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# Petersburg National Battlefield

*Geologic Resources Inventory Report*



Ruins of the Taylor House dependency. It is believed that the original structure was destroyed in the initial attacks on Petersburg in June 1864. The bricks and stones in the structure were likely sourced nearby from Piedmont saprolite (deeply weathered rocks), Coastal Plain sedimentary units, and/or terrace boulder deposits.
© TRISTA L. THORNBERRY-EHRLICH / COLORADO STATE UNIVERSITY (TAKEN IN SPRING 2005)

# Petersburg National Battlefield: Geologic resources inventory report

Science Report NPS/SR—2024/190

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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 Petersburg National Battlefield. Guidance for resource management and information about the previously completed GRI GIS data and posters (separate products) is also provided.

# Acknowledgements

The GRI team thanks the participants of the 2005 scoping meeting and 2022 follow-up meeting for their assistance in this inventory. The lists of participants reflect the names and affiliations of these participants 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 Energy) and the USGS for their 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 the GRI report may also be useful for interpretation.

Petersburg National Battlefield (referred to as the "park" throughout the report) commemorates the longest military siege in American history and the last campaign of the American Civil War. From June 1864 to April 1865, the Petersburg campaign stretched more than 56 km (35 mi) of defensive lines across a broad swath of land east, south, and west of the city of Petersburg, Virginia, which was an important supply center to the Confederate capital at Richmond. Union and Confederate forces fought over five railroad lines and key roads. When the Confederates finally abandoned Petersburg and retreated, Richmond fell, and a week later, the American Civil War was effectively over.

Geology had a fundamental influence on the human history of the park, from the earliest indigenous Native American inhabitants who used the extensive rivers and natural resources, to the founding and settlement of the city of Petersburg at the fall line barrier, to the Civil War battle strategy and aftermath.

This report is supported by a GRI-compiled digital map (GIS data) and posters of the geology of the park. The GRI GIS data were compiled in 2022. The GRI GIS data may be updated if new, more accurate geologic maps become available or if software advances require an update to the digital format.

To create a geologic map with coverage of the entirety of the park lands, the GRI team compiled two separate quadrangle maps published by the US Geological Survey and the Virginia Division of Geology and Mineral Resources (now called Virginia Energy). Two posters (printable PDF documents) illustrate the GRI GIS data draped over shaded relief of the area.

Geologic units are referenced in this report using map unit symbols. Individual bedrock and surficial units are included in the posters' legends and in the GRI GIS data. For example, the Yorktown Formation is map unit **Ty**. The GRI GIS data and posters are available for download on the NPS DataStore and the GRI publications website (see "Access to GRI Products").

This GRI report consists of the following seven chapters:

Introduction—This chapter provides information about the establishment of the park and information about the GRI. It explains the GRI process and products. A geologic map in GIS format is the principal deliverable of the GRI. This chapter highlights the two 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 posters that illustrate 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 the context of geologic time.

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

## Park Establishment, Background, and Landscape

Petersburg National Battlefield (referred to as the "park" throughout the report) consists of five main units spread along a series of historic roads. The units begin at the James River (Grant's Headquarters at City Point) in the northeast, arc around the southern end of the town of Petersburg, continue through the Eastern Front, Western Front, and Poplar Grove, and end at the Five Forks Battlefield in the southwest (Figure 1). At more than 1,072 ha (2,650 ac) with authorization to expand by another 2,929 ha (7,238 ac), the park is one of the larger military parks in the eastern United States, spanning areas in Prince George and Dinwiddie Counties, Virginia (National Park Service 2020). It regularly attracts more than 200,000 visitors each year. The park was originally designated as a national military park on 3 July 1926. Its redesignation as a national battlefield was on 24 August 1962. The battlefield also manages Poplar Grove National Cemetery in the Western Front unit (National Park Service 2016).

For nine months, from June 1864 to April 1865, the Petersburg campaign, or siege of Petersburg, stretched across the area east, south, and west of the city. Petersburg, with a hub of five railroad lines and multiple roads, was an important supply center for Richmond, the Confederate capital, 40 km (25 mi) to the north. Union forces sought to cut off the supply lines from the south into Petersburg and Richmond. The campaign included six major battles, eleven engagements, and countless minor actions and skirmishes. The ultimate result of the fighting was the fall of Richmond, the Confederate retreat to Appomattox, and their subsequent surrender there a week later.

The regional landscape is subdued, with the highest elevations at about 90 m (300 ft) in the west and the lowest elevations near sea level along the lower (tidal) Appomattox River in the east. The landscape consists of rolling, gentle hills between steeper ravines and valleys. The principal drainages of the park area are the Appomattox River to the north, draining into the James River at City Point, and the Rowanty Creek to the south, flowing ultimately to the Nottoway River in southeastern Virginia. The interfluve divide (region between the valleys of adjacent watercourses) between these two drainages lies close and roughly parallel to the Appomattox River (Occhi et al. 2018).

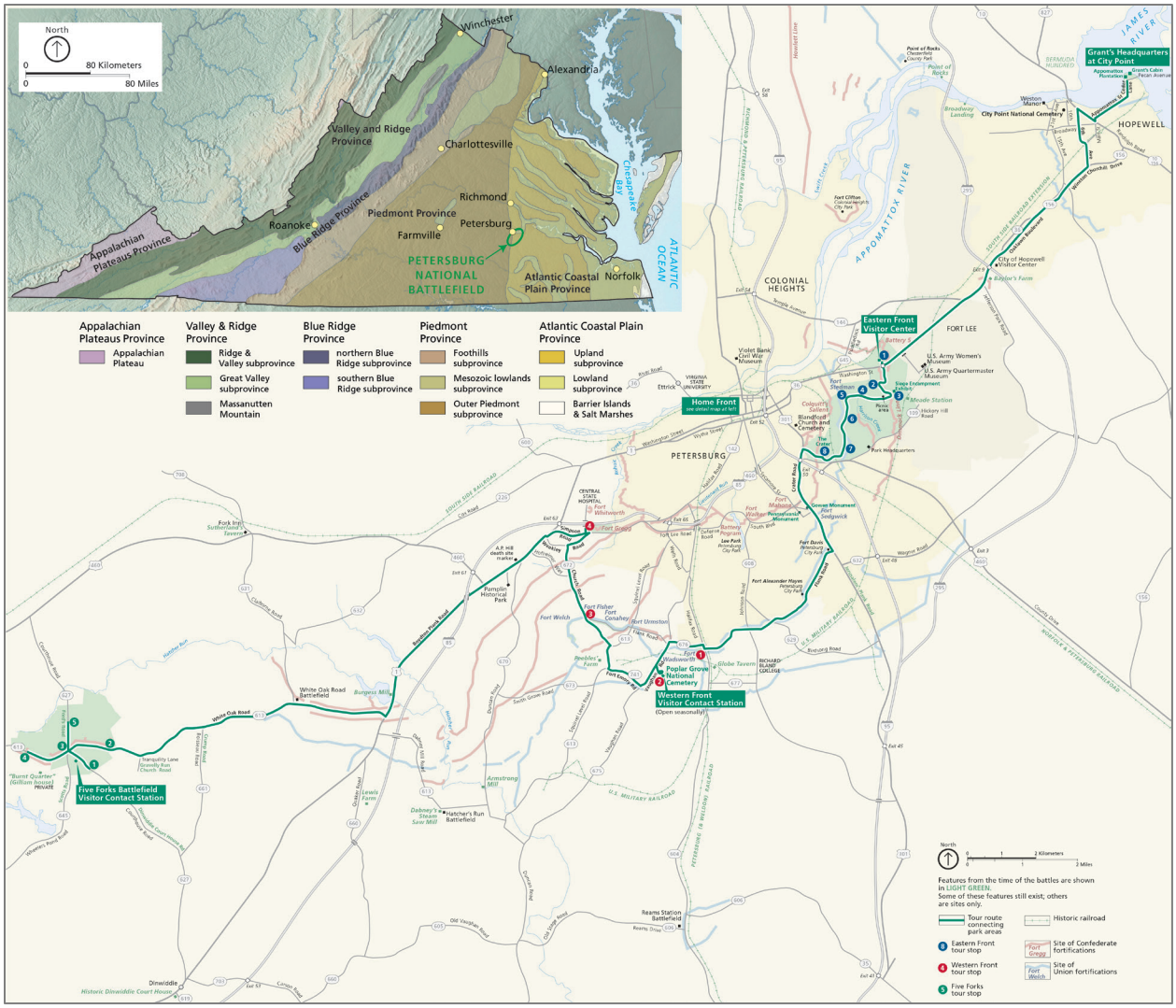



**Figure 1.** Park map and physiographic provinces of Virginia diagram. The units of Petersburg National Battlefield (referred to as the "park" throughout the report) stretch from City Point in the northeast, following a fishhook arc around the south side of the city of Petersburg, trending southwestward to Five Forks Battlefield. This defined a long siege campaign designed to force the abandonment of Richmond and the ultimate surrender of the Confederacy. Geology influenced the strategy and outcome. Trench warfare was refined in areas underlain by the Coastal Plain, whereas only rudimentary fortifications were possible in areas underlain by the Petersburg Granite (geologic map unit PNMpg). Inset graphic is adapted from Bailey (1999) by Trista L. Thornberry-Ehrlich (Colorado State University). Basemap by Tom Patterson (National Park Service), available online: http://www.shadedrelief.com/physical/index.html (accessed 31 March 2021). NPS map from the Harpers Ferry Center is available at: https://www.nps.gov/carto/app/#!/parks/state/va.

## Introduction to the GRI

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.

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 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 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*

The GRI team completed the following tasks as part of the GRI for the park: (1) conduct a scoping meeting and provide a scoping summary, (2) provide digital geologic map data in a geographic information system (GIS), (3) create a poster to display the GRI GIS data, and (4) provide a GRI report (this document). GRI products—GIS data, posters, scoping summaries, and reports—are available on the "Geologic Resources Inventory—Products" website and on the NPS DataStore through the Integrated Resource Management Applications (IRMA) portal (see "Access to GRI Products").

#### GRI Scoping Meeting

On 13 April 2005, the National Park Service held a scoping meeting at 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. The data were updated by the GRI in 2022. The GRI GIS data may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format. The GRI team compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data from two source maps (see "Geologic Map Data"). Two geologic map posters illustrate 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.

#### GRI Report

On 18 August 2022, the GRI team hosted a follow-up meeting for park staff and interested geologic experts. The call 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 2012, the follow-up meeting in 2020, and additional geologic research. The selection of geologic features discussed in the report was guided by the previously completed GRI map data, and the writing reflects the data and interpretation of the source map authors. In addition, the park's foundation document (National Park Service 2016) helped guide the writing of this GRI report; applicable information, as related to the preserve's geologic resources and resource management, was included.

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").

*Use Constraints*
The graphics and written information provided in this report are not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based on the information provided here.

## 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. The GRI GIS data produced for the park follow the source maps listed here and includes components described in this chapter.

### *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 ages. In addition to color, map unit symbols delineate rocks on geologic maps. Usually, a map unit symbol consists of an uppercase letter indicating age (e.g., **K** for Cretaceous, **T** for Tertiary, **PNM** for Pennsylvanian and Mississippian, and **Q** for Quaternary) and lowercase letters indicating the rock formation's name or the type of deposit. In geology, a formation is the basic rock-stratigraphic unit. This means that it can be mapped (at a particular scale), is different from adjacent strata (in terms of rock type and other characteristics such as color, mineral composition, and grain size), and has a clear, definable upper and lower contact (surface between two types or ages of rocks). A formation can be divided into "members" or combined into a "group." Other symbols on geologic maps depict the contacts between map units or structures such as faults (see the "Dutch Gap and Unnamed Faults" section for further explanation). 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 disturbed land (e.g., modified land [**Qml**]), wells, or mines.

Geologic maps are generally one of two types: bedrock or surficial. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, or igneous rocks. In addition, bedrock map units are generally differentiated based on age and rock type. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6

million years (Quaternary Period). 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.

### *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 compiled the following two maps into the GRI GIS data for the park (Figure 2):

- Geologic map of the Petersburg National Battlefield and adjacent areas, Virginia (map code: PETE; Occhi et al. 2018)
- Late Mesozoic and Cenozoic stratigraphic and structural framework near Hopewell, Virginia (map code: CIPO; Dischinger 1987)

The two maps were chosen to provide geologic map coverage for all the units of the park. They share a partial boundary, but the interpretation of the geologic units is slightly different from one map to the next. The more recent, Occhi et al. (2018) map reflects field information gleaned from trenches and cores, as well as a more refined geologic understanding of the area. As of December 2023, updated mapping is available for the City Point coverage (Marcie Occhi, Virginia Energy, geologist, written communication, 20 November 2023) but it is not yet in the GRI GIS format. The park could request this as an updated GRI GIS product.

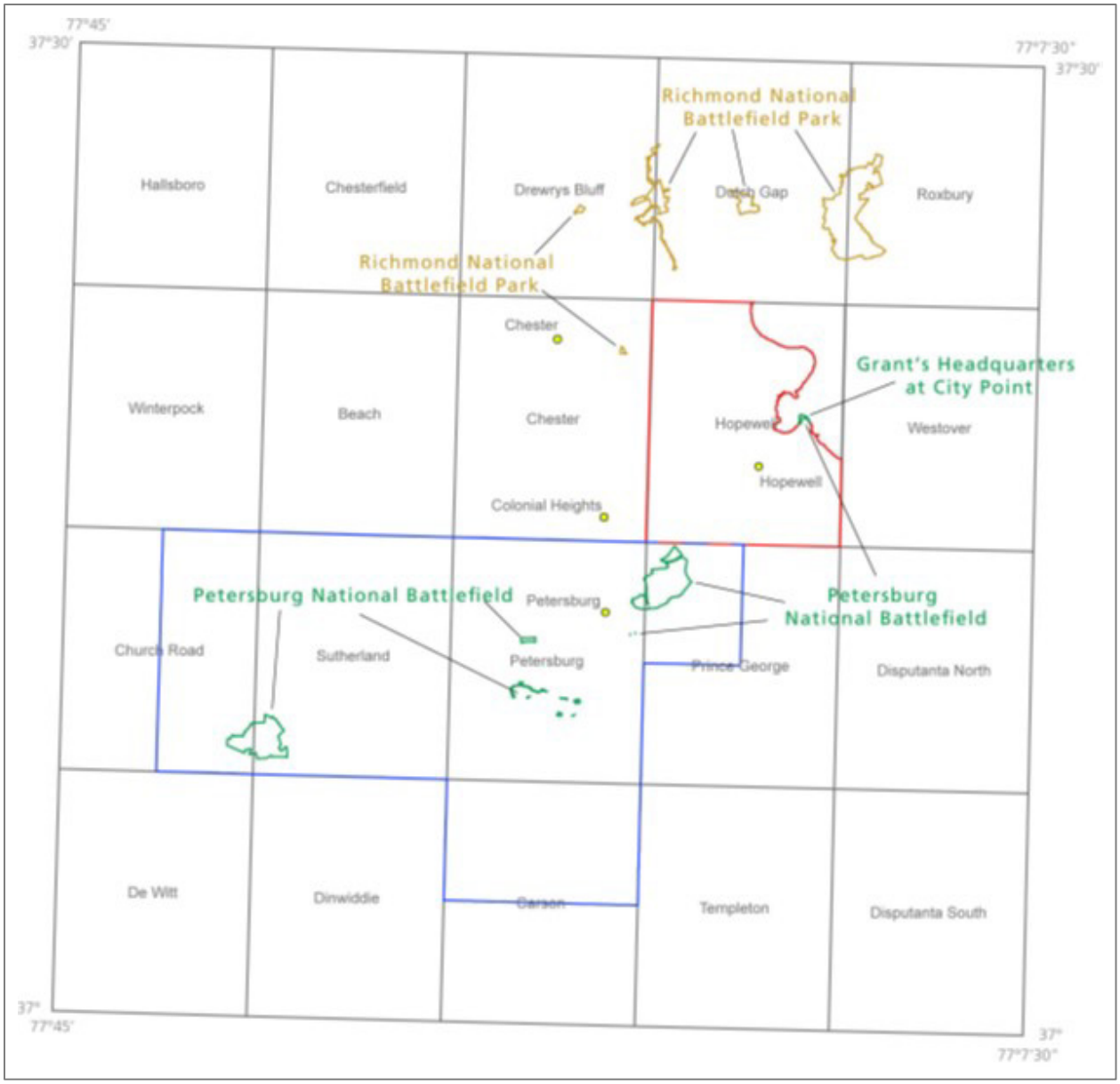



**Figure 2.** Index map of the GRI GIS data. Black text refers to the individual 7.5' quadrangles' names, six of which are part of the GRI GIS data for the park: Hopewell, Church Road, Sutherland, Petersburg, Prince George, and Carson. Blue outline depicts the map coverage by Occhi et al. (2018), whereas the red outline refers to the source map by Dischinger (1987). The green outline areas show the units of Petersburg National Battlefield. The gold outline areas show Richmond National Battlefield Park units. Graphic by James Winter (Colorado State University).

### *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 2.1, 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 at https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.

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

- A GIS readme file (pete_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 1)
- Federal Geographic Data Committee (FGDC)-compliant metadata
- An ancillary map information document (pete_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 (pete_geology.mxd and cipo_geology.mxd) that display the GRI GIS data
- A version of the data viewable in Google Earth (pete_geology.kmz and cipo_geology.kmz; Table 1)

**Table 1.** GRI GIS data layers for Petersburg National Battlefield.

| Data Layer | PETE or CIPO | On Posters | Google Earth Layer |
|---|---|---|---|
| Geologic Attitude Observation Localities | PETE | No | Yes |
| Geologic Sample Localities | PETE | No | Yes |
| Mine Point Features | Both | No | No |
| Geologic Line Features | CIPO | Yes | Yes |
| Geologic Cross Section Lines | Both | No | Yes |
| Geologic Observation Localities | Both | Yes | Yes |
| Hazard Point Features | PETE | Yes | Yes |
| Hazard Area Feature Boundaries | PETE | Yes | Yes |
| Hazard Area Features | PETE | Yes | Yes |
| Map Symbology | Both | Yes | Yes |
| Faults | Both | Yes | Yes |
| Surficial Contacts | PETE | Yes | Yes |
| Surficial Units | PETE | Yes | Yes |
| Geologic Contacts | Both | Yes | Yes |
| Geologic Units | Both | 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 figures referenced throughout 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 1). 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 posters. Based on the source map scale (1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 12 m (40 ft) of their true locations.

# Geologic Heritage

As the final campaign of the American Civil War, the longest military siege in American history was waged in the area surrounding Petersburg, Virginia. For 292 days, the local geology contributed to the importance of the location and the battle and siege strategies employed there. 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 the nation that are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, and economic. The NPS also identifies geologic heritage aspects of museum collections, soils, and scientific data sets.

Geoheritage sites are conserved so that their lessons and beauty will remain as a legacy for future generations. Such areas generally have great potential for scientific studies, use as outdoor classrooms, and enhancing public understanding and enjoyment. 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, the United States does not have a comprehensive national registry that includes all geoheritage sites across the nation, but many entities, including the National Park Service, are working to introduce and advance the idea of geologic heritage for Americans (see "Additional References, Resources, and Websites").

The park's purpose statement highlights the landscape where the Civil War campaign, siege, and defense of Petersburg took place. The landscape, both natural and cultural, is influenced by the underlying geology. The park is a perfect example of geoheritage.

### 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 1). The Piedmont province extends 1,600 km (1,000 mi) from Alabama northeastward to southern New York. The Piedmont contains complex metamorphic (rocks changed by intense heat and pressure) and igneous rocks (rocks solidified from molten lava or magma) that have been weathered and eroded for millions of years to produce a rolling, hilly, and muted landscape adjacent to the rugged Blue Ridge, Ridge and Valley, and Appalachian Plateaus provinces to the northwest and the nearly flat Atlantic Coastal Plain to the east. The park straddles the boundary between the Piedmont Plateau and the Atlantic Coastal Plain provinces (Figure 3). This transitional setting is known as the fall line.

