River in the east. The principal drainages of the park area are Totopotomoy Creek, Beaver Dam Creek, Powhite Creek, Boatswain Creek, White Oak Swamp, Four Mile Creek, and Chickahominy River to the north, and the James River, which flows southeastward through the middle of Richmond toward Chesapeake Bay in southeastern Virginia.

Introduction to the GRI

The GRI team is a collaboration between the NPS, GRD, Colorado State University Department of Geosciences, and University of Alaska Museum of the North. The GRI was established in 1998 by the GRD and the NPS Inventory and Monitoring Program [Division] to meet the NPS need for geologic mapping and related information. Geologic maps were identified as one of 12 natural resource data sets critical for long-term science-informed park management. From the beginning, the GRI has worked with long-time NPS partner Colorado State University to ensure products are scientifically accurate and utilize the latest in geographic information system (GIS) technology. Because Alaskan NPS units have unique scale and resource management challenges, the GRI partnered with the NPS Alaska Regional Office and, starting in 2021, the University of Alaska Museum of the North to develop GRI products.

GRI Products

Starting in 2005, the GRI team completed three tasks as part of the GRI for the park: (1) conducted a scoping meeting and provided a scoping summary, (2) provided digital geologic map data in GIS and poster formats, and (3) provided a GRI report (this document). GRI products—GIS data, map posters, scoping summaries, and reports—are available on the "Geologic Resources Inventory—Products" website and through the NPS Integrated Resource Management Applications (IRMA) portal (see "NPS Reference Tools").

GRI Scoping Meeting

On 13 April 2005, the NPS held a scoping meeting for the park in Petersburg, Virginia. The scoping meeting brought together park staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report. A scoping summary (Thornberry-Ehrlich 2005) summarizes the findings of that meeting.

GRI GIS Data and Poster

Following the scoping meeting, the GRI team compiled the GRI GIS data for the park from seven source maps (see "Geologic Map Data"). A geologic map poster illustrates these data. Because these data are the principal deliverable of the GRI, a more detailed description of the product is provided in the "Geologic Map Data" section of this chapter.

GRI Report

On 31 May 2022, the GRI team hosted a follow-up meeting for park staff and interested geologic experts. The meeting provided an opportunity to get back in touch with park staff, introduce "new" (since the 2005 scoping meeting) staff to the GRI process, and update the list of geologic features, processes, and resource management issues for inclusion in the final GRI report.

This report is a culmination of the GRI process. It synthesizes discussions from the scoping meeting in 2005, the follow-up meeting in 2022, and additional geologic research. The selection of geologic features was guided by the previously completed GRI map data, and the writing reflects the data and interpretation of the source map author. Information from the park's foundation document (National Park Service 2017b) was also included as applicable to the park's geologic resources and resource management.

Information about named geologic units may be found at the US Geologic Names Lexicon ("Geolex"), which is a national compilation of names and descriptions of geologic units maintained by the US Geological Survey (USGS; see "Additional References, Resources, and Websites"). Lists and descriptions of mapped geologic units within the state of Virginia are from the Virginia Division of Mineral Resources (2003; now the Virginia Department of Energy).

Use Constraints

The graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided in this report and associated geologic map data.

Geologic Map Data

A geologic map is the fundamental tool for depicting the geology of an area. A geologic map in GIS format is the principal deliverable of the GRI program.

Introduction to Geologic Maps

Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). The colors on a geologic map indicate the rocks or deposits and their general ages. In addition to color, map unit symbols on geologic maps delineate the ages and types of rocks and their formations. Usually, a map unit symbol consists of an uppercase letter indicating age (e.g., **PNM** for Pennsylvanian and Mississippian, **K** for Cretaceous, **T** for Tertiary, and **Q** for Quaternary) and lowercase letters indicating the rock formation's name or the type of deposit (Table 1). Other symbols on geologic maps depict the contacts (boundaries between rock units) between map units or structures such as faults (fractures within rocks along which displacement has occurred) or folds (structures that are formed by layers or beds of rock being bent). Some map units, such as landslide deposits, delineate the locations of past geologic hazards that may be susceptible to future activity. Geologic maps may also show human-made features, such as wells, or mines.

Table 1. Geologic time scale. The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division and map unit symbols are in parentheses. Geologic units mapped within the park are noted with an asterisk (*), whereas units noted without an asterisk are mapped in the GRI GIS data but are outside park boundaries. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023). Unit age information has been adjusted based on information provided by Mark Carter (geologist, US Geological Survey, written communication 14 November 2023).

Era or Eon	Period	MYA	Geologic Map Units	Local Geologic Events
Cenozoic (CZ)	Quaternary (Q)	2.6–today	Qml* developed, Qal*, Qp, Qpac, Qn deposited QTg3, Qbc*, QTg4, Qw*, Qcc*, Qc*, Qsh, Qeg, Qts deposited; Qcb formed	Human history; fluvial meandering, incision, and deposition Ice age glaciations; weathering and incision accelerated; global sea level fluctuates
Cenozoic (CZ)	Tertiary (T); Neogene (N)	23.0–2.6	Tc*, Te, Tcl*, Tcsg*, Tym, Ty*, Td1, Td2, Tch*, QTg3 deposited	Ongoing erosion and weathering Coastal Plain expands
Cenozoic (CZ)	Tertiary (T); Paleogene (PG)	66.0–23.0	Tpp*, Tl, Toc deposited	Ongoing erosion and weathering Coastal Plain expands
Mesozoic (MZ)	Cretaceous (K)	145.0–66.0	Kp* deposited	**Global mass extinction** at end of Cretaceous (dinosaurs extinct)
Mesozoic (MZ)	Jurassic (J)	201.4–145.0	None mapped	Ongoing erosion and weathering Coastal Plain sediments accumulate
Mesozoic (MZ)	Triassic (TR)	252.2–201.4	None mapped	Global mass extinction at end of Triassic Breakup of Pangaea begins; Atlantic Ocean opened
Paleozoic (PZ)	Permian (P)	298.9–252.2	None mapped	**Global mass extinction** at end of Permian. Supercontinent Pangaea intact
Paleozoic (PZ)	Pennsylvanian (PN)	323.2–298.9	All units deformed and/or metamorphosed Youngest parts of PNMpgu intruded	Alleghany (Appalachian) Orogeny
Paleozoic (PZ)	Mississippian (M)	358.9–323.2	None mapped	Erosion and weathering of overlying sediments
Paleozoic (PZ)	Devonian (D)	419.2–358.9	Oldest parts of PNMpgu intruded	Global mass extinction at end of Devonian

Table 1 (continued). Geologic time scale. The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division and map unit symbols are in parentheses. Geologic units mapped within the park are noted with an asterisk (*), whereas units noted without an asterisk are mapped in the GRI GIS data but are outside park boundaries. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023). Unit age information has been adjusted based on information provided by Mark Carter (geologist, US Geological Survey, written communication 14 November 2023).

Era or Eon	Period	MYA	Geologic Map Units	Local Geologic Events
Paleozoic (PZ)	Silurian (S)	443.8–419.2	Oldest parts of PNMpgu intruded; existing units deformed and/or metamorphosed	Ongoing marine sedimentation Neoacadian Orogeny
Paleozoic (PZ)	Ordovician (O)	485.4–443.8	None mapped	**Global mass extinction** at end of Ordovician; deeper marine settings Sea level fluctuations; marine and nearshore settings Taconic Orogeny; open marine settings
Paleozoic (PZ)	Cambrian (C)	538.8–485.4	None mapped	Extensive oceans covered most of proto-North America (Laurentia); sediments accumulated in ocean basin; erosion and weathering
Proterozoic Eon; Neoproterozoic (Z)	Not applicable.	1,000–538.8	None mapped	Supercontinent Rodinia rifted apart; erosion and uplift
Proterozoic Eon; Mesoproterozoic (Y)	Not applicable.	1,600–1,000	None mapped	Formation of early supercontinent; Grenville Orogeny
Proterozoic Eon; Paleoproterozoic (X)	Not applicable.	2,500–1,600	None mapped	None reported
Archean Eon	Not applicable.	~4,000–2,500	None mapped	Oldest known Earth rocks
Hadean Eon	Not applicable.	~4,600–4,000	None mapped	Formation of Earth approximately 4,600 million years ago

Geologic maps are generally one of two types: bedrock or surficial. Bedrock geologic maps encompass older, typically more consolidated sedimentary (made of pieces of other rocks called clasts), metamorphic (rocks changed by intense heat and pressure), or igneous rocks (rocks solidified from molten lava or magma). In addition, bedrock map units are generally differentiated based on age and rock type. Surficial geologic maps typically encompass deposits that are unconsolidated (i.e., the particles are not cemented together as a cohesive rock) and formed during the past 2.6 million years (Quaternary Period). However, in some settings (e.g., in the Coastal Plain of Virginia), this distinction is unclear as the units are entirely Quaternary and not necessarily consolidated (Marcie Occhi, geologist, Virginia Energy, written communication, 4 March 2024). Geomorphic surfaces, geologic processes, or depositional environments differentiate surficial geologic map units.

The digital geologic map for the park includes both bedrock and surficial geologic data. On the geologic map for the park, purple colors represent the oldest rocks, which are from the Pennsylvanian and Mississippian Periods and part of the hard bedrock of the Petersburg Granite; greens and oranges represent rocks from the Cretaceous and Tertiary Periods; whereas yellow represents the youngest deposits, which are unconsolidated sedimentary units from the Quaternary Period.

Source Maps

The GRI team does not conduct original geologic mapping. Instead, scoping participants and the GRI team identify the best available geologic maps for a park unit. Determinations are made based on coverage (extent of area mapped), map scale, date of mapping, and compatibility of the mapping with the current geologic interpretation of an area. If existing maps are inadequate, the GRI may contract for new mapping with appropriate mapping agencies. The GRI team then compiles the data, converting digital data to conform to the GRI GIS data model and/or digitizing paper maps.

The GRI team may compile multiple source maps to cover a park boundary or provide a greater extent as needed for resource management. Those sources also provided information for this report. The following seven maps (Figure 3) were compiled into the GRI GIS data for the park:

- Geologic Map of the Dutch Gap Quadrangle, Virginia (Berquist and Carter 2009)
- Geologic Map of the Richmond Quadrangle, Virginia (Bleick et al. 2007)
- Geologic Map of the Drewrys Bluff Quadrangle, Virginia (Bondurant et al. 2011a)
- Geologic Map of the Seven Pines Quadrangle, Virginia (Bondurant et al. 2011b)
- Geologic Map of the Roxbury Quadrangle, Virginia (Gilmer and Berquist 2011a)
- Geologic Map of the Chester Quadrangle, Virginia (Occhi et al. 2017)
- Geology of the Studley, Yellow Tavern, Richmond, and Seven Pines Quadrangles, Virginia (Daniels and Onuschak 1974)

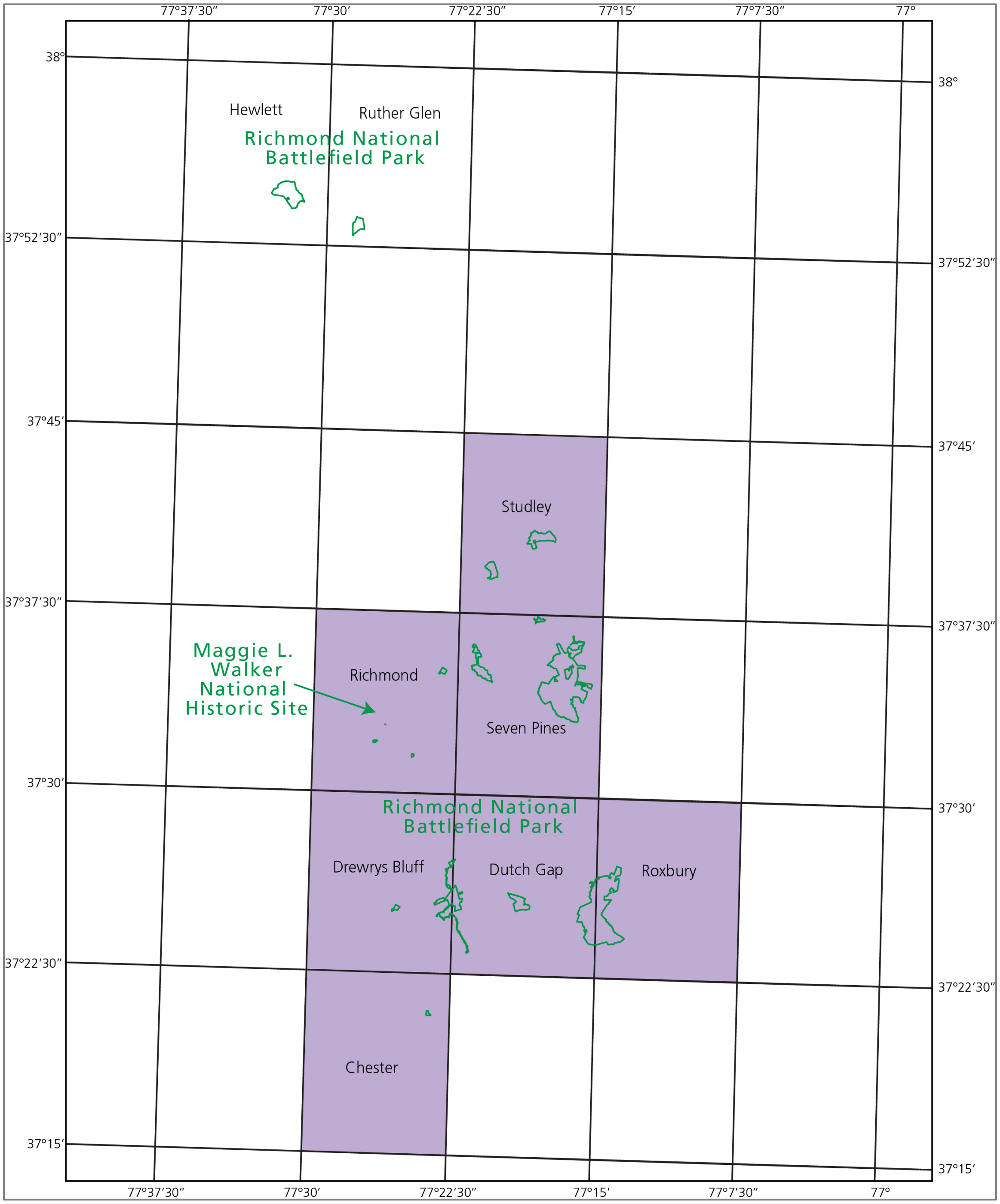

Figure 3. Index map for the quadrangles of interest covering the extent of the park. 7.5' quadrangle names are labeled. Quadrangle names commonly refer to local landforms or geographic names. The park is spread over more than 15 separate units. Large-scale mapping coverage (purple polygon) exists for all but two quadrangles, Hewlett and Ruther Glen, which contain park lands and are included in the GRI GIS geologic map data. Green outline areas show the units of the park. Maggie L. Walker National Historic Site is located within the quadrangles of interest; however, no GRI has yet been completed for this unit. Graphic by James Winter, Stephanie O'Meara, and Trista L. Thornberry-Ehrlich (Colorado State University).

No large-scale map coverage is available (as of 2024) for the Hewlett and Ruther Glen Quadrangles, so these are not part of the GRI GIS geologic map data. These quadrangles are now on a high-priority list of mapping projects for Virginia Energy (Marcie Occhi, geologist, Virginia Energy, written communication, 4 March 2024).

GRI Geodatabase Model and Data Set

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for the park were compiled using data model version 2.3, which is available at http://go.nps.gov/gridatamodel. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software.

The GRI GIS data are available on the GRI publications website (http://go.nps.gov/gripubs) and on the NPS DataStore through the Integrated Resource Management Applications (IRMA) portal at https://irma.nps.gov/Portal/.

The following components are part of the GRI GIS data set for the park:

- A GIS readme file (rich_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information
- Data in ESRI geodatabase GIS format
- Layer files with feature symbology (Table 2)
- Federal Geographic Data Committee (FGDC)-compliant metadata
- An ancillary map information document (rich_geology.pdf) that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures
- ESRI map documents for use in ArcMap 10.x (rich_geology.mxd) that display the GRI GIS data
- A version of the data viewable in Google Earth (rich_geology.kmz; Table 2)

Table 2. GRI GIS data layers for Richmond National Battlefield Park.

Data Layer	On Poster	Google Earth Layer
Geologic Cross Section Lines	No	No
Geologic Observation Localities	No	No
Geologic Sample Localities	No	No
Carolina Bay Boundaries	No	Yes
Carolina Bays	No	Yes
Map Symbology	No	No
Faults	Yes	Yes
Geologic Attitude and Observation Localities	No	No
Geologic Contacts	Yes	Yes
Geologic Units	Yes	Yes

GRI Geologic Map Posters

Posters of the GRI GIS data draped over a shaded relief image of the park and surrounding area are the primary sources of data for the compilation of this GRI report. The posters are not a substitute for the GIS data but are supplied as a helpful tool for office and field use and for users without access to ArcGIS. Not all GIS feature classes are included on the posters (Table 2). Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

Use Constraints

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the poster. Based on the source map scale (1:24,000) and *Map Accuracy Standards* (US Geological Survey 1999), geologic features represented in the geologic map data are horizontally within 12 m (40 ft) of their true locations.

Geologic Heritage

Richmond, the Confederacy's capital, was the focal point of five years of conflict, strategy, and battle in the American Civil War. This history played out on the rolling landscape and along the meandering waterways around the city, situated along the fall line between the Coastal Plain and Piedmont physiographic provinces. This chapter highlights the significant geologic features, landforms, landscapes, and stories of the park preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories.

Geologic Heritage (also referred to as “geoheritage”) encompasses the significant geologic features, landforms, and landscapes characteristic of our nation that are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values. The NPS also identifies geologic heritage aspects of museum collections, soils, and scientific data sets. Geoheritage sites are fundamental to understanding dynamic Earth systems, the succession and diversity of life, climatic changes over time, the evolution of landforms, and the origin of mineral deposits. Currently, there is no comprehensive national registry that includes all geoheritage sites in the United States.

The park’s fundamental resources and values are essential to achieving the purpose of the park and maintaining its significance. This requires primary consideration during planning and management. Among these resources and values are 1862 and 1864–1865 battlefield landscapes, commemorative monuments and markers, and natural communities (National Park Service 2017b). The landscape, both natural and cultural, is heavily influenced by the underlying geology.

The Fall Line—a Zone of Transition

Eastern North America is divided into a series of generally northeast-to-southwest trending physiographic provinces. A physiographic province is a geographic region with a characteristic geomorphology and often specific underlying rock types or geologic structural elements (US Geological Survey 2003). In Virginia, the underlying geology controls the physiography on the surface. The state consists of five provinces, from east to west: the Atlantic Coastal Plain, the Piedmont, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateaus provinces (see Figure 2). The Piedmont province extends 1,600 km (1,000 mi) from Alabama northeastward to southern New York. The Piedmont Plateau contains complex metamorphic and igneous rocks that have been weathered and eroded for millions of years to produce a rolling, hilly, muted landscape adjacent to the rugged Blue Ridge, Ridge and Valley, and Appalachian Plateaus provinces to the northwest and the nearly flat Coastal Plain province to the east. The park is located along the boundary between the Piedmont Plateau and the Atlantic Coastal Plain (Figure 4). This transitional setting is known as the fall line.

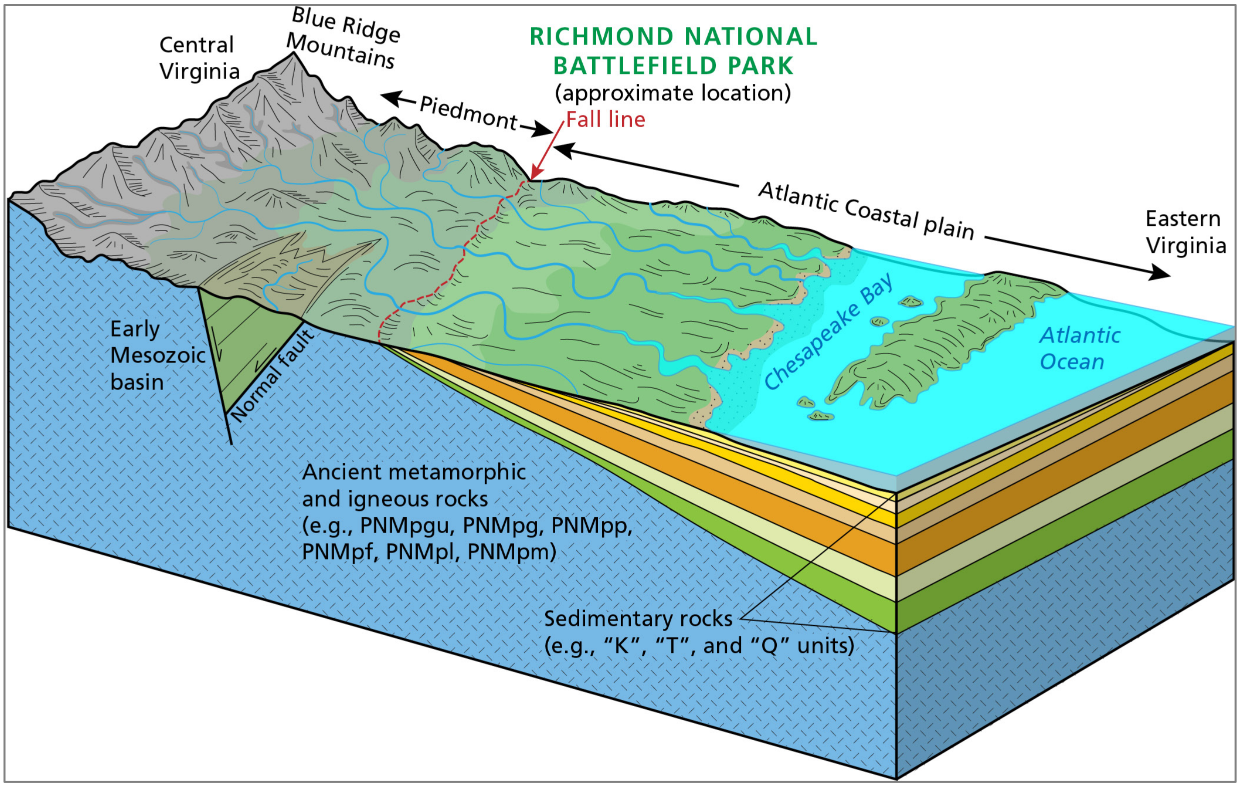

Figure 4. Cross section diagram of the geologic setting of the fall line. The fall line occurs where the soft, sedimentary rocks of the Atlantic Coastal Plain were deposited on the hard, crystalline bedrock of the Piedmont. The sediments are progressively younger and deeper to seaward. The park has both rocks of the Piedmont and the Atlantic Coastal Plain provinces within its boundaries. This setting not only dictated the location of the city of Richmond, but also heavily impacted the battle history there. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Encyclopaedia Britannica (2015).

The fall line is a low, east-facing boundary or escarpment that parallels the Atlantic coastline from New Jersey to Alabama; in reality, likely a series of "fall lines" exist within the Piedmont (Weems 1998; US Geological Survey 2003). An escarpment is a long, steep slope that faces one direction, breaking the continuity of the land by separating two adjacent surfaces. An escarpment is commonly produced by erosion or faulting. The fall line referred to in this report is an erosional escarpment formed where the hard, resistant igneous and metamorphic Paleozoic (542 million–251 million years ago) rocks of the Piedmont Plateau and the softer, gently dipping (angled) Mesozoic (251 million–65.5 million years ago) and Tertiary (65.5 million–2.6 million years ago) sedimentary rocks (made of pieces of other rocks called clasts) and unconsolidated sediments of the Atlantic Coastal Plain meet (juxtapose). Because of the juxtaposition of hard and soft rocks, the fall line is the site of many rapids and waterfalls that spurred flume- and waterwheel-powered industries in colonial times (US Geological Survey 2003). The fall line is the farthest upstream on a coastal river an ocean-going ship can go before encountering waterfalls or rapids. As a result, the fall line became the location of major cities such as Columbia, Philadelphia, Baltimore, Washington, DC, Richmond, and Petersburg (Plebuch 1960).

Stratotypes as Geoheritage

Commonly, when geologic mappers describe and name a new geologic unit (such as a formation), a specific and well-exposed section or outcrop area of the unit is designated as the stratotype—the standard reference exposure (Henderson et al. 2022). Geologic stratotypes are important geoheritage resources with scientific, historical, cultural, natural, educational, and aesthetic significance and should be preserved and remain available for other researchers to evaluate in the future (Henderson et al. 2022). The significance of stratotypes is that they represent important comparative sites where past investigations can be expanded upon or re-examined. Stratotypes can serve as teaching sites for the next generation of geoscientists (Brocx et al. 2019; Henderson et al. 2022). The geoheritage value of stratotypes is analogous to institutions such as libraries and museums because they are natural repositories of Earth history (Henderson et al. 2022). Rocks record the physical and biological evolution of our planet. Rock formations are named after topographic or geologic features and geographic landmarks that are recognizable and even famous to scenic trail staff and visitors. Geologic stratotypes are part of our national geoheritage and function as a cornerstone of the scientific value used to define the societal significance of geoheritage sites (Henderson et al. 2022).