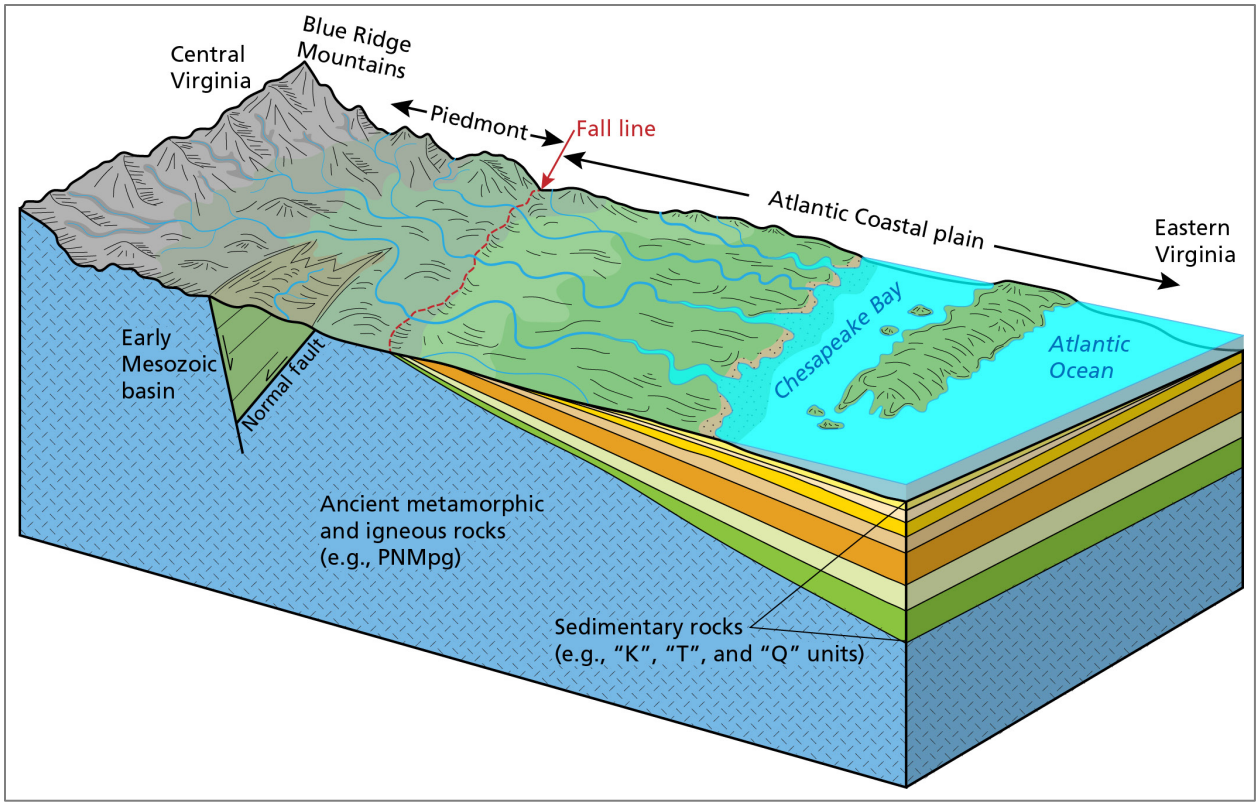



**Figure 3.** Cross section diagram of the geologic setting of the fall line. The fall line occurs where the soft, sedimentary rocks of the Atlantic Coastal Plain meet the hard, crystalline bedrock of the Piedmont to the west. Surficial sediments of the Atlantic Coastal Plain become progressively younger toward the sea (east). The park has both rocks of the Piedmont and the Atlantic Coastal Plain within its boundaries. Rivers fall swiftly from the uplands, tumbling down the fall line, commonly as rapids or waterfalls, before becoming increasingly meandering across the subtle topography of the Coastal Plain. This setting not only influenced the location of the city of Petersburg but also impacted the battle history. The cross sections in the GRI GIS data demonstrate the local setting, with younger sedimentary rocks over the older Petersburg Granite (PNMpg). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 9 in Trapp Jr. and Horn (1997).

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, Petersburg, Richmond, and Washington, DC.

### Geologic Impacts on Human History

The park's geologic setting, from the broad tidal rivers in this part of Virginia (Figure 4) to the unconsolidated Cenozoic sediments of the Coastal Plain, influenced human history there. This section provides a summary of how the local geology affected the area's history of human habitation as well as the Battle of Petersburg.

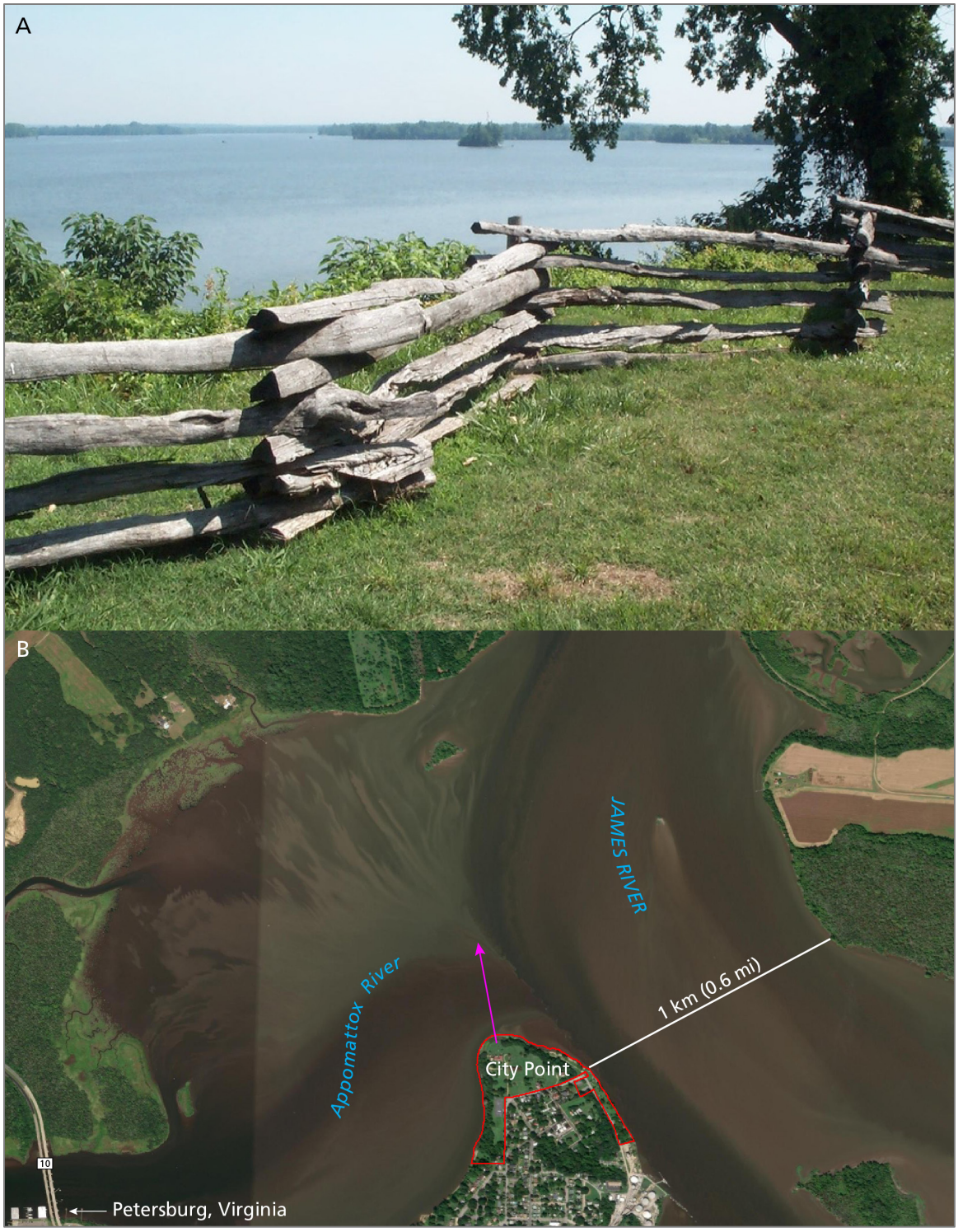



**Figure 4.** Photographs of the tidal confluence of the James and Appomattox Rivers. A) Below the fall line, the courses of large rivers in southeastern Virginia are influenced by tidal fluctuations coming from the mouth of the Chesapeake Bay. If these fluctuations are extreme (e.g., during storms), they can be erosive. The tidal reaches of the rivers flood broad channels. NPS photograph (date unknown). B) At the confluence, both rivers are more than 1 km (0.6 mi) wide. The purple arrow shows the direction of the photograph shown above (A). Imagery is an ESRI World Imagery basemap.

### *Indigenous Native American History*

Native American presence in the park area dates back over 10,000 years (Auwaerter 2009). Prior to European contact in 1608, Appomattocs (part of the Powhatan Confederacy of the Tidewater region of Virginia) lived in the area of what is now Petersburg. They called the (now) James River "Powhatan," named after one of their chief's many names, meaning "at the falls"—a location where the chief lived closer to Richmond (Huber 2020). Early English colonists would rename the river for their leader, King James I (Cross et al. 2017). The first recorded European eyewitness accounts of local villages noted cultivated cornfields throughout the area (Hodge 1912; Lookingbill et al. 2013). The geology of the region affected First Americans for years before the Petersburg campaign; the fall line served as a regional and cultural boundary between tribes of Algonquian speakers in the coastal plain and tribes of Siouan speakers on the Piedmont (Hatfield 2007). The United States government recognizes seven Indian tribes in Virginia that continue to practice their distinct cultures in the present day (Bureau of Indian Affairs 2023).

### *Siting of Petersburg*

The city of Petersburg was founded in 1748, just east of the fall line along what is now called the Appomattox River, about six river miles west of the confluence with the James River (see Figure 3). The fall line had a great impact on the cultural geography of Virginia and the greater eastern seaboard. Physically, it barred ships from sailing further upstream from Chesapeake Bay and delayed the European colonial incursion into the Piedmont. European settlements were established at this barrier, and agriculture (e.g., tobacco, wheat, and corn) was common until soil depletion (by 1800) caused local agricultural decline (Lookingbill et al. 2013; Virginia Museum of History & Culture 2023). Petersburg grew up around wharves and warehouses at the limits of ship navigation on the James and Appomattox Rivers. The city also hosted some of the first railroad tracks laid down in the US, codifying the city as the transportation hub for Richmond and, later, the Confederacy.

### *American Civil War Stories*

Geology affected military operations at Petersburg during the American Civil War and thus helped shape the course of American history (Cross et al. 2017). Many Civil War battles were decided by which side had the advantage(s) of familiarity with terrain, preparation to utilize the natural features, and/or manipulation of the focal points, gaps, ravines, cuts, hills, and ridges. Union forces drew on the open geomorphology of the broad tidal rivers to supply their army, both leading up to and during the siege and battles at Petersburg. Geology also informed the choice of the port of City Point as General Grant's headquarters and the Union supply hub for the siege; the Point is situated on a defensible but accessible 12 m (40 ft) high peninsular bluff at the confluence of the James and Appomattox Rivers (Figure 5 and Figure 6). The bluff consists of riverine terraces of sand, silt, clay, and peat of the Shirley and Chuckatuck alloformations (geologic map units **Qsh** and **Qc**, respectively; Cross et al. 2017; Occhi et al. 2018). Alloformations are bodies of sedimentary rock defined and identified only by their bounding discontinuities; in the case of the Coastal Plain, the discontinuities are the successive terraces. At this time, these units are not formally identified stratotype sections, and thus their names are lowercase (see "Stratotypes as Geoheritage"). During the Civil War, when a typical supply train carried about 100 wagons per mile of road, navigable rivers allowed for safer and more efficient hauling of heavier loads (Cross et al. 2017). City Point

soon became one of the busiest ports in the world, with a maze of pontoon wharves and an engine house and rail yard at the base of the bluffs (Cross et al. 2017).



**Figure 5.** Historic painting of City Point. At the confluence of the Appomattox and James Rivers, the City Point area contains a long record of human history. City Point was a bustling plantation prior to the Civil War. Union General Ulysses S. Grant used the riverside location and bluff top to create a supply hub for the Union troops at Petersburg, which was one of the busiest ports in the world at the time (National Park Service 2009a). This reliable supply chain contributed to the Union's eventual success at Petersburg. At the riverside base of the bluff are exposures of the Aquia and Potomac Formations (Ta and Kp, respectively). The bluff is capped by the Shirley Formation (or Shirley alloformation) (Qsh). A portion of the original painting by E. L. Henry presented as a figure in National Park Service (2009a).

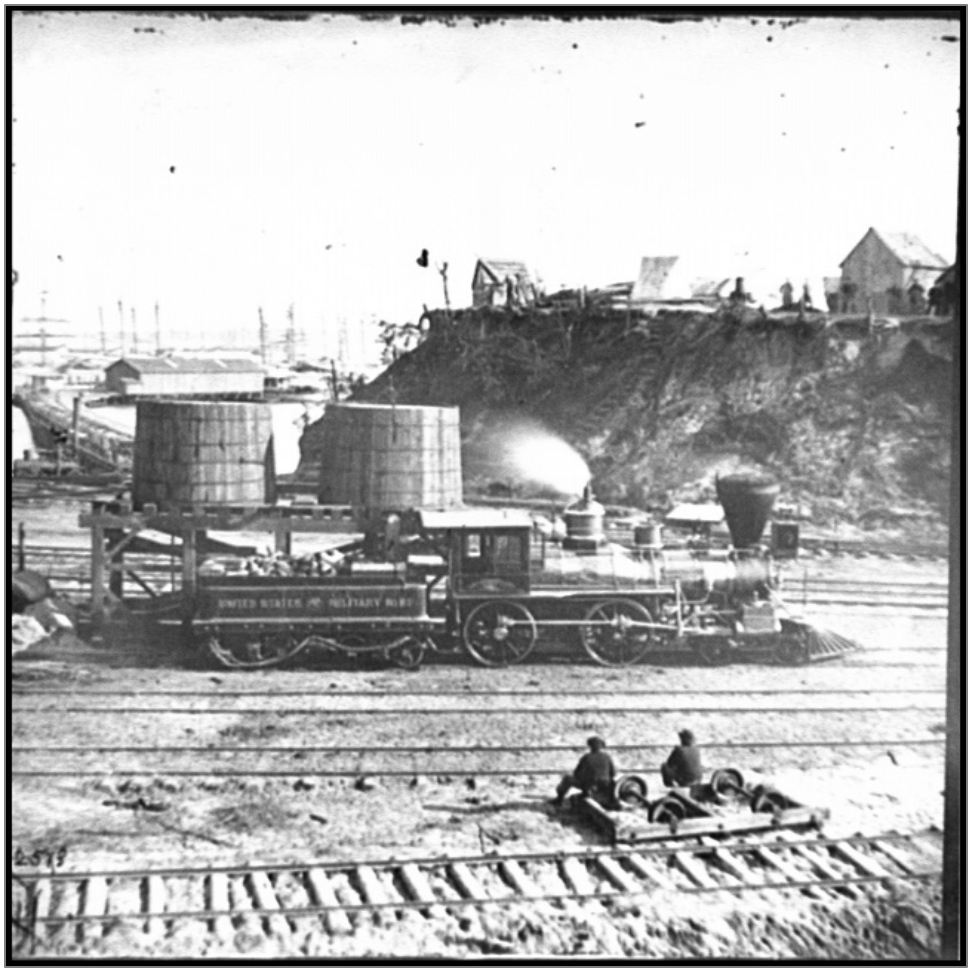


**Figure 6.** Historic photograph of a railroad operation at the base of the bluffs at City Point. During the Petersburg campaign, this area was a hubbub of activity as supply boats delivered goods to support the Union cause. The deforested bluffs were oversteepened, and the gullies on their slopes indicate pervasive erosion. At the riverside base of the bluff are exposures of the Aquia and Potomac Formations (Ta and Kp, respectively). The bluff is capped by the Shirley alloformation (Qsh). Photograph is courtesy of Petersburg National Battlefield presented as an unnumbered figure in Lookingbill et al. (2013).

The 10-month campaign played out across a variety of geological settings (Cross et al. 2017). Troops from both sides modified the landscape significantly. Large swaths of the surrounding land were cleared of trees to open fields for better visibility and maneuverability and to provide building materials and fuel. This likely caused a major increase in local erosion and sedimentation in streams and rivers. Over 48 km (30 mi) of earthworks were dug into the soft Coastal Plain sediments south and east of Petersburg, making it the longest combative military front on American soil (Figure 7; National Park Service 2016; Occhi et al. 2018). In fact, some of the earthworks were used in the early 20$^{th}$ century to train soldiers for trench warfare in World War I (National Park Service 2020).



**Figure 7.** Historic photograph of trenches at Petersburg. Miles of trenches and earthworks define a more than 56 km (35 mi) long military front. In areas underlain by soft, unconsolidated Coastal Plain deposits, manipulating the earth was relatively easy, and trenches were extensive. By contrast, at Five Forks Battlefield, which is located on the Piedmont province, the ground was hard, underlain by granite. Fortifications could not easily be entrenched. Forests were cleared and the ground was disturbed, causing a period of extreme erosion and sedimentation into local streams. Photograph from inside cover image in National Park Service (2016).

The earthworks follow a long, curved drainage divide around Petersburg to the south (Figure 8). This divide, capped by mud, sand, and gravel of the (informal) Cold Harbor formation and Bacons Castle Formation (**Tch** and **Qbc**, respectively), separates small, short, single streams draining northward into the Appomattox River and Chesapeake Bay from the headwaters of extensive, longer, and branching drainages of the Roanoke and Chowan Rivers to the south. Those rivers ultimately drain into Albemarle Sound (Figure 9; Cross et al. 2017). Union soldiers attempting to outflank the

Confederates north of the divide had to contend with the mucky, low-relief drainages; these included Arthur Swamp, Reedy Branch, and Hatcher's Run, which erode into the clayey, acidic, and poorly draining Eastover Formation (part of the Lower Chesapeake Group, undivided; **Tcl**; Cross et al. 2017).

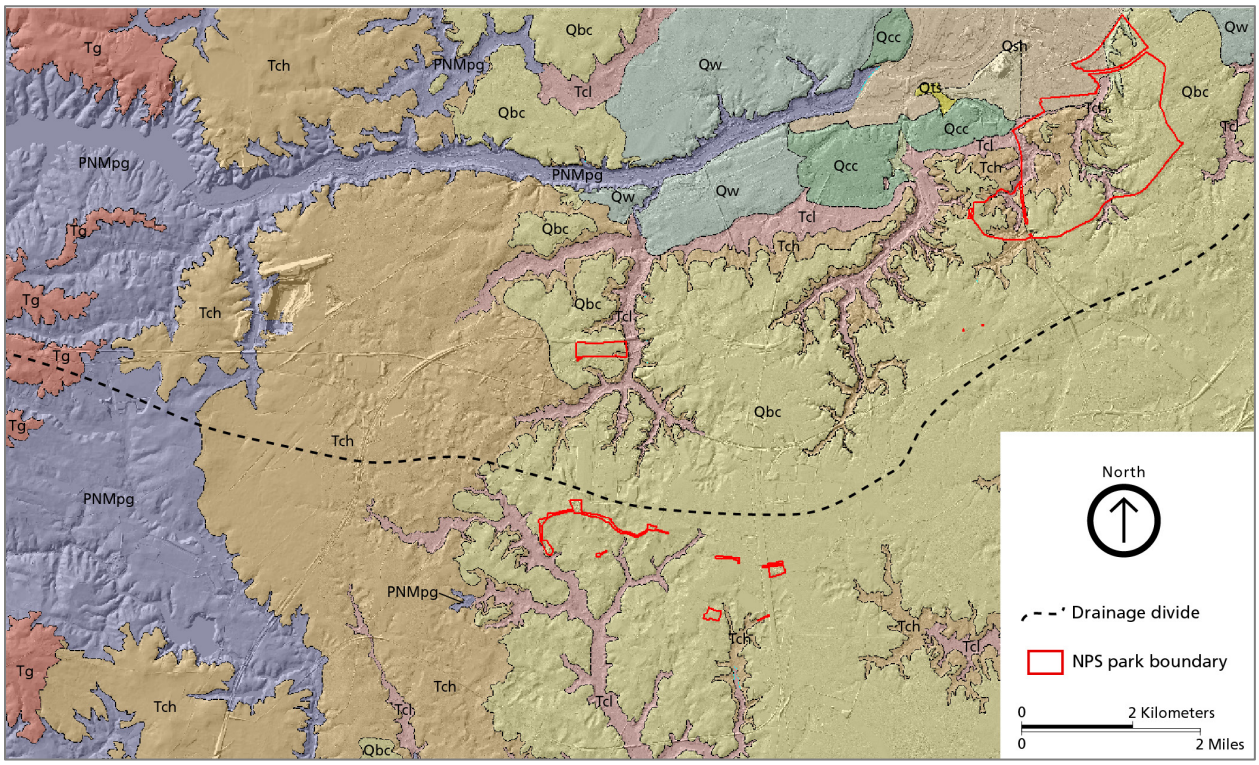



**Figure 8.** Map of the drainage divide that influenced Civil War-era earthworks. The dashed black line indicates the approximate location of a drainage divide that separates the headwaters of streams flowing north towards the Appomattox and James Rivers and the headwaters of streams flowing south towards Albemarle Sound. Earthwork locations roughly paralleled this divide in the eastern part of this map. Confederate earthworks stayed in the easily dug sand and gravel layers, and the Union earthwork lines simply followed the Confederates' pattern. These locations have not yet been field-verified. Their exact locations are sensitive data and will not be included here. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and hillshades provided by Occhi et al. (2018).

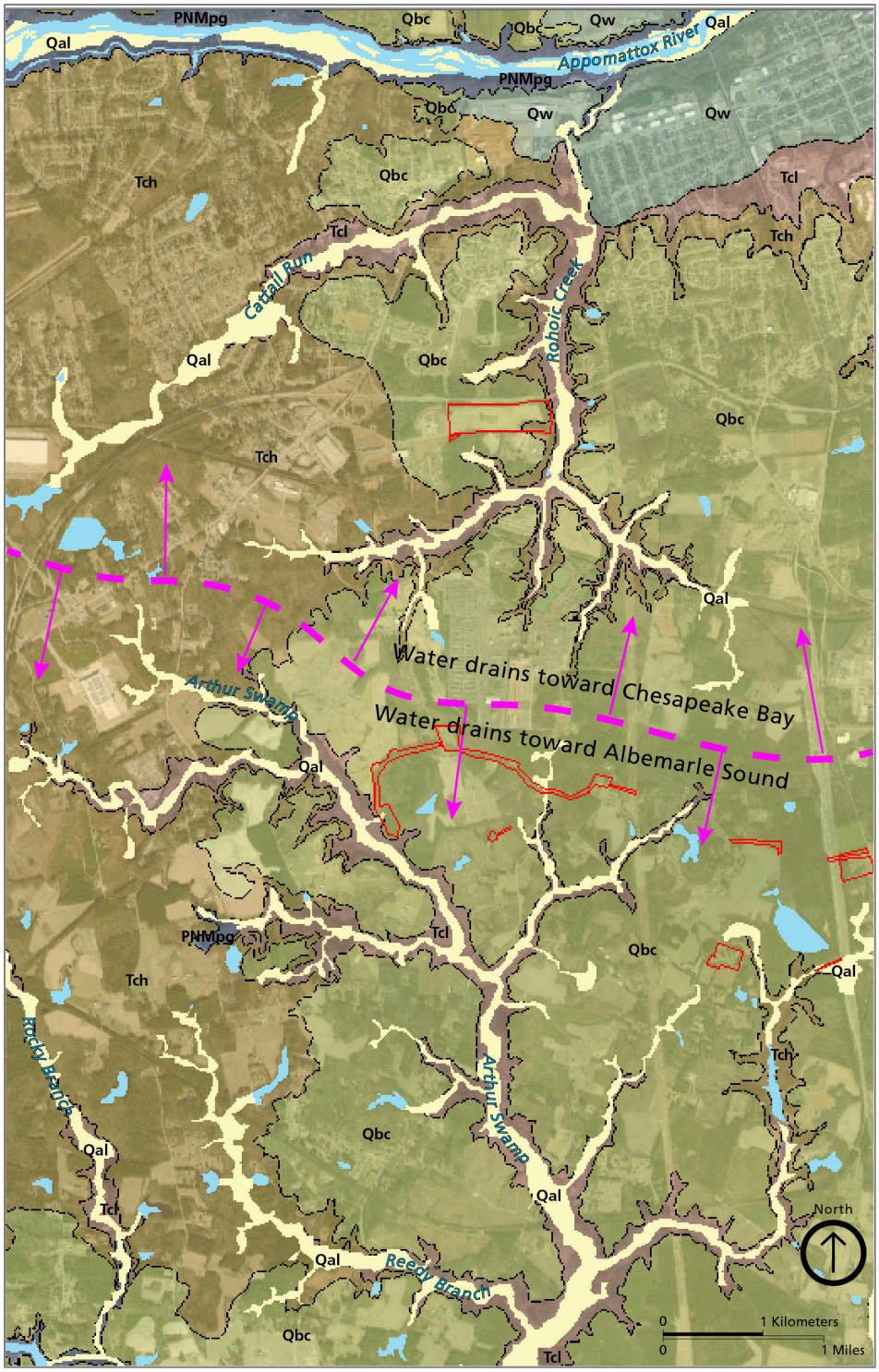



**Figure 9.** Aerial imagery showing the drainage divide between Arthur Swamp and Rohoic Creek. GRI GIS geologic map data overlies the aerial image to demonstrate how streams are incising down through the Coastal Plain sediments in dendritic (tree-like) patterns. The land south of the divide (pink dashed line) is swampy, which would have complicated conditions for the Union troops against the Confederate defenses north of the divide. Red lines are the park unit boundaries. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and an ESRI World Imagery basemap.

Toward the end of the campaign, on 25 March 1865, Confederate troops attempted to break out of the siege lines at Fort Stedman with the goal of destroying the supply hub at City Point. Harrison Creek and Poor Creek dissect the topography near Fort Stedman; the fort is perched on a high point underlain by the Bacons Castle Formation (**Qbc**) and bounded to the east and west by the two creek channels. The creeks are oriented more or less parallel to the battle lines at Fort Steadman. The western side of the area is underlain by an inset, flat riverine terrace of sand, silt, clay, and peat of the Chuckatuck alloformation (**Qc**), which is juxtaposed against the older Charles City alloformation (**Qcc**), which is in turn juxtaposed against the lower part of the Chesapeake Group (**Tcl**; Cross et al. 2017; Occhi et al. 2018). The eastern slope along Harrison Creek occurs at the base of the erosional scarp formed along the trace of the Dutch Gap fault and is underlain by older, cross-bedded, pebbly sand of the Cretaceous Potomac Formation (Cross et al. 2017). This scarp created an uphill fight for the Confederates at Fort Stedman, who were then driven back to their original lines (Cross et al. 2017)

Up to 46 m (150 ft) of unconsolidated sedimentary layers partially impacted the infamous "Battle of The Crater," where in the summer of 1864, Union forces attempted to breach the Confederate defenses at Elliot's Salient (on farmland owned by the Griffith family) by tunneling through the sedimentary layers and detonating 320 kegs (roughly 8,000 pounds) of gun powder beneath enemy lines (Berquist et al. 2014; Occhi et al. 2018). Digging was stymied by the geology at depth, which was characterized by wet ground, incohesive shelly layers, and putty-like marl layers (channel turned oxbow lake [curved lake formed from a bend in a river where the channel cut across the narrow neck and no longer flows around the loop of the bend] deposits) within the Lower Chesapeake Group and Yorktown Formation (**Tcl** and **Ty**, respectively; Figure 10, Figure 11, and Figure 12; Pranger 2000; Cross et al. 2017; Occhi et al. 2018). Berquist et al. (2014) identified this layer as the Yorktown Formation (Ty); however, that unit is not mapped at the tunnel site by Occhi et al. (2018) because it was less than 3 m (10 ft) thick and too thin to be mapped at 1:24,000 scale (Marcie Occhi, Virginia Energy, geologist, written communication, 18 December 2023). The overlying Cold Harbor formation (**Tch**) was more manageable to excavate, and the diggers therefore moved toward the surface through the sediments, slightly at an angle to access the Cold Harbor layers (Rick Berquist, Virginia Energy, geologist, GRI follow-up meeting, 18 August 2022). The tactic ultimately failed, causing thousands of casualties. The explosion blasted a crater 40 m (130 ft) long, 23 m (75 ft) wide, and 9 m (30 ft) deep, with steep walls of jagged, slippery clay. The crater's bottom was filled with loose material, great blocks of clay, guns, sharp timbers, and men buried in various ways (Slotkin 2009). The resulting crater was an impassable barrier, causing a logjam of men and equipment (Slotkin 2009). The crater (Figure 13) was eventually re-incorporated into the Confederate defenses (National Park Service 2016; Cross et al. 2017) and became an almost instant tourist attraction that made money for the Griffith family (National Park Service 1996).

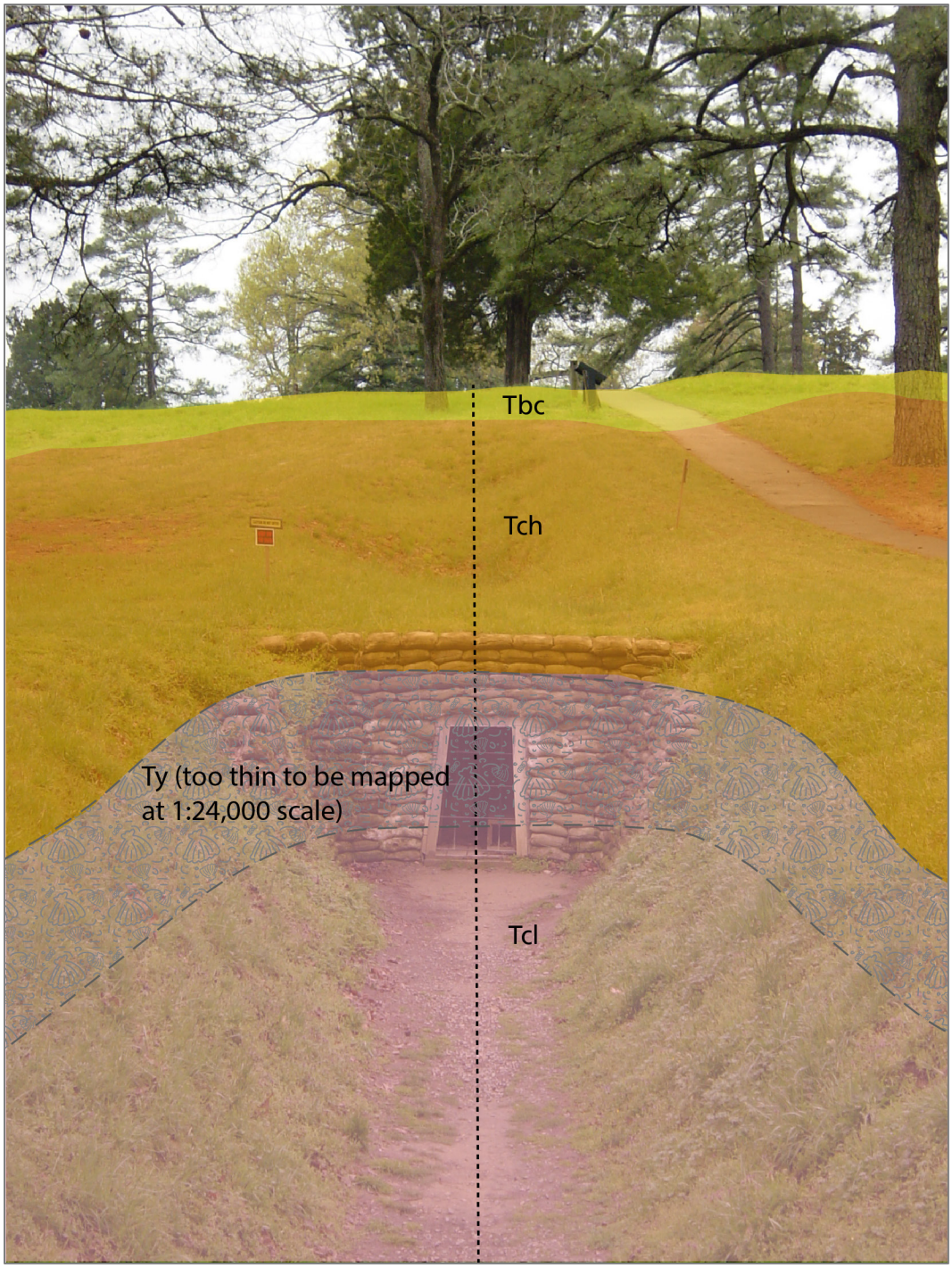



**Figure 10.** Diagram of the tunnel entrance into the sediments at The Crater. Tunneling proved challenging when the excavators intercepted unstable wet shelly sand and a sticky clay marl layer in the Yorktown Formation (Ty). This unit is too thin to appear on the 1:24,000 scale mapping at this location. Digging upsection, out of the marl and into the Cold Harbor formation (Tch), facilitated better tunneling. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with GRI GIS geologic map data and information from Marcie Occhi, Virginia Energy, geologist, written communication, 18 December 2023. Photography by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2005.

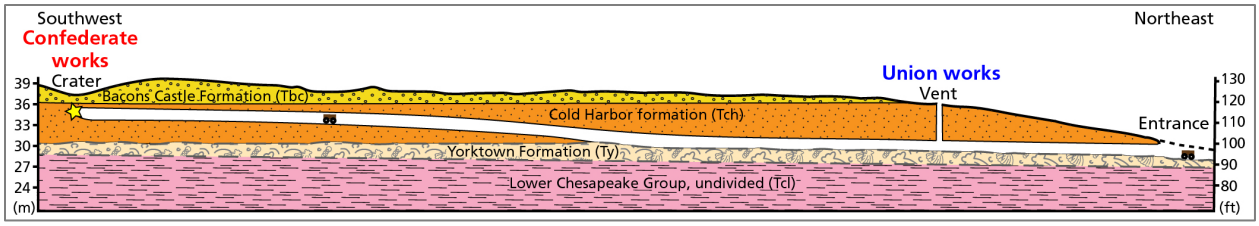



**Figure 11.** Cross section of the tunnel at The Crater. After excavators intercepted a sticky, clay marl layer in the Yorktown Formation (Ty; too thin to be mapped at 1:24,000 scale at this location), they dug at an upward angle into the Cold Harbor formation (Tch) for easier tunneling. A vent at the Union works provided breathing air to avoid asphyxiation. The yellow star indicates the location below the Confederate works where the charges were detonated. Elevations in meters and feet are from above mean sea level. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with GRI GIS geologic map data and adapted from figure 8 in Cross et al. (2017), Pranger (2000), Berquist et al. (2014), and information from Marcie Occhi, Virginia Energy, geologist, written communication, 18 December 2023.



**Figure 12.** Photographs of a geologic sample boring. The gray, sticky clay marl layer inhibited Union tunneling efforts in their ill-fated attempt to blow through Confederate defenses near Elliott's Salient. This is a clay layer in the Lower Chesapeake Group, undivided (Tcl). The Yorktown Formation (Ty) is too thin to be mapped at 1:24,000 scale at this location. Upsection, the deposits are much sandier and easier to dig through. The solid stem auger boring was taken immediately adjacent to the tunnel near The Crater at Petersburg National Battlefield by geologists from the Virginia Department of Mines, Minerals, and Energy. Photographs by Hal Pranger (National Park Service) taken in 2000.



**Figure 13.** Historic photograph of The Crater compared to today's landscape. The Battle of the Crater took place on the Griffith farm that was taken over as the Elliot's Salient Confederate position. In 1866, visitors were photographed standing on the rim of The Crater, surveying the feature in the foreground of the black and white image. Today, the sharp edges of the crater are muted and rounded, but because of its notoriety and value as a tourist attraction following the battle, it was never reclaimed as agricultural land. View is to the east. Historic photograph courtesy of Petersburg National Battlefield presented as figure 6 in Layton et al. (2017). Modern photograph by Noah_Loverbear available at https://commons.wikimedia.org/wiki/File:The_Crater_Petersburg_National_Battlefield_-_panoramio_(1).jpg (accessed 9 September 2023). Unmodified and used under license, CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/deed.en).

Thanks to the readily diggable sediments and the sheer duration of the conflict, numerous areas of countermining occurred in places such as Elliot's Salient, Fort Stedman, and Gracie's Salient (Figure 14; Occhi et al. 2018). This mining was commonly done to establish listening posts to detect the enemy's mines or troop movements (Jackson and Ellis 1998). Today, because of the explosion and the ensuing heat in the ground, the soils around the site contain fragments of metal melted at high temperatures, elevated lead (Pb), nickel (Ni), and chromium (Cr) concentrations, as well as higher than expected arsenic concentrations, all likely due to the sulfur contained in the gunpowder used for the explosion (Pascoe and Sikder 2021).



**Figure 14.** Historic stereo image photograph of a Confederate mine entrance. Mines and countermines were excavated during the lengthy Petersburg campaign. Most mines were used for surveillance. Some were loaded with explosives and detonated with varying degrees of success. The park is still trying to determine the full extent and location of mines, tunnels, and other excavations on the battlefield landscape. NPS photograph, date unknown.

To the west, across the fall line, the Five Forks Battlefield is centered on a thin (up to 10 m [32 ft] thick) veneer of gravel terrace (**Tg**) and/or Petersburg Granite saprolite (rock that has disintegrated or "rotted" in place) overlying solid Petersburg Granite (**PNMpg**; Cross et al. 2017; Occhi et al. 2018). Because of the sturdier substrate, digging was difficult to impossible, and the battlefield excavations were less extensive, shallower, and, in general, poorly constructed (Occhi et al. 2018). The battle was fought at the intersection of five roads (White Oak traverses the intersection where Dinwiddie Courthouse Road, Scott's Road, and Ford's Road converge) and to defend the South Side Railroad, the last supply line into the city. The crossroads is situated at the relatively flat drainage divide between Hatcher Run to the north and the drainages of Rowanty Creek to the south (Cross et al. 2017). Here, the Union forces were free of the boggy Coastal Plain and could sortie freely across the Piedmont. A frontal attack all along the siege line caused the collapse of Confederate defenses, the abandonment of the capital at Richmond, the subsequent retreat to Appomattox Courthouse, and soon after, the end of the American Civil War (National Park Service 2016; Cross et al. 2017).

### *Civil War Monuments*

After the Civil War, veterans and other groups sought to erect monuments to honor the fallen and to commemorate the siege and battles that took place at Petersburg. The park has more than 20 monuments spread across the various units (most of these are in the Eastern Front unit), all of which are listed on the NPS List of Classified Structures (National Park Service 2004). Maintaining, stabilizing, and preserving these monuments requires cleaning, repointing, and preservation treatments as necessary (National Park Service 2004). Maintenance practices depend on the material used to build the monument. Some monuments are made of relatively resilient granite, including the 1st Maine Heavy Artillery Regiment (granite from Hollowell, Maine), the State of Massachusetts (granite from local sources [Petersburg Granite?]), and William Mahone (granite from local sources [Petersburg Granite?]) monuments (National Park Service 2004; 2017a; Hawks 2023). Other monuments are made of soluble limestone: United States Colored Troops. The monument to Stephen Tyng Mather is made of bricks and mortar. Even some of the resistant granite monuments also contain soluble concrete mortar that requires maintenance (e.g., repointing).

## Geologic Connections to the Park Ecosystem

Varied natural communities were listed among the park's fundamental resources (National Park Service 2016). Because the park spans the Atlantic Coastal Plain and Piedmont provinces, the ecosystems are a mix of wetlands, mixed hardwood-pine forests, open fields, and grasslands characteristic of both provinces, all of which provided important habitat for flora and fauna (National Park Service 2016). Overall, the condition of the park's natural resources was listed as "fair" considering the following vital signs: air quality, water quality, biological integrity, and landscape dynamics (Lookingbill et al. 2013).

Because geology and geologic processes control topography and influence soil formation, strong ties exist between geology and vegetation classes, which in turn support fauna. The vegetation classes mapped at the park correlate with the underlying geology (e.g., acidic oak-hickory forest, coastal plain mixed oak, disturbed calcareous forest, Piedmont acidic seepage swamp, Piedmont floodplain swamp forest, Piedmont small-stream floodplain forest) and even history (e.g., forested earthworks, open earthworks, built-up land) (Patterson 2008; Lookingbill et al. 2013).

Soil resources are beyond the scope of this report and are the subject of another natural resource inventory in the NPS. Soil resources inventory products for the park were completed in 2013. The Natural Resources Conservation Service (NRCS) maintains the Web Soil Survey (WSS), which makes these data accessible (see "Guidance for Resource Management").

## 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 exposure (Henderson et al. 2022). Geologic stratotypes are important geoheritage resources with historic and scientific 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 biologic evolution of our planet. Rock formations are named after topographic or geologic features and geographic landmarks that are recognizable 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 designated stratotypes identified within the boundaries of the park. There are 11 identified stratotypes located within 48 km (30 mi) of park boundaries that may be relevant in case of future park boundary expansion: Piney Point Formation; Old Church Formation; Eastover Formation; Eastover Formation, Cobham Bay Member; 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).

Many of the geologic map-unit names in the GRI GIS data refer to local geographic features, and some are very well exposed at locations in or near the park. For example, the Petersburg Granite (**PNMpg**), exposed in the Five Forks Battlefield unit, was named and described by Anna Jonas in 1928 for occurrences near Petersburg (Nelson 1928); however, she was unable to formally publish the definition because of her gender (Carter et al. 2021; Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023). The Potomac Formation (**Kp**) was named for the Potomac River; however, its exact type locality was never designated. The Aquia Formation's (**Ta**) type locality was established in 1901 at Aquia Creek in Stafford County in eastern Virginia. The Yorktown Formation (**Ty**) was first described in 1906 and has a type locality on the southwest side of the York River in York County, Virginia (Ward and Blackwelder 1980). The Cold Harbor formation (**Tch**) was named for borings in the Seven Pines quadrangle at Cold Harbor Battlefield (Berquist and Gilmer 2014). The Bacons Castle Formation (**Qbc**) was named for a town in Isle of Wight County in 1965. The Shirley Formation (**Qsh**) was named in 1989 after the Shirley Plantation, but its type section is at the north-south face of the Tarmac-LoneStar borrow pit in Charles City County. The Virginia Division of Mineral Resources (now Virginia Energy; 2003, updated in 2020) lists and describes the mapped geologic units within the state of Virginia.

# Geologic History

This chapter describes the order of geologic events that formed the present landscape. Emphasis is placed on the history recorded in the geologic units mapped in the park's region. A geologic time scale (Table 2) shows the chronology of geologic events (bottom to top) that led to the park's present-day landscape; this story covers more than 600 million years.