There are no formally designated stratotypes identified within the boundaries of the park; however, formalization of the Cold Harbor alloformation (**Tch**) is in progress (Rick Berquist, geologist, College of William and Mary, written communication 23 February 2024). There are 16 identified stratotypes located within 48 km (30 mi) of park boundaries that may be relevant in case of future park boundary expansion, with unit symbols provided in parentheses where possible: Po River Metamorphic Suite, Holly Corner Gneiss, Ta River Metamorphic Suite, Falmouth Intrusive Suite, Doswell Formation, Doswell Formation, Falling Creek Member, Piney Point Formation; Old Church Formation; Eastover Formation; Eastover Formation, Claremont Manor Member; Bacons Castle Formation (**Qbc**); Bacons Castle Formation, Barhamsville Member; Yorktown Formation (**Ty**), Sunken Meadow Member; Charles City alloformation (**Qcc**); Elsing Green alloformation (**Qeg**); and Shirley alloformation (**Qsh**; Henderson et al. 2022). Alloformations are bodies of sedimentary rock defined and identified only by their bounding discontinuities (not their compositions or lithologies); in the case of the Coastal Plain, the discontinuities are the successive terraces. It is the morphologic setting and basal unconformity (gap in the geologic record) that differentiate the Pleistocene map units (Rick Berquist, geologist, College of William and Mary, written communication, 26 March 2024). At this time, these units are not formally identified stratotype sections, and thus their "alloformation" labels are lowercase.

Many of the geologic map unit names in the GRI GIS data refer to local geographic features, and some are well exposed at locations in or near the park region. Lists and descriptions of mapped geologic units within the state of Virginia are in Virginia Division of Mineral Resources (2003).

- The Petersburg Granite (**PNMpgu**, **PNMpg**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**) was named by Anna Jonas in 1928 for occurrences near Petersburg in Dinwiddie County, Virginia (Nelson 1928).
- The Potomac Formation (**Kp**) was named for the Potomac River; however, its exact type locality was never designated. In the park, the Potomac Formation is visible at the base of

Fort Brady, along the bottom of Chimborazo Hill, Drewry's Bluff, and in the valley of Gillie Run.

- The Piney Point Formation's (**Tpp**) type locality was established in 1950 near the tip of the Piney Point Peninsula in St. Mary's County, Maryland; however, locally, a reference section occurs as exposures along the right bank of the Pamunkey River in Hanover County, Virginia. It appears near Turkey Island Creek in the park.
- The Calvert Formation (**Tc**) has a type locality at the Calvert Cliffs in southern Maryland. It occurs along the James River and is present inside park boundaries along Totopotomoy Creek and Pollard Creek.
- The Eastover Formation (**Te**) type section consists of exposures above Mount Pleasant on the south bank of the James River, Surry County, Virginia. Inside the park, it is mapped along Turkey Island Creek.
- The Yorktown Formation (**Ty** and **Tym**) has a type locality on the southwest side of the York River in York County, Virginia (Ward and Blackwelder 1980). It was first described in 1906. Inside the park, it occurs near Western Run and Turkey Island Creek.
- The (informal) Cold Harbor formation (**Tch**) was named for two sediment borings at the Cold Harbor Battlefield (Bondurant et al. 2011b; Berquist and Gilmer 2014; Tim Henderson, geologist, NPS Geologic Resources Division, follow-up meeting, 31 May 2022). However, it is not yet formalized as a type section, so other locations could serve as a future formal stratotype (Marcie Occhi, geologist, Virginia Energy, written communication, 4 March 2024). It is mapped inside the park near Pollard Creek, Totopotomoy Creek, and at Ramblewood Drive. The map group in charge of formalizing this unit plans to use two cores in the battlefield, one within park boundaries, the other just outside the park, but in the battlefield. A third bore in the Quinton quadrangle to the east will be a reference section (Rick Berquist, geologist, College of William and Mary, written communication, 26 March 2024).
- Bacons Castle Formation (**Qbc**) was named for a town in Isle of Wight County, Virginia in 1965. It is mapped inside the park underlying high ground at Drewry's Bluff, Fort Harrison, Chimborazo Hill, and Glendale/Malvern Hill.
- The Windsor alloformation (**Qw**) is named after the town of Windsor, Isle of Wight County, Virginia. Its type section is from a core taken along a farm road in Nansemond, County, near Kings Fork. In the park, the Windsor alloformation occurs at Fort Harrison, Four Mile Creek, Beaver Dam Creek, Chickahominy River, and near Mechanicsville Turnpike.
- The Charles City alloformation (**Qcc**), named for Charles City, Virginia, has a type section exposure within a sand and gravel pit north of the James River in Charles City County, Virginia. Inside the park, the Charles City alloformation is mapped near the James River at Battery Hill Drive and Fort Darling Road.

- The Chuckatuck alloformation (**Qc**) was defined by Johnson and Berquist (1989) for exposures on the Brandon and Norge 7.5-minute quadrangle maps (Bondurant et al. 2017). It is mapped inside the park at Crewes Channel and Griggs Pond.

Wetland and Ecosystem Connections

Wetlands are transitional areas between land and water bodies where water periodically floods the land or saturates the soil. Wetlands include marshes, swamps, seeps, pools, and bogs. Wetlands provide several significant functions, including (1) the provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) the retention of sediments. Wetlands in the park are covered in shallow surface water, have water within the root zone most of the year, or are wet only seasonally (Figure 5). There are more than 260 ha (650 ac) of wetland areas in the park. These include 4 ha (9 ac) of Coastal Plain/Piedmont acidic seepage swamp at the Cold Harbor unit and 20 ha (50 ac) of Coastal Plain and Piedmont floodplain swamp forest at Turkey Hill (National Park Service 2017b). Other notable wetland areas occur at Beaver Dam Creek (both emergent and forested), Gaines' Mill, Malvern Hill, Fort Harrison, Chickahominy Bluffs, Totopotomoy Creek, and Drewry's Bluff units (Schneider et al. 2012; Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, written communication, 12 March 2024). The park also has areas within it where wetland systems have been anthropogenically created in many cases by past earthwork activities related to Civil War-era infantry trenches and other culturally significant earthworks that, over time, have retained enough surface water to develop wetland conditions (Peter Sharpe, hydrologist, NPS Northeast Region, written communication, 29 February 2024).

Figure 5. Photographs of wetland areas. Wetland adapted plants flourish in water-saturated/flooded areas of the park. The first image is a wetland at Turkey Creek. The second image is a wetland along Western Run at Glendale Battlefield. Wetlands were pivotal in some of the battles at the park, acting as barriers and inhibitors to troop movements. Photographs are Figures 69 and 13 in Schneider et al. (2012) and Hammond (2017a), respectively.

Wetlands commonly form where surface soils (within 30 cm [12 in] depth) are saturated, ponded, or flooded for a sufficient duration of time during the growing season to develop soil geochemical and microbial communities conducive to hydric soil and hydrophytic vegetation formation. At Cold Harbor, Beaver Dam Creek, Gaines' Mill, and Turkey Hill, the clay and silt of the Lower Chesapeake Group, undivided (geologic map unit **Tcl**), and clay layers in the Windsor alloformation (**Qw**), may support the formation of wetland habitats as well as low-lying areas along the streams (**Qal**; Bondurant et al. 2011b). At Malvern Hill, clay and peat layers within the Chuckatuck alloformation (**Qc**), clay in alluvium (**Qal**), and gray clay in the Eastover Formation (**Te**) may underlie some wetland areas (Gilmer and Berquist 2011b). At Fort Harrison, wetland areas are underlain by the Windsor alloformation (**Qw**) and Lower Chesapeake Group, undivided (**Tcl**; Berquist and Carter 2009). At Drewry's Bluff, clay and silt layers in low-lying depressions in the Potomac Formation (**Kp**) may underlie wetland areas (Bondurant et al. 2011a).

Varied natural communities were listed among the park's fundamental resources (National Park Service 2017b). Forest vegetation and soils, wetland and riparian habitats, water quality, and wildlife communities are all listed as priority resources or values (National Park Service 2015). Geology underpins every ecosystem in the park and impacts these resources and values. Because geology and geologic processes control topography and influence soil formation, strong ties exist between geology and vegetation classes, which in turn support fauna (23 amphibian, 24 reptile, 30 fish, 137 bird, and 23 mammal species; National Park Service 2015). The vegetation classes mapped at the park correlate with the underlying geology (e.g., Coastal Plain acidic seepage swamp, acidic oak-hickory forest, Coastal Plain mixed oak/heath forest, Piedmont acidic seepage swamp, mesic mixed hardwood forest, Coastal Plain swamp forest, non-riverine saturated forest, and Piedmont swamp forest) and even history (e.g., forested earthworks, open earthworks, and built-up land) (Schneider et al. 2012; National Park Service 2015). More than 91 ha (225 ac) of forest harbor diverse assemblages of flora and fauna (National Park Service 2017b). Overall, the condition of the park's natural resources was listed as "good." This was based on landscape dynamics, vegetation communities, wetland and riparian resources, biological integrity, water resources, and park-wide resources such as soils, air quality, visitor use, viewscape, and soundscape (Schneider et al. 2012).

Geologic Cultural Connections

Richmond's geologic setting, including the broad tidal rivers of Virginia (see Figure 3), the high-energy fall line, and the unconsolidated Cenozoic sediments of the Coastal Plain, influenced human history. Rather than an exhaustive compilation of human history or the events leading up to the military engagements at Richmond, which are better covered elsewhere in historical reports such as Cullen (1961), this discussion will focus on the roles geology played in the stories at Richmond.

American Indian History

American Indian presence in the park area dates back over 10,000 years, spanning three pre-European contact periods: Paleoindian, Archaic, and Woodland (Auwaerter 2009; Northeast Regional Office and Others 2015a; Hammond 2019). The earliest inhabitants were migratory, moving from the rich coastal regions to the seasonally available resources located within upland terraces, near lithic sources that contained cryptocrystalline stone (e.g., flint), and resource-rich wetlands (Northeast Regional Office and Others 2015a; Hammond 2017a; Hammond 2019). High-density quartz and quartzite lithic scatters on bluffs or ridgetops near Western Run attest to these uses (Hammond 2017b). As the sea level rose following the last Pleistocene glacial retreat around 10,000 to 12,000 years ago (see "Geologic History"), the Chesapeake Bay estuary and tidal rivers began to stabilize. Virginia Indian populations spread along major rivers and within rich environmental areas associated with the fall line (Northeast Regional Office and Others 2015a). Over time, pottery development and greater reliance on agricultural crops (e.g., beans, corn, and squash) increased the establishment of territories and settlements near rivers and floodplains, where fertile soil, favorable terrain, and access to hunting could be found (Northeast Regional Office and Others 2015a; Hammond 2019). By about 1600, Virginia Indians utilized forests for hunting game and gathering plants, estuaries for fishing and taking shellfish, and cleared upland fields for growing crops (Hammond 2019). Forests were managed, using techniques such as fire, to maximize game and other food resources, produce wood for structures, tools, canoes, and fishing gear, and facilitate habitation, circulation, and defense (Hammond 2019).

Prior to European contact in 1608, American Indians cultivated agricultural fields throughout the area and learned to manage the forests (Hammond 2019; Hodge 1912; Lookingbill et al. 2013). Local groups included the Weanock, Arrohattoc, and Chickahominy peoples (Hammond 2019). The larger rivers facilitated transportation and trade by canoe (Hammond 2019). They called the (now) James River Powhatan, one of their chief's many names, meaning "at the falls." Early English colonists renamed the river for their leader, King James I (Cross et al. 2017).

Siting of Richmond

Richmond was founded north of Petersburg, along the fall line separating the hard bedrock of the Piedmont, locally the Petersburg Granite (geologic map units **PNMpgu**, **PNMpg**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**; Figure 6), from the soft sediments of the Coastal Plain (most of the "**T**" and "**Q**" units; see Figure 4; GRI GIS data). This line or zone had a great impact on the cultural geography of Virginia and the greater Eastern Seaboard. Physically, with its characteristic rapids and waterfalls (e.g., the rapids in downtown Richmond or the Great Falls on the Potomac River), it barred ships from sailing further upstream from Chesapeake Bay. In addition to being vital trade outposts and transportation hubs, settlements took advantage of the natural high-energy setting. In Richmond, the James River drops 32 m (105 ft) over 11 km (7 mi). This steep drop, relative to the gentler slopes on either side, provided hydropower for mills and industry such as various grist mills (e.g., Ellerson's Mill, Graine's Mill, Fussell's Mill, and French's Mill) and the Tredegar Iron Works—a critical industrial asset to the Confederacy (Cullen 1961; National Park Service 2017b; Hammond 2017b; James River Park System 2019; Hammond 2019).

Figure 6. Photographs of Petersburg Granite outcrops. The Petersburg Granite is not exposed within the mapped park boundaries, but it features prominently in the history of the area. Where the hard, resistant granite is juxtaposed against softer sediments of the Coastal Plain, a high-energy river setting forms. Richmond was founded at such a boundary to take advantage of the hydrologic energy available there. Photographs are from locality 11 (first photo) and locality 4 (second photo) from the GRI GIS data (Occhi et al. 2017; Bleick et al. 2007).

The fall line barrier delayed European expansion further inland from the Piedmont. European settlements and plantations were established at this “barrier,” and agriculture (e.g., tobacco, wheat, and corn) was common until soil depletion caused local decline (Lookingbill et al. 2013). The long history of agriculture and settlement in the area is reflected in the topography. Areas were leveled for structures, and roads were cut and filled. Fields were leveled, and drainage ditches and berms were constructed around their perimeters. Because the vegetative mass in fields was removed each season, eventually the fields had a lower elevation than adjacent forested land and depleted soils (Northeast Regional Office and Others 2015b; Hammond 2016). This was compounded by bare-field erosion (Hammond 2016).

Unimproved local roads commonly became impassible swamps during wet seasons; therefore, water transportation was long preferred throughout the Coastal Plain Region of Virginia (Northeast Regional Office and Others 2015b). Higher, well-drained land was prized for transportation corridors such as roads and railroads. Roads such as the Osborne Turnpike figured in the American Revolution, at which time General Lafayette and his troops marched from the Richmond area to Yorktown in 1781 to assist in the final defeat of the British Army (Northeast Regional Office and Others 2015b). The first commercial canal in the US opened in 1790, paralleling the James River between Richmond and Westham. This accompanied an increase in overall industrialization and manufacturing after American independence from England (Northeast Regional Office and Others 2015b). The roads, canals, and railroads would prove decisive in the battles fought throughout the Richmond region during the American Civil War.

American Civil War Stories

During the American Civil War, geology influenced military operations in Richmond. This helped to change the course of history. In many battles, it was an advantage to have familiarity with the terrain, which aided in the use of the natural features of the area. The manipulation of the focal points, gaps, ravines, cuts, hills, and ridges gave one side or the other the chance to decide the outcome of a battle (Figure 7, Figure 8, and Figure 9). The park lands include 25,000 m^2 (270,000 ft^2) of original fortifications, historic road traces, field and forest patterns, watercourses, and bluffs (National Park Service 2017b). Five key historical components of the park are listed in the park’s foundation document: the Seven Days Campaign, the Overland Campaign, the Richmond-Petersburg Campaign, Chimborazo Hospital, and Tredegar Iron Works. Each component has ties to the geologic heritage of the area (Table 3; Lee 1863; Mills 1865; Cullen 1961; Dischinger 1987; Dickinson 1990; Sams 1999; Sams and Brown 1999a, b; Bleick et al. 2007; Berquist and Carter 2009; Gilmer and Berquist 2011b; Bondurant et al. 2011b; Northeast Regional Office and Others 2015b; Hammond 2017b; National Park Service 2017b; Occhi et al. 2018).

Figure 7. Historic map of the Civil War-era defenses around Richmond. Richmond was at the confluence of many railroad lines and roads, as well as at the fall line on the James River. Many of today's roads trace the historic routes, which commonly took advantage of any higher, well-drained land between swampy drainages. Small uplands and hills were used for fortifications and lookouts. Trenches and earthworks were constructed easily in the unconsolidated sediments of the Coastal Plain. Map by Robert Knox Sneden in 1865, presented in Northeast Regional Office and Others (2015b).

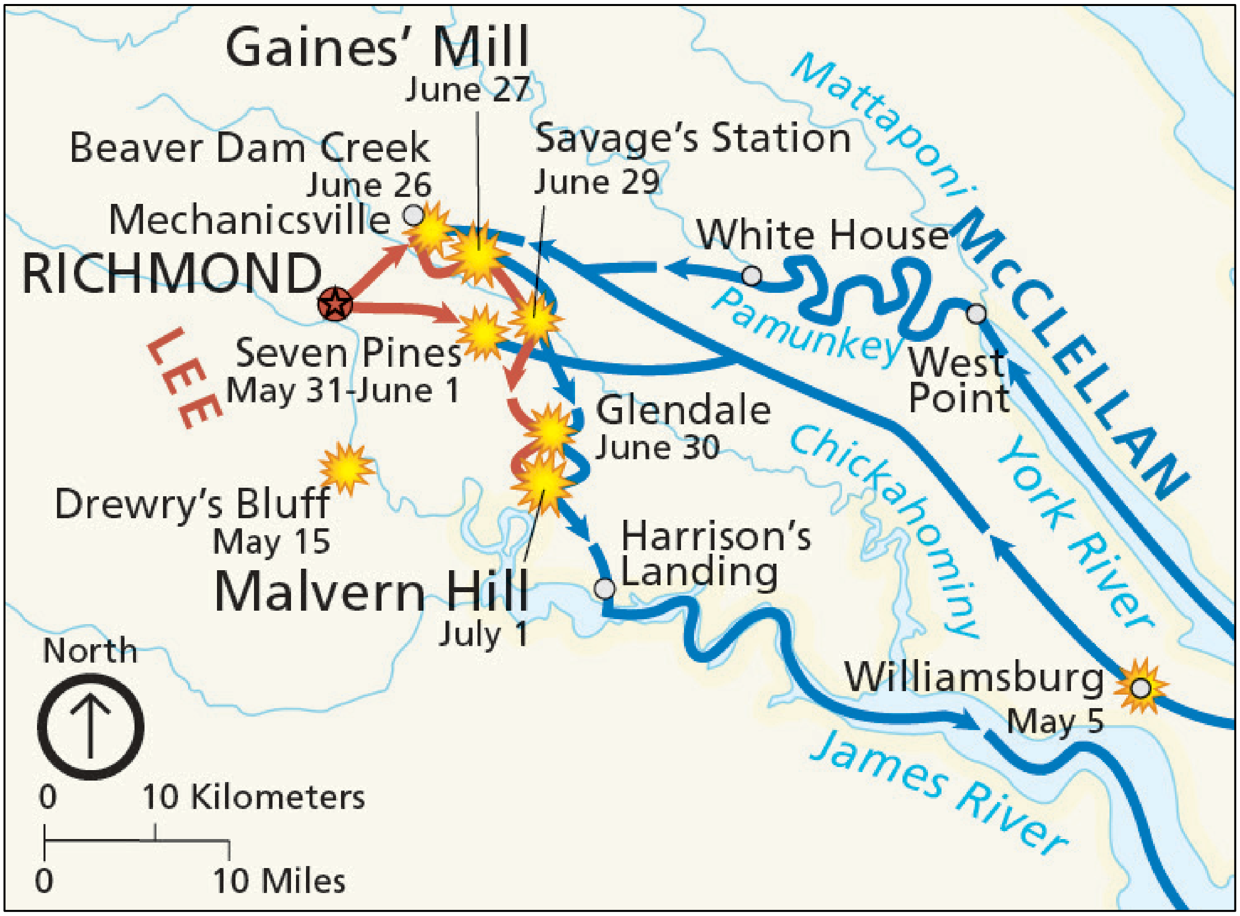

Figure 8. Battle map of the 1862 campaigns to capture Richmond. Red arrows indicate Confederate troop movements and blue arrows indicate Union troop movements. Major battles are marked as orange-yellow bursts. Union forces used the major rivers to approach Richmond from the south and east. Battles at Williamsburg, Drewry's Bluff, Seven Pines, Beaver Dam Creek, Savage's Station, Glendale, and Malvern Hill ended in Union forces ultimately retreating. National Park Service map from the Harpers Ferry Center available online: https://www.nps.gov/carto/app/#!/parks/state/va

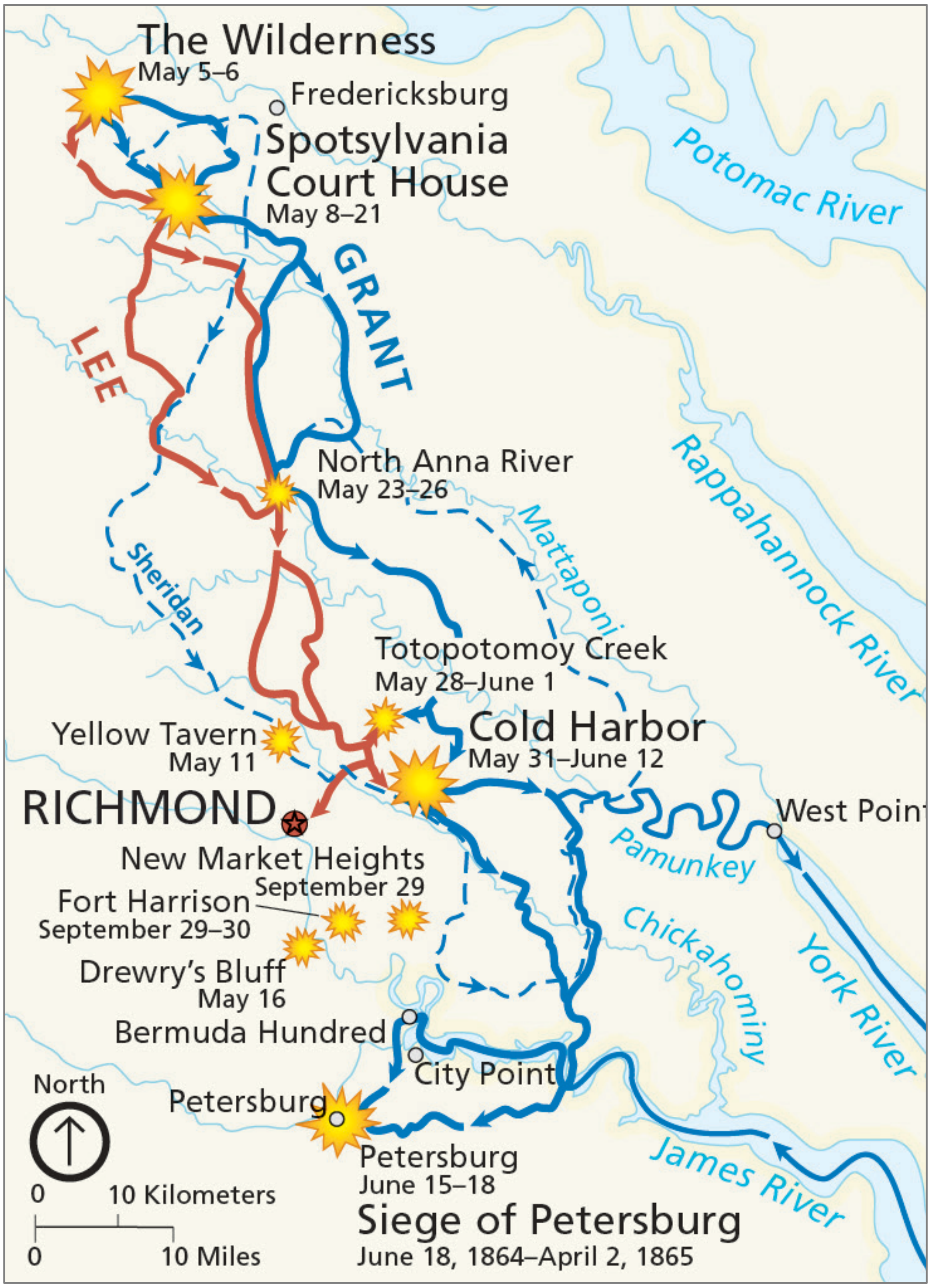

Figure 9. Battle map of the 1864 campaigns to capture Richmond. Red arrows indicate Confederate troop movements and blue arrows indicate Union troop movements. Major battles are marked as orange-yellow bursts. Following major battles at The Wilderness and Spotsylvania Court House, Union forces moved south, engaging Confederate troops at Yellow Tavern, North Anna River, Totopotomoy Creek, Drewry's Bluff, Cold Harbor, Fort Harrison, and New Market Heights, before devoting their efforts to the Siege of Petersburg, which ended in 1865 just prior to Confederate surrender at Appomattox Court House. National Park Service map from the Harpers Ferry Center available online: https://www.nps.gov/carto/app/#!/parks/state/va

Table 3. Civil War historical components and connections with geology. The park's foundation document lists five historical components that are locations and/or events that are interpreted as separate "units" at the park. Exhaustive histories of the battle sequences are described in historical reports such as Cullen (1961).