**Table 2.** 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. Letters in parentheses are abbreviations for geologic time units. Only geologic units mapped within the park are included. The Quaternary and Tertiary Periods are part of the Cenozoic Era. The Triassic, Jurassic, and Cretaceous Periods are part of the Mesozoic Era. The periods from Cambrian through Permian are part of the Paleozoic Era. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2020). Updated unit age information from Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023.

| Era | Period | MYA | Geologic Map Units | Local Geologic Events |
|---|---|---|---|---|
| Cenozoic (CZ) | Quaternary (Q) | 2.6–today | • Qml developed, Qal deposited<br>• Qbc, Qtu, Qw, Qcc, Qc, Qsh, Qeg, Qts deposited | • Human history; fluvial meandering, incision, and deposition<br>• Ice age glaciations; weathering and incision accelerated; global sea level fluctuates |
| Cenozoic (CZ) | Tertiary (T); Neogene (N) | 23.0–2.6 | • Tg, Tcl, Tsm, Ty, Tch deposited | • Ongoing erosion and weathering<br>• Coastal Plain expands |
| Cenozoic (CZ) | Tertiary (T); Paleogene (PG) | 66.0–23.0 | • Ta and Tn deposited | • Ongoing erosion and weathering<br>• 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) | 201.3–145.0 | • None mapped | • Ongoing erosion and weathering<br>• Coastal Plain sediments accumulate |
| Mesozoic (MZ) | Triassic (TR) | 252.2–201.3 | • None mapped | • Global mass extinction at end of Triassic<br>• 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<br>• Youngest parts of PNMpg intruded | • Alleghany (Appalachian) Orogeny |
| Paleozoic (PZ) | Mississippian (M) | 358.9–323.2 | • None mapped | • Erosion and weathering of overlying sediments |

**Table 2 (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. Only geologic units mapped within the park are included. The Quaternary and Tertiary Periods are part of the Cenozoic Era. The Triassic, Jurassic, and Cretaceous Periods are part of the Mesozoic Era. The periods from Cambrian through Permian are part of the Paleozoic Era. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2020). Updated unit age information from Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023.

| Era | Period | MYA | Geologic Map Units | Local Geologic Events |
|---|---|---|---|---|
| Paleozoic (PZ) | Devonian (D) | 419.2–358.9 | • Oldest parts of PNMpg intruded | • Global mass extinction at end of Devonian |
| Paleozoic (PZ) | Silurian (S) | 443.8–419.2 | • Oldest parts of PNMpg intruded; existing units deformed and/or metamorphosed | • Ongoing marine sedimentation<br>• Neoacadian Orogeny |
| Paleozoic (PZ) | Ordovician (O) | 485.4–443.8 | • Existing units deformed and/or metamorphosed | • Global mass extinction at end of Ordovician; deeper marine settings<br>• Sea level fluctuations; marine and nearshore settings<br>• Taconic Orogeny; open marine settings |
| Paleozoic (PZ) | Cambrian (C) | 541.0–485.4 | • PNMa deposited | • Extensive oceans covered most of proto-North America (Laurentia); sediments accumulated in ocean basin; erosion and weathering |
| Proterozoic Eon; Neoproterozoic (Z) | Not applicable | 1,000–541 | • Zmsv deposited and erupted close to Gondwana | • Supercontinent Rodinia rifted apart to form Laurentia (proto–North America) and Gondwana (South America and Africa); 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 |

More than 600 million years ago, during the Neoproterozoic Era, the ancient supercontinent Rodinia was breaking (rifting) apart. The basin formed between the rifting continents became the Iapetus Ocean. Sediments and igneous rocks accumulated in the basin (Figure 15). Over millions of years,

these materials were metamorphosed and deformed into metasedimentary and metaigneous rocks mixed with continental fragments (geologic map unit **Zmsv**) within the Roanoke Rapids terrane—a complexly constructed package of rock that extends south into North Carolina (Occhi et al. 2018). A terrane is a group of rocks with similar characteristics and geologic history 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.

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. Three Paleozoic Era orogenies (mountain building events during convergence; see Figure 15)—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)—facilitated much of the construction of the Piedmont (Figure 16A). Iapetus sediments, fragments of landmasses, 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 (large body of intrusive igneous rock) and metamorphosed rocks that compose what is mapped as the Petersburg Granite (**PNMpg**) (Carter et al. 2023). These rocks formed in the Silurian to Devonian Periods, about 425 million to 400 million years ago (Carter et al. 2023).

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**) that underlies a large region of east-central Virginia (see Figure 15 and Figure 16A; Occhi et al. 2018). 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 (pieces of rock within an igneous rock that are not derived from the original molten rock) in the solidified granite. One such example, amphibole-mineral-rich amphibolite (**PNMa),** likely started out as basalt or similar rock and is now metamorphosed (Occhi et al. 2018).

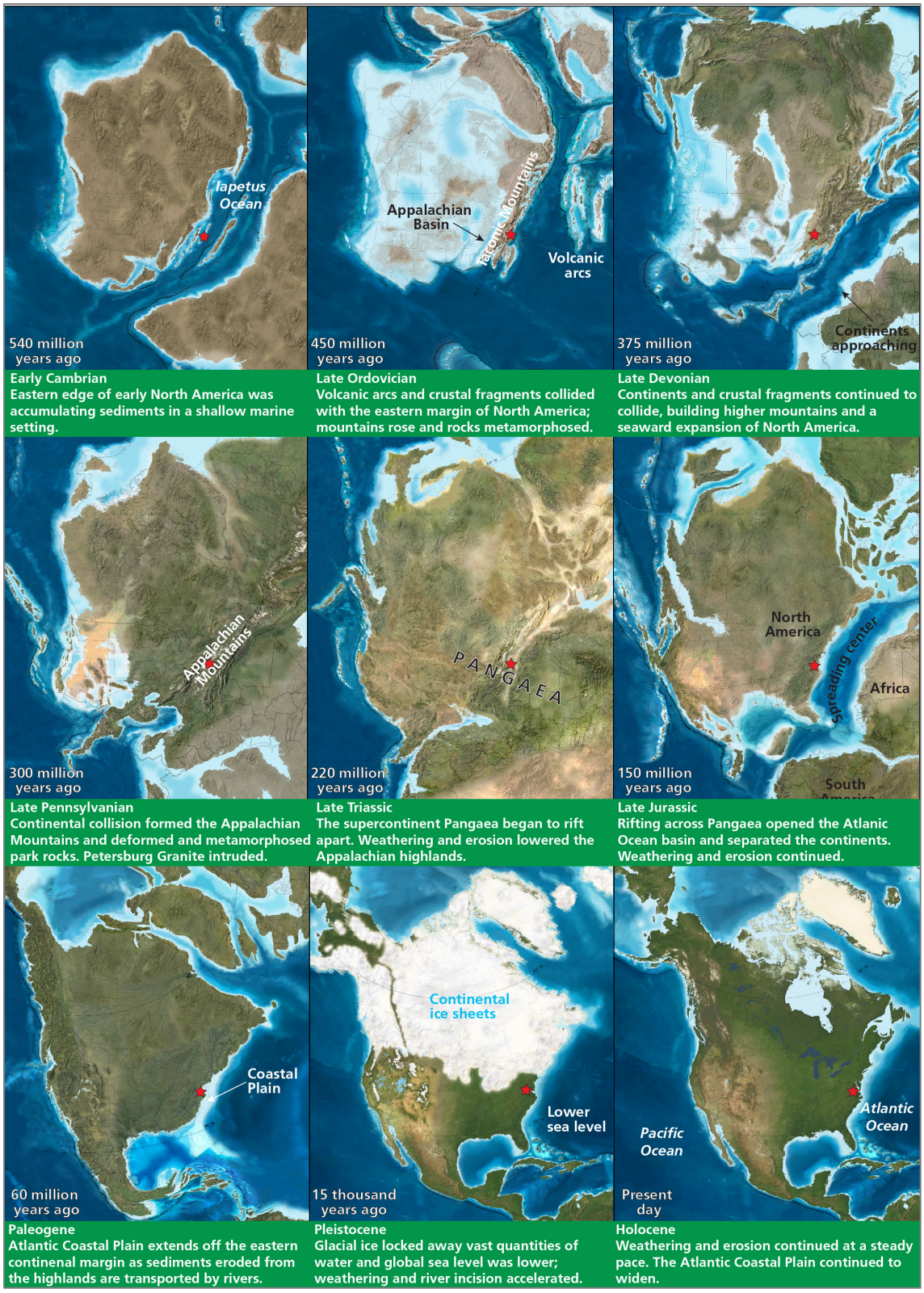



**Figure 15.** Paleogeographic maps of North America. The red star indicates the approximate location of the park. Graphic compiled by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.).

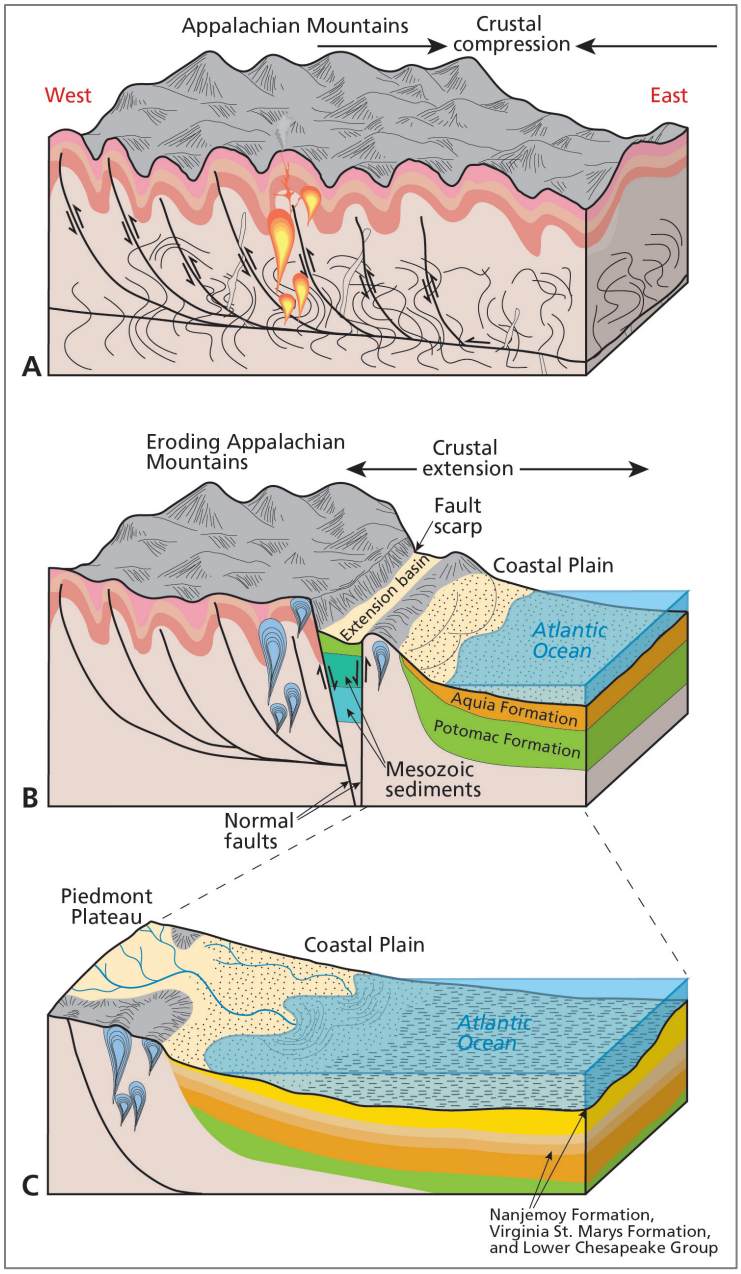



**Figure 16.** Diagram of the geologic evolution of the park's landscape. The park spans the boundary between the Atlantic Coastal Plain and the Piedmont Plateau and thus has characteristics of both provinces. This in turn impacted the park's human history. A) 450 million to 280 million years ago, Paleozoic 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, and 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 million 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 geologic map data.

The Paleozoic orogenies culminated in the uplift of the Appalachian Mountains and the formation of another 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 16B). Across Virginia, relatively small, elongate, fault-bound basins opened as Earth's crust was extended and thinned during rifting. One of these basins, the Richmond-Taylorsville basin, bounds the Petersburg Granite (**PNMpg**) 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 (Figure 16C) 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**), which began to sharply dip to the east (approximately where it is crossed by the I-95 corridor near Petersburg) to become part of the Atlantic Coastal Plain (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 15; 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**) in a complex of fluvial, deltaic, and nearshore depositional environments. Sediments containing mixes of sand, granules, pebbles, and cobbles are characteristic of these settings (Dischinger 1987; Occhi et al. 2018). The Potomac Formation is widespread across Virginia, Maryland, Delaware, and southern New Jersey (Occhi et al. 2018).

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 sandy Aquia Formation (**Ta**), atop an irregular, eroded surface in the City Point area (Dischinger 1987). This unit is dated by its fossil assemblage to the Paleocene Epoch (66 million to 56 million years ago; see Table 2). Yet another period of erosion or nondeposition preceded the deposition of the Nanjemoy Formation (**Tn**) of the Eocene Epoch (56 million to 33.9 million years ago). Both the Aquia and Nanjemoy Formations represent sediments that were deposited during marine transgressions or sea level rises; they were lumped as the Lower Pamunkey Group (only noted in cores; **Tl**) by Occhi et al. (2018).

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 this time in the Petersburg area were terrestrial gravel terraces (**Tg**), the fossiliferous, marine, fine-grained sandy clay Virginia St.

Marys Formation (**Tsm**; Dischinger 1987), and marine to nearshore clay-silt-sand of the Lower Chesapeake Group (**Tcl**; Occhi et al. 2018).

Fluctuating sea levels and accompanying cycles of deposition and erosion continued into the Pliocene during the deposition of the Yorktown Formation (**Ty**) and younger Cold Harbor formation (**Tch**; Figure 17A; Dischinger 1987; Occhi et al. 2018). The Yorktown Formation records a shifting depositional environment. As sea level rose, the setting changed from a high energy nearshore zone to a sub-wave base area (shallow marine depths below where wave energy passes to the shore) and then to deeper, possibly back-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. 2018).

Throughout the Pleistocene (2.6 million to 10,000 years ago), climate fluctuations caused a series of ice ages or continental-scale glacial advances (see Figure 15). Although the ice sheets did not reach as far south as Virginia, their formation and subsequent melting lowered and raised sea level, respectively. In Virginia, falling sea level caused a marine regression and subsequent downcutting and deep erosion of older Coastal Plain sedimentary layers and crystalline Piedmont rocks. Put another way, the sea level fell faster than the topography eroded, leading to steeper topography and deeper river channels. This was followed by erosion of older valley-wall sediments. As sea level rose during the next marine transgression between ice ages, the rivers flooded and eventually created estuaries wherein deposits filled the previously eroded areas (Figure 17B). Successive sea-level rises did not reach the elevations of preceding transgressions, creating a stair-step pattern of successively younger terraces toward the Chesapeake Bay.

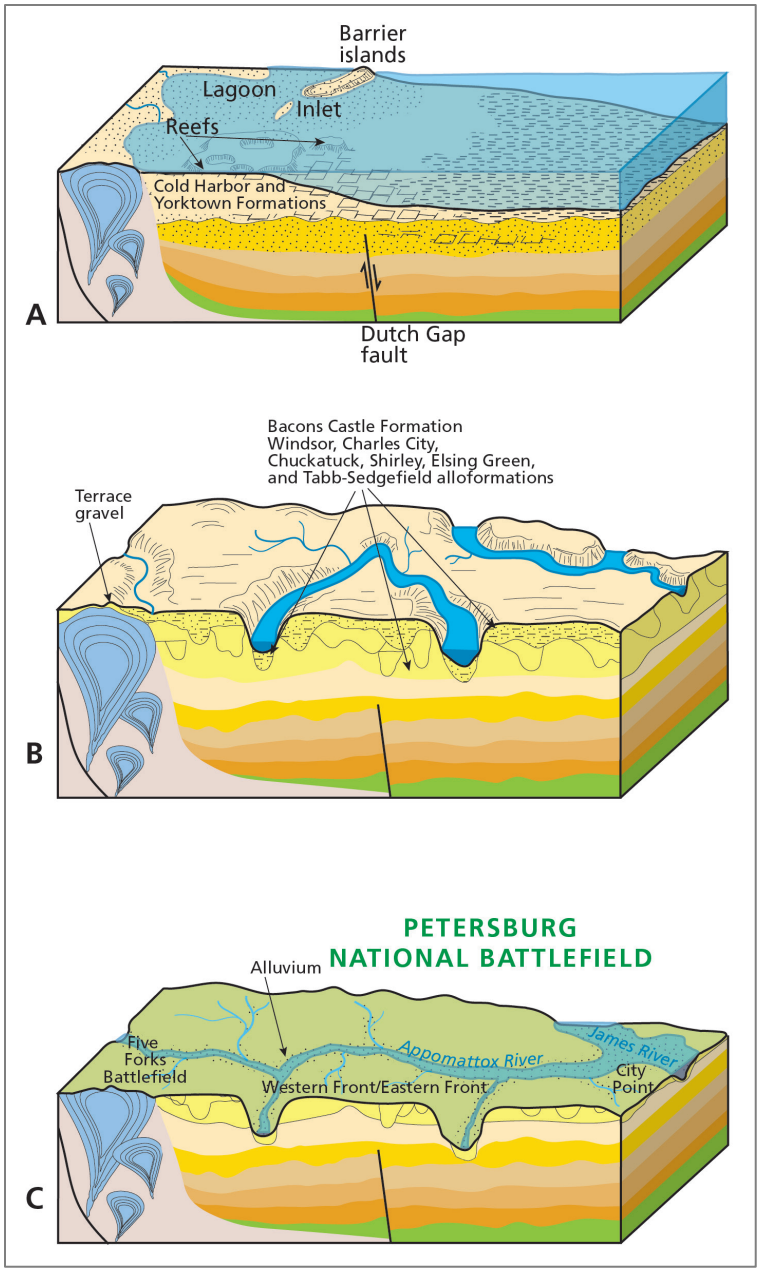



**Figure 17.** Diagram of the geologic evolution of the park's landscape. A) 11 million to 2.5 million years ago, shallow marine conditions were prevalent during the deposition of the Eastover Formation. After a period of erosion or nondeposition, the mixed sands, carbonates (shells), and muds of the 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 (times 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 (times of high sea level), these canyons were flooded and accumulated nearshore and marine sediments. C) By 10,000 years ago, sea-level rise flooded the James and Appomattox River valleys, 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.

A widespread, defined topographic scarp is present at an elevation of approximately 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**) on top of the partially eroded Cold Harbor (**Tch**) and older Coastal Plain sediments; the Cold Harbor and other sediments had been eroded prior to the Bacons Castle deposition. The lower part of the Bacons Castle Formation was deposited in a fluvial to marginal marine environment and commonly contains clasts larger than those found in the Cold Harbor formation (Figure 18; Occhi et al. 2018). Then began the Pleistocene cycles of sea level rise (deposition) and fall (erosion) that deposited the characteristic stair-step terrace pattern (Figure 19) in fluvial, estuarine, and tidal environments. The following units comprise that record (listed from oldest to youngest): Windsor alloformation and Quaternary terrace (**Qw** and **Qtu**, respectively), Charles City alloformation (**Qcc**), Chuckatuck alloformation (**Qc**), Shirly alloformation (**Qsh**), Elsing Green alloformation (**Qeg**), and the Tabb-Sedgefield alloformation (**Qts**; Dischinger 1987; Occhi et al. 2018). The sea level began to stabilize throughout the Holocene Epoch (10,000 years ago to the present), and the modern coastline and river courses took shape (see Figure 17C). Weathering and erosion continue to reshape and refine the landforms throughout the park area. Rivers such as the Appomattox River and Rowanty Creek incise their channels further into the deeply weathered bedrock (**PNMpg**) and assorted unconsolidated units deposited during the Cretaceous, Tertiary, and Pleistocene. These rivers deposit and rework alluvium (**Qal**), consisting of pebbly sand, sand, silt, and clay, the youngest surficial geologic map unit along their channels and adjacent floodplains (Dischinger 1987; Occhi et al. 2018).




**Figure 18.** Photograph of the sedimentary textures of the Bacons Castle Formation. Pebbly, clayey, and fine to coarse sand characterize the Bacons Castle Formation (geologic map unit Tbc) unit locally. Visible are successions of fining upward sequences, wherein base layers of pebbles as much as 5 cm (2 in) in diameter fine upsection to a fine or medium sand size with abundant clay. This records a change from high-energy to lower-energy depositional environments. Photograph is part of figure 11 in Occhi et al. (2018).

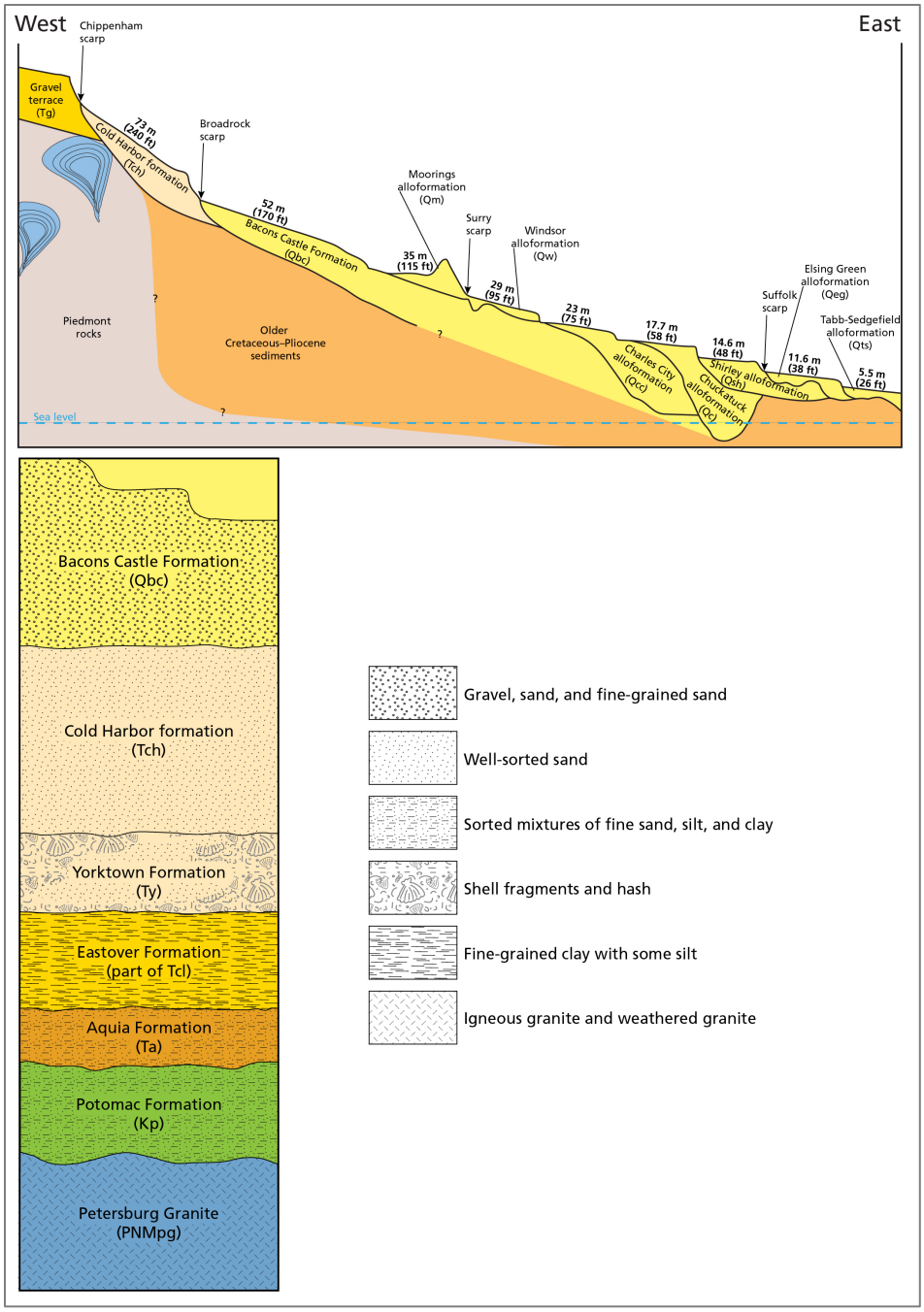



**Figure 19.** Stratigraphic column and diagram of the Coastal Plain stair-step terraces. Almost all the units within the park are unconsolidated sediments of the Coastal Plain. The solid but weathered Petersburg Granite underlies the western areas. Graphics not to scale; however, the stair-step terraces begin at sea level and the Chesapeake Bay (right side) moves westward to the first exposures of the Bacons Castle Formation (Qbc) in the Petersburg area over 35 km (22 mi) inland. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from figure 3 of Johnson (2007), Rick Berquist, written communication, 5 November 2023, and GRI GIS geologic map data.