Historical Component	Location(s)	Relevant Geologic Map Units	Connection or Influence
The Seven Days Campaign	Drewry's Bluff/Fort Darling on the James River on 15 May 1862	Potomac Formation (Kp) Lower Tertiary sediments, undivided (Tl) Bacons Castle Formation (Qbc) Charles City alloformation (Qcc)	The James River, cutting through the geologic layers at a sharp bend, left a 27-m (90-ft) high bluff that Confederate forces used to hold off the Union army. Well-drained Qbc caps the heights of the bluff, but clay layers in Tl undermine the bluff's integrity.
The Seven Days Campaign	Seven Pines (Fair Oaks) on 31 May 1862	Bacons Castle Formation (Qbc) Windsor alloformation (Qw) Lower Chesapeake Group, undivided (Tcl) Upper Chesapeake Group, sand and gravel (Tcsg)	High ground, underlain by Qbc, was dissected by the swampy ground along the Chickahominy River (flanked by Qw, Tcl, and Tcsg) and caused the Union forces to split. After this, on 1 June 1862, an elaborate system of trenches and earthwork fortifications was excavated by the Confederates in the Coastal Plain sediments around Richmond before starting an offensive on 26 June. This strategy took advantage of the regional topography (e.g., the heights of the Chickahominy Bluff, underlain by Tcl, Tcsg, and Qw) to oversee the military maneuvers and coordinate attacks.
The Seven Days Campaign	Beaver Dam Creek on 26 June 1862	Lower Chesapeake Group, undivided (Tcl) Upper Chesapeake Group, sand and gravel (Tcsg)	Beaver Dam Creek cuts through Tcl and Tcsg. The creek acted as a barrier and low point. Chickahominy Bluff is the local high point. Well-drained Tcsg caps the heights of the bluff, but clay layers in Tcl undermine the bluff's integrity.
The Seven Days Campaign	Gaines' Mill on 27 June 1862	Windsor alloformation (Qw) Lower Chesapeake Group, undivided (Tcl) Upper Chesapeake Group, sand and gravel (Tcsg)	Boatswain Creek incises through Qw, Tcl, and Tcsg. Confederates formed a line of battle along the soft marshy bottom and steep wooded sides of Powhite Creek (incising into Tcl and Tcsg) prior to attacking the Union position behind Boatswain's ravine. The Confederates gained advantages, but not clear victories, near features such as Boatswain Swamp and Chickahominy River. The swampy ground, underlain by Qal and Tcl, inhibited troop movement and slowed advances and retreats.
The Seven Days Campaign	Savage's Station on 29 June 1862	Bacons Castle Formation (Qbc) Alluvium (Qal)	Savages Station is along the Richmond and York River Railroad trace underlain by Qbc near the crossing over the Chickahominy River. The crossing avoids swampy lowlands underlain by Qal.

Table 3 (continued). Civil War historical components and connections with geology. The park's foundation document lists five historical components that are locations and/or events that are interpreted as separate "units" at the park. Exhaustive histories of the battle sequences are described in historical reports such as Cullen (1961).

Historical Component	Location(s)	Relevant Geologic Map Units	Connection or Influence
The Seven Days Campaign	Frayser's Farm (Glendale) on 30 June 1862	Bacons Castle Formation (Qbc)	The farm is underlain by well-drained Qbc. Confederates gained advantages near features such as the sharp ravines near White Oak Swamp (underlain by Qal and cutting through Tcl, Ty, Te, and Qcc).
The Seven Days Campaign	Malvern Hill on 1 July 1862	Piney Point formation (Tpp) Lower Chesapeake Group, undivided (Tcl) Eastover Formation (Te) Upper Chesapeake Group, sand and gravel (Tcsg) Yorktown Formation (Ty) Bacons Castle Formation (Qbc)	Creeks such as Western Run, Turkey Island Creek, and Crewes Channel incise through Tpp, Tcl, Te, Tcsg, Ty, and Qbc. This created a dissected landscape that was difficult to move through. Malvern Hill is a level plateau and one of the highest spots in eastern Virginia at 40 m (130 ft) above sea level, capped by Qbc, which is cut with 18-m (60-ft) deep drainage ravines and bordered with steep escarpments formed in Tpp, Tcl, Te, Tcsg, and Ty on the south and west sides. Confederate General Lee attributed the failure to annihilate the Union army to the character of the country or the nature of the landscape.
The Overland Campaign	North Anna River 23–26 May 1864	Not part of GRI GIS data	The Union army crossed the North Anna River and engaged the Confederate Army at Jericho Mill (located on the fall line) on 23 May. The Confederate army responded by creating a defensive position of peculiar shape, now known as the "inverted V" line.
The Overland Campaign	Totopotomoy Creek (Rural Plains) 28 May–1 June 1864	Calvert Formation (Tc) Cold Harbor formation (Tch)	Union forces crossed the Pamunkey River and approached Totopotomoy Creek, which incises into Tc and Tch. Confederate forces resisted them there using high bluffs and steep banks capped by Tch, which sparked further fighting up and down the creek corridor.
The Overland Campaign	Cold Harbor starting on 1 June–12 June 1864	Upper Chesapeake Group, sand and gravel (Tcsg)	Both armies shifted southeastward toward the dusty crossroads of Cold Harbor, underlain mostly by Tcsg. The heaviest fighting since Spotsylvania occurred on 1 June and 3 June 1864, across a front that stretched for 11 km (7 mi). The area around Cold Harbor was a flat, featureless plain intersected by hundreds of small creeks, gullies, and swamps between the Pamunkey and Chickahominy Rivers. Subtle low ridges provided defense lines. Static fighting followed, including instances of soldiers getting lost in the swamps and using every creek, gully, ravine, and swamp (all lined with Qal) for cover.

Table 3 (continued). Civil War historical components and connections with geology. The park's foundation document lists five historical components that are locations and/or events that are interpreted as separate "units" at the park. Exhaustive histories of the battle sequences are described in historical reports such as Cullen (1961).

Historical Component	Location(s)	Relevant Geologic Map Units	Connection or Influence
The Richmond-Petersburg Campaign	Forts Harrison, Gregg, and Gilmer on 29–30 September 1864	Bacons Castle Formation (Qbc) Windsor alloformation (Qw) Lower Chesapeake Group, undivided (Tcl)	Union forces crossed the James River and made a dawn attack with nearly 30,000 men on Richmond's defenses, including Forts Harrison, Gregg, and Gilmer, underlain by Qw, Tcl, and Qbc. The surprise strategy succeeded, and Fort Harrison, the largest of the forts below Richmond and located on Varina Road atop an escarpment of Tcl capped by Qbc, was taken quickly.
The Richmond-Petersburg Campaign	Petersburg June 15–18 June 1864, then 18 June 1864–2 April 1865	Windsor Formation (Qw) Bacons Castle Formation (Qbc) Charles City alloformation (Qcc) Elsing Green alloformation (Qeg) Chuckatuck alloformation (Qc) Aquia Formation (Ta) Cold Harbor formation (Tch) Potomac Formation (Kp)	A permanent presence of the Union army 8 km (5 mi) south of Richmond at Fort Harrison necessitated a stronger Confederate presence there during the winter and a weaker position in Petersburg.
The Richmond-Petersburg Campaign	Petersburg and The Bermuda Hundred peninsula, located between the James and Appomattox Rivers 18 June 1864–2 April 1865	Windsor Formation (Qw) Bacons Castle Formation (Qbc) Charles City alloformation (Qcc) Elsing Green alloformation (Qeg) Chuckatuck alloformation (Qc) Aquia Formation (Ta) Cold Harbor formation (Tch) Potomac Formation (Kp)	10-month siege on the unconsolidated Coastal Plain deposits, into which extensive earthworks, trenches, and redoubts were excavated. This included the Bermuda Hundred peninsula, located between the James and Appomattox Rivers. Union forces dug a canal at Dutch Gap to allow ships to bypass the meander loop of the James River around Confederate batteries on Farrar's Island. The Confederate forces of Parker's Battery and the Howlett Line, stretching between the James and Appomattox Rivers underlain by Tch, forced a stalemate for months, during which time Ware Bottom Spring provided an unspoken "truce" ground that guaranteed a moment of safety while the other army gathered fresh water.

Table 3 (continued). Civil War historical components and connections with geology. The park's foundation document lists five historical components that are locations and/or events that are interpreted as separate "units" at the park. Exhaustive histories of the battle sequences are described in historical reports such as Cullen (1961).

Historical Component	Location(s)	Relevant Geologic Map Units	Connection or Influence
Chimborazo Hospital	Chimborazo Hospital (Chimborazo Medical Museum)	Bacons Castle Formation (Qbc) Lower Chesapeake Group, undivided (Tcl), Lower Tertiary sediments, undivided (Tl)	Chimborazo Hospital served as the chief medical center for the Confederacy because of its proximity to many battlefields and the number of vital railroad lines that ran nearby. The site of the hospital is located on a hill capped by the Bacons Castle Formation (Qbc) and underlain by the Lower Chesapeake Group, undivided (Tcl; Figure 10), and Lower Tertiary sediments, undivided (Tl). The location overlooks the James River at its confluence with Gillie Creek (now largely paved over).
Tredegar Iron Works	470 Tredegar St, Richmond, VA 23219	Modified land (Qml) Petersburg Granite (PNMpl and PNMpg)	The Tredegar Iron Works was among the most critical industrial assets to the Confederacy and was among the reasons Richmond was chosen as capital. The iron works produced a tremendous amount of war material between 1861 and 1865, including over 1,100 cannons, as well as mines, torpedoes, propeller shafts, armor plating for warships, and other war machinery. The presence of the iron works in Richmond made defense of the city mandatory. The iron works site is now on modified land (Qml), and its proximity to bedrock islands made of Petersburg Granite (PNMpl and PNMpg) in the James River attests to its high-energy location at the time when water energy was being provided by the fall line.

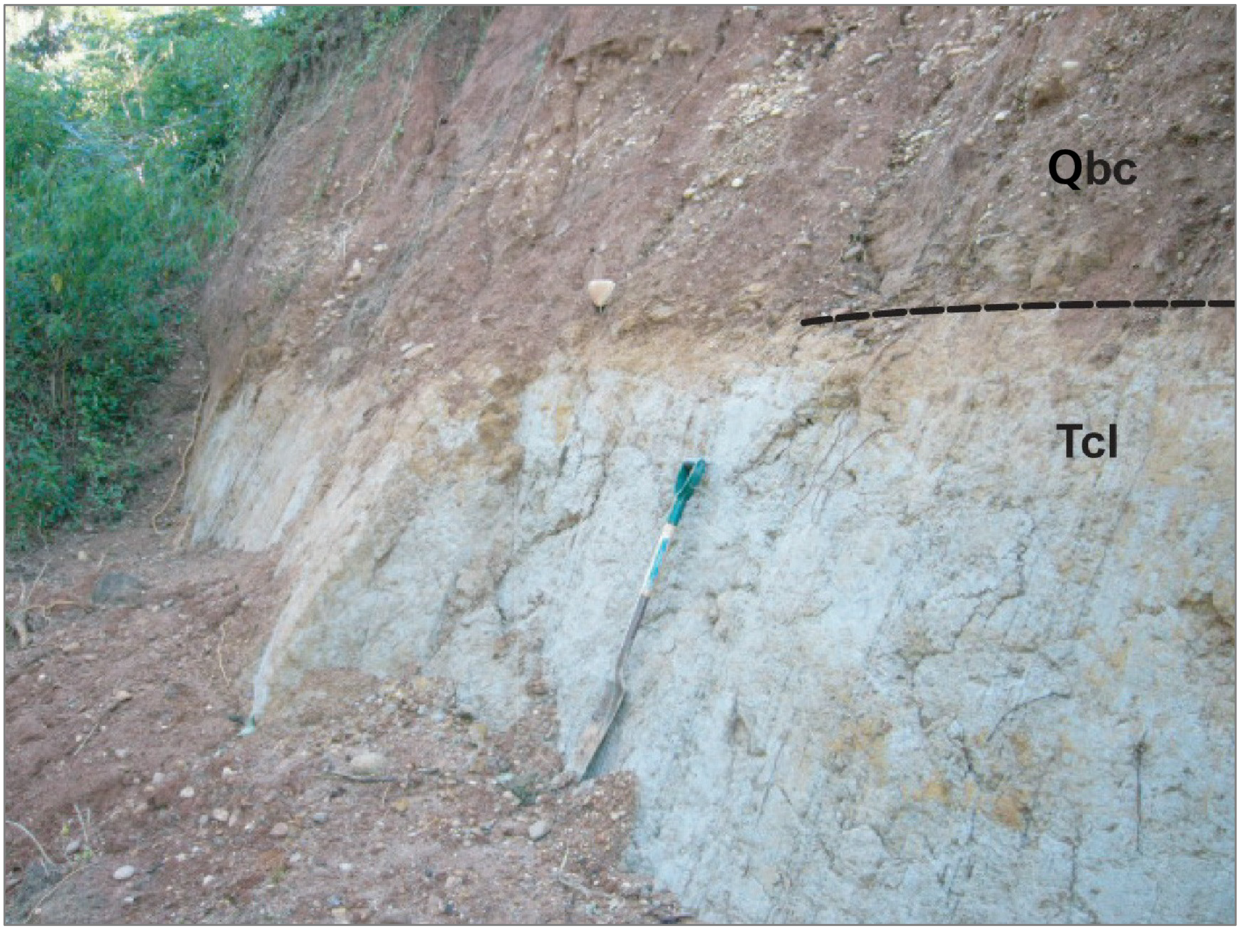

Figure 10. Photograph of the contact between the Lower Chesapeake Group and the Bacons Castle Formation. Here, sand and gravel of the Bacons Castle Formation (geologic map unit Qbc) overlies the pale, clayey silt of the Lower Chesapeake Group (Tcl). The contact is partially denoted by the dashed black line. The noticeable contact is unconformable, which means there was a period of erosion or nondeposition between the two units. In 2004, heavy rains from Tropical Depression Gaston caused a landslide that exposed the contact. Shovel is included for scale. Photograph is near the confluence of Gillie Creek and the James River (locality 2 from the GRI GIS data; Bleick et al. 2007).

Geologic History

This chapter describes the order of geologic events that formed the present landscape of the park. Emphasis is placed on the history recorded in the geologic units mapped in the park's region. A geologic time scale (Table 1) shows the chronology of geologic events (bottom to top) that led to the park's present-day landscape; this story covers more than 300 million years.

The Piedmont Plateau largely comprises terranes that were accreted (added) onto the eastern edge of North America throughout the Paleozoic Era via the convergence of lithospheric plates, which contain both Earth's crust and the upper layer of the mantle, approximately 100 km (60 mi) thick. A terrane is a group of rocks with similar characteristics and geologic history that is different from surrounding rocks that may have formed somewhere other than their present location (Neuendorf et al. 2005). Terranes are often associated with continent-scale plate tectonic forces that displace, squeeze, or rip apart large bodies of rock across distances ranging from a few to thousands of kilometers.

Three Paleozoic Era orogenies (mountain-building events during convergence; Figure 11, Figure 12A, and Table 1) facilitated much of the construction of the Piedmont—the Taconic (440 million to 420 million years ago), the Acadian-Neoacadian (360 million years ago), and the Alleghany (325 million to 265 million years ago). Iapetus sediments, fragments of landmasses from elsewhere (e.g., Africa's precursor), and volcanic arcs became terranes that were thrust or pushed onto the edge of the continent. One of these, the Dinwiddie terrane, contains a composite batholith (a large body of intrusive igneous rock) and metamorphosed rocks that compose what is mapped as the Petersburg Granite (**PNMpgu**), and the Pocoshock Creek gneiss (mapped as **PNMpf** and **PNMpl**) (Occhi et al. 2017; Carter et al. 2021; Carter et al. 2023; Mark Carter, geologist, US Geological Survey, written communication, 12 February 2024). These rocks formed in the Silurian to Devonian Periods, about 425 million to 400 million years ago (Carter et al. 2023).

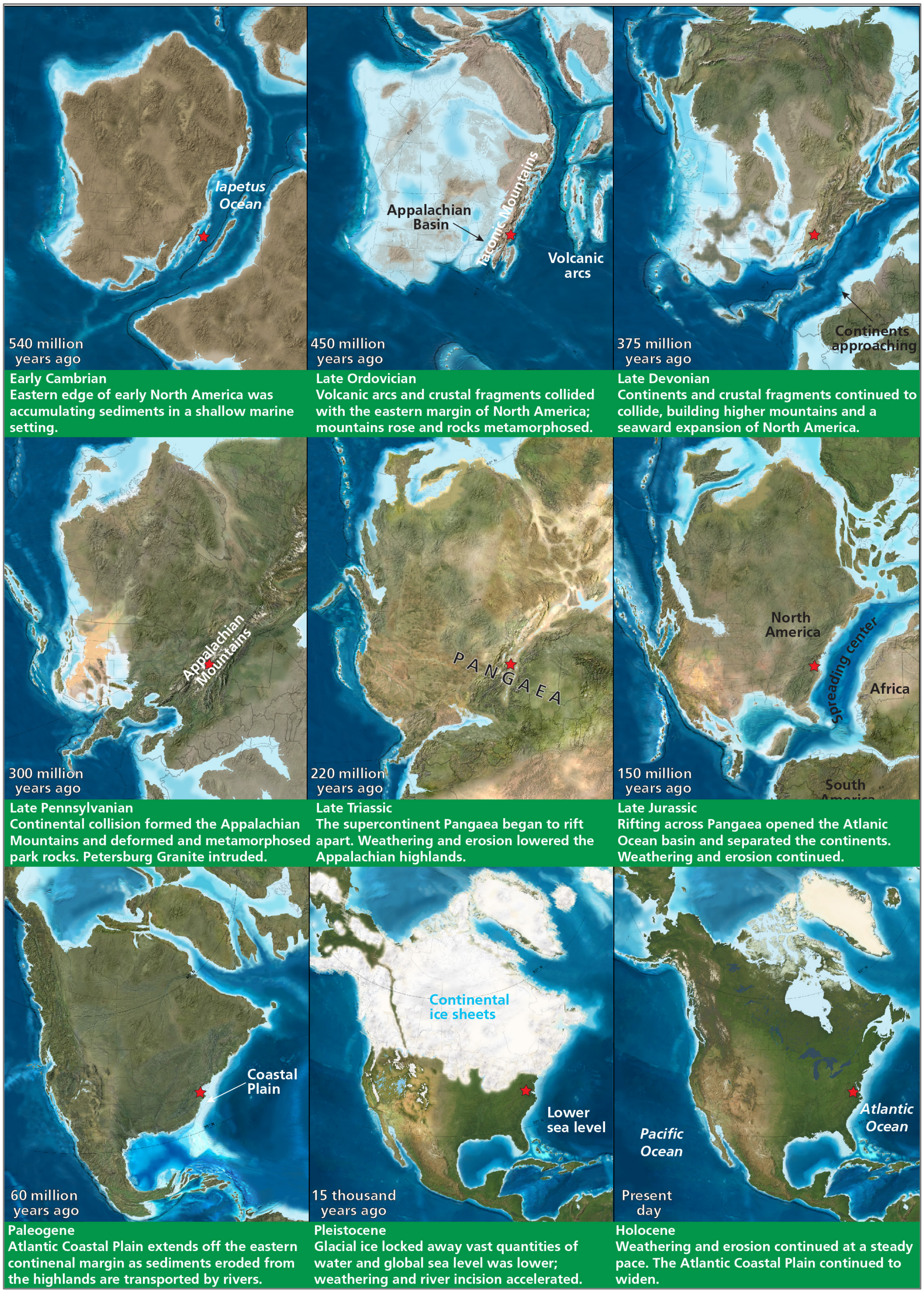

Figure 11. Paleogeographic maps of North America. The red star indicates the approximate location of the park. Graphic compiled by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.).

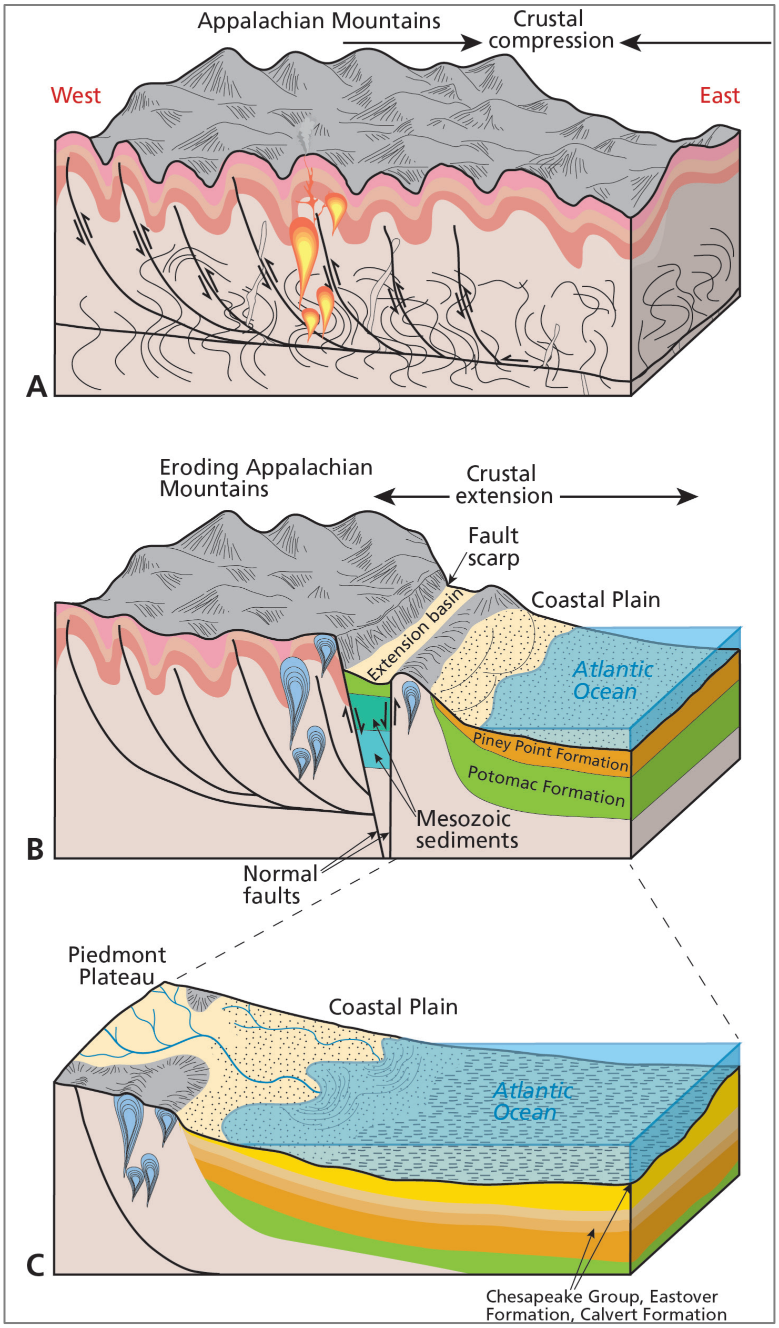

Figure 12. Diagram of the geologic evolution of the park's landscape. The park spans the boundary between the Atlantic Coastal Plain and the Piedmont Plateau and thus has characteristics of both provinces. This in turn impacted the park's human history. A) 450 to 280 million years ago, Paleozoic orogenies moved, deformed, and metamorphosed rocks during the construction of the Appalachian Mountains. Granitic magma intruded the deformed rocks. Mountain building culminated in the formation of the supercontinent, Pangaea. B) About 200 million years ago, Pangaea began to rift apart, the Atlantic Ocean began to open. Normal faulting opened basins along the eastern edge of North America and sediments accumulated in the basins and onto the Coastal Plain. C) 150 to 11 million years ago, fluctuating sea level and continual weathering and erosion lowered the highlands to the west and built the Coastal Plain ever eastward. A thick stack of sediments accumulated. Graphics not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from GRI GIS data.

About 300 million years ago, during the Alleghany Orogeny, a series of granitic plutons (igneous intrusions of molten rock that cool slowly below the surface) formed. These are the youngest parts of what is mapped as the Petersburg Granite (**PNMpg**, **PNMpp**, and likely **PNMpm**) that underlies a large region of east-central Virginia (see Figure 5 and Figure 12A; Daniels and Onuschak 1974; Berquist and Carter 2009; Bondurant et al. 2011a, b; Occhi et al. 2017; Carter et al. 2021; Mark Carter, geologist, US Geological Survey, written communication, 12 February 2024). As the intrusion (a partially molten rock body) formed, it displaced, truncated, and/or incorporated fragments of preexisting rocks via material transfer processes (e.g., Paterson and Fowler 1993). Some of the incorporated rocks persist as xenoliths (a piece of rock within an igneous rock that is not derived from the original molten rock) in the solidified granite.

The Paleozoic orogenies culminated in the uplift of the Appalachian Mountains and the formation of a supercontinent called Pangaea at the end of the Permian Period, about 350 million years ago. At that time, the Appalachians were like the modern Himalayas in scale, with one difference being that the region was situated on the equator. Pangaea was not to last. The continents began to break apart about 230 million to 200 million years ago. Rifting of North America from Africa and Europe opened the Atlantic Ocean basin (Figure 12B).

During rifting, the Earth's crust was stretched, which caused small, pull-apart basins to form across Virginia. One of these basins, the Richmond-Taylorsville basin, bounds the Petersburg Granite on its northern and western sides (Occhi et al. 2018). These rift basins were then filled with sediments shed from the adjacent higher areas and some accompanying volcanic deposits.

Throughout the Mesozoic and Cenozoic eras, as the eastern margin of North America became relatively passive, thick deposits of unconsolidated gravel, sand, and silt were transported downslope (see Figure 12B) and began building out the Coastal Plain. They accumulated seaward of the mountains unconformably, indicating a period of erosion and/or nondeposition, atop and beyond the Petersburg Granite (**PNMpg**, **PNMpgu**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**), which begins to sharply dip to the east (approximately where it is crossed by the I-95 corridor near Richmond) to become part of the Atlantic Coastal Plain basement (Occhi et al. 2018).

In the Triassic Period, roughly 200 million years ago, and as the continents were breaking apart, regional rivers and their tributaries began carving their courses, transporting and reworking sediments, and flowing into the widening Atlantic Ocean basin (see Figure 11; James River Park System 2019). Eventually, river systems would coalesce into modern waterways, but the timing of this remains unclear.

About 145 million years ago, at the beginning of the Cretaceous Period, the Potomac Formation (**Kp**) was deposited atop the Petersburg Granite (**PNMpg**, **PNMpgu**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**) in a complex of fluvial, deltaic, and nearshore depositional environments. Fluvial settings involve flowing water in streams and rivers. Where the river meets a lake or sea, a delta extends seaward of the river. Nearshore areas are those along a coast that are affected by wave action (e.g., a beach). Sediments of mixed sand, granules, pebbles, and cobbles are characteristic of these settings (see Figure 12B and Figure 13; Bondurant et al. 2011a, b; Occhi et al. 2017). The Potomac Formation is widespread across Virginia, Maryland, Delaware, and southern New Jersey (Occhi et al. 2018).

Figure 13. Photograph of the cobbles, gravel, and sand of the Potomac Formation. Cretaceous sediments accumulated across the Coastal Plain after Triassic sediments accumulated in the pull-apart basins formed as the supercontinent, Pangaea, rifted apart and opened the Atlantic Ocean. In the park, the Potomac Formation underlies and is exposed in some of the steeper areas (e.g., Drewry's Bluff). Scale bar is 18 cm (7 in) long. Photograph is near Pickadat Corner on the north side of Swift Creek (locality 10 from the GRI GIS data; Occhi et al. 2017).

Another period of erosion or nondeposition occurred after the deposition of the Potomac Formation (Kp) and prior to the deposition of the next unit: the Lower Tertiary sediments, undivided, Piney Point Formation, and Old Church Formation (**Tl**, **Tpp**, and **Toc**, respectively) atop an irregularly eroded surface; the deposition of each was punctuated by periods of erosion (Gilmer and Berquist 2011b; Bondurant et al. 2011a, Occhi et al. 2017). These units are dated to the Paleocene to Oligocene Epochs (66 million to 23 million years ago; see Table 1).

The deposition of units during the Miocene Epoch (23 million to 5.3 million years ago) left a record of sea level rise (deposition) and fall (erosion). The units deposited at that time in the Richmond area were the Calvert Formation (**Tc**), Eastover Formation (**Te**), and Lower Chesapeake Group, undivided (**Tcl**) (Figure 12C; Gilmer and Berquist 2011b; Bondurant et al. 2011a, b; Occhi et al. 2017).

Fluctuating sea levels and accompanying cycles of deposition and erosion continued into the Pliocene (5.333 million to 2.58 million years ago) during the deposition of the Upper Chesapeake Group, sand and gravel (**Tcsg**), Yorktown Formation (**Ty** and **Tym**), some sand and gravel terrace deposits (**Td1**, **Td2**, **QTg3**), and younger Cold Harbor formation (**Tch**; Figure 14A; Daniels and Onuschak 1974; Bondurant et al. 2011a; Gilmer and Berquist 2014). Unconformable contacts and stratigraphic positions indicate the Cold Harbor formation, and some of the sand and gravel (new mapping will differentiate this from **Tcsg** as **Tchsg**) are younger than the Yorktown Formation (Marcie Occhi, geologist, Virginia Energy, written communication, 4 March 2024; Rick Berquist, geologist, College of William and Mary, written communication, 26 March 2024). Typical sea level rise sequences would fine (grainsize) upwards from fluvial sand and gravel to swamp muds, to estuarine fill of mostly sand and mud exhibiting tidal sedimentary structures and trace fossils (Rick Berquist, geologist, College of William and Mary, written communication, 18 March 2024). As the sea level rose in the Pliocene, the depositional environment in the Yorktown Formation changed from a high-energy nearshore zone (e.g., beach) to a sub-wave base (depth that is not affected by surficial wave activity) area to possibly deeper back-bay or protected bay deposition (Dischinger 1987). Back bays are lagoon-like areas of relatively calm deposition protected from open-water wave energy by geologic features such as barrier islands and peninsulas. The Cold Harbor formation was deposited in shallow marine, tidal channels and flats, and tidal marsh environments (Occhi et al. 2017; Occhi et al. 2018).

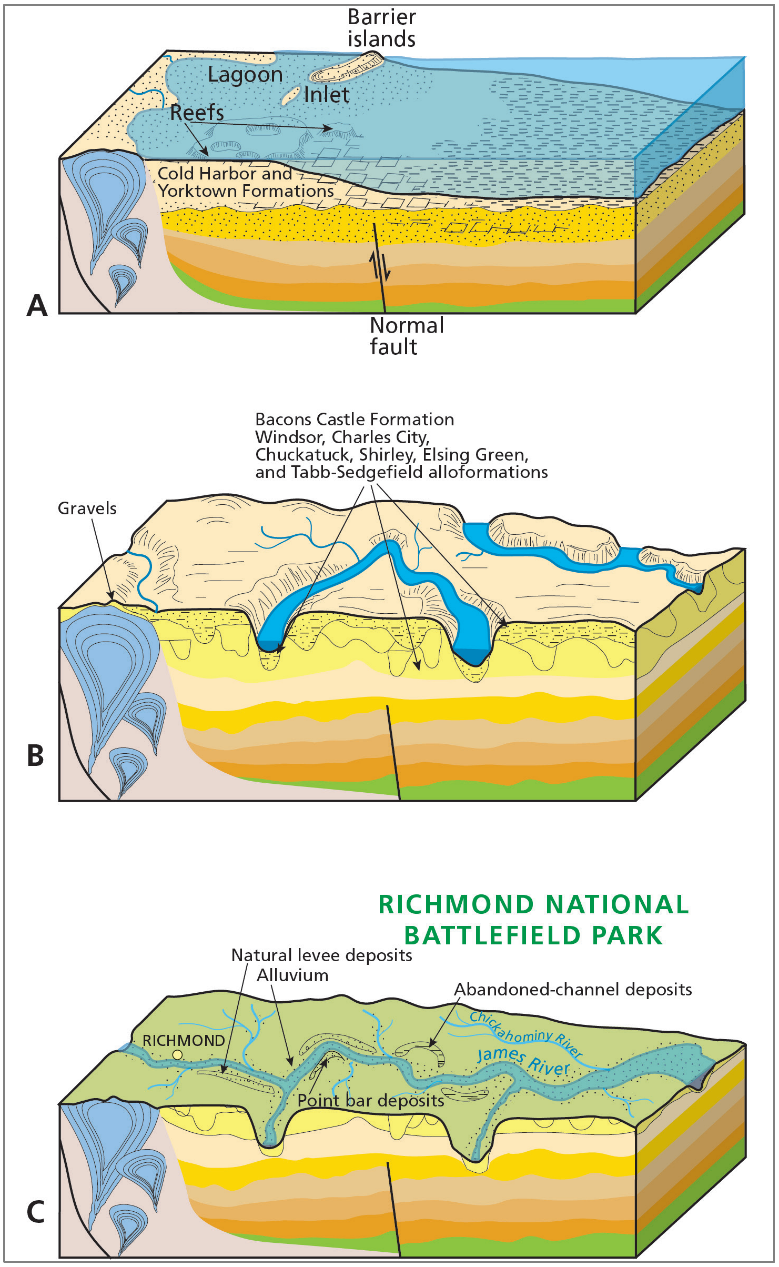

Figure 14. Diagram of the geologic evolution of the park's landscape. A) 11 to 2.5 million years ago, shallow marine conditions were prevalent during the deposition of the Eastover Formation. After a period of erosion or nondeposition, the mixed sands, carbonates (shells), and muds of the Yorktown Formation accumulated in a variety of shallow marine, open marine, lagoon, and barrier settings. B) 2.5 million to 33,000 years ago, fluctuating sea levels prevailed. During sea level lowstands (periods of low sea level), rivers carved deep canyons through the Coastal Plain's sediments and left discontinuous deposits in their channels. During sea level highstands (periods of high sea level), these canyons were flooded and accumulated nearshore and marine sediments. C). By 10,000 years ago, the rise in sea level had flooded the James River valley, and the Chesapeake Bay began to resemble its present-day morphology. Modern swamps and marshes formed, and alluvium deposits accumulated on the landscape. Graphics not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from GRI GIS geologic map data.

Throughout the Pleistocene (2.6 million to 10,000 years ago), climate fluctuations led to a series of ice ages or continental-scale glacial advances (see Figure 11). Although the vast ice sheets did not extend as far south as Virginia, their formation and subsequent melting lowered and raised the sea level, respectively. In Virginia, falling sea level caused a marine regression and subsequent deep erosion and downcutting of older Coastal Plain sedimentary layers and crystalline Piedmont rocks as river systems adjusted to the change in base level (sea level). This was followed by the erosion of older valley-wall sediments. As the sea level rose during the subsequent marine transgression between ice ages, the rivers flooded and eventually created estuaries where deposition gradually filled the previously eroded areas (Figure 14B). Successive sea level rise did not reach the elevations of preceding transgressions, creating a stair-step pattern of successively younger terraces towards Chesapeake Bay.

A widespread, clearly defined topographic scarp is present at an elevation of 53 m (175 ft) throughout the Virginia Coastal Plain. The scarp is associated with the sea level rise that deposited the Pleistocene Bacons Castle Formation (**Qbc**) and Quaternary-Tertiary gravels (**QTg4**) on top of the partially eroded Cold Harbor (**Tch**) and older Coastal Plain sediments in fluvial to estuarine environments (Berquist and Carter 2009; Gilmer and Berquist 2010; Bondurant et al. 2011a). The lower part of the Bacons Castle Formation was deposited in a fluvial to marginal marine environment and commonly contains clasts (pieces of rock) larger than those found in the base of the Cold Harbor formation (Occhi et al. 2018). Then began the Pleistocene cycles of sea level rise (deposition) and fall (erosion) that deposited the characteristic stair-step scarp and terrace pattern (Figure 15) in fluvial, estuarine, and tidal environments. The following units comprise the record (from oldest to youngest): Windsor alloformation (**Qw**), Charles City alloformation (**Qcc**), Chuckatuck alloformation (**Qc**), Shirley alloformation (**Qsh**), Elsing Green alloformation (**Qeg**), and the Tabb alloformation, Sedgefield Member (**Qts**; Gilmer and Berquist 2010; Bondurant et al. 2011a; Occhi et al. 2017).

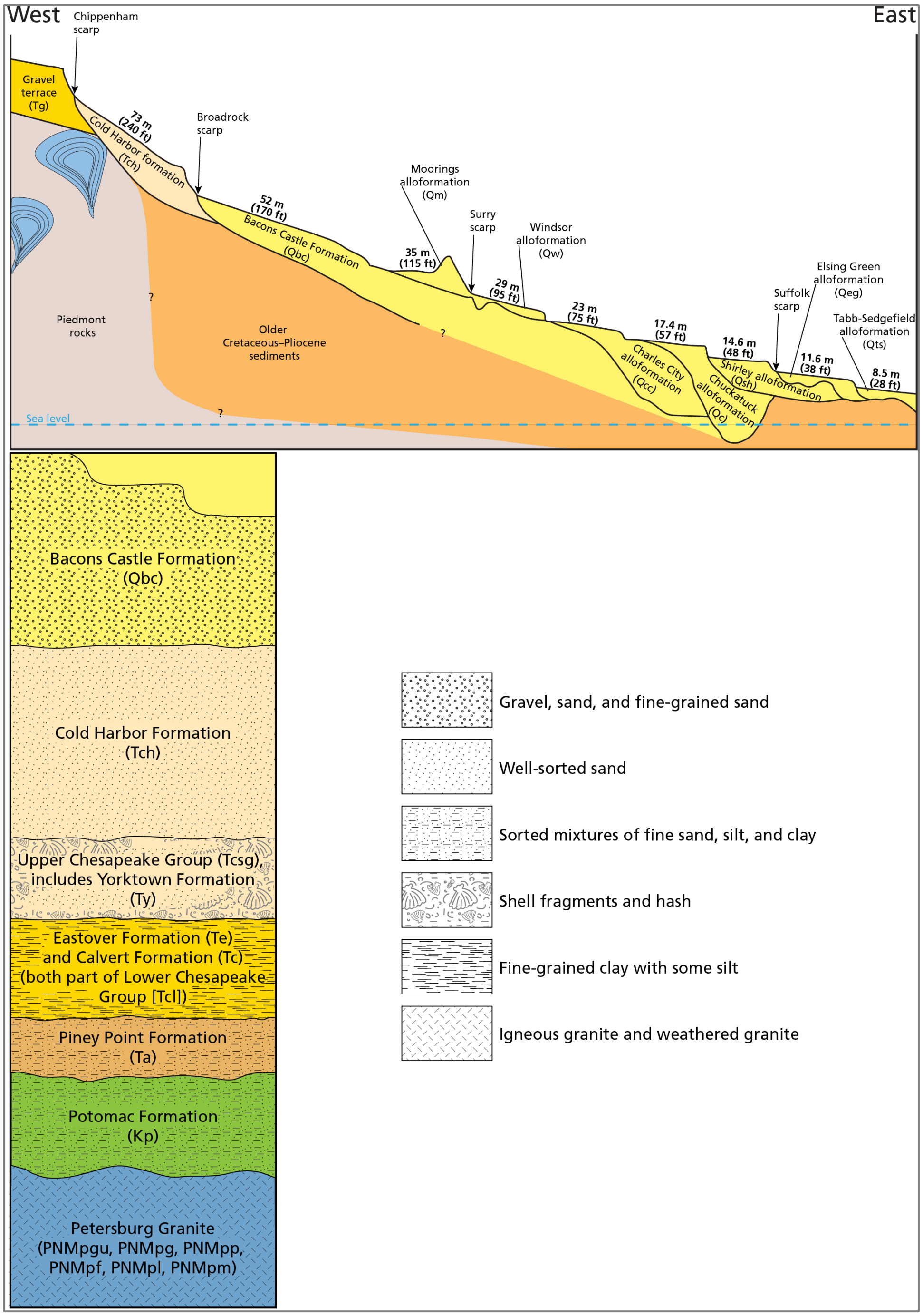

Figure 15. Stratigraphic column and diagram of the Coastal Plain stair-step terraces. Almost all the units within the park are unconsolidated sediments of the Coastal Plain. The solid but weathered Petersburg Granite underlies the western areas mapped outside park boundaries. Graphic not to scale; however, the stair-step terraces begin at sea level and the Chesapeake Bay (right side) moving westward to the first exposures of the Bacons Castle Formation (Qbc) in the Richmond area over 48 km (30 mi) inland. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Figure 3 of Johnson (2007), Rick Berquist, geologist, College of William and Mary, written communication 5 November 2023 and March 2024, and GRI GIS geologic map data.

At the end of the Pleistocene, elliptical depressions (Carolina bay (**Qcb**) features) formed atop the relatively flat upland surfaces underlain by the Bacons Castle Formation (**Qbc**) and Upper Chesapeake Group sand and gravel (**Tcsg**) units (Bondurant et al. 2011a). Throughout the region, these depressions are filled with 1.5 to 3 m (5 to 10 ft) of massive, brownish-gray silty clay with scattered quartz pebbles and a rim or low ridge of fine sand, which may support unique habitats (Johnson 1942; Bondurant et al. 2011a). According to popular theories, Carolina bays were once thermokarst lakes (lakes that develop in frozen ground) that had been altered by eolian (wind) and lacustrine (lake) processes. These conditions reflect a much colder, drier, and windier climate (Johnson 1942; Brooks et al. 2010; Swezey 2020).

For the past 10,000 years, throughout the Holocene Epoch, the sea level began to stabilize, and the modern coastline and river courses took shape (see Figure 14C). Weathering and erosion continued to reshape and refine the landforms throughout the park area. Rivers such as the James River incise their channels further into the deeply weathered granite bedrock (**PNMpg**, **PNMpgu**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**) and assorted unconsolidated units (**T** and **Q** units) deposited during the Cretaceous, Tertiary, and Pleistocene Periods. These rivers deposit and rework alluvium (**Qal**) in various forms, such as natural-levee clays and sands (**Qn**), abandoned-channel clays, sands, and gravels (**Qac**), and point-bar sands and gravels (**Qp**; Daniels and Onuschak 1974; Occhi et al. 2017). These are the youngest natural surficial geologic map units, reflecting the very active fluvial processes modifying the landscape.

The Anthropocene Epoch (as of 2024, unofficial unit of geologic time) is the age of humans, and our modifications of the landscape can be mappable but not necessarily formalizable in the geologic sense as stratotypes according to the North American stratigraphic code (North American Commission on Stratigraphic Nomenclature 2021). Where significant changes occurred around Richmond, mappers denoted these areas as modified land (**Qml**). Examples of modified land include cut and fill, mines, and excavation features (Occhi et al. 2017).

Geologic Features and Processes

The geologic features and processes highlighted in this chapter are significant to the park's landscape and history. Selection of these features and processes was based on input from scoping and follow-up meeting participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. These features and processes are discussed more or less in order of geologic age (oldest to youngest) and include references to the geologic units mapped within the park.

Geologic map units that occur within the park (geologic map symbol), from oldest to youngest:

- Potomac Formation (**Kp**)
- Piney Point Formation (**Tpp**)
- Calvert Formation (**Tc**)
- Eastover Formation (**Te**)
- Lower Chesapeake Group, undivided (**Tcl**)
- Upper Chesapeake Group, sand and gravel (**Tcsg**)
- Yorktown Formation (**Ty**)
- Cold Harbor formation (**Tch**)
- Bacons Castle Formation (**Qbc**)
- Windsor alloformation (**Qw**)
- Charles City alloformation (**Qcc**)
- Chuckatuck alloformation (**Qc**)
- Alluvium (**Qal**)
- Modified land (**Qml**)

Table 4 summarizes the occurrence of each geologic map unit inside the park and the features, processes, and issues associated with them. Formalization of the Cold Harbor formation (**Tch**) will revise the age of the Upper Chesapeake Group to younger than **Tch**. According to mappers, **Tcsg** will become **Tchsg** (Rick Berquist, geologist, College of William and Mary, written communication, 26 March 2024).

Table 4. Geologic map units within Richmond National Battlefield Park. Units within this table are listed according to percentage of total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the posters. Detailed descriptions are part of the rich_geology.pdf in the GRI GIS data.

Geologic Map Unit (symbol)	Occurrence within Richmond National Battlefield Park and Unit Description	Geologic Features and Processes	Geologic Resource Management Issues
Bacons Castle Formation (Qbc)	**Qbc** is the most prevalent unit in the park; it is mapped in 29% of the park area. **Qbc** is mapped primarily at Chimborazo Hospital, Malvern Hills, Glendale, Fort Harrison, and Drewry's Bluff. **Qbc** is mostly yellowish brown, red, and gray sand that grades downward to include coarser granules, pebbles, and cobbles. **Qbc** is commonly mapped at higher elevations, capping hills and upland areas.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils • Coastal Plain stair-step terraces	• Erosion of bluffs along the James River • Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Slope movements and instability • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection
Upper Chesapeake Group, sand and gravel (Tcsg)	**Tcsg** is the second most prevalent unit in the park; it is mapped in 27% of the park area. **Tcsg** is mapped at the Glendale, Cold Harbor, Gaines' Mill, Chickahominy Bluff, Beaver Dam Creek, and Bethesda Church units. **Tcsg** is mostly brownish yellow clayey sand to gravel in the lower part and clayey sand in the upper part. Some layers are high in heavy minerals.	• Unconformity	• Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality
Alluvium (Qal)	**Qal** is mapped in 15% of the park. **Qal** is mapped in the Totopotomoy Creek, Enon Church-Haws Shop, Chickahominy Bluff, Beaver Dam Creek, Cold Harbor, Gaines' Mill, Glendale, Malvern Hill, Fort Harrison, and Four Mile Creek units. **Qal** includes pebbly sand, sand, silt, and clay with organic material.	• Unconformity • Fossils • Fluvial features and processes	• Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Paleontological resource inventory, monitoring, and protection

Table 4 (continued). Geologic map units within Richmond National Battlefield Park. Units within this table are listed according to percentage of total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the posters. Detailed descriptions are part of the rich_geology.pdf in the GRI GIS data.

Geologic Map Unit (symbol)	Occurrence within Richmond National Battlefield Park and Unit Description	Geologic Features and Processes	Geologic Resource Management Issues
Chuckatuck alloformation (Qc)	**Qc** is mapped in 7% of the park area. **Qc** is mapped in the Four Mile Creek, and Malvern Hill units. **Qc** is predominantly brownish yellow pebbly sand that grades upward into clayey, finer grained sand.	• Unconformity • Fossils • Coastal Plain stair-step terraces • Fluvial features and processes	• Flooding, channel erosion, and sediment loading • Hydrogeologic characterization and groundwater quality • Paleontological resource inventory, monitoring, and protection
Cold Harbor formation (Tch)	**Tch** is mapped in 6% of the park. **Tch** is mapped in the Enon Church-Haws Shop, Totopotomoy Creek, and Parker's Battery units. **Tch** is yellow to red, commonly multicolored muddy sand with some clay layers. Weathered exposures are reddish-orange.	• Unconformity • Fossils	• Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Paleontological resource inventory, monitoring, and protection
Windsor alloformation (Qw)	**Qw** is mapped in 6% of the park area, specifically the Chickahominy Bluff, Beaver Dam Creek, Gaines' Mill, Four Mile Creek, Malvern Hill, and Fort Harrison units. **Qw** includes red to yellow to brown pebbly sand that grades upward to clayey fine-grained sand. Coarse component can include cobbles and boulders.	• Unconformity • Fossils • Coastal Plain stair-step terraces • Fluvial features and processes	• Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Paleontological resource inventory, monitoring, and protection
Lower Chesapeake Group, undivided (Tcl)	**Tcl** is mapped in 5% of the park. **Tcl** is mapped as part of the Chickahominy Bluff, Beaver Dam Creek, Cold Harbor, Gaines' Mill, Malvern Hill, Four Mile Creek, and Fort Harrison units. **Tcl** is predominately bluish to greenish gray clay, silt, and fine-grained sand. Weathered (oxidized) exposures appear yellowish brown.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Sinkhole Formation • Flooding, Upland Erosion, and Sediment Loading • Wetland Management • Hydrogeologic Characterization • Active Faults and Earthquakes • Civil War Artifacts and Monuments • Paleontological Resource Inventory, Monitoring, and Protection

Table 4 (continued). Geologic map units within Richmond National Battlefield Park. Units within this table are listed according to percentage of total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the posters. Detailed descriptions are part of the rich_geology.pdf in the GRI GIS data.

Geologic Map Unit (symbol)	**Occurrence within Richmond National Battlefield Park and Unit Description**	**Geologic Features and Processes**	**Geologic Resource Management Issues**
Yorktown Formation (Ty)	**Ty** is mapped in 2% of the park, specifically along Western Run in the Malvern Hill and Glendale units. **Ty** is gray to bluish gray sandy silty clay. When weathered, **Ty** is yellow, reddish brown, and brown. Layers of shell hash and heavy mineral concentrates are common locally.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Flooding, channel erosion, and sediment loading • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection
Calvert Formation (Tc)	**Tc** is mapped in 1% of the park area. **Tc** is mapped at the Totopotomoy Creek and Enon Church-Haws Shop units. **Tc** consists of dark blue to greenish gray, silty to clayey sand. Heavy mineral and phosphate concentrations can be as much as 10% in some layers.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection
Eastover Formation (Te)	**Te** is mapped in 1% of the park area, specifically in the Malvern Hill and Glendale units, along Western Run. **Te** is light gray to dark bluish gray silty to clayey, fine-grained sand and some massive sandy clay layers. Rusty weathered surfaces are common.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Flooding, channel erosion, and sediment loading • Hydrogeologic characterization and groundwater quality • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection
Modified land (Qml)	**Qml** is mapped in less than 1% of the park area. The unit appears in the Chickahominy Bluff, Chimborazo Hospital, Gaines' Mill, Four Mile Creek, Drewry's Bluff, and Fort Harrison units. **Qml** includes cut and fill areas, as well as mined areas.	• None noted	• Erosion of bluffs along the James River • Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Slope movements and instability • Landcover changes, disturbed lands, and abandoned mineral lands

Table 4 (continued). Geologic map units within Richmond National Battlefield Park. Units within this table are listed according to percentage of total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the posters. Detailed descriptions are part of the rich_geology.pdf in the GRI GIS data.