The Anthropocene Epoch (as of 2023, an unofficial unit of geologic time) is the age of humans, and our modifications of the landscape can be mappable. Where significant changes occurred around Petersburg, mappers denoted these areas as modified land (**Qml**). Examples of modified land include cut and fill, excavation, and mining-related features (Occhi et al. 2018).

# 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 conference-call participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. These features and processes are generally discussed in order of geologic age (oldest to youngest) and include references to the geologic units mapped within the park. Table 3 summarizes the occurrence of each geologic map unit inside the park and the features, processes, and issues associated with them. Geologic map units that occur within the park (geologic map symbol), from oldest to youngest:

- Petersburg Granite (**PNMpg**)
- Potomac Formation (**Kp**)
- Aquia Formation (**Ta**)
- Gravel terrace (**Tg**)
- Lower Chesapeake Group, undivided (**Tcl**)
- Yorktown Formation (**Ty**)
- Cold Harbor formation (**Tch**)
- Bacons Castle Formation (**Qbc**)
- Shirley alloformation (**Qsh**)
- Alluvium (**Qal**)
- Modified land (**Qml**)

**Table 3.** Geologic map units within Petersburg National Battlefield. Units within this table are listed according to their percentage of the total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the poster. Detailed descriptions are part of the pete_geology.pdf in the GRI GIS data. Definitions of some terms are provided in the table; a few (i.e., quartz and feldspar) are defined elsewhere in the text. In addition, figures illustrate some terms.

| Geologic Map Unit (symbol) | Occurrence within Petersburg National Battlefield and Unit Description | Geologic Features and Processes | Geologic Resource Management Issues |
|---|---|---|---|
| Petersburg Granite (PNMpg) | **PNMpg** as mapped encompasses 39% of the park; it is the most prevalent unit. **PNMpg** is mapped exclusively in the Five Forks Battlefield unit. Hard, dense, crystalline rock with visible pale pink feldspar crystals and bluish gray matrix. Pods and lenses of foliated (layered) granite are part of **PNMpg**. It weathers into smooth, round boulders and bedrock pavement. | • Weathered Petersburg Granite Exposures<br>• Unconformity<br>• Mineral Resource Development | • Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Determination of Extent of Civil War Earthworks<br>• Radon<br>• Active Faults and Earthquakes<br>• Urban Development and Utility Corridors<br>• Abandoned Mineral Lands<br>• Monuments |
| Bacons Castle Formation (Qbc) | **Qbc** is the second most prevalent unit in the park; it is mapped in 32% of the park area. **Qbc** is mapped in every park unit except for Five Forks Battlefield and City Point units. **Qbc** includes coarser granules, pebbles, and cobbles in the basal layers and fines upward into yellowish-brown, red, and gray sand. The sands form most of the unit. **Qbc** is commonly mapped at higher elevations. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils<br>• Coastal Plain Stair-Step Terraces<br>• Mineral Resource Development | • Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Determination of Extent of Civil War Earthworks<br>• Active Faults and Earthquakes<br>• Paleontological Resource Inventory, Monitoring, and Protection |
| Cold Harbor formation (Tch) | **Tch** is mapped in 11% of the park. **Tch** is mapped in the Eastern Front and Fort Gregg units. **Tch** is yellow to red, muddy sand with some clay layers. It is an informal unit. | • Unconformity<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils | • Sinkhole Formation<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Determination of Extent of Civil War Earthworks<br>• Paleontological Resource Inventory, Monitoring, and Protection |

**Table 3 (continued).** Geologic map units within Petersburg National Battlefield. Units within this table are listed according to their percentage of the total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the poster. Detailed descriptions are part of the pete_geology.pdf in the GRI GIS data. Definitions of some terms are provided in the table; a few (i.e., quartz and feldspar) are defined elsewhere in the text. In addition, figures illustrate some terms.

| Geologic Map Unit (symbol) | Occurrence within Petersburg National Battlefield and Unit Description | Geologic Features and Processes | Geologic Resource Management Issues |
|---|---|---|---|
| Lower Chesapeake Group, undivided (Tcl) | **Tcl** is mapped in 6% of the park, specifically the Eastern Front and Fort Fisher units. **Tcl** is predominately bluish to greenish gray clay, silt, and fine-grained sand. Weathered (oxidized) exposures appear yellowish brown. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils | • Sinkhole Formation<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Determination of Extent of Civil War Earthworks<br>• Active Faults and Earthquakes<br>• Paleontological Resource Inventory, Monitoring, and Protection |
| Gravel terrace (Tg) | **Tg** is mapped in 4% of the park. **Tg** is mapped exclusively in the Five Forks Battlefield unit. **Tg** is yellowish brown, white, and red sand, granules, pebbles, and cobbles with some clayey layers. **Tg** is commonly mapped on top of ridges and hills. | • Unconformity | • Determination of Extent of Civil War Earthworks |
| Shirley alloformation (Qsh) | **Qsh** is mapped in 3% of the park, including areas in the Eastern Front and City Point units. **Qsh** is predominantly gray to brown gravel, sand, silt, and clay. The grain size decreases from bottom to top. It is commonly mapped on broad flats near the Appomattox River. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils<br>• Coastal Plain Stair-Step Terraces<br>• Fluvial Features and Processes | • Shoreline Changes at City Point<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Active Faults and Earthquakes<br>• Determination of Extent of Civil War Earthworks<br>• Paleontological Resource Inventory, Monitoring, and Protection |

**Table 3 (continued).** Geologic map units within Petersburg National Battlefield. Units within this table are listed according to their percentage of the total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the poster. Detailed descriptions are part of the pete_geology.pdf in the GRI GIS data. Definitions of some terms are provided in the table; a few (i.e., quartz and feldspar) are defined elsewhere in the text. In addition, figures illustrate some terms.

| Geologic Map Unit (symbol) | Occurrence within Petersburg National Battlefield and Unit Description | Geologic Features and Processes | Geologic Resource Management Issues |
|---|---|---|---|
| Potomac Formation (Kp) | **Kp** is mapped in 2% of the park, only at the Eastern Front unit along the edge of the Appomattox River floodplain. **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. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils<br>• Mineral Resource Development | • Flooding, Upland Erosion, and Sediment Loading<br>• Active Faults and Earthquakes<br>• Determination of Extent of Civil War Earthworks<br>• Paleontological Resource Inventory, Monitoring, and Protection |
| Yorktown Formation (Ty) | **Ty** is mapped in 2% of the park, only at the Eastern Front unit along Harrison Creek. **Ty** is gray to bluish gray sandy silty clay. When weathered, **Ty** is yellow, reddish brown, and brown. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils | • Sinkhole Formation<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Active Faults and Earthquakes<br>• Determination of Extent of Civil War Earthworks<br>• Paleontological Resource Inventory, Monitoring, and Protection |
| Alluvium (Qal) | **Qal** is mapped in less than 1% of the park in places where it is mapped adjacent to other units (i.e., in the City Point unit; map code: CIPO). On the rest of the map (map code: PETE), **Qal** is mapped as a separate surficial unit, with other units mapped beneath it. In these data, it is mapped in 3% of the park. **Qal** is mapped in nearly every park unit except for Fort Gregg. **Qal** includes pebbly sand, sand, silt, and clay with organic material. | • Unconformity<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils<br>• Fluvial Features and Processes | • Shoreline Changes at City Point<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Determination of Extent of Civil War Earthworks<br>• Paleontological Resource Inventory, Monitoring, and Protection |

**Table 3 (continued).** Geologic map units within Petersburg National Battlefield. Units within this table are listed according to their percentage of the total area within park boundaries. Unit colors reflect the colors presented in the GRI GIS data and on the poster. Detailed descriptions are part of the pete_geology.pdf in the GRI GIS data. Definitions of some terms are provided in the table; a few (i.e., quartz and feldspar) are defined elsewhere in the text. In addition, figures illustrate some terms.

| Geologic Map Unit (symbol) | Occurrence within Petersburg National Battlefield and Unit Description | Geologic Features and Processes | Geologic Resource Management Issues |
|---|---|---|---|
| Aquia Formation (Ta) | **Ta** is mapped in less than 1% of the park, all areas in the City Point unit along the shoreline of the Appomattox River. **Ta** is a dark greenish gray to black, fine-grained sand. Some clay layers and flaky mineral (mica) layers are present, and at its base is a gravel layer. Weathered exposures range from greenish gray to reddish brown. | • Unconformity<br>• Dutch Gap and Unnamed Faults<br>• Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils | • Shoreline Changes at City Point<br>• Flooding, Upland Erosion, and Sediment Loading<br>• Slope Movements<br>• Active Faults and Earthquakes<br>• Paleontological Resource Inventory, Monitoring, and Protection |

### Weathered Petersburg Granite Exposures

Geologic map unit: Petersburg Granite (**PNMpg**)

Bedrock is the older rock that underlies the younger, unconsolidated surficial deposits of the park. Locally, bedrock almost entirely consists of the Petersburg Granite, which dominates the western third of the mapped area, including the Five Forks Battlefield unit (Figure 20; Occhi et al. 2018). New studies reveal that granite is part of a composite batholith (a large body of intrusive igneous rock) and metamorphosed rocks that compose what is mapped as the Petersburg Granite (Carter et al. 2023). Bedrock can be sedimentary, igneous, or metamorphic, though only igneous and sedimentary rocks are present in the park. Sedimentary rocks form from fragments of other rocks or chemical precipitation. Igneous rocks form by the cooling of molten material. Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids.

In geology, the name granite denotes a specific mineral composition and genesis. Its mineral components must include quartz, alkali feldspar, and plagioclase. Granite is an igneous rock that forms from partially molten rock, a material called magma (a mixture of liquid rock, crystals, and gases). Granitic magmas have a high content of silica relative to other magma types and cool slowly underground. If one were to split the Petersburg Granite open and observe a fresh surface, minerals such as quartz, plagioclase, potassium (alkali) feldspar, muscovite, biotite, hornblende, zircon, epidote, and smaller amounts of ilmenite/magnetite, apatite, and garnet would be visible as tightly woven crystals. The GRD rocks and minerals website (https://www.nps.gov/subjects/geology/rocks-and-minerals.htm) has more detailed mineral descriptions. The composition of the Petersburg Granite at the park ranges from granite to granodiorite (Figure 21), with more plagioclase and dark mineral components (Virginia Division of Mineral Resources 2003). Overall, the rock is a light bluish gray (Figure 22). The size of the individual crystals may be roughly the same, or in some areas, crystals of pink potassium feldspar may reach up to 30 cm (12 in) in length, surrounded by smaller crystals of the other minerals (Occhi et al. 2018).




**Figure 20.** Photographs of Petersburg Granite. The 300-million-year-old Petersburg Granite underlies the western portion of the park. A) A stream is slowly cutting a notch through an exposure of the granite. The granite is very resistant to erosion, and stream development is locally limited in contrast to the deeply incised channels in the unconsolidated sediments of the Coastal Plain. B) In some places, the granite is exposed as unweathered pavements with little to no soil development. The granite impacted battle history since trenches and earthworks were difficult to construct in the bedrock. C) The granite's texture is mostly not foliated, but in some areas a fabric is visible. Magmatic fabrics can be records of a variety of large- and/or small-scale processes (e.g., Paterson et al. 1998) but generally signify that some internal or external stress acted on the magma as it crystallized. However, in this instance, new studies conclude the foliated rocks are actually a gneiss, with the foliation coming from metamorphism (Mark Carter, US Geological Survey, written communication, 14 November 2023). The large white crystals are feldspars in the darker matrix. D) Some portions of the granite have deeply weathered into crumbly saprolite. In this image, the unconformable contact between the Petersburg Granite and the overlying Cold Harbor formation represents more than 295 million years of Earth's history. Photograph A is an unnumbered figure in Lookingbill et al. (2013). Photographs B, C, and D are figures 8, 9, and 3, respectively, in Occhi et al. (2018). Notation by Trista L. Thornberry-Ehrlich (Colorado State University).

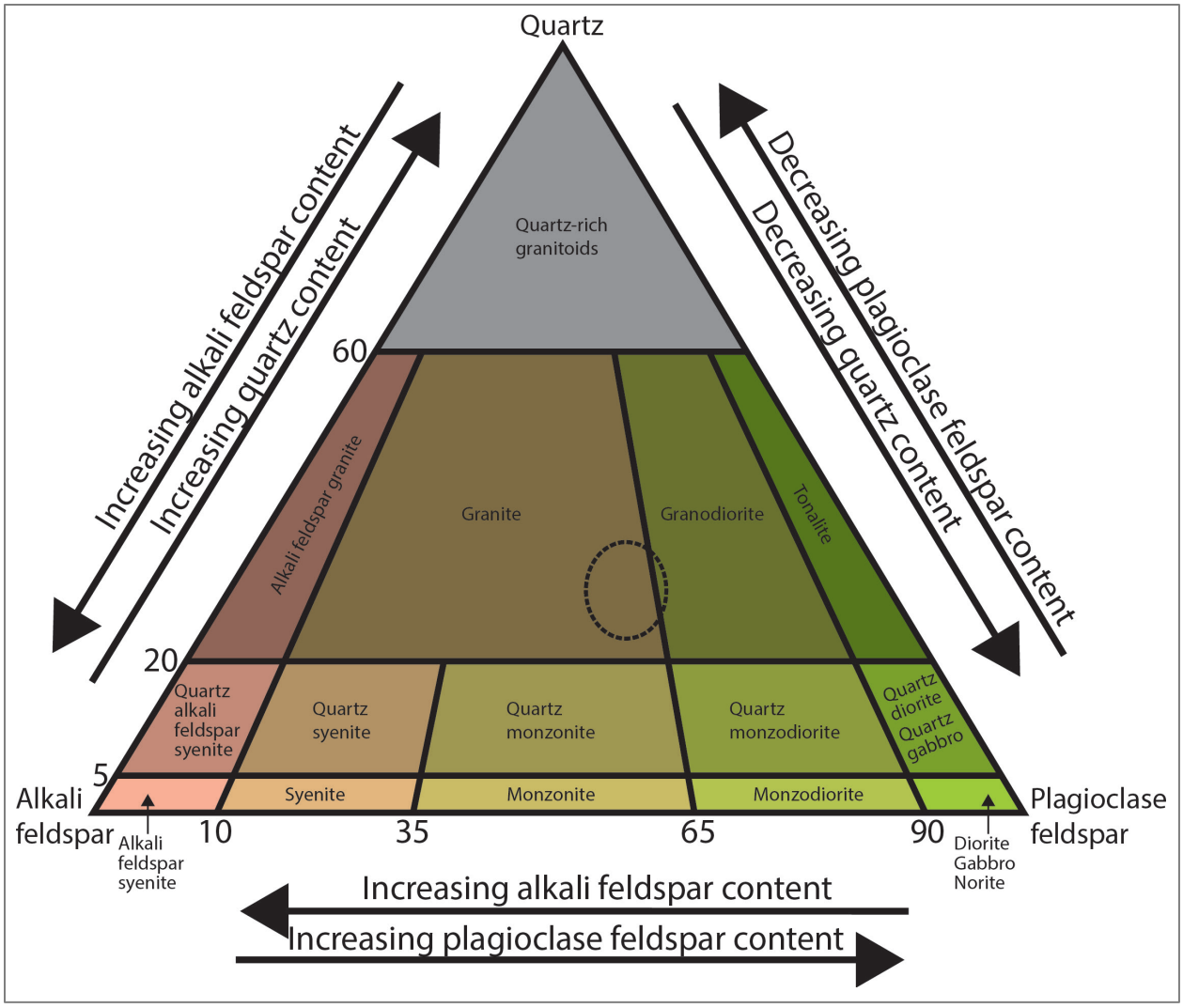



**Figure 21.** Diagram showing the classification of intrusive igneous rocks. Numbers refer to the percentage of the mineral constituent (quartz, alkali feldspar, or plagioclase feldspar) in the overall composition of the rock. Numbers 5, 20, and 60 refer to the overall quartz component, whereas numbers 10, 35, 65, and 90 refer to the contribution of plagioclase to the overall composition. The corners represent compositions that are very rich in the corresponding mineral and poor in the two other minerals, but not necessarily other possible component minerals. The dashed circle indicates the approximate composition of the Petersburg Granite (PNMpg). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) following standard International Union of Geological Sciences (IUGS) nomenclature.

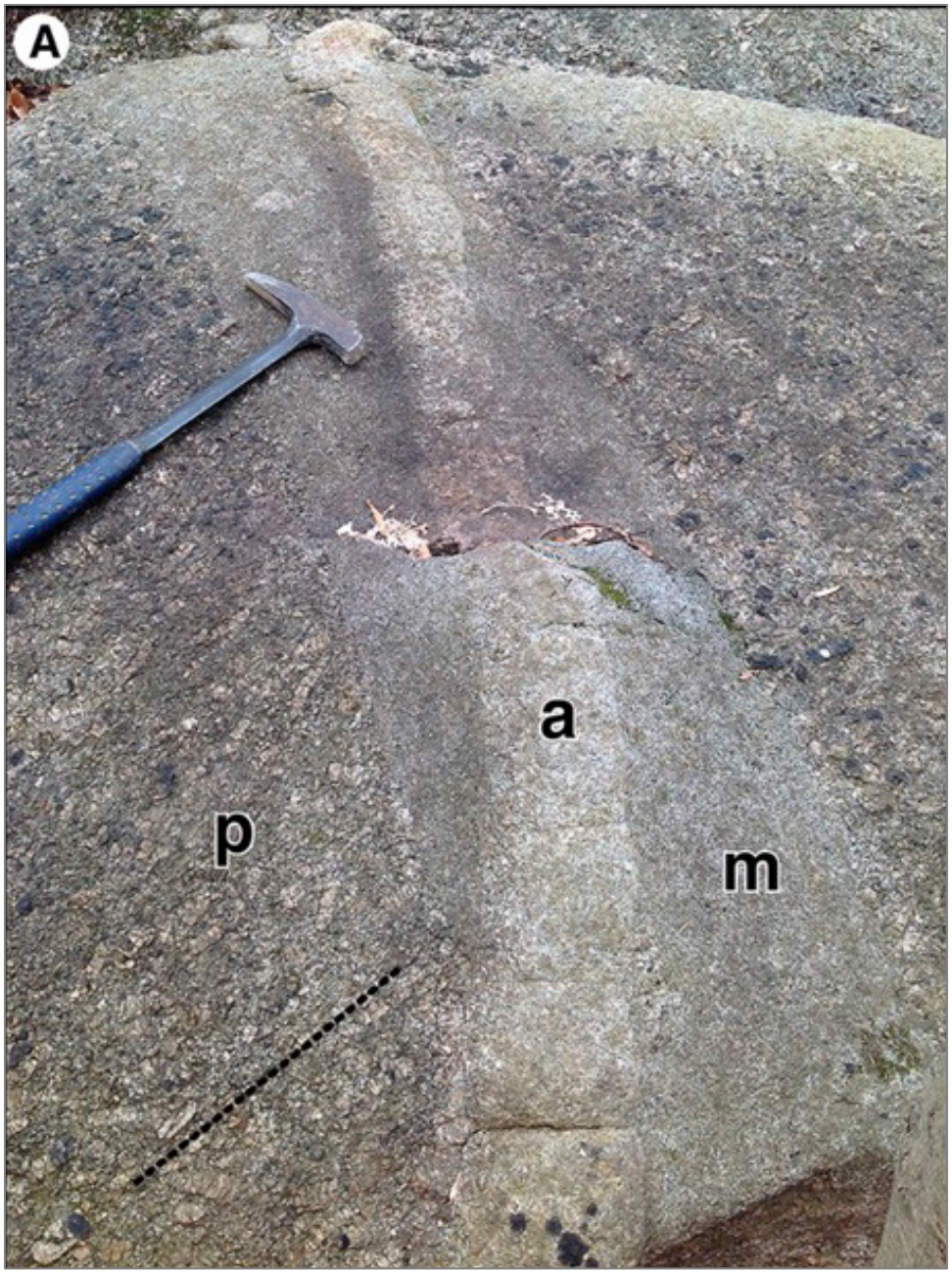



**Figure 22.** Photograph of Petersburg Granite exposure. Unweathered exposures of the Petersburg Granite (PNMpg) appear banded and bluish gray. A dike of massive equigranular (crystals are roughly the same size) granite (m) crosscuts porphyritic granite (p) in an outcrop near Richmond, Virginia. Weakly aligned potassium feldspar crystals (marked by a black dotted line) in porphyritic granite may represent a magmatic foliation (Owens et al., 2017). A light-colored dike (a) crosscuts both massive equigranular granite and porphyritic granite in the outcrop. In places, the granite may be covered by loose sediments, or the surface may be otherwise obscured by weathering or even lichen growth. Exposure near Richmond, some 40 km (25 mi) north of Petersburg. Photograph is figure 3A from Carter et al. (2023).