Geologic Map Unit (symbol)	Occurrence within Richmond National Battlefield Park and Unit Description	Geologic Features and Processes	Geologic Resource Management Issues
Water	**Water** is mapped in less than 1% of the park area. Water as streams is present in nearly every park unit. In mappable areas, it is part of the map data in the Fort Harrison, Cold Harbor, and Gaines' Mill units.	• Fluvial features and processes	• Erosion of bluffs along the James River • Flooding, channel erosion, and sediment loading • Hydrogeologic characterization and groundwater quality • Climate change
Potomac Formation (Kp)	**Kp** is mapped in less than 1% of the park, only at Drewry's Bluff and Fort Brady along the James River bluffs. **Kp** contains gray to grayish pink mostly coarse sand with some granules, pebbles, and cobbles. The sand has feldspar and quartz grains. **Kp** has some thin lenses containing boulders and plant fragments.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Erosion of bluffs along the James River • Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Slope movements and instability • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection
Piney Point formation (Tpp)	**Tpp** is mapped in less than 1% of the park area, specifically in the Malvern Hill and Glendale units, along Western Run. **Tpp** is dark greenish gray, shelly glauconitic sand with abundant pyrite and some limestone rich layers.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils	• Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection

Table 4 (continued). Geologic map units within Richmond National Battlefield Park. Units within this table are listed according to percentage of total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the posters. Detailed descriptions are part of the rich_geology.pdf in the GRI GIS data.

Geologic Map Unit (symbol)	**Occurrence within Richmond National Battlefield Park and Unit Description**	**Geologic Features and Processes**	**Geologic Resource Management Issues**
Charles City alloformation (Qcc)	**Qcc** is mapped in less than 1% of the park area. It appears only at Drewry's Bluff and Fort Brady along the James River. **Qcc** includes yellowish red to brown clayey sand grading downward to sand and pebbles with interlayers of peat, organics, and muddy sands.	• Unconformity • Dutch Gap, Malvern Hill, and unnamed faults • Fossils • Coastal Plain stair-step terraces • Fluvial features and processes	• Erosion of bluffs along the James River • Flooding, channel erosion, and sediment loading • Management of a historic and commemorative landscape • Hydrogeologic characterization and groundwater quality • Slope movements and instability • Active faults and earthquakes • Paleontological resource inventory, monitoring, and protection

Unconformity

Layers of rock are referred to as "conformable" where they are found to have been deposited essentially without interruption. Although particular sites may exhibit conformable beds representing significant spans of geologic time, no place on Earth contains a full set of conformable strata. Breaks in conformable strata are called "unconformities." Each unconformity represents a period when deposition ceased, or where erosion removed, previously formed rocks. An unconformity represents a lack of interpretable information in the geologic record. Unconformable contacts occur between every geologic map unit in the park (see Figure 15 and Figure 16).

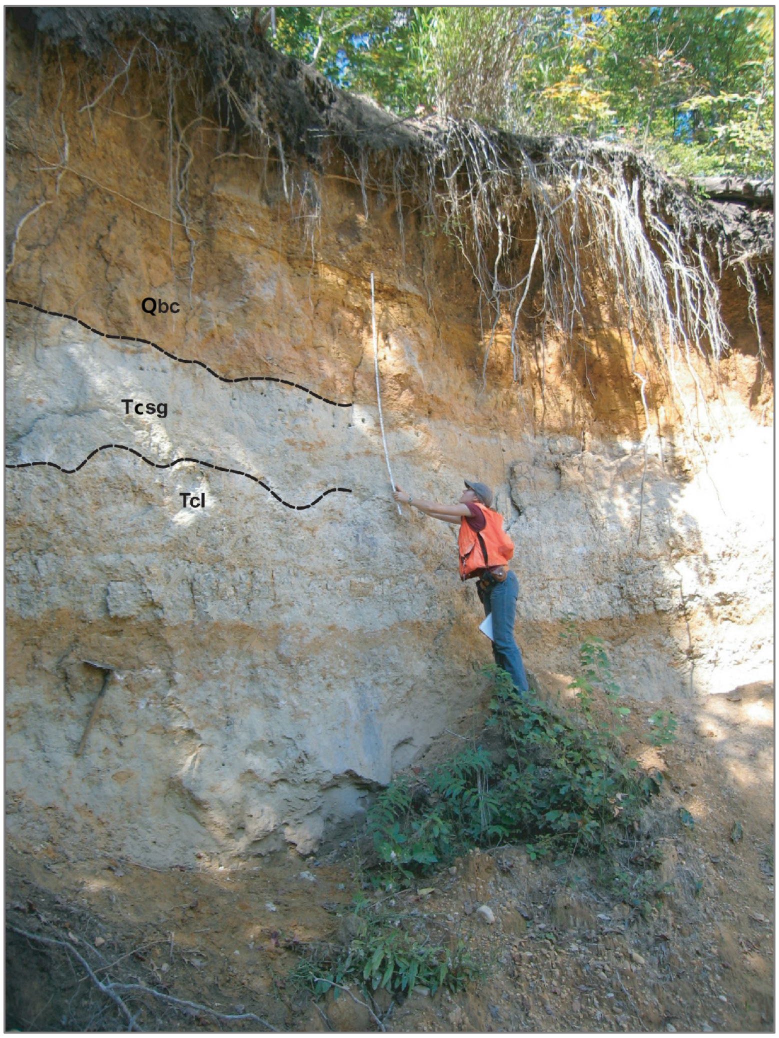

Figure 16. Photograph of unconformable contacts in Coastal Plain sediments. The lowermost unit, the Lower Chesapeake Group (geologic map unit Tcl) is composed of clayey fine sand with scattered pebbles. At least 1 m (3 ft) of pebbly sand in the Upper Chesapeake Group (Tcsg) is probably from the Yorktown Formation or Cold Harbor formation (Tch, not yet delineated at the time of this photograph in 2011). The uppermost unit is the Bacons Castle Formation (Qbc) composed of quartzite pebbles and cobbles. Erosion between all three units resulted in wavy, channelized contacts. Photograph is locality 6 in the GRI GIS data (Berquist and Carter 2011b) with some symbology changed by Trista L. Thornberry-Ehrlich (Colorado State University).

Dutch Gap, Malvern Hill, and Unnamed Faults

Faults occur where rocks have been compressed, stretched, sheared, fractured, or moved. They are common structural features in areas where mountain building has occurred, such as the Appalachian Mountains, but may also occur in areas where Earth's crust has stretched, or a heavy load of sediments has accumulated, such as the Coastal Plain. Faulting within the Coastal Plain indicates recent tectonic activity in the area (Thornberry-Ehrlich 2005). The three primary types of faults are normal faults, reverse faults, and strike-slip faults (Figure 17). Faults are classified based on the motion of rocks on either side of the fault plane, as described in Figure 17. For normal faults, the block above the fault plane moves down relative to the block below. For reverse faults, the opposite is true, with the block above the fault moving up relative to the block below. For strike-slip faults, the blocks slide laterally past each other with little to no vertical movement. Reverse faults and high-angle faults of unknown offset/displacement are mapped within GRI GIS data for the park (Figure 18) and include the Malvern Hill fault and the Dutch Gap fault—named for a 17th century palisaded fosse (a trench reinforced by wooden poles entrenched in the ground) installed by Sir Thomas Dale to protect a narrow-necked peninsula (now Farrar's Island) with high bluffs that became a settlement called Henricus (Dischinger 1987; Gilmer and Berquist 2011a, b; Berquist and Carter 2009; Cross et al. 2017).

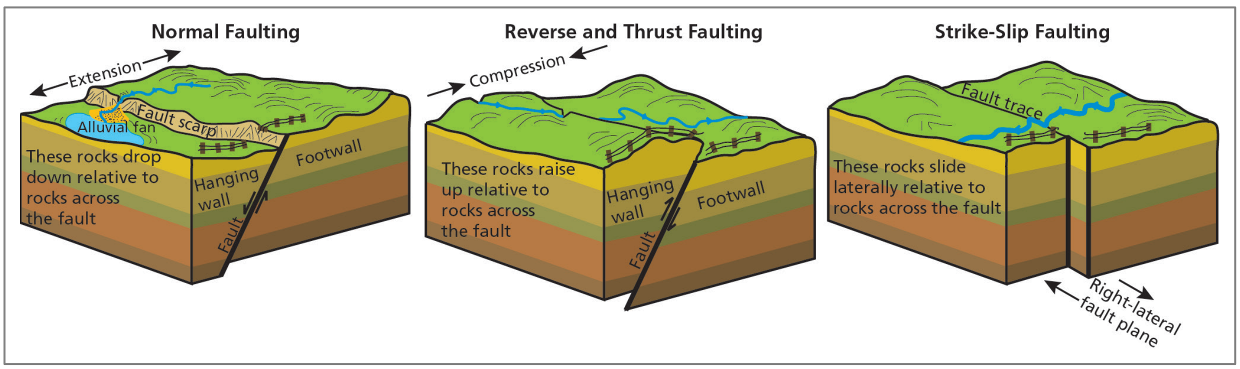

Figure 17. Graphic of fault types. Movement occurs along a fault plane. Footwalls are the blocks of rock below the fault plane, and hanging walls are the blocks of rock above the fault plane. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging wall up relative to the footwall. A thrust fault is a type of reverse fault that has a dip angle of less than 45°. In a strike-slip fault, movement is horizontal. When movement across a strike-slip fault is to the right, it is a right-lateral strike-slip fault, as illustrated above. When movement is to the left, it is a left-lateral strike-slip fault. A strike-slip fault between two tectonic plates is called a transform fault. Transtension (transform plate motion and extension) is characterized by strike-slip and normal faulting. Transpression (transform plate motion and compression) is characterized by strike-slip faulting and reverse and thrust faulting. Normal faults are common throughout the Coastal Plain as Earth's crust was stretched during the opening of the Atlantic Ocean basin. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

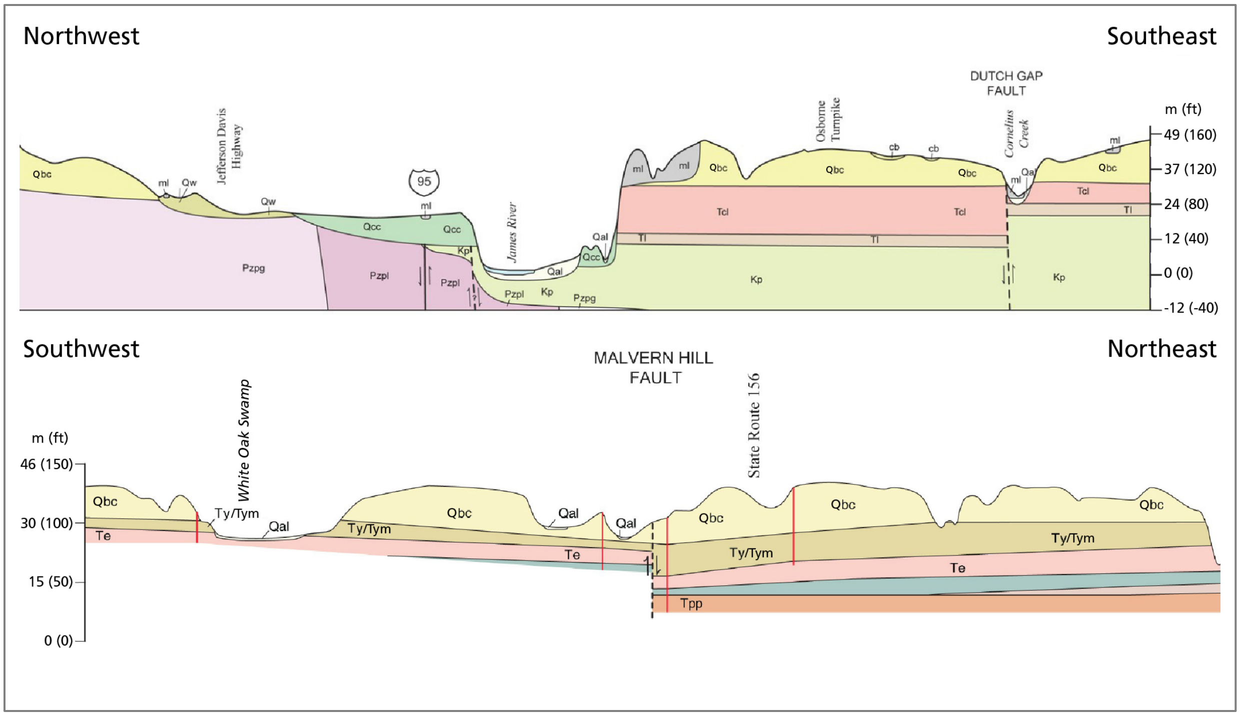

Figure 18. Excerpts from geologic cross sections showing named faults at the park. In the top graphic, the Dutch Gap high-angle fault juxtaposes geologic map units. To the east, a section of Potomac Formation (geologic map unit Kp), Lower Tertiary sediments (Tl), Lower Chesapeake Group (Tcl), and Bacons Castle Formation (Qbc) are about 12 m (40 ft) higher than their counterparts across the fault to the west. In the lower graphic, layers of the Eastover Formation (Te), Yorktown Formation (Ty and Tym), and Bacons Castle Formation (Qbc) on the western side of the fault plane are higher than their counterparts on the eastern side. Graphics extracted and adapted by Trista L. Thornbery-Ehrlich (Colorado State University) after cross sections in the GRI GIS data by Gilmer and Berquist (2011) and Bondurant et al. (2011a).

The Dutch Gap is mapped as a north–south to northeast–southwest trending series of reverse faults that juxtapose older Potomac Formation (**Kp**) sediments to the east against younger (Lower Tertiary sediments, undivided, Lower Chesapeake Group, undivided [**Tl** and **Tcl**, respectively]) sediments to the west (Bondurant et al. 2011a). In other areas, older Petersburg Granite (**PNMpm**) and younger Potomac Formation (**Kp**) are juxtaposed (Berquist and Carter 2009). The fault is obvious in cross sections (see rich_geology.pdf described under "Geologic Map Data") with as much as 20 m (66 ft) of displacement (Thornberry-Ehrlich 2005; Bleick et al. 2007). The faulted zone extends at least 30 km (18 mi) from the northwestern corner of the Eastern Front unit at Petersburg National Battlefield northward across the James River up to Gillie Creek (Dischinger 1987; Thornberry-Ehrlich 2005; Bleick et al. 2007). South of the park, overall displacement along the fault was up to 24 m (80 ft), with the down-dropped side of the fault lying to the west (Dischinger 1987). The surficial trace of the Dutch Gap Fault is commonly buried by younger units, e.g., Charles City alloformation (**Qcc**) or Bacons Castle Formation (**Qbc**) and younger (Bondurant et al. 2011a).

Coring near State Route 156 (on the Roxbury quadrangle map) revealed the location of the Malvern Hill fault (Gilmer and Berquist 2011a). This fault drops down to the east as a high-angle fault, and its map trace is subparallel to that of the Dutch Gap fault. The Malvern Hill fault juxtaposes older Piney Point Formation (**Tpp**), Calvert Formation (**Tc**), and Eastover Formation (**Te**) units against younger Yorktown Formation (**Ty**) and Bacons Castle Formation (**Qbc**) units (Gilmer and Berquist 2011a).

Many small faults in the unconsolidated sedimentary units, which aren't always mapped, also have a big effect on landform development and indicate that tectonic activity in the park area happened recently. Where faulting and sedimentation occurred simultaneously, like north of the James River, the upthrown block may be thickened and the downthrown part may be thinned (e.g., Potomac Formation [**Kp**] or Yorktown Formation [**Ty**]; Dischinger 1987; Thornberry-Ehrlich 2005; Gilmer and Berquist 2011a; Bondurant et al. 2011a).

Fossils

Geologic map units: Potomac Formation (**Kp**), Piney Point Formation (**Tpp**), Calvert Formation (**Tc**), Eastover Formation (**Te**), Yorktown Formation (**Ty**), Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Windsor alloformation (**Qw**), Charles City alloformation (**Qcc**), Chuckatuck alloformation (**Qc**), Alluvium (**Qal**)

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism's activity such as nests, burrows, tracks, or coprolites [fossil dung]). All fossils are nonrenewable. Fossils in NPS areas occur in situ in rocks or unconsolidated deposits, in museum collections, and in cultural contexts such as building stones or archeological resources. As of October 2023, 286 parks had documented paleontological resources in at least one of these contexts (Justin Tweet, paleontologist, NPS Geologic Resources Division, written communication, 12 October 2023). Name-bearing fossil type specimens are the material on which a species, subspecies, or variety is based as a point of future reference. Fossil type specimens ideally preserve morphological characteristics that allow the species to be distinguished from all other species. Six such fossil type specimens may occur within the park (Tweet et al. 2016).

Drewry's Bluff has been noted as a paleobotanical site since the early 20th century and is particularly noted for palynomorphs (organic microfossils such as spores and pollen) of Cretaceous plants (Justin Tweet, paleontologist, NPS Geologic Resources Division, follow-up meeting, 31 May 2022). Organic "bits," carbonaceous fragments, and leaves have also been reported. The exact collection site is unlocated as of 2022, and the park boundary itself cuts across the face of the bluff and does not include the entire bluff, so it is possible the published site is beyond the boundary (Justin Tweet, paleontologist, NPS Geologic Resources Division, follow-up meeting, 31 May 2022), but it is likely the same kinds of fossils can be found on either side of the ownership boundary, as the Potomac Formation is exposed on both sides. Research suggests the site is below the parking lot between the fort and the landfill, toward the creek. The creek also contains fossil bits washed from its banks (Mark Carter, geologist, US Geological Survey, follow-up meeting, 31 May 2022).

The Coastal Plain geologic map units in the park, spanning more than 140 million years of Earth's history, are fossiliferous. Fossils also occur in cobbles washed from elsewhere, including reworked

Paleozoic cobbles with *Skolithos* burrows (vertical feeding structures, likely produced by a worm-like creature) that have been found throughout the greater Potomac and James Rivers' drainages. The following units are known to contain fossils throughout the Coastal Plain (from Kenworthy et al. 2006; Bailey 2014; Mark Carter, geologist, US Geological Survey, follow-up meeting, 31 May 2022; Justin Tweet, paleontologist, NPS Geologic Resources Division, follow-up meeting, 31 May 2022):

- Potomac Formation: pollen, ferns, horsetails, cycads (palm-like plants), gnetales (a family of tropical plants), conifers, mollusks, fish, amphibians, crocodiles, turtles, birds, small mammals, ichnofossils (trace fossils), dinosaurs
- Piney Point Formation: fossiliferous with oyster guide fossil *Cubitostrea sellaeformis*, mollusks, foraminifera (single-celled organisms), dinoflagellates (single cell plankton)
- Calvert Formation: fossiliferous with mollusks, shark teeth, marine mammals, foraminifera, diatoms (algae), burrows, fish teeth, wood pieces, sponge spicules, barnacles, coprolites (fossil dung)
- Lower Chesapeake Group, undivided: shark teeth, bone, shell material, *Mercenaria* (a clam), *Turritella* (sea snail), *Isognomon maxillata* (giant fossil oyster)
- Eastover Formation: fossiliferous with bivalves (mollusks with hinged shells), gastropods (snails or whelks), brachiopods (marine creatures with upper and lower shells), crustaceans, guide fossil *Spisula rappahannockensis* (small bivalve that is useful to date the layer in which it is found)
- Yorktown Formation: very fossiliferous with mollusks, coral, shark teeth, shell debris, gastropods, whales, walrus, fish, cephalopods (squid and octopus), scaphopods ("tusk shells," burrowing mollusks), crabs, echinoids (sea urchins), brachiopods, bryozoans (marine creatures forming branching, encrusting, or gelatinous mosslike colonies), sponges, ostracodes ("seed shrimp," tiny crustaceans), foraminifera. Martin Lister described and published the first fossil from North America in 1687, a scallop shell later named *Chesapecten jeffersonius* from the Yorktown Formation (Figure 19; Ward and Blackwelder 1975). This species is the earliest fossil representation from North America and is now recognized as the state fossil of Virginia. Burrows are known from this unit within the park.
- Cold Harbor formation: root casts, *Ophiomorpha* shrimp burrows
- Bacons Castle Formation: pollen and other microfossils
- Windsor alloformation: *Ophiomorpha* shrimp burrows, pollen
- Charles City alloformation: invertebrate burrows
- Chuckatuck alloformation: *Ophiomorpha* shrimp burrows

Figure 19. Photograph of a fossil scallop from the James River. The fossil likely washed out from exposures of the Yorktown Formation (geologic map unit Ty and Tym) along the James River downstream from the park. Though not formally identified as such, the fossil is similar to the Virginia state fossil *Chesapecten jeffersonius*. Inset is a copy of Martin Lister's 1687 figure of the *Chesapecten jeffersonius*—the first such publication of fossil material from North America. Image is the cover graphic from Kenworthy and Santucci (2003) from Ward and Blackwelder (1975). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2021.

Coastal Plain Stair-Step Terraces

Geologic map units: Bacons Castle Formation (**Qbc**), Windsor alloformation (**Qw**), Charles City alloformation (**Qcc**), Chuckatuck alloformation (**Qc**), Shirley alloformation* (**Qsh**), Elsing Green alloformation * (**Qeg**), and Tabb-Sedgefield alloformation* (**Qts**). *Units are not exposed at the surface within the park but may be buried and are part of the complete Coastal Plain assemblage.

The Pleistocene unconsolidated geologic map units that are exposed or buried at the park today were deposited in successive sea level highstands. Each recorded successive sea level rise did not appear to reach as high an elevation as the previous highstand. This created the characteristic stair-step terraces from west to east, wherein each step gets lower and younger, toward Chesapeake Bay (Occhi et al. 2017). Each terrace is generally a broad flat with characteristic elevations (see Figure 15):

- Windsor alloformation 23 to 29 m (75 to 95 ft)
- Charles City alloformation 18 to 23 m (60 to 75 ft)
- Chuckatuck alloformation 15 to 17 m (50 to 57 ft)
- Shirley alloformation 14 to 15 m (45 to 49 ft)
- Elsing Green alloformation 11 to 12 m (35 to 38 ft)
- Tabb alloformation, Sedgefield Member 6 to 9 m (20 to 28 ft)

Fluvial Features and Processes

Geologic map units: alluvium (**Qal**), Pleistocene alloformations ("**Q**" units)

Fluvial features are those that are formed by flowing water, typically in rivers and streams. Fluvial processes both construct (deposit alluvium; geologic map units **Qal**, **Qp**, **Qac**, **Qn**) and erode landforms (e.g., the drainages through the Coastal Plain sediments). Rivers and streams cross the landscape within and surrounding the park, including the James River, Chickahominy River, Totopotomoy Creek, Beaver Dam Creek, Bloody Run, Powhite Creek, Boatswain Creek, Western Run, and White Oak Swamp (see Figure 2; Thornberry-Ehrlich 2005). This prevalence of flowing water makes the quality of the surface water at the park important to park management, and the drainages themselves were crucial factors during the battle history at the park (see "Geologic Heritage").

Fluvial features occur on many scales in the park, ranging from the wide, tidal river valleys (James River) to the smallest streams and gullies. Examples of the park's fluvial features (with geologic map unit symbols where possible) include meandering river channels, point bars (part of **Qp**), gravel bars (part of **Qp**), islands, natural levees (**Qn**), floodplains, back swamps, oxbows (part of **Qac**), and terraces (Figure 20). River channels are the perennial course of flowing water. As a river flows around curves, the flow velocity (and thus erosive energy) is greatest on the outside of the bend. The river erodes into its bank on the outside of a curve and leaves point-bar deposits (part of **Qp**) on the inside of the bend. Point bars are crescent-shaped ridges of sand, silt, and clay deposited on the inside of meander loops where the water's velocity is slowest. As the process continues, the outside bend retreats farther, while the inside bend migrates laterally, thus creating migrating meanders.

Meandering reaches its extreme when the narrow neck of land between two bends is breached, leaving an oxbow lake or an abandoned meander (part of **Qac**). Examples of oxbows or abandoned meanders are all along the James River as it flows across the Coastal Plain. Historically, some meanders were forced to be abandoned to facilitate faster shipping or avoid defenses during the Civil War, such as the Dutch Gap canal, which bypasses the channel around Farrar's Island (see "Geologic Heritage").