The youngest parts of the mapped Petersburg Granite crystallized about 300 million years ago (e.g., Carter et al. 2023), followed by a long history of weathering after being exhumed in the Triassic

(e.g., Owens et al. 2017) and re-covered by sediments from subsequent marine transgressions over the area (Mark Carter, US Geological Survey, geologist, written communication, 15 November 2023). Exposures of the granite have weathered to varying degrees, ranging from deep saprolite to rounded boulders to nearly unweathered bedrock pavements, which are surfaces of bare bedrock on the ground surface (see Figure 20 and Figure 22). Saprolite is chemically weathered rock and represents extensive weathering *in situ* of the bedrock surface. They maintain a characteristic semblance to the original texture and structure of the bedrock. Therefore, the nature of saprolite depends on the original rock type. For the Petersburg Granite, the developing saprolite consists of granular, resistant quartz, and biotite flakes and clays, which replaced the feldspar minerals. In exposures, the saprolite is gray to orangish tan. East of the Five Forks Battlefield unit, the saprolite is about 9 m (30 ft) thick, whereas in other areas no saprolite has developed to cover the granite. Rounded boulders of granite appear in the field as "whalebacks" or "sleeping elephants" with a humped appearance. Northwest of the Five Forks Battlefield unit, a level bedrock pavement was noted and included in the GRI GIS data as a geologic photograph locality (Occhi et al. 2018).

### Unconformity

Geologic map units: Petersburg Granite (**PNMpg**), Potomac Formation (**Kp**), Aquia Formation (**Ta**), gravel terrace (**Tg**), Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty**), Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), and alluvium (**Qal**)

Layers of rock are referred to as "conformable" when they have been deposited essentially without interruption. Although locations 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 information in the geologic record to interpret. Unconformable contacts occur between every geologic map unit at the park (see Figure 19).

The longest gap in the park's geologic record reflected in the sequence of rocks, from one unit to the next older unit, is between the Petersburg Granite and the Potomac Formation—at least 155 million years. In some areas, because the granite provided an irregular, undulating depositional surface, much younger units are in contact with the Petersburg Granite (e.g., gravel terrace, Lower Chesapeake Group, Cold Harbor formation, alluvium). This is because during the series of sea level rises associated with the deposition of the younger units, some depressions in the granite were protected from erosion and the previously deposited marine sediments were preserved there, whereas in other locations, the previous sediments were stripped away and new sediments were deposited (Occhi et al. 2018). Due to the nature of their formation via cycles of sea level rise and fall, periods of erosion and deposition alternated, causing unconformities between every unit.

### Dutch Gap and Unnamed Faults

Geologic map units: Potomac Formation (**Kp**), Aquia Formation (**Ta**), Nanjemoy Formation* (**Tn**), Virginia St. Marys Formation* (**Tsm**), Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty**),

Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), Elsing Green alloformation * (**Qeg**). *Units are not exposed at the surface within the park but may be buried and offset by 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. A fault is a fracture in rock along which rocks have moved. The three primary types of faults are normal faults, reverse faults, and strike-slip faults (Figure 23). Faults are classified based on the motion of rocks on either side of the fault plane. 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. Normal faults and faults of unknown offset/displacement are mapped within the GRI GIS data for the park and include the Dutch Gap fault. This fault was named for a 17th century moat dug by Sir Thomas Dale to protect a narrow-necked peninsula with high bluffs that became a settlement called Henricus, which, in connection with the canals dug by Union forces to bypass Confederate batteries to the north, is today part of the main commercial shipping channel of the James River (Dischinger 1987; Cross et al. 2017; Occhi et al. 2018).

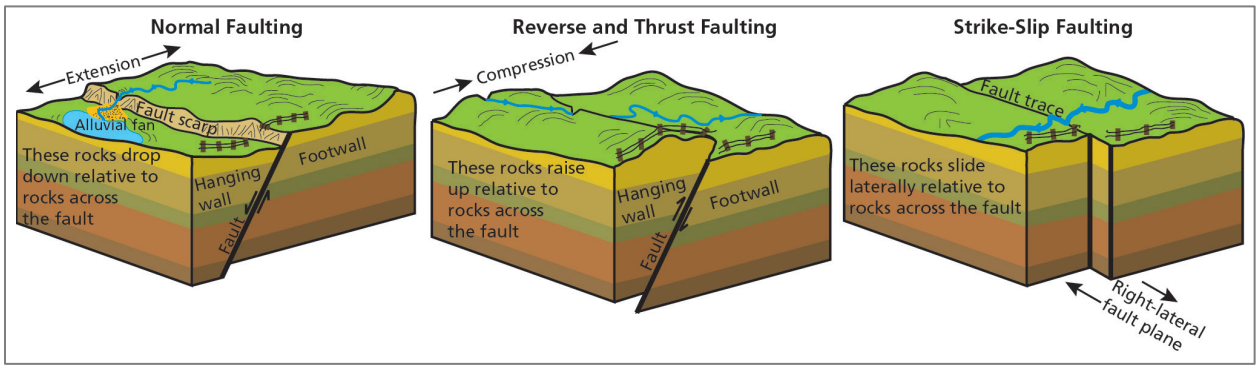



**Figure 23.** Graphic of fault types. Movement occurs along a fault plane. Footwalls are below the fault plane, and hanging walls are above. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging 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. The Dutch Gap fault is an example of a reverse fault. 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).

Occhi et al. (2018) describe the Dutch Gap fault as a north-south to northeast-southwest trending series of reverse faults that juxtapose the older Potomac Formation (**Kp**) sediments to the east against

the younger (Lower Chesapeake Group and Cold Harbor formation [**Tcl** and **Tch**, respectively]) sediments to the west. The fault is obvious in cross sections (see pete_geology.pdf described under "Geologic Map Data"). The faulted zone extends at least 13 km (8 mi) from the northwestern corner of the battlefield northward across the James River (Dischinger 1987; Thornberry-Ehrlich 2005). Overall displacement along the fault is up to 24 m (80 ft), with the down-dropped side of the fault lying to the west. The presence of the Dutch Gap fault may possibly control the sharp turn to the north of the Appomattox River, just west of Petersburg, and north of the Eastern Front unit of the park (Dischinger 1987; Occhi et al. 2018). The surficial trace of the Dutch Gap fault is buried by younger units, e.g., Bacons Castle Formation (**Qbc**) and younger (Occhi et al. 2018).

Myriad small-scale faults (not necessarily mapped) in the unconsolidated sedimentary units influence landform development and reveal more recent tectonic activity in the park area. Topographically high areas near Bailey Creek and the southward stretch of the James River from Richmond to Drewrys Bluff are likely there because of other faults that run parallel to the Dutch Gap fault. In places where faulting was contemporaneous with sedimentation, such as to the north of the James River, deposited sedimentary layers can be thicker in the down-dropped portion and thinner in the upthrown block (Dischinger 1987; Thornberry-Ehrlich 2005).

### Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils

Geologic map units: Potomac Formation (**Kp**), Aquia Formation (**Ta**), Eastover Formation, part of Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty**), Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), and 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, NPS Geologic Resources Division, paleontologist, written communication, 12 October 2023).

The Coastal Plain geologic map units in the park, spanning approximately 100 million years of Earth's history, are fossiliferous. Fossil discoveries from within the park date to the middle 1800s. An early paleontologist, Timothy Abbott Conrad, was active in the park area. His earliest publication from this area was in 1840, wherein he presented several species collected near City Point: *Astarte arata* (a large mollusk), *Pecten virginianus* (a crenulated mollusk), *Ostrea subfalcata* (an oyster), and *Ostrea disparilis* (a variety of oyster) (Conrad 1840).

Some reports state that fossils were found during military engagements at Petersburg. Union soldiers digging wells noted a number of shells in the underlying sediments (Lyman 1994; Kenworthy et al. 2006). Recent excavations at The Crater found fossil shark teeth (Figure 24; Alexis Morris, NPS Petersburg National Battlefield, natural resources lead, GRI follow-up meeting, 18 August 2022).

Although there are documented occurrences of fossils within the park, no fossils are present in the park's collection, and the park is not aware of their location (Alexis Morris, NPS Petersburg National Battlefield, natural resources lead, GRI follow-up meeting, 18 August 2022),

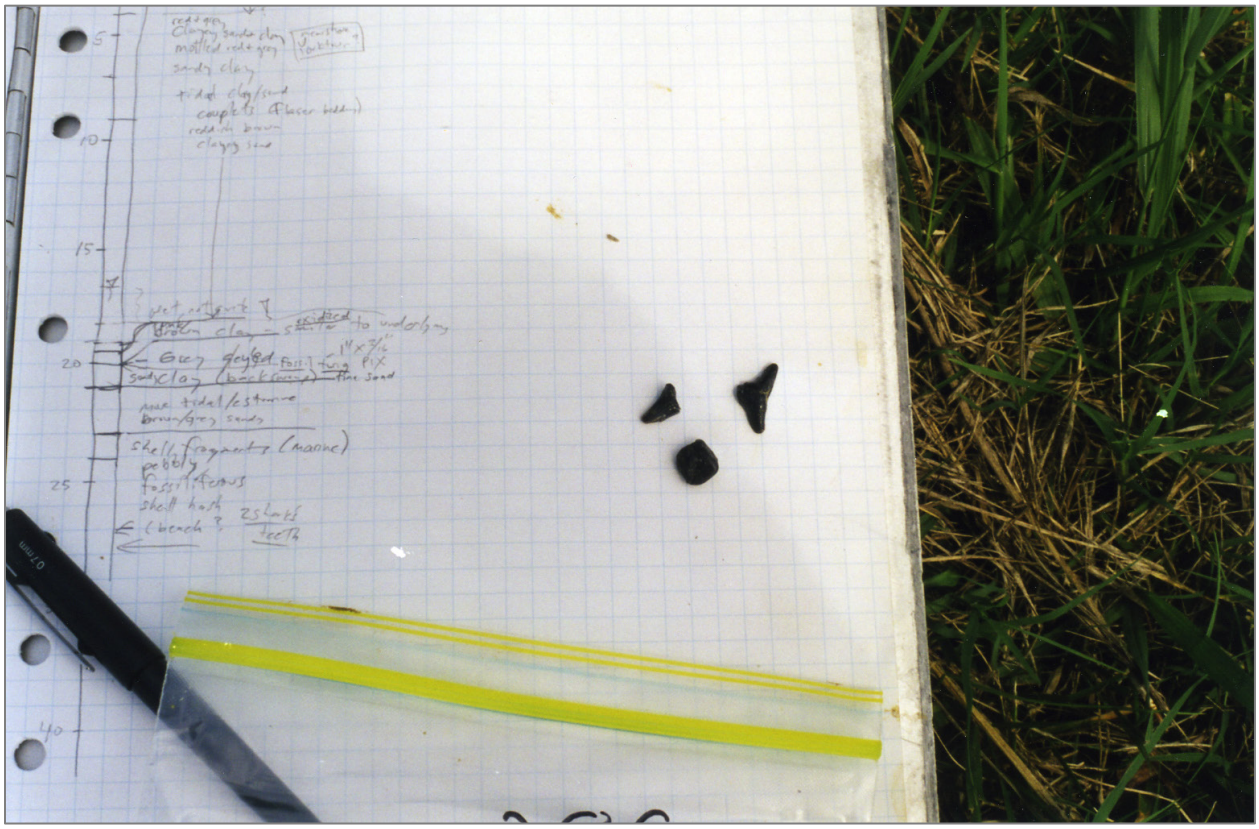


**Figure 24.** Photograph of fossil shark teeth. Fossil teeth were found adjacent to The Crater at the park during a coring project. The local layers of the Yorktown Formation (geologic map unit Ty) are fossiliferous, and historic accounts indicate that the Union soldiers who excavated the tunnel noted fossils in the material they were removing. NPS photograph taken by Hal Pranger in 2000.

Fossil type specimens are the material on which a species, subspecies, or variety is based; they may have historic significance. Ideally preserving distinguishing morphological characteristics, they represent a reference for the description and subsequent evaluations and discussions of that creature and provide the basis for comparisons with others (Tweet et al. 2016). Historical locality information for fossil name-bearing type specimens is lacking at the park; at least 140 fossil taxa, mostly mollusks, have been named from specimens recovered from localities potentially within park boundaries—representing the Pliocene Yorktown Formation (Justin Tweet, NPS Geologic Resources Division, paleontologist, written communication, 12 October 2023). The inception and growth of American paleontology through the 19th century can be seen in a chronological breakdown of the species associated with NPS areas, including the oldest names coming from the park, Colonial National Historical Park, and Vicksburg National Military Park (Tweet et al. 2016). Specific localities related to 1800s paleontological work are difficult to determine, as the publications of that time commonly just refer to "Petersburg" (Justin Tweet, NPS Geologic Resources Division, GRI

follow-up meeting, 18 August 2022). Some of this obscurity is possibly related to landscape changes, both natural and anthropogenic, since the American Civil War.

The following units are known to contain fossils throughout the Coastal Plain (from Kenworthy et al. 2006 and Crane and Upchurch 1987):

- Potomac Formation: pollen, ferns, horsetails, cycads, gnetales (a family of tropical plants), conifers, mollusks, fish, amphibians, crocodiles, turtles, birds, small mammals, trace fossils, dinosaurs
- Aquia Formation: mollusks, burrows, dinoflagellates (single cell plankton), dinocysts, foraminifera (single-celled organisms), ray plates, shark teeth, marine fish, crocodiles, sea turtles, birds, terrestrial mammals. Dr. Richard Eppes collected giant fossil oyster shells at City Point.
- Eastover Formation: bivalves, mollusks, diatoms (algae). Fossils were noted in The Crater from the Yorktown and Eastover Formations.
- Yorktown Formation: mollusks, coral, shark teeth, shell debris, whales, walrus, fish, cephalopods (squid and octopus), scaphopods (burrowing mollusk), crabs, echinoids (sea urchins), brachiopods (marine creatures with upper and lower shells), bryozoans (marine creature forming branching, encrusting, or gelatinous mosslike colonies), sponges, ostracodes, foraminifera. Fossils were noted in "The Crater" from the Yorktown and Eastover Formations (see Figure 24). Martin Lister illustrated the first fossil from North America in 1687, a scallop shell later named *Chesapecten jeffersonius* from the Yorktown Formation (Figure 25), probably collected from within or near Colonial National Historical Park. This species is the earliest fossil representation from North America and is now recognized as the state fossil of Virginia. The Yorktown is also known to be fossiliferous within Petersburg National Battlefield (Kenworthy et al. 2006).
- Bacons Castle Formation: pollen
- Shirley alloformation: mollusks, coral, plant fragments



**Figure 25.** Photograph of a fossil scallop from the James River. The fossil likely washed out from exposures of the Yorktown Formation (geologic map unit Ty) along the James River downstream from Petersburg National Battlefield. Though not formally identified as such, the fossil is similar to the Virginia state fossil, *Chesapecten jeffersonius* (an extinct scallop). Inset is a copy of Martin Lister's 1687 figure of the *Chesapecten jeffersonius*—the first such illustration 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 or periods of relatively high sea level. 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. 2018). Each terrace is generally a broad flat with characteristic elevations (see Figure 19):

- Windsor alloformation 30 to 38 m (100 to 125 ft)
- Charles City alloformation 18 to 23 m (60 to 75 ft)
- Chuckatuck alloformation 15 to 18 m (50 to 59 ft)
- Shirley alloformation 14 to 15 m (45 to 49 ft)
- Elsing Green alloformation 11 to 12 m (35 to 39 ft)
- Tabb-Sedgefield alloformation 6 to 9 m (20 to 28 ft)

Note: these units have not been formally defined and registered, so their formation name is not capitalized.

### Fluvial Features and Processes

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

Fluvial features are formed by flowing water, typically in rivers and streams. Fluvial processes both construct (deposit alluvium; geologic map unit **Qal**) and erode landforms (e.g., the drainages through the Coastal Plain sediments and Appomattox River valley). Rivers and streams cross the landscape within and surrounding the park, including the James River, Appomattox River, Harrison's Creek, Rohoic Creek, Poor Creek, Hatcher Run (and accompanying 2 ha [4–5 ac] pond), Lieutenant Run, Brickhouse Run, Cattail Run, Arthur Swamp, Second Swamp, Picture Branch, Rocky Branch, Wallace Creek, Gravelly Run, Reedy Branch, and Bailey Creek (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 siege 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. All the streams in the park are headwater streams, draining small watersheds (National Park Service 2017b). Examples of the park's fluvial features include meandering river channels, point bars, gravel bars, islands, floodplains, back swamps, and terraces (Figure 26). The flow of a river itself provides energy to the system, altering the landscape. 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 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. When meandering reaches an extreme, the narrow neck of land between two bends is breached, leaving an area called an oxbow lake or abandoned meander. Gravel bars are in-channel accumulations of coarser material that may or may not emerge above the water's surface. When an area stays above the surface of the stream, it becomes an island.

Floodplains are areas of typically low-lying ground adjacent to a river (Figure 27). They are commonly formed of river sediments (e.g., alluvium) 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—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, 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). At City Point, the bluff is a riverine terrace composed of sand, silt, clay, and peat of the Shirley alloformation (**Qsh**) and underlying Chuckatuck alloformation (**Qc**) atop the Aquia Formation (**Ta**) (Figure 28; Cross et al. 2017). The western part of the battlefield at Fort Stedman is underlain by an inset, flat terrace composed of the Chuckatuck alloformation (Qc). The latter is inset against the older Charles City alloformation, which is in turn inset against the older Chesapeake Group sediments (Yorktown and Eastover Formations [**Ty** and **Tcl**]; see Figure 19; Cross et al. 2017; Occhi et al. 2018).

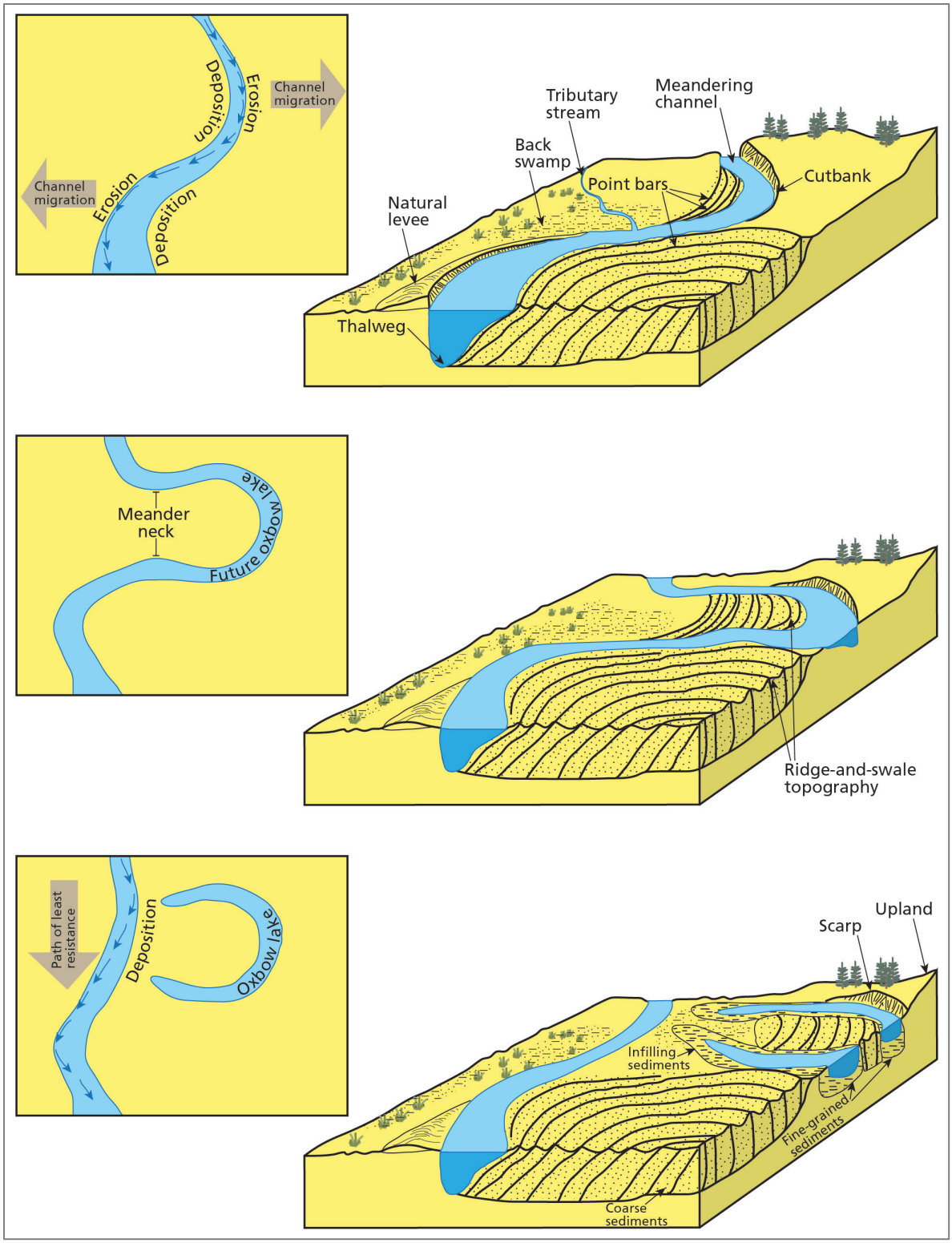



**Figure 26.** Illustration of fluvial processes of meandering. River meandering causes the formation of abandoned channels that infill with fine-grained sediments. Fluvial features at the park range from broad, tidal James and Appomattox Rivers to small, unnamed streams and gullies. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Allen (1964).