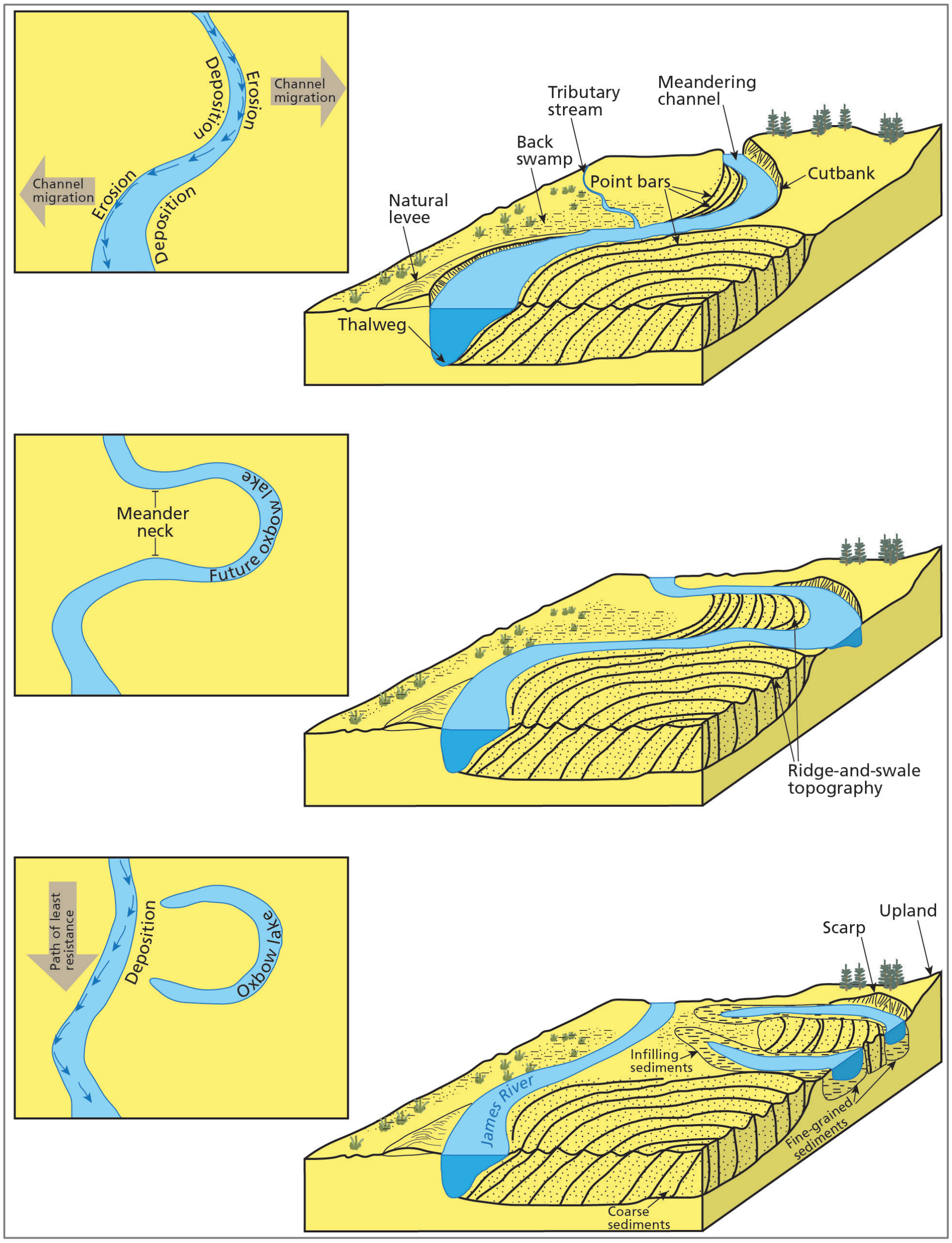

Figure 20. Illustration of fluvial processes of meandering. River meandering causes the formation of abandoned channels that infill with fine-grained sediments. Fluvial features at the park range from the broad, tidal James River to small, unnamed streams and gullies. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Allen (1964).

Floodplains are areas of typically low-lying ground adjacent to a river (see Figure 20). They are commonly formed of river sediments (e.g., alluvium, geologic map units **Qal**, **Qp**, **Qac**, and **Qn**) and are subject to flooding. A backswamp is commonly found in a floodplain. Backswamps occur where deposits of fine silts and clays settle after a flood. Backswamps usually lie behind a stream's natural levees (**Qn**)—landforms that flank a river channel that form as cresting water dumps its heaviest sediments before flowing across the floodplain. During a flood, if water levels rise above the height of the levee, the floodplain is inundated with water and sediments. When active flooding stops, water and sediments may remain trapped and settle, forming a backswamp.

The fluvial terraces perched above the modern floodplain are a clear record of stream incision. A stream flows at a certain elevation for some time, building a floodplain and natural levees. As the stream meanders away or incises lower elevations, some older terraces are left behind. At the park, most of the Pleistocene alloformations ("**Q**" units) form a sequence of inset terraces with younger units underlying lower elevation terraces (see "Coastal Plain Stair-Step Terraces"; Cross et al. 2017; Occhi et al. 2018); however, younger fluvial terraces are similarly forming along the park's rivers. They are not delineated in the GRI GIS data.

Local bedrock can have a strong influence on the type of fluvial features forming at the park. A stark contrast exists between the solid bedrock of the Petersburg Granite (**PNMpgu**, **PNMpg**, **PNMpp**, **PNMpf**, **PNMpl**, and **PNMpm**) and the softer, unconsolidated Coastal Plain deposits ("**K,**" "**T,**" and "**Q**" units). Though not mapped at the surface inside the park, in areas underlain by the granite, stream development is limited, and the streams do not meander as much. In areas underlain by the softer sediments, complex dendritic drainages (systems of stream channels that look like tree branches on a trunk in map view) form.

Geologic Resource Management Issues

Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues (see “Guidance for Resource Management”). The issues are ordered with respect to management priority.

Erosion of Bluffs Along the James River

Maximum relief in the park is only about 45 m (150 ft) total; however, this relief largely occurs as steep slopes on the bluffs facing the James River. Bluffs along the James River are prone to erosion and land loss. Most of the park lands along the river are located at Drewry’s Bluff. Drewry’s Bluff, atop which Fort Darling is located, is among the areas most at risk as it is on an outer bend of the river. Erosion (both natural and due to passing vessels) threatens the cultural resources there (Thornberry-Ehrlich 2005; National Park Service 2017b). In 2008, a site survey revealed erosion scars, bluff edges, and cliff depressions, a term encompassing trenches or pools associated with the Civil War fortifications and quarrying to build the fort (Gerstel 2008; EA Engineering 2021). These tend to gather water and funnel it toward the bluff, exacerbating erosion (Figure 21; Gerstel 2008; Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, written communication, 12 March 2024). Another site visit in 2011 noted near-vertical faces along some parts of the escarpment (Figure 22) near the top of Drewry’s Bluff that will eventually fail, slumping down the hillside as a series of landslides, while also noting some fairly stable, slowly eroding toe slopes in other areas (Martin 2011).

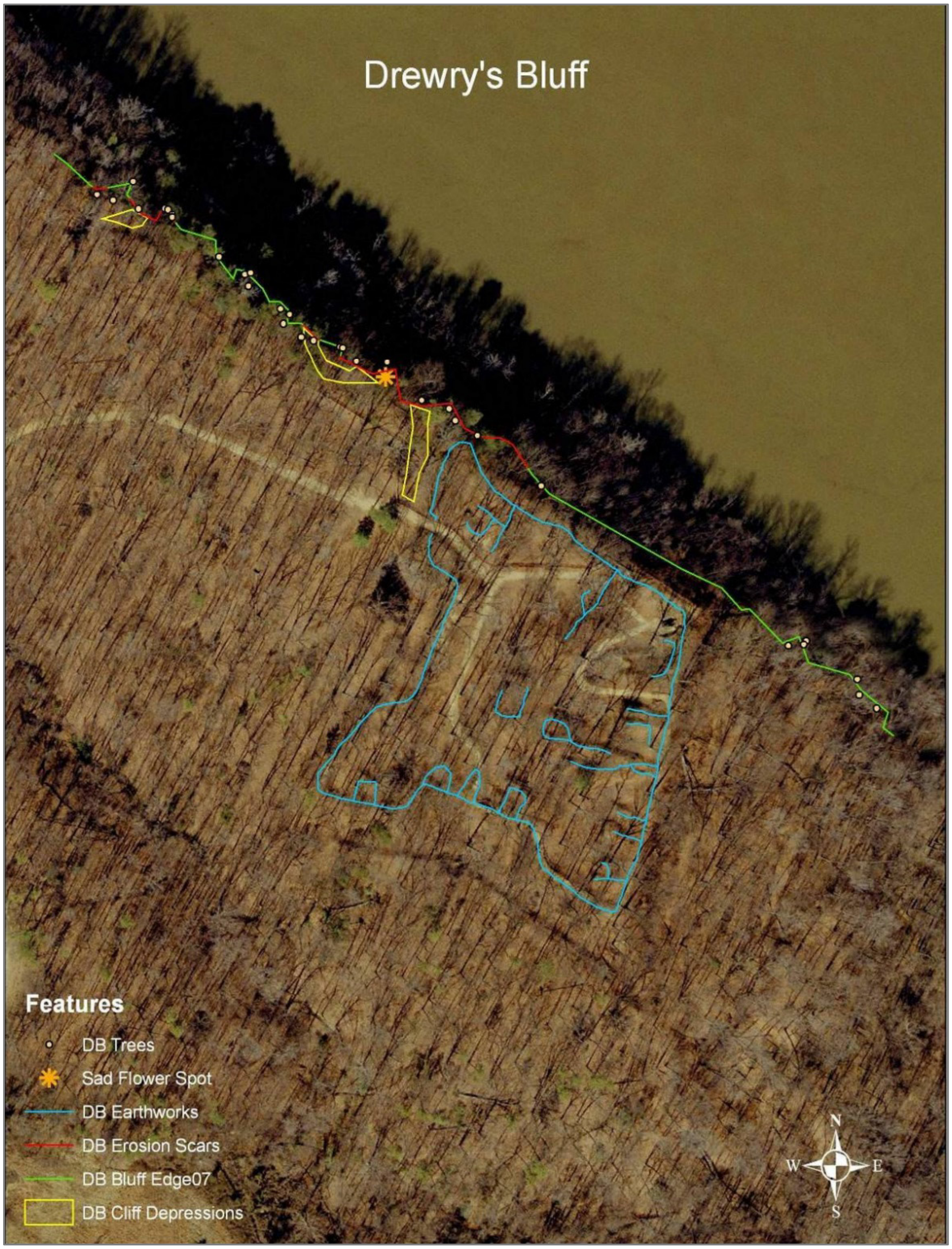

Figure 21. Aerial photograph of Drewry's Bluff with GPS-located features. White dots represent trees at the bluff crest, red lines are erosion scars, green lines are the bluff crest, yellow areas are cliff depressions, and blue lines outline the earthworks associated with the cultural resources at the site. The "Sad Flower Spot" refers to an unofficial memorial site (with flowers) that had been established near the bluff edge around the time of the map's creation. A correlation seems to exist between erosion scars and depressions (e.g., trenches funneling water toward the bluff), while more stable bluff segments are occupied by trees. Graphic by K. Allen and A. Trivizas (Richmond National Battlefield Park) presented as Figure 1 in Gerstel 2008.

Figure 22. Photograph of near-vertical slopes at Drewry's Bluff. Failure and slumping in these steep areas are inevitable, and the bluff is inherently unstable. As slumping proceeds, the edge of the bluff will migrate some distance inland and the slope will eventually reach a new, temporary equilibrium. The material exposed on the face of the bluff is predominantly sand, gravel, and some clay layers in the Bacons Castle Formation (Qbc). Photograph is an unnumbered figure from Martin (2011).

Drewry's Bluff is eroding and retreating as a result of two main processes: 1) the river-dominated, bottom-up process (i.e., erosion from the bottom at the toe of the slope by the river); and 2) the groundwater-dominated, top-down process (i.e., a process by which groundwater percolating through the bluff from the top, through low cohesive soils, and emerging on the face of the bluff might undermine its stability) (Gerstel 2008; EA Engineering 2021). Seeps occurring on the bluff face can also contribute to instability because they can weaken and erode overlying sand layers. In the toe erosion process, the thalweg (deepest point in the channel) of the James River (see Figure 20) is aimed directly at Drewry's Bluff, so the river's erosive energy is focused there. Where the lower slope sediments of the Potomac Formation and Lower Tertiary sediments, undivided (geologic map units **Kp** and **Tl**, respectively), are undermined, oversteepened or overhanging slopes collapse as shallow slides or slumps, and the scarp migrates inland, contributing to the retreat of the bluff (Gerstel 2008; Bondurant et al. 2011a). It remains unclear how much of each process (bottom-up or top-down) is responsible for the bluff retreat.

The second, top-down process of groundwater infiltration and discharge involves topographic depressions (including historic trenches acting as infiltration beds; Figure 23) along with cobble gravel sites in the upland areas underlain by the Bacons Castle Formation (**Qbc**), which act as recharge points to mid-slope springs or seeps. In turn, the seeps may function as trigger points for slump formation (Gerstel 2008; Martin 2011; Bondurant et al. 2011a). The local sedimentary layers dip northward, contributing to groundwater flow toward the face. Rills and gullies develop in the slope face several meters below the crest of the bluff (Gerstel 2008).

Figure 23. Photograph of Civil War trenches atop Drewry's Bluff. Topographic lows, such as the trenches excavated during the construction of the fort atop the bluff, may be acting as sinks to infiltrating groundwater, which may in turn funnel water toward the eroding bluff face and contribute to its instability. Photograph is an unnumbered figure from Martin (2011).

The cultural landscape condition at Drewry's Bluff was listed as poor, given in part the threat from bluff erosion (National Park Service 2017a). Currently, the situation at Drewry's Bluff has been left to natural processes, some GPS monitoring of the bluff edge, as well as terrestrial scanning, with plans to repeat the scans every five years (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). Mitigating slope loss at Drewry's Bluff may involve several overlapping strategies directed in part to reduce the top-down groundwater flow and to protect the toe of the slope from erosion. Stabilizing roots from trees and shrubs were noted by both Martin (2011) and Gerstel (2008), contributing to the structural support for the bluff. For these strategies to be employed, a keen understanding of the historic bluff retreat rates is necessary, as is the identification of potential future changes in the river channel that might affect slope mitigation (Gerstel 2008). Any engineered solution should consider the groundwater seepage at the bluff face (Gerstel 2008). Gerstel (2008) provided a series of potential Scientists in Parks (SIP) program projects to determine the nature and contribution of shallow groundwater seepage at the bluff face.

- Conduct channel migration studies of the James River both upstream and downstream of the bluff site to characterize and evaluate past changes in riverbank morphology to help forecast changes that might occur in the future to the reach below Fort Darling.
- Conduct GIS analysis of GPS mapping of riverbank changes as they occur with the intent to monitor changes and update the model after storm events and seasonal changes.
- Investigate and inventory any landslides as soon as possible after they happen to determine local groundwater flow patterns, river levels, and the contribution of each to the ensuing slope instability.
- Establish photographic stations at critical areas to periodically monitor and capture changes in the bluff position and geomorphic features. Ideally, some photo stations might be from across the river or other fixed locations with direct views of Drewry's Bluff.
- Review any existing borehole or well data for information on groundwater conditions.
- Install shallow groundwater monitoring wells (piezometers) and an on-site rain gauge with continuous-reading data loggers to establish the local groundwater response to storm events. This is important in the areas of most active bluff retreat.
- Install nested piezometers with continuous-reading data loggers to various depths in the (identified) geologic units to characterize both local and regional groundwater response to storm events, the impact the geologic unit has on groundwater response, and to measure aquifer recharge and draining.
- Install horizontal drains in the most prevalent seepage areas of the bluff. These areas should then be monitored after drain installation to evaluate the effectiveness of the drains. Care should be taken to avoid degrading the visual landscape with drains.

Additionally, EA Engineering (2021) provided recommendations based on previous work and more recent LiDAR (light detection and ranging remote sensing) data. Recommendations included an adaptive management framework for the site to allow for initial stabilization of identified erosive situations and monitoring for further/increasing impacts. These data will inform future decisions about more aggressive stabilization methods. The monitoring aspect involves repeated LiDAR surveys and/or establishing monitoring benchmarks for GPS surveys. River monitoring using a water level logger will ascertain when and if the local erosion rate at the base of the bluff slope increases. Stabilization strategies included fencing to keep pedestrian traffic away from the bluff crest, increasing stabilizing vegetation, filling and regrading ponding areas at the top of the bluff, or installing drains to divert subsurface flow (EA Engineering 2021).

Flooding, Channel Erosion, and Sediment Loading

The park protects areas of the James and Chickahominy Rivers, White Oak Swamp, Western Run, Boatswain and Powhite Creeks, as well as other local streams. Flooding and channel erosion are naturally occurring along most of the streams and rivers within the park, which can threaten wetlands, aquatic habitats, cultural resources, and visitor facilities. Flooding and channel meandering are natural processes, (e.g., beaver activity at the Boatswains Creek bridge causes local flooding), but in some locations, such as Beaver Dam Creek, the situation is likely exacerbated by increased runoff caused by ground compaction due to increased use, climate change, and the removal or disturbance of vegetation, as well as impervious surfaces such as parking lots and large buildings (Thornberry-Ehrlich 2005; Schneider et al. 2012; Kristen Allen and Michael Fiasco, natural and cultural resources division lead and facility manager, respectively, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). This leads to flash flow or flash flood conditions on several park streams, including Beaver Dam Creek. Consistent stream flow data and monitoring are data needs at the park (Schneider et al. 2012). Fortunately, many of the newly acquired lands have adequate riparian buffer zones to maintain the intact nature of the streams therein (GRI follow-up meeting participants, follow-up meeting, 31 May 2022).

Sediment loads in several of the smaller streams and creeks at the park appear unnaturally high with muddy flows and clogged channels (Figure 24; Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). Rapid runoff-causing flash flows entrain unnaturally high sediment loads. This may be due in part to agricultural clearing and farming practices in nearby areas. Erosion from upstream urbanization causes increased sediment loads downstream into the park’s Beaver Dam Creek area. This low-lying area is a natural deposition site, but the riparian zone vegetation has shown signs of stress or die-off (Gregory et al. 1987).

Figure 24. Photograph of unidentified stream at Chickahominy Bluff. The stream is choked with sediment after a flash flood event washed eroded material from adjacent areas. Aquatic habitats are degraded in such instances. Park streams may be becoming “flashier” as impervious surfaces associated with adjacent urbanization prevent widespread infiltration and increase surface flow. Vegetation disturbances also contribute to increased erosion and sediment loads in local streams. Photograph is Figure 92 in Schneider et al. (2012), taken in February 2006.

Management of a Historic and Commemorative Landscape

Park managers strive to restore and preserve a wartime condition (National Park Service 2017a, b). The 1862 and 1864–65 battlefield landscapes are listed among the park’s fundamental and priority resources. The patterns of forests, fields, historic roads, streams, and fence lines help visitors envision the pivotal battles that took place there (National Park Service 2017a). That wartime condition requires both rehabilitating post-Civil War disturbed lands while also resisting some natural processes (e.g., beaver dam activity, natural erosion, tree blowdowns, etc.) acting on the battlefield landscapes. Some recent land acquisitions (e.g., 255 ha [630 ac] at North Anna battlefield; 89 ha [220 ac] at Frayser’s Farm [Glendale] battlefield, and 1.3 ha [3.2 ac] at Gaines’ Mill battlefield) require structural removal, dumpsite cleanup, and rehabilitation (Figure 25; National Park Service 2017b).

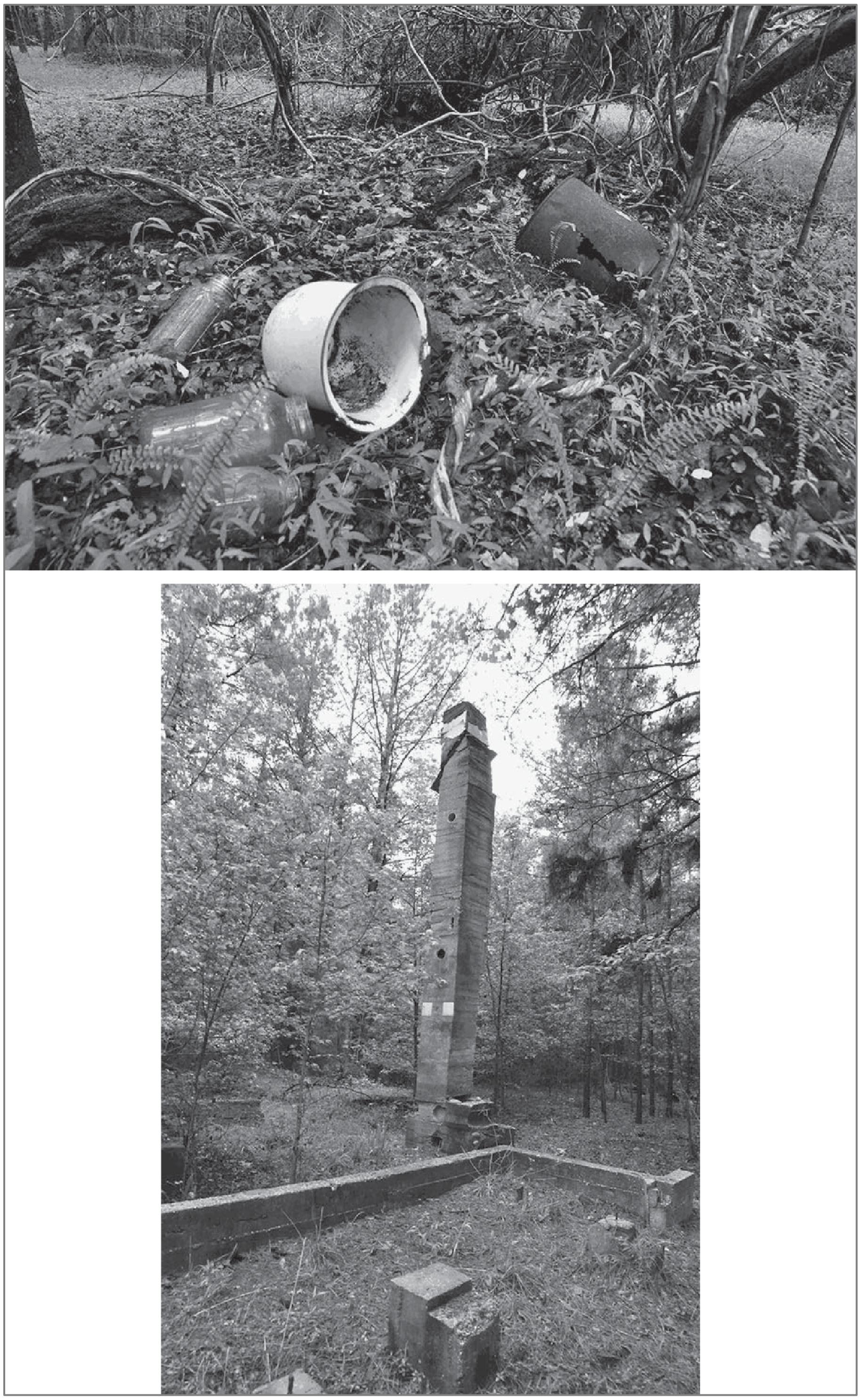

Figure 25. Photographs of a dump site and relic housing features at the park. The first image shows glass, metal, and other objects at a forested dumpsite near the Isaac Sykes farm. The second image shows a foundation and chimney left from the 20th century Morrow House located near Whitlock Farm. Photographs are Figures 27 and 26 from Hammond (2017a).

Understanding erosion at some of the newly acquired units is a resource management need (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). At the Totopotomoy Creek unit, the soil is very erodible, and the landscape includes a plateau that slopes down to the creek. Erosion is causing large gullies to form on the slopes and drain down to the creek. At Rural Plains, erosion is threatening trails while washing sediments off the cleared fields and into the adjacent woods. Upland gullies are forming because of erosion at Drewry's Bluff as well (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). Exposures at Fort Harrison/Fort Brady on the north side of the James River are also experiencing issues with erosion impacting the historic landscape; some of this area is beyond park boundaries (Mark Carter, geologist, US Geological Survey, follow-up meeting, 31 May 2022).

During the time of the Civil War, the park's landscape was very different, with open fields, agricultural lands, and streams in different places. Today, these areas are mostly forested or are part of suburban development associated with modern Richmond (Thornberry-Ehrlich 2005). Threats to the landscape include vandalism, inappropriate recreational activities, erosion exacerbating off-trail use, illegal dumping (particularly at Fort Darling and Parkers Battery units), relic hunting, and off-road use (Sams and Brown 1999a, b; National Park Service 2017b). The park's earthworks include about 24 km (14 mi) of earthen trenches, batteries, and fortifications as primary resources (National Park Service 2017a). Tree growth, leaf litter, and erosion affect the shape and integrity of the earthworks in places like Fort Harrison, Fort Gilmer, Fort Maury, Fort Brady, and Fort Johnson (Northeast Regional Office and Others 2015b). Earthworks are more prone to erosion due to their inherent steep slopes, visitor appeal, disturbed and naturally infertile soils, and inadequate ability to support stabilizing plants (Schneider et al. 2012).

Occasionally, the park's missions of maintaining a historical landscape and preserving natural habitats run counter to each other. For example, clearing trees and their stabilizing roots for historical restoration, such as on earthworks (Figure 26), can lead to localized erosion, increased sediment load in nearby streams, and could potentially contribute to slumps and landslides. The park tries to keep the earthworks forested or covered in native grasses or leaf litter. In some places (e.g., Fort Brady), the James River has eroded 9 to 15 m (30 to 50 ft), and the fort appears directly above the river channel, at odds with its historic appearance (Northeast Regional Office and Others 2015b). As of 2022, the park's priority was given to protecting viewsheds that were most likely to enhance visitors' understanding of the park's history. Other areas are mostly left to allow natural processes to proceed; this especially includes streams, wetlands, and erodible soils (National Park Service 2017a; Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022).