**Figure 27.** Photograph of a small stream in flood. Flooding at the park ranges in scope from the broadest rivers (e.g., the James and Appomattox Rivers) to the smallest unnamed ephemeral streams. Here, a small stream is flowing through a forested area. Recent precipitation raised the level of the stream above its normal channel and onto the low-lying adjacent floodplain area. The cloudiness of the water is attributed to a rise in suspended sediment following the inundation of runoff into the stream. Photograph is from an unnumbered figure in Lookingbill et al. (2013).

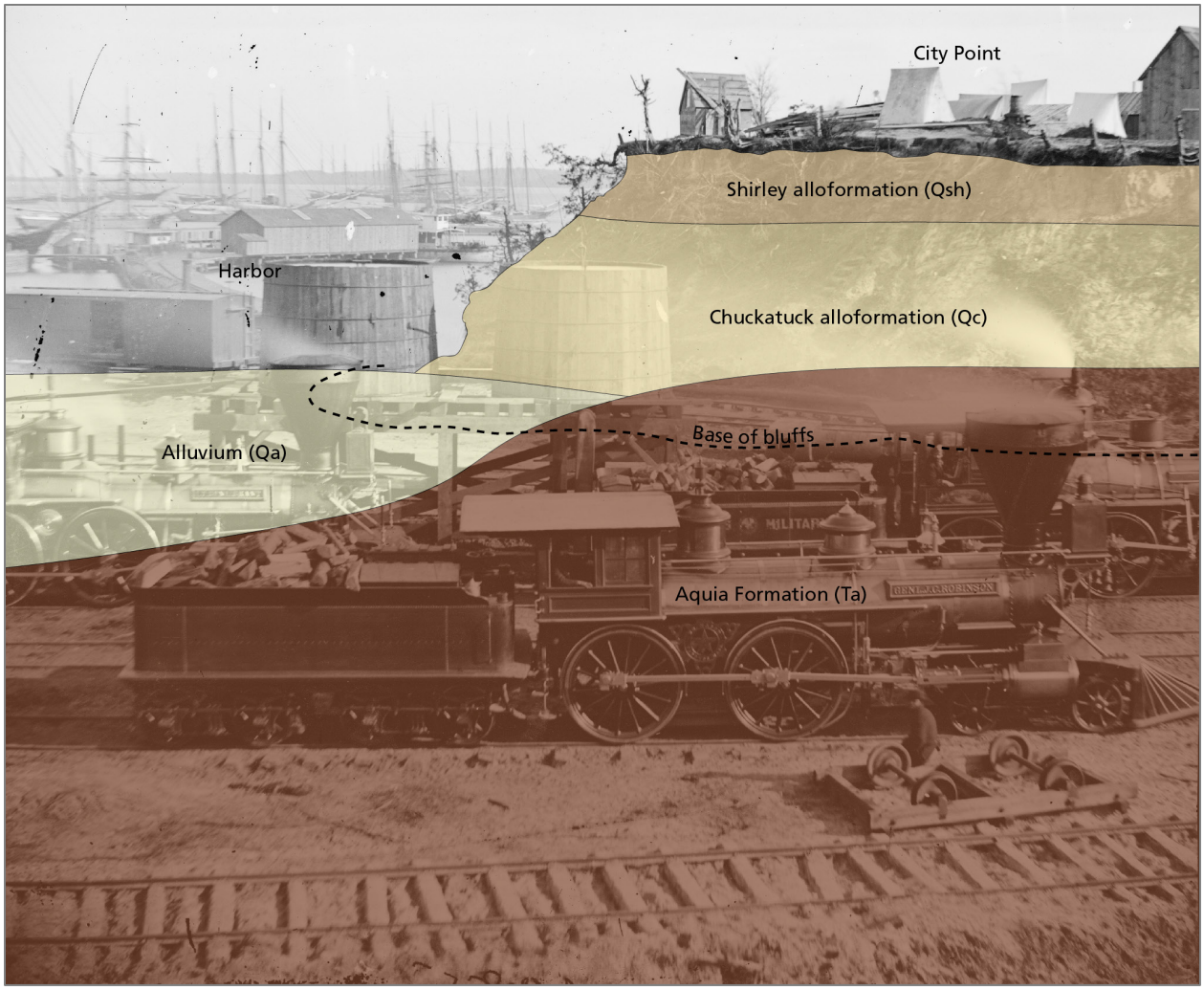



**Figure 28.** Overlay of GRI GIS data on a historic photograph at City Point. The base of the bluffs is composed of the Paleocene Aquia Formation (Ta), and the slopes of the bluffs are the Chuckatuck alloformation (Qc) overlain by the Shirley alloformation (Qsh). View is to the southwest. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Cross et al. (2017) and Occhi et al. (2018). Photograph is courtesy of Petersburg National Battlefield, presented as an unnumbered figure in Lookingbill et al. (2013).

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 (**PNMpg**) and the softer, unconsolidated Coastal Plain deposits (**K**, **T**, and **Q** units). In areas underlain by the granite, stream development is limited, and the streams do not meander as much. Bedrock channels tend to be narrower and straighter, with the incised meanders constraining the river course. They may have little to no floodplain development. Whereas in areas underlain by the softer sediments, complex dendritic (like a tree with branches) drainages form.

### Mineral Resource Development

Map units: Petersburg Granite (**PNMpg**), Potomac Formation (**Kp**), Bacons Castle Formation (**Qbc**)

Over the past 150 years, mineral resource development in the region has been driven by a demand for construction materials. Dimension stone cut from the Petersburg Granite was prized for its sizable blocks (widely spaced joints), which are featured in historic buildings as far away as Denver, Colorado. Historic quarries include the Petersburg Granite Company quarry, the D. W. Lassiter quarry, the Ferndale Park quarry, and the Rocky Run quarry (Occhi et al. 2018). Vulcan Construction Materials, LLC, is the only active granite quarry in the Petersburg area operating out of the Jack Stone quarry (Occhi et al. 2018).

In addition to Petersburg Granite dimension stone and riprap quarrying, geological units within the overlying Coastal Plain sediments have also been mined to produce aggregate materials for construction. Notable local quarries included a pit in Cretaceous-age units, located just outside of Colonial Heights, and a quarry on the Lilia Whitt Beck property in the Bacons Castle Formation (Occhi et al. 2018).

The park contains a creek and geologic setting of great mineral resource potential interest. Harrison Creek, as mapped, shows the transition from Yorktown Formation (**Ty**) on the eastern side to Cold Harbor formation (**Tch**) on the western side at the same elevation and on the western side of the Dutch Gap fault (Mark Carter, US Geological Survey, geologist, written communication, 15 November 2023). On the western side, closer to The Crater, the Yorktown is too thin to map at a 1:24,000 scale (Marcie Occhi, Virginia Energy, geologist, written communication, 19 December 2023). Accurately mapping these units locally and defining their relations is of great importance because one or both of these units contain rare earth element heavy minerals in placer deposits of southern Virginia (Virginia Energy 2021; Mark Carter, US Geological Survey, geologist, written communication, 15 November 2023). Placers are a type of mineral deposit in which grains of a valuable mineral like gold or REE are mixed with sediments like alluvium deposited by a river. Rare earth elements (REE) include the 15 lanthanide elements on the periodic table from lanthanum (La) to lutetium (Lu), as well as the transition metals scandium (Sc) and yttrium (Y). REE are metals that are relatively soft, ductile, and malleable (Virginia Energy 2021). REE are used as catalysts in chemical reactions, in the production of glass and ceramics, and in fiber optics. REE are used to produce strong magnets for computers and cell phones and are important for rechargeable batteries and other industries.

Mine point features are part of the GRI GIS data compiled for the park. Access to these data is restricted upon request (see “Geologic Map Data”) and not available to the general public. For the City Point Unit (map code: CIPO), 31 points are included. The majority are boreholes, as well as two gravel pits, two sand pits, and eight sand and gravel pits. Within the current park boundaries are three mapped boreholes (Dischinger 1987). For the rest of the park (code: PETE), 158 mine point features are in the GRI GIS data, with water wells and dimension stone quarries also included. Within the park are six mapped boreholes and two water wells (Occhi et al. 2018).

Abandoned mineral lands (AML) are lands, waters, and surrounding watersheds that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation. The NPS takes action under various authorities to mitigate,

reclaim, or restore these areas to reduce hazards to and impacts on resources. The NPS AML database does not currently identify any AML features or sites within the park (Burghardt et al. 2014; Anthony Gallegos, NPS Geologic Resources Division, geologist, written communication, 19 October 2023). However, given that mine point features are present in the GRI GIS data, it is plausible that AML sites are underrepresented in the database.

# 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 GRD provides technical and policy assistance for these issues (see "Guidance for Resource Management"). The issues are ordered with respect to management priority.

### Shoreline Changes at City Point Unit

Geologic map units: Aquia Formation (**Ta**), Shirley alloformation (**Qsh**), and alluvium (**Qal**)

City Point, the unit overlooking the confluence of the Appomattox and James Rivers, is considered a fundamental resource for the park (National Park Service 2016) and a resource management priority (Alexis Morris, Petersburg National Battlefield, natural resources lead, GRI follow-up meeting, 18 August 2022). Rising waters pose immediate threats to resources such as historic structures and archeological resources, as well as the 9 to 15 m (30 to 50 ft) high bluffs (National Park Service 2016). Sea level rise is relative to a particular geographic location and its unique circumstances. Locally, the current rate of sea level rise is exacerbated by climate change and local sediment compression, as well as impacted by pro-glacial forebulge collapse. Considering all the factors, the relative rate of sea level rise is 0.3–0.6 m (1–2 ft) per century (Caffrey et al. 2018). Throughout the greater Chesapeake Bay region, the ground surface is subsiding (possibly more than 15 cm [6 in] in the next century) from pro-glacial forebulge collapse (DeJong et al. 2015; Hal Pranger, NPS Geologic Resources Division, geologist, GRI follow-up meeting, 18 August 2022). This process is connected to the Pleistocene ice age, more than 12,000 years ago, when thick, heavy ice sheets piled so much weight on the Earth that a bulge formed outward from the ice, analogous to putting a weight on a very viscous waterbed (DeJong et al. 2015). Now that the weight of the ice is gone, the former bulge is settling back to an equilibrium level, and sea level is rising relative to the sinking land surface.

Near City Point, the fluctuating water level of the James River is largely controlled by tidal surges coming up the Chesapeake Bay. In addition to regular tidal fluctuations, storm surges can dramatically raise water levels, causing flooding conditions (Thornberry-Ehrlich 2005). Hurricanes and tropical storms, such as Hurricane Isabel in 2003 and Tropical Storm Ivan in 2004, increased the water level significantly with rapidly rising, erosive waves. Storm damage from both storms has exposed the bluffs on the James and Appomattox Rivers due to downed trees, which previously stabilized the bluff (Figure 29; National Park Service 2016). The battery at City Point, once a few feet away from the edge, is now at the very edge of the bluff (Alexis Morris, NPS Petersburg National Battlefield, GRI follow-up meeting, 18 August 2022).




**Figure 29.** Photographs of the eroding bluffs at City Point and vulnerability along the shoreline. Photographs A), B), and C) are exposures along the very northern end of the point after erosive storms. D) is the northwestern side of the point, and E) is the peninsula's eastern shore. The gray arrows point to the approximate locations of the photographs in the lowermost aerial image. All three stretches of the shoreline have high levels of exposure and coastal vulnerability. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using a draft graphic from Peek et al. (2022) and NPS photographs taken in March 2004.

Erosion of the James and Appomattox Rivers bluffs is enabled by both undercutting from the rivers and from infiltration (a leaky septic system). The septic system at City Point is in disrepair, and part of it has already failed, causing filtration down to a clay layer (likely the contact between the Aquia Formation and overlying units), where water migrates out to the bluff and exacerbates existing erosion issues. Water has been observed pooling on the surface and damaging the foundations and basements of the carriage house and ice house near the edge of the bluff; these issues may be related to the seeping (US Army Corps of Engineers 2004). Seeps occur at several levels on the bluff face; some of these may correspond to dense, clay-rich layers that prevent or inhibit the downward percolation of groundwater, and instead the water flows laterally until it reaches the bluff face to emerge as a seep (US Army Corps of Engineers 2004). More geologic testing is needed to determine how water is moving through the subsurface (Alexis Morris, NPS Petersburg National Battlefield, GRI follow-up meeting, 18 August 2022).

Attempts to mitigate the overall trend of bluff retreat have taken place over the past several decades with limited success. The US Army Corps of Engineers installed riprap along the shoreline in 1987 (Pranger 2000). Prior to 2009, large blocks of earth material were shed off the bluffs at City Point (Figure 30), and a stabilization project was completed to contain the eroding bluff and protect resources located within the bluff (Thornberry-Ehrlich 2005; Eshleman 2009). Concrete structures were installed to match the surrounding natural landscape and promote infilling vegetation (Figure 31; US Army Corps of Engineers 2004; Eshleman 2009). Despite this, erosion and management concerns continue.

According to the park's foundation document (National Park Service 2016), if bluff stabilization is not undertaken soon, portions of the embankment are in danger of failing, damaging, or undermining the entire site. Because of previous slope failures on the bluffs and storm damage on the river front, archeological resources at City Point are in fair to poor condition (National Park Service 2016). The park's resource stewardship strategy document (National Park Service 2020) highlighted shoreline changes at City Point and the need to stabilize the bluffs as management priorities. In 2022, a coastal vulnerability study undertaken by Western Carolina University pinpointed particularly at-risk areas, with the northern end of the peninsula at the highest risk (see Figure 29; Alexis Morris, NPS Petersburg National Battlefield, GRI follow-up meeting, 18 August 2022; Peek et al. 2022). In 2023, planning for another bluff stabilization project began with consultation with archeologists and tribal partners (Alexis Morris, NPS Petersburg National Battlefield, GRI follow-up meeting, 18 August 2022).



**Figure 30.** Photograph showing scarps developing in the slope above the bluffs at City Point. Erosive waves undercutting the slope caused instability in the overlying slope. Large blocks of earth were slumping down toward the river below. Photograph is unnumbered from Lookingbill et al. (2013).




**Figure 31.** Photographs of shoreline stabilization structures installed at City Point. A) View of the Appomattox Plantation House above the riprap and concrete stabilization structures as viewed from the confluence of the James and Appomattox Rivers. B) A shoreline trail stretches between riprap and the concrete stabilization structures. C) Granite blocks and geoengineered fabric were installed at the edges of the concrete stabilization structure to lend a more natural look to the bluffs. D) Vegetation is encouraged to grow through the concrete stabilization structure to enhance slope stabilization and make it more natural-looking. Photograph A is an unnumbered figure in Lookingbill et al. (2013). Photographs B, C, and D are unnumbered figures in Eshleman (2009).

## Sinkhole Formation

Geologic map units: Yorktown Formation (**Ty**), Lower Chesapeake Group (**Tcl**)

Sinkholes are depressions or holes in the ground wherein some form of erosion occurs with a resulting subsurface layer collapse, causing surface layer subsidence. Sinkholes are typically found in

karst landscapes that are made up of rocks that are rich in soluble carbonate ($CaCO_3$), like limestone. Groundwater dissolves the rock, and the overlying material subsides, forming a depression. At the park, the underlying geologic units are not conducive to this kind of dissolution, possibly with the exception of some thick fossil shell-rich layers in units such as the Yorktown Formation (geologic map unit **Ty**). Therefore, the formation of sinkholes within the park is more likely formed by soil piping and the collapse of rock layers due to the dissolution of the carbonate matrix of the subsurface rock, in both cases largely due to ponding of water, or by the collapse of overlying soil layers into Civil War-era tunnels, trenches, or excavations (Patricia Seiser, NPS GRD, geologist-cave specialist, written communication, 12 October 2023).

At least four sinkholes are forming at the Eastern Front unit. Sinkholes near The Crater are as large as 3 m (9 and 11 ft) wide. Sinkholes are known to occur in the area due to the subsidence of the Civil War-era tunnel leading to The Crater (Bevan 2004); however, the new sinkholes are apart from those. Sinkholes are forming near the tour road east of Harrison Creek in an area near the contact between the Yorktown Formation (**Ty**) and the Lower Chesapeake Group (**Tcl**) (Figure 32; Occhi et al. 2018; Fuka and Clarke 2022). In some areas, poor drainage conditions (e.g., insufficient storm runoff management and/or infrastructure) seem to be contributing to sinkhole formation by localizing erosion. The road is underlain by several layers of impervious former road surfaces: a 1930s-era tour road built by the Civilian Conservation Corps with salvaged Fort Lee concrete, and beneath that, the unimproved Prince George Courthouse Road trace (Fuka and Clarke 2022). It is possible these layers are impacting local groundwater flow patterns enough to cause sinkhole formation. In other places, proximity to local creeks and/or known Civil-War era tunneling might be a factor. The Dutch Gap fault (see "Dutch Gap and Unnamed Faults") also crosses the Harrison Creek sinkhole area, and the subsurface discontinuity may impact groundwater flow (GRI follow-up meeting participants, 18 August 2022). Some sinkholes in the park have been filled to address immediate safety concerns, but they often re-form, sometimes within a few months. Therefore, a longer-term solution is required.

An investigation into the location and mechanisms of formation is needed; however, the park does not currently have the time or funding to conduct such an investigation. Geophysical surveys (testing for subsurface cavities using ground penetrating radar) and coring could help determine what layers are being eroded below the ground surface. The park's tour road is slated to be refinished, and perhaps a sinkhole study could be incorporated into that effort to improve the longevity of the road surface (GRI follow-up meeting participants, 18 August 2022). The Geology and Mineral Resources Program of Virginia Energy functions as the state geological survey and can provide technical assistance for these projects.




**Figure 32.** Photographs of sinkhole formation. Several sinkholes are opening at the park. Despite previous efforts to fill the sinkholes, they continue to reopen. As of fall 2022, it is unclear how and why the sinkholes are forming at the park. Photographs are from a sinkhole in the Eastern Front unit near the tour road and Harrison Creek. A) shows an overview of the sinkhole in the road during initial excavations. B) shows a close view of a narrow cavity extending toward the east from the main cavity of the sinkhole. C) shows a cross-sectional view of the buried road trace exposed in the wall of the sinkhole. Images are figures 6, 7, and 13, respectively, from Fuka and Clarke (2022).

### Flooding, Upland Erosion, and Sediment Loading

Geologic map units: Petersburg Granite (**PNMpg**), Potomac Formation (**Kp**), Aquia Formation (**Ta**), Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty)**, Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), and alluvium (**Qal**)

Flooding and channel erosion occur along most of the streams and rivers within the park (see Figure 26). Severe storm events result in significant runoff and scouring of the streams, increasing erosion, and impacting natural communities (National Park Service 2016). Climate change is predicted to increase the intensity and frequency of these events (see "Climate Change" section; National Park Service 2016). Natural fluvial processes are also commonly impacted by anthropogenic alterations to the fluvial system or increased stormwater runoff due to impervious surfaces (e.g., parking lots, roofs, and roadways). Because of upstream manipulation resulting in long-term increased runoff (see "Urban Development and Utility Corridors"), Poor Creek is cutting deep channels near The Crater that are nearly scoured to a hard surface with no loose sediments (Gregory et al. 1987, 1991; Lookingbill et al. 2013). Poor Creek is flowing through an altered channel configuration, causing extensive lateral and vertical channel erosion and some slumping along the banks without subsequent restabilization (Gregory et al. 1991; Thornberry-Ehrlich 2005; Lookingbill et al. 2013). A slump is mass wasting where a coherent mass of loosely consolidated materials or a rock layer moves a short distance down a slope. Slumps commonly have heads or scarps upslope and bulbous toes downslope. Harrison Creek is also experiencing channel erosion but still has extensive sediment deposits and has less development upstream (Gregory et al. 1991). In situ archeological resources are at risk of loss due to erosion and scouring along streams in the park (National Park Service 2016). In some areas, flooding within the park is causing negative interactions with adjacent private properties. Drains from the park entering the city of Petersburg's storm water drainage system are too small and easily overwhelmed. This is causing flooding in the Eastern Front Pin Oaks neighborhood and White Hill neighborhood (Alexis Morris and Mary Krueger, NPS Petersburg National Battlefield and NPS Northeast Region, natural resource lead and energy specialist, respectively, GRI follow-up meeting, 18 August 2022).

The topography, watercourses, and other physiographic features that helped to define tactical and strategic military positions during the Civil War merit protection (National Park Service 2020). Reclamation after the war to return fortifications to farmland has leveled and obscured some historic earthworks (e.g., Fort Morton and Battery 13) (Bevan 2007; 2009). The geologic forces of erosion and weathering are constantly active on the landscape (Figure 33). Areas such as social trails and overused trails exacerbate erosion in places such as the Five Forks Battlefield unit (National Park Service 2016). Runoff erodes sediments from any open areas and carries them down streams and gullies, gradually diminishing higher areas such as ridges and hills, foundations, and earthworks, as well as filling in the lower areas such as trenches, railroad cuts, and stream ravines, distorting the historical context of the landscape. Some areas are subsiding due to tunneling (e.g., The Crater); this causes a potential visitor hazard. In other areas, persistent sinkholes are forming (see "Sinkhole Formation"). Earth surface processes can also degrade bridge foundations and erode streams back into historic restoration areas (Thornberry-Ehrlich 2005).