Figure 26. Photographs of historic features and trees growing on earthworks. At the park, historic landscapes are a resource management priority. Many have been altered from their historic appearance by intervening land use, trees and vegetation, and visitor use. The upper left image shows the Federal well at Fort Harrison. Note the large trees growing on the adjacent earthworks. The upper right image shows trees growing in earthworks at Fort Brady. The bottom left image shows a trail to earthworks flanked by trees at Fort Brady overlook. The bottom right image shows trees growing on earthworks near a park trail at Fort Gilmer. Photographs were presented as Figures 27, 17, 20, and 16 from Northeast Regional Office and Others (2015b), respectively.

The commemorative markers (e.g., "Freeman markers") and monuments (e.g., the Connecticut, Wilcox, Parker's Battery, and Texas monuments) at the park are threatened by nearby roads, weathering, erosion, general aging, vandalism, and cracking mortar (National Park Service 2017a). The Freeman markers consist of cast iron plaques set into a concrete base, and they required rehabilitation in 2010; they will require future monitoring and protection from damage inflicted by vehicles (National Park Service 2017a). Some of the threats to monument and marker integrity may be exacerbated by climate change due to increases in flooding and associated erosion (see "Climate Change"). These features are listed in good condition and documented in the list of classified structures database; however, baseline natural and cultural resource data for newly acquired or future-acquired lands was listed as a data need in the foundation document (National Park Service 2017b). This may be an opportunity to use volunteers to help maintain monuments and regularly monitor them with yearly condition surveys (National Park Service 2017b).

Hydrogeological Characterization and Groundwater Quality

The hydrogeological system at the park is highly variable and bisected by the fall line. West of the fall line, the aquifer yields groundwater from secondary porosity and permeability along fractures in the bedrock and thin layers of overlying surficial deposits. East of the fall line, sand, gravel, and limestone aquifers occur in layers separated by less permeable silts and clays (US Geological Survey 2009; Schneider et al. 2012). The balance between infiltration (the amount of precipitation that can be absorbed into the groundwater) and runoff varies significantly on either side of the fall line (Schneider et al. 2012). There is a great need to understand how groundwater is percolating through the subsurface system of interlayered, discontinuous aquifers and impermeable layers because groundwater from the shallow aquifer system contributes to the flow in streams and a large part of the water in wetlands. If groundwater quantity or quality is compromised, the negative effects will ripple through the entire stream and wetland system.

Factors affecting groundwater-level fluctuations are complex and include variations in rainfall and evapotranspiration, aquifer rock types, geologic structures, and human activity. Droughts and human water use have the potential to deplete the shallow aquifer system. Knowledge of groundwater ages and recharge rates helps to constrain groundwater flow models within the shallow water aquifer system and can help remediation activities by providing estimates of the speed at which contamination moves through the hydrogeologic system and how this varies spatially (Nelms et al. 2001).

The park does not have a groundwater management plan (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). A comprehensive understanding of the connections between the groundwater and surface water features would facilitate management of the quantity and quality of water in the park's streams, wetlands, and associated riparian habitats. At Drewry's Bluff, if groundwater drainage was somehow diverted away from the bluff, it may help prolong or protect the bluff face. It would also help with cultural resource management. Some older structures, like a house built in the 1700s, have a problem with basement moisture, which calls for an awareness of how groundwater is moving toward the building and grading the surrounding land to solve the issue (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022).

Because of chemical reactions between percolating groundwater and the local geology, well-water quality can be low (acidic) in the park area. Some parts of the park, like Fort Harrison and Gaines' Mill, get their water from wells. A well inventory is a resource management need at the park, as is a comprehensive groundwater monitoring program (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). Long-term monitoring of the system would provide information for evaluating long- and short-term trends. This would involve installing wells, as well as monitoring groundwater levels and rates of discharge at springs and stream flows. The Mid-Atlantic Inventory and Monitoring Network monitors water quality and quantity in some of the park's streams, which receive some input from the groundwater system. Their website has more information: https://www.nps.gov/im/midn/rich.htm. Detailed water quality discussions are beyond the scope of this report. Contact the NPS Water Resources Division at https://www.nps.gov/orgs/1439/index.htm for more information and assistance.

Slope Movements and Instability

Slope movements, also called “mass movements” or referred to generally as “landslides,” have occurred and will continue to occur in the park. Slope movements are the downslope transfer of material (e.g., soil, regolith, and/or rock). Slope movements can occur rapidly (e.g., debris flows or rockfall) or over extended periods (e.g., slope creep; Figure 27). Gravity, frost and plant-root wedging, erosion, seeping groundwater, and swelling clays are the primary causes of slope instability at the park. The magnitude of slope failures depends on slope, aspect, soil type, and geology. Within the park, much of the landscape is low rolling to moderate slopes except for the steep bluffs along the James River (see “Erosion of Bluffs along the James River”).

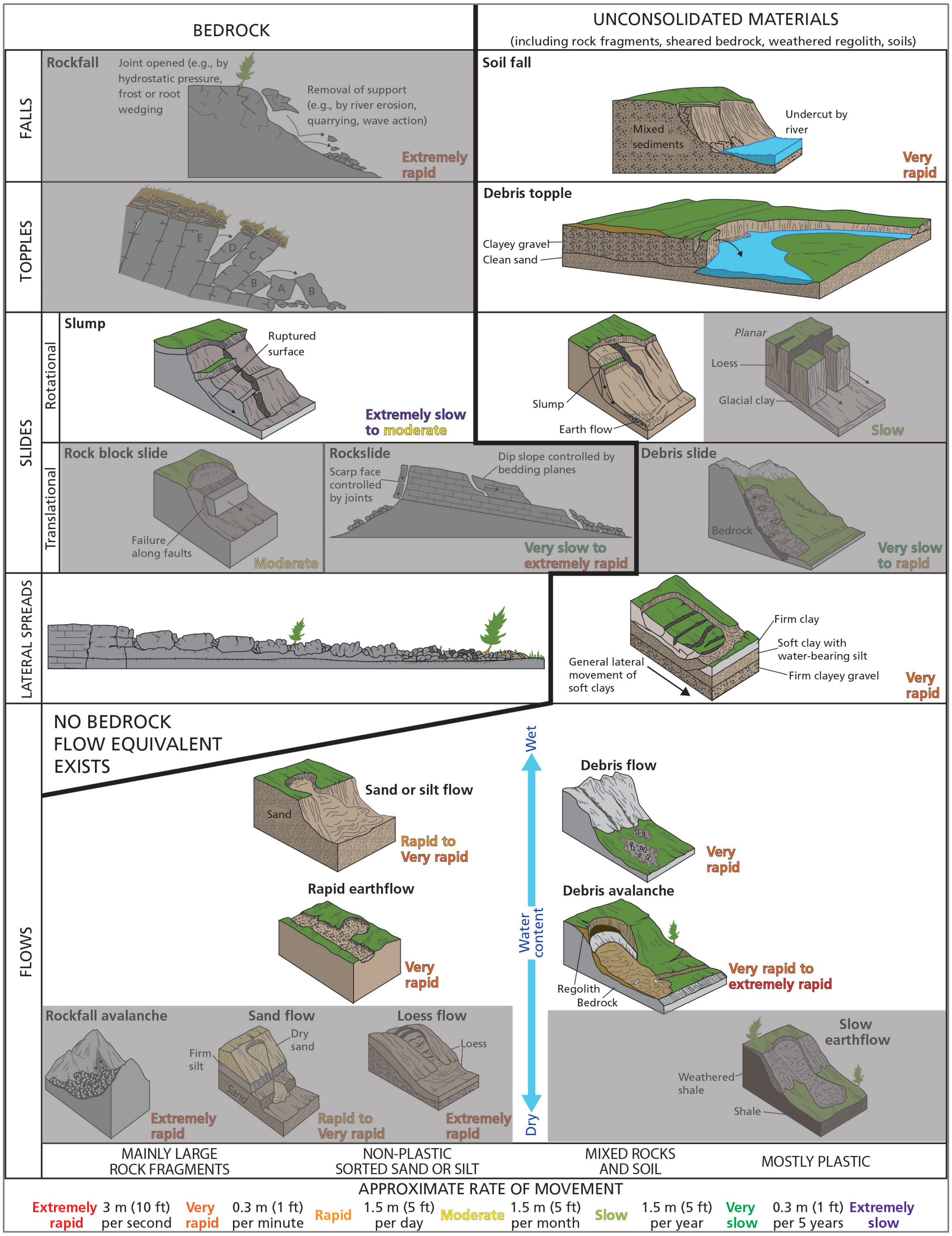

Figure 27. Illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at the park. The abundant vegetation in the park stabilizes some slopes, but slope issues could be exacerbated by factors such as natural or anthropogenic removal of vegetation, upstream development, and climate change. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

A landslide near the Chimborazo Hospital occurred in 2004 in the wake of Tropical Depression Gaston, which drenched the area in rain. The slide happened near 31st and Grace Streets, west of the park boundary; however, the slide is part of a much larger, translational slide (downslope movement of material that occurs along a distinctive planar surface of weakness) that covers approximately 4 ha (11 ac) on the west-facing slope of Chimborazo Hill, capped by the Bacons Castle Formation (geologic map unit **Qbc**) and underlain by the Lower Chesapeake Group, undivided (**Tcl**), and Lower Tertiary sediments, undivided (**Tl**). The greater slide structure extends from the southeastern corner of the Chimborazo Park playground southward to the Norfolk Southern Railroad tracks south of Chimborazo Hill, and from the crest of Chimborazo Hill westward to the abandoned railroad grade in the stream valley of Blood Run (Carter and Berquist 2005). Tension cracks on the slope and minor scarps along the slide structure suggest future failures are likely. Unresolved issues, including the understanding of the geometry and physical properties of the underlying rupture surface, the timing and progression of slope failure, and the role that the fill material at the playground (**Qml**) and preexisting discontinuities within the Coastal Plain formations played during the catastrophic failure of Chimborazo Hill (Carter and Berquist 2005).

At the Gaines Mill area, the Miocene-age blue-gray Richmond clay beneath the Yorktown Formation and Cold Harbor formation (**Tym**, **Ty**, and **Tch**) is creating a situation that may be unstable when saturated with water. Water filters down to the blue-gray clay and pushes outward along the top of the natural aquiclude (a relatively impermeable layer that restricts the percolation of groundwater). Beaver Dam Creek may also be an area of landslide concern (Mark Carter, geologist, US Geological Survey, follow-up meeting, 31 May 2022).

The GRD employs three landslide management strategies: (1) an Unstable Slope Management Program (USMP) for transportation corridor risk reduction, (2) quantitative risk estimation for specific landslide hazards, and (3) monitoring of potential landslide areas. Park managers can contact the GRD to discuss these options and determine if submitting a technical request is appropriate. Further information about slope movements is provided in "Guidance for Resource Management" and the slope movement monitoring website: http://go.nps.gov/monitor_slopes. The Virginia Department of Energy has also created a landslide inventory and is mapping extensively in the Richmond area (information at https://www.energy.virginia.gov/geology/Landslides.shtml).

Active Faults and Earthquakes

Seismic events, though rare, are possible at the park (Figure 28 and Figure 29). Nevertheless, as indicated by its occurrence in the USGS Quaternary fault database, an area between Richmond and Charlottesville has experienced the most recent seismicity activity—called the Central Virginia seismic zone. In 2003, a 4.8 magnitude earthquake occurred in the area. Notably, in 2011, the 5.8-magnitude Virginia earthquake caused major damage in an area of the Central Virginia seismic zone that was considered to be at relatively low risk for earthquakes (Mark Carter, geologist, US Geological Survey, written communication, 21 July 2018). Within a week in May 2022, two detectable earthquakes occurred in the seismic zone, and one was centered in the Richmond area (Mark Carter, geologist, US Geological Survey, follow-up meeting, 31 May 2022). As proven by the 2011 Virginia earthquake, major damage from an earthquake can occur in an area that was previously considered to be relatively inactive. It was possibly caused by the relaxation of Earth's crust in response to the load of sediments accumulating on the Coastal Plain. In addition to the ground shaking associated with earthquakes, there are landslides, damage to buildings and structures, and ground- and surface-water disturbances. Though the probability of a destructive seismic event at the park is low, resource management should be aware of the potential.

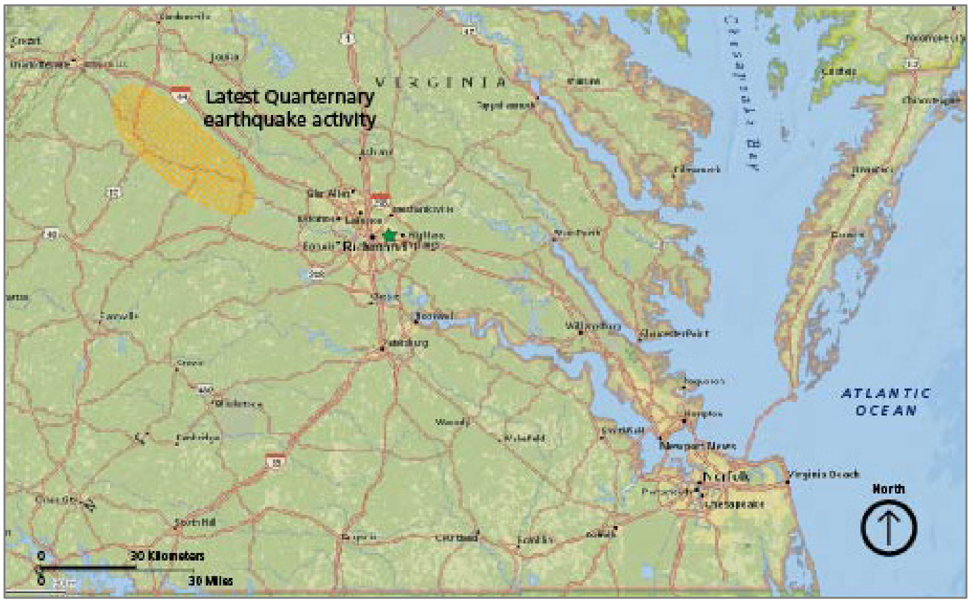

Figure 28. Map of eastern Virginia Quaternary earthquake activity. The orange hatched area northwest of Richmond and Petersburg indicates an area of latest Quaternary (<15,000 years) seismicity in a well constrained location. This area was the epicenter of the 2011 earthquake that shook the eastern US. Map courtesy of the US Geological Survey; available at https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf

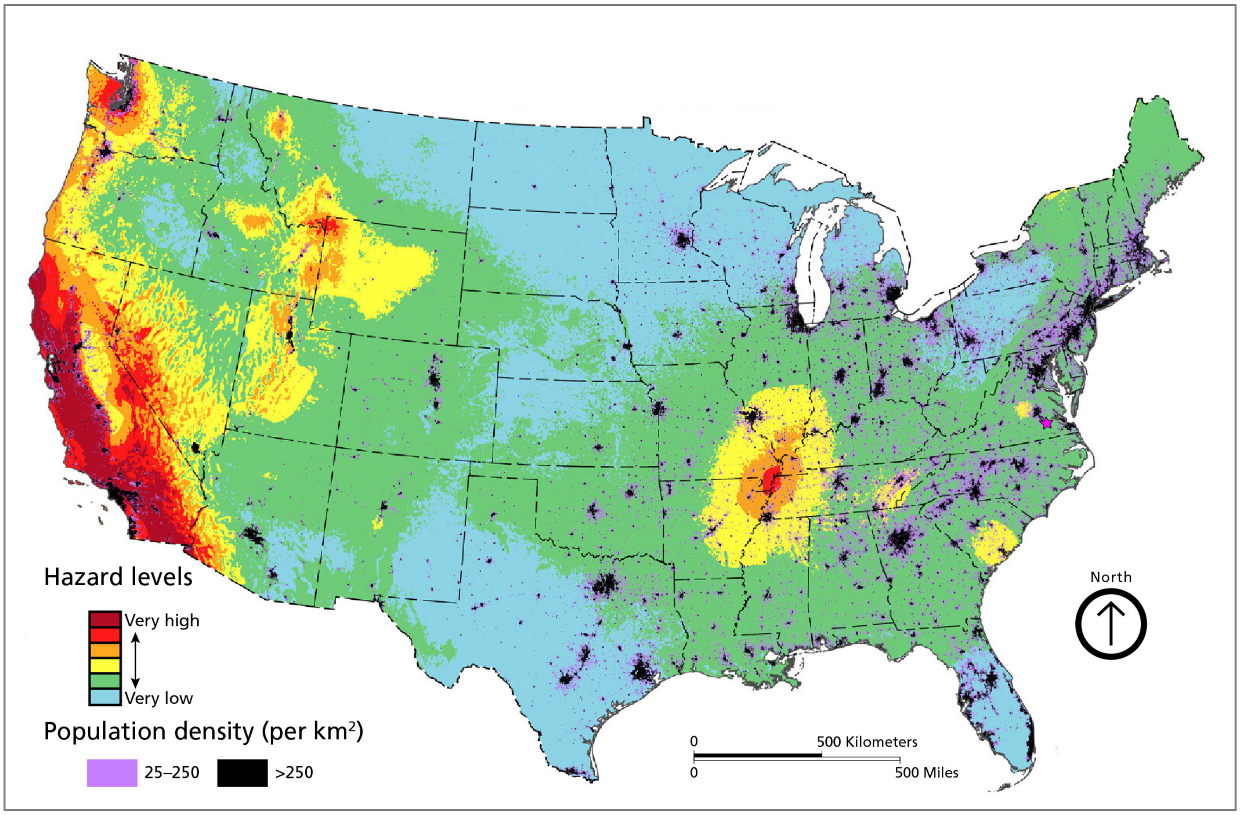

Figure 29. National seismic hazard map. The map shows the chance of any level of damaging earthquake shaking in 100 years from the 2023 50-State National Seismic Hazard Model. The shaking is equivalent to Modified Mercalli Intensity VI and higher and is based on the average peak ground acceleration and 1-s horizontal spectral response acceleration (using Worden et al. 2012 model without uncertainty). Ground motions are amplified using hybrid VS30 estimates (Heath et al. 2020). Population density (LandScan, Dobson et al. 2000 with 1 km×1 km resolution from Oak Ridge National Laboratory) is superimposed on the map. Locally, the hazard may be greater than shown because site geology may amplify ground motions. Because of the strong 2011 earthquake in Central Virginia, the area near the park is a "bullseye" of hazard potential and has moderate probability of seismicity. Park location is purple star. Map by Petersen et al. (2024, Figure 3) available at https://doi.org/10.1177/87552930231215428

The park has no earthquake plans in place, and there is some concern over the potential impacts of seismicity on historic structures (e.g., necessary masonry repairs in the Totopotomoy Creek and Rural Plains areas) and park slopes (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). The NPS Geologic Resources Division Seismic Monitoring website (http://go.nps.gov/seismic_monitoring), and the US Geological Survey Earthquakes Hazards website (http://earthquake.usgs.gov/) provide more information about seismic hazards. In the *Geological Monitoring* chapter about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

Land Cover Change, Disturbed Lands, and Abandoned Mineral Lands

Population and urban sprawl are ongoing issues in Richmond, Virginia. One of the park's largest management challenges is its fragmented nature and the nature of the surrounding land use (National Park Service 2015). Individual units are islands of protected land, a fragmented ecosystem, amidst suburban sprawl. Land cover change, encroaching development, urban expansion, and heavy vehicle use are ongoing issues for the park, commonly serving as a primary threat to natural resources (Schneider et al. 2012; National Park Service 2015, 2017a). Issues with electrical lines and poles, sewer pipes, soil and gas line proposals, and stone-blasting questions are all common for park resource management and have geologic connections (Mary Krueger, NPS Northeastern Region, follow-up meeting, 31 May 2022). Among the greatest impacts on geologic resources at the park from increasing adjacent urbanization are:

- An increase in impervious surfaces (roofs, parking lots, roads, etc.) exacerbates surface runoff during precipitation.
- An acceleration in erosion through ground surface disturbances and the removal of stabilizing vegetation, which in turn leads to soil degradation and subsequent suspended sediment in streams and aquatic habitat impacts.
- A decrease in deep-rooted trees reduces the potential for woody material to be introduced into the stream channel, which dissipates energy and increases aquatic habitat diversity.
- Unauthorize roads and social trails.
- Occasional illegal dumping.
- An addition of point sources of pollution (e.g., chemical spills at Drewry's Bluff) and stormwater drainage problems.
- An increase in visitation and human use is leading to trail degradation, overused areas, social trails, and more (Schneider et al. 2012; National Park Service 2015; National Park Service 2017a, b).

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by human activities such as development, agricultural activities (such as farming, grazing, timber harvest, and abandoned irrigation ditches), and overuse or inappropriate use. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Restoration activities return a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. At the park, many of the disturbed lands are considered historic and fundamental to the purpose of the park (e.g., earthworks or trenches). Early settlers' farming and homestead activities created an unnatural landscape that persists to this day. Minor irrigation features, removal of soil and rocks, stone fences, grazed pastures, extensive logging, farm roads, and other homestead features dot the park's landscape (Thornberry-Ehrlich 2005). Every time the park increases its land holdings, many come with modern buildings and debris that must be removed.

Drewry's Bluff is surrounded by industrial and/or potentially impaired sites. An old county landfill was part of a 1970s-era land acquisition adjacent to the Drewry's Bluff unit along the James River. This landfill was active before current regulations (including lining and capping landfills) were put in place to control water contamination by chemicals and other leachate waste. In 2022, it remains a resource management concern and target for restoration (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, follow-up meeting, 31 May 2022). A stream near the landfill, which has an unnatural reddish color, is not currently being regularly monitored or studied (Kristen Allen, natural and cultural resources division lead, Richmond National Battlefield Park, GRI scoping meeting communication, 13 April 2005). This landfill and associated stream are being investigated through the Comprehensive Environmental Response, Compensation, and Liability Act (National Park Service 2017a, b). Of additional concern is an asphalt plant that is upstream from the park, which has a state National Pollutant Discharge Elimination System permit to release its stormwater into the park stream (Figure 30; National Park Service 2017b).

Figure 30. Scoured stream channel near Drewry's Bluff. Releases from a retention pond at the neighboring asphalt company caused degradation to the aquatic habitats along this stream. Sudden pulses of water flooded through this drainage, removing stabilizing woody debris while scouring and deepening the channel. The current source for this stream is the oil-water separator at the neighboring asphalt plant (Kristen Allen, natural and cultural resources division lead, NPS Richmond National Battlefield Park, written communication, 12 March 2024). Photograph is Figure 29 from Schneider et al. (2012).

According to the NPS Abandoned Mineral Lands (AML) database (accessed 31 May 2022 by Kyle Hinds, mine engineer, NPS Geologic Resources Division) and Burghardt et al. (2014), the park contains one inventoried AML feature: a surface mine that is noted as remediated, filled, graded, and vegetated; however, known mined areas such as abandoned sand and gravel pits and quarries occur throughout the area. Furthermore, with so much additional land added to the park since 2005, the potential for more AML features is high (Thornberry-Ehrlich 2005; GRI follow-up meeting participants, follow-up meeting, 31 May 2022). In the Malvern Hill area, the park filled most of the sand pits. A sand pit across Picnic Road is now filled with runoff and groundwater; an artificial pond might serve hydrogeologic modeling purposes (Thornberry-Ehrlich 2005). The state of Virginia's abandoned mine land program has an inventory of mine features such as small open pit mines. Mines are constantly being identified and scanned into their database. As of 2023, none of the state's inventoried features are located within the park, but this is a consideration for future land acquisitions and adjacent land-use concerns. AML features present a variety of resource management issues for visitor and staff safety; air, water, and soil quality; as well as providing habitat for animals. Resource management of AML features requires accurate inventory and reporting. All AML features should be recorded in the AML database (the NPS Geologic Resources Division may be able to provide assistance). An accurate inventory can identify human safety hazards and facilitate the reclamation and restoration of features. When appropriate for resource management and visitor safety, features can also present opportunities for interpretation as cultural resources. The NPS AML Program website, https://www.nps.gov/subjects/abandonedminerallands/index.htm, provides further information.

Paleontological Resource Inventory, Monitoring, and Protection

Nearly all the sedimentary geologic map units at the park are known to contain fossils elsewhere. In most cases, these fossils remain buried, but RICH has never had a formal paleontological inventory, and such a project would likely uncover a variety of paleontological resources (Justin Tweet, paleontologist, NPS Geologic Resources Division, written communication, 31 January 2024). Drewry's Bluff provides a leading example of a fossiliferous exposure within the park. Unfortunately, the bluff is actively eroding, threatening fossil and cultural resources that may be present (see "Erosion of Bluffs along the James River"). Recommendations for paleontological resources include periodic monitoring of any paleontologically significant outcrops, as well as studying the effects of erosion management, flooding, and earthquakes on fossil deposits (Kenworthy et al. 2006).

Climate Change

Although climate change planning is beyond the scope of this GRI report, a brief discussion of climate change is included because of the potential disruption it may cause to the park's resources, including geologic resources. Climate models report that recent climatic conditions are already shifting beyond the historical range of variability for temperature and precipitation (Monahan and Fisichelli 2014). Over a 119-year record (1894–2012), mean annual temperature showed an increasing linear trend of +0.06°C (+0.1°F) per decade; however, warming since 1960 has been more rapid, +0.09°C (+0.17°F) per decade (Fisichelli 2013). That same record showed annual precipitation increasing on a linear trend, +17 mm (+0.66 in) per decade (Fisichelli 2013). The year 2020 was the third warmest and wettest year ever recorded in the park’s counties (Wofford 2018, 2020, 2021). Climate models predict increased annual temperatures, intensified storms, stronger winds, floods, and/or drought periods, as well as an overall increase in visitation, which in turn may lead to overuse, social trail development, and erosion (Monahan and Fisichelli 2014; Fisichelli and Ziesler 2015). During high-precipitation storms, such as Hurricane Gaston in 2004, flooding of the James River inundates the city of Richmond with mud and debris. Storms may also trigger landslides and slumps along cliff faces and bluffs (e.g., Drewry’s Bluff) by saturating the underlying soil material, removing stabilizing vegetation (windblown trees), and undercutting slopes (National Park Service 2017a; EA Engineering 2021). Knowledge of fracture patterns, such as those that parallel cliff or bluff faces, is important in understanding and predicting which features are more prone to failure following a storm event (Thornberry-Ehrlich 2005).

Planning adaptation to climate change and the need for a climate change vulnerability assessment were listed as planning needs in the park’s foundation document (National Park Service 2017b). Park managers are directed to the NPS Climate Change Response Program (https://www.nps.gov/orgs/ccrp/index.htm), which helps park managers develop plausible, science-based scenarios that inform strategies and adaptive management activities.

Recognizing that climate change can result in shifts in precipitation patterns, increased erosion, infiltration, and streambank undercutting, the park is a “Climate Friendly Park” (see https://www.nps.gov/subjects/climatechange/cfpprogram.htm). This means the park has conducted a greenhouse gas emission inventory, participated in a climate change and sustainability educational workshop, set climate change mitigation and greenhouse gas emission reduction goals, and integrated these actions into a park-wide Environmental Management System (EMS).

Guidance for Resource Management

This chapter provides information to assist resource managers in addressing geologic resource management issues and applying NPS policy. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), NPS 2006 Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75).

Access to GRI Products

- GRI products (scoping summaries, GIS data, posters, and reports): http://go.nps.gov/gripubs
- GRI products are also available on the NPS Datastore through the Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.
- GRI GIS data model: http://go.nps.gov/gridatamodel
- Additional information regarding the GRI, including contact information: https://www.nps.gov/subjects/geology/gri.htm

Three Ways to Receive Geologic Resource Management Assistance

- Contact the GRD (https://www.nps.gov/orgs/1088/contactus.htm). GRD staff members provide coordination, support, and guidance for geologic resource management issues in three emphasis areas: (1) geologic heritage, (2) active processes and hazards, and (3) energy and minerals management. GRD staff can provide technical assistance with resource inventories, assessments, and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; laws, regulations, and compliance; resource management planning; and data and information management.
- Formally request assistance at the Solution for Technical Assistance Requests (STAR) webpage: https://irma.nps.gov/Star/ (available on the Department of the Interior [DOI] network only). NPS employees (from a park, region, or any other office outside of the Natural Resource Stewardship and Science [NRSS] Directorate) can submit a request for technical assistance from NRSS divisions and programs.
- Submit a proposal to receive geologic expertise through the Scientists in Parks program (SIP; see https://www.nps.gov/subjects/science/scientists-in-parks.htm). Formerly the Geoscientists-in-the-Parks program, the SIP program places scientists (typically undergraduate students) in parks to complete science-related projects that may address resource management issues. Proposals may be for assistance with research, interpretation and public education, inventory, and/or monitoring. The GRD can provide guidance and assistance with submitting a proposal. The Geological Society of America and Environmental Stewards are partners of the SIP program. Visit the internal SIP website to submit a proposal at https://doimspp.sharepoint.com/sites/nps-scientistsinparks (only available on DOI network computers).

Geological Monitoring

Geological Monitoring (Young and Norby 2009) provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Chapters are available online at https://www.nps.gov/subjects/geology/geological-monitoring.htm

Park-Specific Documents

The park's resource stewardship strategy summary (National Park Service 2017a), foundation document (National Park Service 2017b), state of the parks report (National Park Service 2015), and natural resource condition assessment (Schneider et al. 2012) are primary sources of information for resource management within the park. These reports also contain long- and short-term goals, as well as high-priority activities. Cultural landscape reports also contain references to natural features and recommendations for landscape restoration (Dickinson 1987; 1990; Sams 1999; Sams and Brown 1999a, b; Northeast Regional Office and Others 2015a, b; Hammond 2016; 2017a, b; 2019).

NPS Natural Resource Management Guidance and Documents

- National Parks Omnibus Management Act of 1998: https://www.congress.gov/bill/105th-congress/senate-bill/1693
- NPS-75: Natural Resources Inventory and Monitoring guideline: https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Management Policies 2006 (Chapter 4: Natural Resource Management): https://www.nps.gov/subjects/policy/management-policies.htm
- NPS Natural Resource Management Reference Manual #77: https://irma.nps.gov/DataStore/Reference/Profile/572379
- Resist-Accept-Direct (RAD)—A Framework for the 21st-century Natural Resource Manager: https://irma.nps.gov/DataStore/Reference/Profile/2283597

Geologic Resource Laws, Regulations, and Policies

The following sections, which were developed by the GRD, summarize laws, regulations, and policies that specifically apply to NPS geologic resources, geologic processes, energy, and minerals. The first section summarizes law and policy for geoheritage resources, which includes caves, paleontological resources, and geothermal resources. The energy and minerals section includes abandoned mineral lands, mining, rock and mineral collection, and oil and gas operations. Active processes include geologic hazards (e.g., landslides), coastal processes, soils, and upland and fluvial processes (e.g., erosion). Laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, NEPA, or the National Historic Preservation Act) are not included, but the NPS Organic Act is listed when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

Geoheritage Resource Laws, Regulations, and Policies

Caves and Karst Systems

Resource-specific laws:

- **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester.
- **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources.
- **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.

Resource-specific regulations:

- **36 CFR § 2.1** prohibits possessing/destroying/disturbing…cave resources…in park units.
- **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.

NPS Management Policies 2006:

- **Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts.
- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact the cave environment, and to remove existing developments if they impair caves.
- **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.

Geothermal

Resource-specific laws:

- **Geothermal Steam Act of 1970, 30 USC. § 1001** et seq. as amended in 1988, states:
    - No geothermal leasing is allowed in parks.
    - "Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead).
    - NPS is required to monitor those features.

    - Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects.

- **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.

Resource-specific regulations:

- **43 CFR Part 3200** requires BLM to include stipulations when issuing, extending, renewing, or modifying leases or permits to protect significant thermal features in NPS-administered areas (see 43 CFR §3201.10), prohibit the bureau from issuing leases in areas where geothermal operations are reasonably likely to result in significant adverse effects on significant thermal features in NPS-administered areas (see 43 CFR §3201.11 and §3206.11), and prohibit BLM from issuing leases in park units.

NPS Management Policies 2006:

- **Section 4.8.2.3** requires NPS to:
    - Preserve/maintain integrity of all thermal resources in parks.
    - Work closely with outside agencies.
    - Monitor significant thermal features.

<u>Paleontological Resources</u>

Resource-specific laws:

- **Archaeological Resources Protection Act of 1979, 16 USC §§ 470aa – mm Section 3 (1)** Archaeological Resource—nonfossilized and fossilized paleontological specimens, or any portion or piece thereof, shall not be considered archaeological resources, under the regulations of this paragraph, unless found in an archaeological context. Therefore, fossils in an archaeological context are covered under this law.

- **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309 Section 3 (5)** Cave Resource—the term "cave resource" includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems. Therefore, every reference to cave resource in the law applies to paleontological resources.

- **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects.

- **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa** et seq. provides for the management and protection of paleontological resources on federal lands.

Resource-specific regulations:

- **36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof.
- **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted.
- **43 CFR Part 49** contains the DOI regulations implementing the Paleontological Resources Preservation Act, which apply to the NPS.

NPS Management Policies 2006:

- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.

Energy and Minerals Laws, Regulations, and Policies

Abandoned Mineral Lands and Orphaned Oil and Gas Wells

Resource-specific laws:

- **The Bipartisan Infrastructure Law**, **Inflation Reduction Act**, and **NPS Line Item Construction** program all provide funding for the reclamation of abandoned mineral lands and the plugging of orphaned oil and gas wells.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Coal

Resource-specific laws:

- **Surface Mining Control and Reclamation Act (SMCRA) of 1977, 30 USC § 1201** et. seq. prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.

Resource-specific regulations:

- **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.

NPS Management Policies 2006:

- None applicable.

Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)

Resource-specific laws:

- **Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.
- **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas.
- **16 USC §90c-1(b)** authorizes sand, rock, and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and:
    - Only for park administrative uses;
    - After compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment;
    - After finding the use is the park's most reasonable alternative based on environment and economics;
    - Parks should use existing pits and create new pits only in accordance with park-wide borrow management plan;
    - Spoil areas must comply with Part 6 standards; and
    - NPS must evaluate use of external quarries.
- Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Federal Mineral Leasing (Oil, Gas, and Solid Minerals)

Resource-specific laws:

- **The Mineral Leasing Act, 30 USC § 181** et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq. do not authorize the BLM to lease federally owned minerals in NPS units.

- **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in Glen Canyon National Recreation Area, which is the only park unit that contains a STSA.
- **Exceptions:** Glen Canyon National Recreation Area (NRA) (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.) authorize the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration.
- **American Indian Lands** Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108, all minerals on American Indian trust lands within NPS units are subject to leasing.
- **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.

Resource-specific regulations:

- **36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law.
- **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing.
- Regulations re: Native American Lands within NPS Units:
    - **25 CFR Part 211** governs leasing of tribal lands for mineral development.
    - **25 CFR Part 212** governs leasing of allotted lands for mineral development.
    - **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development.
    - **25 CFR Part 224** governs tribal energy resource agreements.
    - **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC §§ 2101-2108).
    - **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases.
    - **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases.
    - **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases.
    - **30 CFR § 1206.450** governs the valuation of coal from Indian Tribal and Allotted leases.

  - **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.

NPS Management Policies 2006:

- **Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

Mining Claims (Locatable Minerals)

Resource-specific laws:

- **Mining in the Parks Act of 1976, 54 USC § 100731** et seq. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas.
- **General Mining Law of 1872, 30 USC § 21** et seq. allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA.
- **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.

Resource-specific regulations:

- **36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law.
- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9**, Subpart A requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability.
- **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 CFR Parts 6 and 9A.
- **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

Nonfederal Minerals other than Oil and Gas

Resource-specific laws:

- NPS Organic Act, 54 USC §§ 100101 and 100751

Resource-specific regulations:

- **NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a business operation (§ 5.3) or for construction of buildings or other facilities (§ 5.7), and to comply with the solid waste regulations at Part 6.

NPS Management Policies 2006:

- **Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.

Nonfederal Oil and Gas

Resource-specific laws:

- **NPS Organic Act, 54 USC § 100751** et seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- Individual Park Enabling Statutes:
  - 16 USC § 230a (Jean Lafitte NHP & Pres.)
  - 16 USC § 450kk (Fort Union NM)
  - 16 USC § 459d-3 (Padre Island NS)
  - 16 USC § 459h-3 (Gulf Islands NS)
  - 16 USC § 460ee (Big South Fork NRRA)
  - 16 USC § 460cc-2(i) (Gateway NRA)
  - 16 USC § 460m (Ozark NSR)
  - 16 USC § 698c (Big Thicket N Pres.)
  - 16 USC § 698f (Big Cypress N Pres.)

Resource-specific regulations:

- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights in parks outside of Alaska to:
  - Demonstrate valid right to develop mineral rights;
  - Submit an Operations Permit Application to NPS describing where, when, and how they intend to conduct operations;

- Prepare/submit a reclamation plan; and
- Submit financial assurance to cover reclamation and potential liability.

- **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 8.7.3** requires operators to comply with 9B regulations.

Recreational Collection of Rocks and Minerals

Resource-specific laws:

- **NPS Organic Act, 54 USC. § 100101** et seq. directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law.
- **Exception: 16 USC. § 445c (c)** – Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).

Resource-specific regulations:

- **36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units.
- **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown National Recreation Area.
- **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.

NPS Management Policies 2006:

- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Transpark Petroleum Product Pipelines

Resource-specific laws:

- The **Mineral Leasing Act, 30 USC § 181** et seq., and the **Mineral Leasing Act for Acquired Lands, 30 USC § 351** et seq. authorize new rights of way across some federal lands for pipelines, excluding NPS areas.
- The only parks with the legal authority to grant new rights of way for petroleum product pipelines are:
    - Natchez Trace Parkway (16 USC §460a)
    - Blue Ridge Parkway (16 USC §460a-8)
    - Great Smoky Mountains National Park (P.L. 107-223 – 16 U.S.C. §403 notes)

- Klondike Gold Rush National Historical Park (16 USC §410bb(c) (limited authority for the White Pass Trail unit)
- Gulf Islands National Seashore – enabling act authorizes rights-of-way for pipelines for oil and gas transported across the seashore from outside the unit (16 USC §459h-3)
- Gateway National Recreation Area – enabling act authorizes rights-of-way for gas pipelines in connection with the development of methane gas owned by the City of New York within the unit (16 USC §460cc-2(i))
- Denali National Park – 2013 legislation allows for issuance of right-of-way permits for a natural gas pipeline within, along, or near the approximately 7-mile segment of the George Parks Highway that runs through the park (Public Law 113–33)

Resource-specific regulations:

- NPS regulations at **36 CFR Part 14 Rights of Way**

NPS Management Policies 2006:

- **Section 8.6.4** states that new rights of way through, under, and across NPS units may be issued only if there is specific statutory authority and there is no practicable alternative.

Uranium

Resource-specific laws:

- **Atomic Energy Act of 1954** allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Active Processes and Geohazards Laws, Regulations, and Policies

Coastal Features and Processes

Resource-specific laws:

- **NPS Organic Act, 54 USC § 100751** et. seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- **Coastal Zone Management Act, 16 USC § 1451** et. seq. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone.

- **Clean Water Act, 33 USC § 1342/Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit.
- **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs.
- **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.

Resource-specific regulations:

- **36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands.
- **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.

NPS Management Policies 2006:

- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/park facilities/historic properties.
- **Section 4.8.1.1** requires NPS to:
    - Allow natural processes to continue without interference,
    - Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions,
    - Study impacts of cultural resource protection proposals on natural resources,
    - Use the most effective and natural-looking erosion control methods available, and
    - Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.

Geologic Hazards

Resource-specific laws:

- **National Landslide Preparedness Act, 43 USC §§ 3101–3104** strengthens the mandate to identify landslide hazards and reduce losses from landslides. Established the National

Landslide Hazards Reduction Program. "…the United States Geological Survey and other Federal agencies, shall – identify, map, assess, and research landslide hazards;" Reduce landslide losses, respond to landslide events.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.8.1.3**, Geologic Hazards
- **Section 9.1.1.5**, Siting Facilities to Avoid Natural Hazards
- **Section 8.2.5.1**, Visitor Safety
- **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.

Soils

Resource-specific laws:

- **Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources.
- **Farmland Protection Policy Act, 7 USC § 4201** et. seq. requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).

Resource-specific regulations:

- **7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. Part 610 governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. Part 611 governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.

NPS Management Policies 2006:

- **Section 4.8.2.4** requires NPS to (1) prevent unnatural erosion, removal, and contamination; (2) conduct soil surveys; (3) minimize unavoidable excavation; and (4) develop/follow written prescriptions (instructions).

Upland and Fluvial Processes

Resource-specific laws:

- **Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE.
- **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]).
- **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**).
- **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1**).

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems.
- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding.
- **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams.
- **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes.
- **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Additional References, Resources, and Websites

Abandoned Mineral Lands

- NPS AML: https://www.nps.gov/subjects/abandonedminerallands/index.htm
- NPS AML, reclamation and restoration: https://www.nps.gov/subjects/abandonedminerallands/reclamation-and-restoration.htm

Bedrock References

- NPS Geologic Resources Division Rocks and Minerals website: https://www.nps.gov/subjects/geology/rocks-and-minerals.htm

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- *Global and regional sea level rise scenarios for the Unites States* (Sweet et al. 2022): https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
- NPS Climate Change Response Strategy (2023 Update): https://www.nps.gov/subjects/climatechange/response-strategy.htm
- NPS Green Parks Plan: https://www.nps.gov/subjects/sustainability/green-parks.htm
- NPS National Climate Change Interpretation and Education Strategy: https://www.nps.gov/subjects/climatechange/nccies.htm
- NPS Policy Memorandum 12-02—Applying NPS Management Policies in the Context of Climate Change: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Policy Memorandum 15-01—Addressing Climate Change and Natural Hazards for Facilities: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Sea Level Change website: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- *Sea level rise and storm surge projections for the National Park Service* (Caffrey et al. 2018): https://irma.nps.gov/DataStore/Reference/Profile/2253283
- U.S. Global Change Research Program: http://www.globalchange.gov/home

Days to Celebrate Geology

- Geologist Day—the first Sunday in April (marks the end of the winter and beginning of preparation for summer field work; formally celebrated in Ukraine, Kazakhstan, Belarus, Kyrgyzstan, and Russia)
- National Cave and Karst Day—6 June, also known as International Day of Caves and Subterranean World
- International Geodiversity Day—6 October: https://www.geodiversityday.org/

- Earth Science Week—typically the second full week of October: https://www.earthsciweek.org/
- National Fossil Day—the Wednesday of Earth Science Week: https://www.nps.gov/subjects/fossilday/index.htm

Disturbed Lands Restoration

- Geoconservation—Disturbed Lands Restoration: https://www.nps.gov/articles/geoconservation-disturbed-land-restoration.htm

Earthquakes

- International Code Council (ICC) International Building Code (IBC): https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/ibc/
- "Seismic Monitoring" (Braile 2009) in *Geological Monitoring* (Young and Norby 2009) describes the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics
- US Geological Survey (USGS), Earthquake Hazards Program: https://earthquake.usgs.gov/
- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/
- NPS Geologic Resources Division Geohazards website: http://go.nps.gov/geohazards
- Natural hazards science strategy: Holmes et al. (2013)
- Landslide hazards and climate change: Coe (2016)
- US Geological Survey Quaternary fault database: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf

Energy Development and Mining

- NPS Energy and Mineral Development: https://www.nps.gov/subjects/energyminerals/index.htm
- NPS Geologic Resources Division completed an oil, gas, and minerals management handbook in 2017 that provides guidance for implementing existing NPS policy. Contact the NPS GRD (https://www.nps.gov/orgs/1088/contactus.htm) to request a copy.

Flooding

- Federal Emergency Management Agency (FEMA) flood maps: https://www.fema.gov/flood-maps
- Water resources preservation strategy: National Park Service (2001)

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- NPS Geoheritage Sites – Examples on Public Lands, Natural Landmarks, Heritage Areas, and The National Register of Historic Places: https://www.nps.gov/subjects/geology/geoheritage-sites-listing-element.htm
- NPS Museum Collection (searchable online database): https://museum.nps.gov/ParkPList.aspx
- NPS National Natural Landmarks Program: https://www.nps.gov/subjects/nnlandmarks/index.htm
- NPS National Register of Historic Places: https://www.nps.gov/subjects/nationalregister/index.htm
- NPS Stratotype Inventory: https://www.nps.gov/subjects/geology/nps-stratotype-inventory.htm
- UNESCO Global Geoparks: https://en.unesco.org/global-geoparks

Geologic Maps

- American Geosciences Institute (provides information about geologic maps and their uses): http://www.americangeosciences.org/environment/publications/mapping
- *General Standards for Geologic Maps* (Evans 2016)
- USGS MapView by National Geologic Map Database: https://ngmdb.usgs.gov/mapview
- USGS National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geological Surveys and Societies

- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/
- Geological Society of America: http://www.geosociety.org/
- US Geological Survey: http://www.usgs.gov/
- Virginia Department of Energy: https://www.energy.virginia.gov/geology/geologymineralresources.shtml

Geophysical Surveys

- Bevan (2004) provided detailed appendices for geophysical exploration techniques and considerations for subsurface investigations.

Landslide Information

- *Geological Monitoring* chapter about slope movements (Wieczorek and Snyder 2009): https://www.nps.gov/articles/monitoring-slope-movements.htm
- *The Landslide Handbook—A Guide to Understanding Landslides* (Highland and Bobrowsky 2008): http://pubs.usgs.gov/circ/1325/

NPS Geology

- NPS America's Geologic Legacy: http://go.nps.gov/geology. This primary site for information about NPS geology includes a geologic tour, news, and other information about geology in the NPS, and resources for educators and park interpreters.
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm. The NPS Geodiversity Atlas is a collection of park-specific webpages containing information about the park's geology and links to additional resources.
- NPS Geologic Resources Inventory: http://go.nps.gov/gri

NPS Reference Tools

- NPS Technical Information Center (TIC; repository for technical documents and means to receive interlibrary loans): https://www.nps.gov/orgs/1804/dsctic.htm
- GeoRef. The GRI team collaborates with TIC to maintain an NPS subscription to GeoRef (the premier online geologic citation database) via the Denver Service Center Library interagency agreement with the Library of Congress. Multiple portals are available for NPS staff to access these records. Park staff can contact the GRI team or GRD for access.
- NPS Integrated Resource Management Applications (IRMA) DataStore portal: https://irma.nps.gov/DataStore/Search/Quick. *Note*: The GRI team uploads scoping summaries, maps, and reports to IRMA. Enter "GRI" as the search text and select a park from the unit list.

Photogrammetry

- NPS Photogrammetry, applications and examples: https://www.nps.gov/articles/series.htm?id=4B2E480A-1DD8-B71B-0B41FD201137856F
- Fossils in 3D: https://www.nps.gov/subjects/fossils/photogrammetry.htm

Paleontological Resources

- GRI GIS data (limited on non-NPS computers to data not considered sensitive, e.g., paleontological locations or mine features): https://irma.nps.gov/DataStore/Reference/Profile/2194568
- "Monitoring in situ Paleontological Resources" (Santucci et al. 2009) in *Geological Monitoring* (Young and Norby 2009) detailed paleontological resource monitoring strategies, including five methods and vital signs for monitoring in situ paleontological resources: (1)

erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use

- A preliminary inventory of NPS paleontological resources found in cultural resource contexts: Kenworthy and Santucci (2006)
- NPS Fossils and Paleontology website, http://go.nps.gov/paleo

Radon in Virginia

- Virginia Department of Health: https://www.vdh.virginia.gov/radiological-health/indoor-radon-program/epa-radon-risk-map-for-virginia/
- Environmental Protection Agency (EPA), radon information: http://www.epa.gov/radon/

Relevancy, Diversity, and Inclusion

- NPS Office of Relevancy, Diversity, and Inclusion: https://www.nps.gov/orgs/1244/index.htm
- Changing the narrative in science & conservation: an interview with Sergio Avila (Sierra Club, Outdoor Program coordinator). Science Moab radio show/podcast: https://sciencemoab.org/changing-the-narrative/

Slope Movements

- *The Landslide Handbook—A Guide to Understanding Landslides* (Highland and Bobrowsky 2008):http://pubs.usgs.gov/circ/1325/
- Landslide hazards and climate change: Coe (2016)
- "Monitoring Slope Movements" (Wieczorek and Snyder 2009) in *Geological Monitoring* (Young and Norby 2009) described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks.
- Natural hazards science strategy: Holmes et al. (2013)
- NPS Geologic Resources Division Geohazards: http://go.nps.gov/geohazards
- NPS Geologic Resources Division Slope Movement Monitoring: https://www.nps.gov/articles/monitoring-slope-movements.htm
- US Geological Survey, landslide hazards: http://landslides.usgs.gov/

Soils

- Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS): https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
- WSS_four_steps (PDF/guide for how to use WSS): https://irma.nps.gov/DataStore/Reference/Profile/2305342

USGS Reference Tools

- Geographic Names Information System (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex
- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- NGMDB Geochron Downloader: https://ngmdb.usgs.gov/geochron/
- Publications Warehouse: http://pubs.er.usgs.gov
- A Tapestry of Time and Terrain (descriptions of physiographic regions; Vigil et al. 2000): http://pubs.usgs.gov/imap/i2720/
- USGS Store (find maps by location or by purpose): http://store.usgs.gov

Virginia Geology

- Geology and Mineral Resources: Virginia Department of Energy: https://www.energy.virginia.gov/geology/geologymineralresources.shtml
- Description of geologic map units of Virginia (Virginia Division of Mineral Resources 2003)

Water Resources

- NPS Water Resources Division, information regarding the park's water resources: http://go.nps.gov/waterresources
- Lord et al. (2009) provided guidance for monitoring fluvial geomorphology.
- The NPS Mid-Atlantic Network monitors water quality and quantity at Richmond National Battlefield Park: https://www.nps.gov/im/midn/rich.htm

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