**Figure 33.** Photographs of historic features and landscape management efforts. A) A concrete walkway winds across and around the battlefield grounds to avoid social trail development and natural erosion in high-traffic areas. B) Trails are routed to avoid earthwork areas. C) A small well or borehole is cordoned off and marked for safety. D) Slumping associated with tunneling at The Crater is causing trail damage and visitor hazards. E and F) Signs warning visitors to stay off the sinking earth associated with the collapsing tunnel at The Crater. All photographs are by Trista L. Thornberry-Ehrlich (Colorado State University), taken in spring 2005.

Except for City Point, the park's land is more wooded (about 25% more) than it was during the war or even when the park was established in 1933 (Lookingbill et al. 2013). Trees, rooted in earthworks (Figure 34), create several challenges. If the trees fall naturally, the earthworks would be damaged, and the exposed roots may in turn expose artifacts. Many of the archeological resources in the park are under constant threat from illegal relic hunting (National Park Service 2016; 2020), which would be exacerbated by exposed root systems. However, if the trees were removed, erosion would increase (National Park Service 2016). Lack of treatment strategies for earthworks, including previously unmapped earthworks, was identified as a key issue, stressor, and threat to the park's resources (National Park Service 2020).



**Figure 34.** Photograph of trees rooted in an earthwork adjacent to a small stream. During the Petersburg Campaign of the Civil War, the landscape was almost devoid of trees. They had been cleared for building, fuel, and visibility. In the years since, trees and forests have been reestablished on the landscape. Park resource managers must contend with conflicting values to preserve a purely historic context and remove the trees, but this may in turn damage the earthworks as trees provide stabilizing root structures, holding the sediments in place. Picture is an unnumbered figure in Lookingbill et al. (2013).

Erosion of the landscape and disturbances to stabilizing vegetation at Petersburg and upstream areas lead to increases in sediment being carried by the park's rivers and streams. Sediment loads and

distribution affect aquatic and riparian ecosystems, and sediment loading can result in changes to channel morphology, degradation of aquatic habitat, and increased overbank flooding frequency by shallowing the streambed (Gregory et al. 1991; Thornberry-Ehrlich 2005). However, fine-grained sediments are vital in the overall fluvial transport of contaminants in a water system. Natural channel storage of fine sediment (and the contaminants contained therein) follows a seasonal cycle. This cycle is subject to not only human disturbance but also hydrologic variability, with increased availability during the highstands of spring and decreased availability during the lowstands of autumn (Miller et al., 1984; Thornberry-Ehrlich 2005).

Both within and surrounding the park, many of the streams are impaired, likely due to agricultural activity or other anthropogenic changes (National Park Service 2017b). Nearby chemical plants and paper mills are introducing contaminants into the James and Appomattox Rivers. Dredging proposals for tour boats on the Appomattox River were considered too risky because of the contaminants they might disturb in the river bottom sediments (Blumenshine and Shockley, GRI scoping meeting communication, 13 April 2005). Fine-grained sediments do not travel downstream in a single pulse but are often resuspended bottom material that is stirred up during high flows or floods (Miller et al., 1984). This intermittent transport of contaminants and fine-grained sediment increases the affected area. This could pose a threat to the park if a focused, severe contamination were to occur within a watershed such as Harrison Creek or the Appomattox River (Thornberry-Ehrlich 2005).

### Slope Movements

Geologic map units: Petersburg Granite (**PNMpg**), Aquia Formation (**Ta**), Lower Chesapeake Group, undivided (**Tcl**), Yorktown formation (**Ty**), Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), and alluvium (**Qal**)

Potential for slope movement exists where the rivers cut steeply through the unconsolidated sedimentary units in the park area. Slope movements are the downslope transfer of material (e.g., soil, regolith, and/or rock; Figure 35). Slope movements can occur rapidly (e.g., debris flows or rockfalls) or over long periods of time (e.g., slope creep). The magnitude of slope failures depends on slope, aspect, soil type, and geology. Frost and plant-root wedging, fluvial undercutting, erosion, and swelling clays are the primary causes of slope instability in the park area.

Geologic slope processes such as landsliding, slumping, chemical weathering, and slope creep are changing the landscape at the park (Thornberry-Ehrlich 2005) and degrading cultural resources (National Park Service 2016). Slope movements are possible on any slope. At City Point, slope failures on the bluffs and storm damage at the toe of the slope on the river front are threatening the cultural (archeological) resources (see “Shoreline Changes at City Point Unit;” National Park Service 2016).

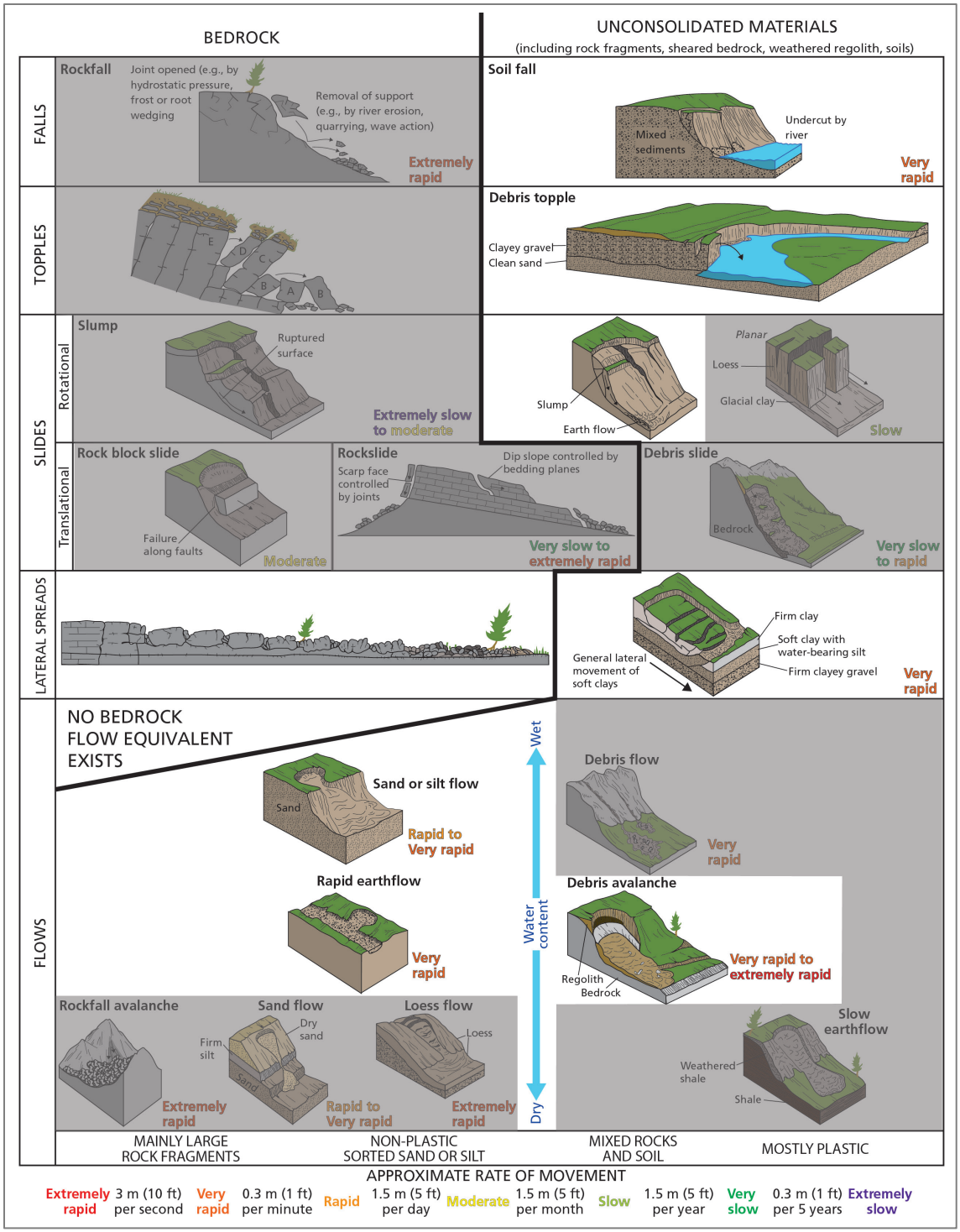



**Figure 35.** Illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at Petersburg National Battlefield. The abundant vegetation in the park 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).

In some settings, specific units juxtaposed against other units across a fault or geologic contact create conditions under which slipping may be more likely—commonly where the properties of the units (e.g., hardness, degree of weathering, porosity, composition) are quite different from each other. Occhi et al. (2018) mapped two prominent landslide features—a block slide and a rotational landslide—beyond park boundaries on the northern side (east bank) of the Appomattox River in the city. The slides developed within the unconsolidated Windsor alloformation (**Qw**), which overlies the solid Petersburg Granite (**PNMpg**). Similar settings with the contact between the Petersburg Granite and unconsolidated Quaternary units occur along streams and rivers throughout the Petersburg area (Occhi et al. 2018; Marcie Occhi, Virginia Energy, geologist, GRI follow-up meeting, 18 August 2022). Pliocene sand and gravel layers (e.g., Yorktown Formation and Cold Harbor formation [**Ty** and **Tch**, respectively]) that overlie Miocene clays (e.g., Lower Chesapeake Group, undivided [**Tcl**]) are prone to regional landslides (Figure 36; Mark Carter, US Geological Survey, GRI follow-up meeting, 18 August 2022). Detailed mapping by Virginia Energy reveals more slides that were previously obscured by vegetation or developments.

The potential for landslides should be incorporated into emergency management information. The NPS GRD employs three rockfall management strategies: (1) an Unstable Slope Management Program (USMP) for transportation corridor risk reduction; (2) quantitative risk estimation for specific rockfall hazards; and (3) monitoring of potential rockfall areas. Park managers can contact the GRD to discuss these options and determine if submitting a technical request is appropriate.

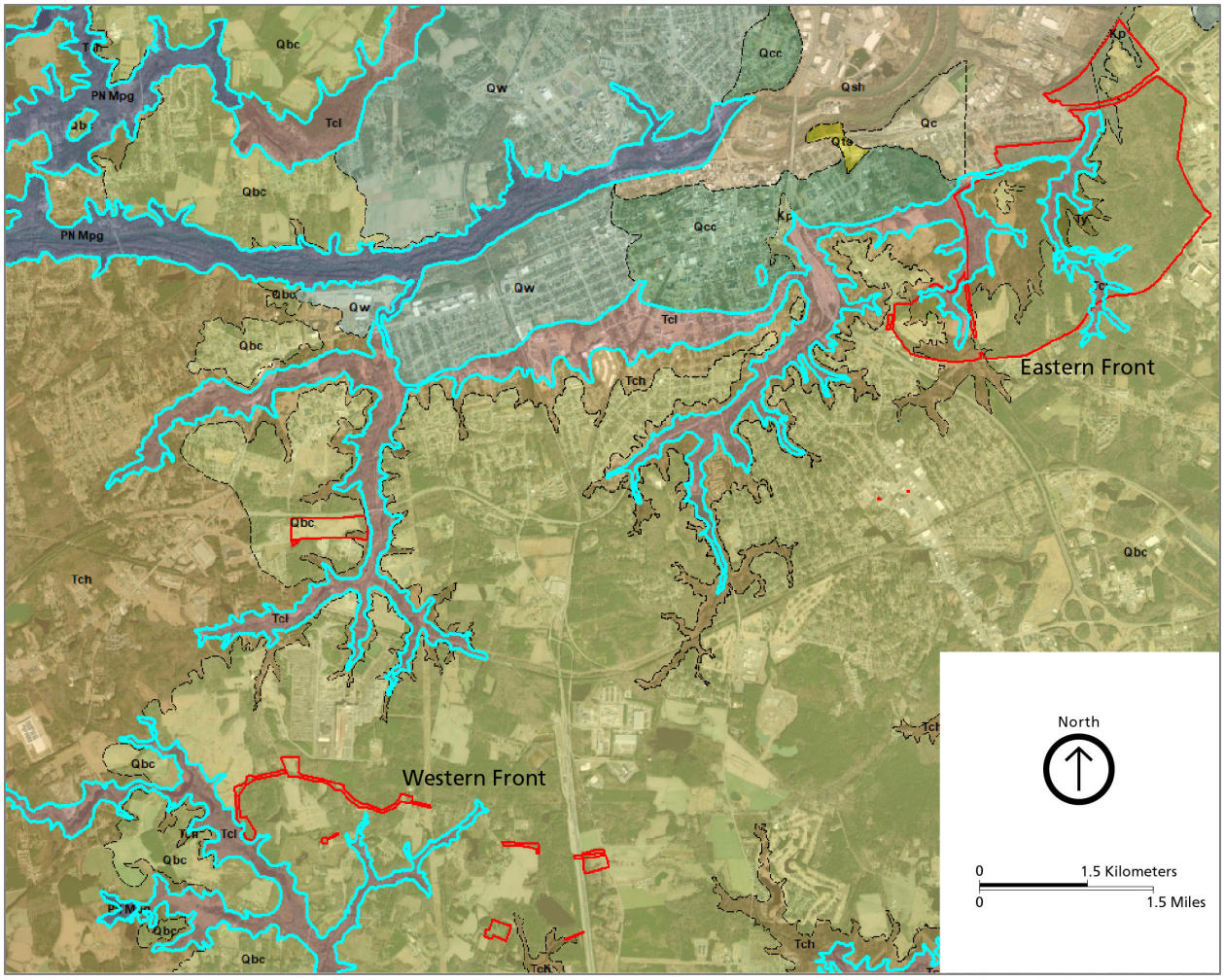



**Figure 36.** Aerial image of the eastern side of the park with slump-prone contacts highlighted. Geologic contacts between the Petersburg Granite (PNMpg) and the overlying Windsor alloformation (Qw) and other unconsolidated alloformations may be prone to slumping in some settings. Streams are cutting into Miocene clays of the Lower Chesapeake Group, undivided (Tcl). In sloped places where the Yorktown Formation (Ty) or the Cold Harbor formation (Tch) overlie the Lower Chesapeake Group, another slump-prone setting exists as the clay is more easily removed and leaves the overlying unit perched. Permeability contrasts between the Yorktown (Ty) and Cold Harbor formation (Tch) may also be problematic; however, this stratigraphic relationship requires careful definition in this area (Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023). Many stretches of these contacts exist inside the park along streams, as indicated by the pale blue lines. The park boundary is the red line. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and an ESRI World Imagery basemap.

## Determination of the Extent of Civil War Earthworks

Map units: Petersburg Granite (**PNMpg**), Potomac Formation (**Kp**), Aquia Formation (**Ta**), Gravel terrace (**Tg**), Lower Chesapeake Group, undivided (**Tcl**), Yorktown Formation (**Ty**), Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), Alluvium (**Qal**), Modified land (**Qml**)

Because of the strategic importance of Petersburg during the American Civil War, significant efforts were made to fortify the areas around the city to protect key supply lines. Earthworks changed the landscape forever and are considered engineering marvels, elements of which are not duplicated elsewhere (National Park Service 2020). The siege landscape took shape over the course of nearly 10 months, with conflict lines extending more than 56 km (35 mi). Of these lines, 32 km (20 mi) are inside the current park boundaries (National Park Service 2016; 2020). Considerable earthworks remain, many of which are beyond park boundaries. Some earthworks (trenches, powder magazine, and revetments) also date to World War I, when the area was used for training purposes (National Park Service 2020).

Earthworks are the largest historic resource at the park and include batteries, breastworks, forts, redans, redoubts, and salients. The very nature of many of the earthworks suggests they were constructed of unconsolidated, easily diggable material. As such, the material remains "mobile" to earth surface processes. High areas are eroding, and low areas are slowly being filled in, muting the historic character of the landforms. Others were obliterated or reincorporated into agricultural endeavors after the Civil War.

As of September 2022, a full-scale assessment of the park's earthworks remains a resource management need (National Park Service 2020; GRI follow-up meeting participants 18 August 2022). Occhi et al. (2018) produced hillshade maps. These maps were helpful in identifying disturbances on Earth's surface. This effort, combined with battlefield maps, indicated approximately 21 km (13 mi) of probable earthworks outside park property, including Fort Dushane, a large star fort located less than 1 km (0.6 mi) southeast of the Poplar Grove National Cemetery (Figure 37). An additional line feature class has been added to the GRI GIS data that contains probable or possible earthworks identified using the hillshade basemaps (see Figure 8; Occhi et al. 2018). However, these features have not yet been field-verified; therefore, field verification represents the next step in confirming that these features are, in fact, earthworks.

After the tunneling that led to The Crater battle, troops on both sides engaged in tunneling efforts to get behind enemy lines. One area of interest is at Colquitt's Salient on the Eastern Front. Today, these underground cavities could be collapsing, causing surface subsidence (sinking of the ground) and perhaps even sinkholes (see "Sinkhole Formation"). Geologists with Virginia Energy are attempting to locate these tunnels and their entrances; this effort was stymied during the COVID-19 pandemic restrictions, and more inter-agency coordination is needed to proceed (Alexis Morris and Marci Occhi, NPS and Virginia Energy, natural resources lead and geologist, respectively, GRI follow-up meeting, 18 August 2022). Ground-penetrating radar (GPR) could prove a useful tool for determining discontinuities in the subsurface in limited areas (Rick Berquist, Virginia Energy, geologist, GRI follow-up meeting, 18 August 2022).

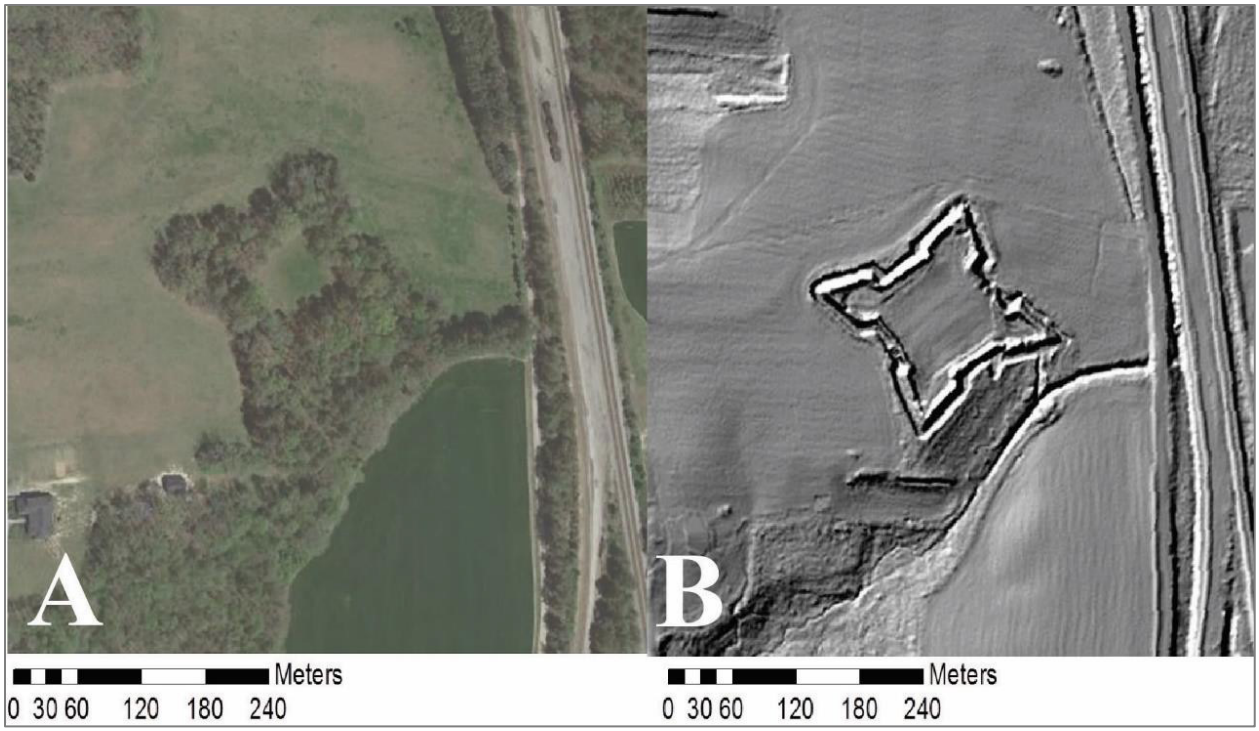



**Figure 37.** Aerial (A) and LiDAR (B) imagery of Fort Dushane. This feature is outside park boundaries, but overgrown areas such as this one (A) highlight the utility of LiDAR imagery (B) to locate historically relevant features during boundary expansion considerations. Vegetation obscures slope features and disturbed areas. Graphic is figure 15 in Occhi et al. (2018).

### Radon

Radon is a heavier-than-air, colorless, odorless, radioactive gas and a natural decay product from uranium and thorium (also naturally occurring). Long-term exposure to elevated levels of radon creates an increased risk for lung cancer. Radon naturally accumulates in caves, basements, and other subterranean cavities. Limited air circulation in these spaces concentrates radon gas to levels appreciably higher than outside. Radon is measured in picocuries per liter of air (pCi/L), a measurement of radioactivity. In the United States, the average indoor radon level is about 1.3 pCi/L. The average outdoor level is about 0.4 pCi/L. The US Surgeon General and Environmental Protection Agency (EPA) recommend fixing spaces with radon levels at or above 4 pCi/L. In spaces where people spend a significant amount of time, such as homes or offices, the EPA also recommends fixing radon levels between 2 pCi/L and 4 pCi/L. Because radon is naturally occurring, remediation of the threat requires monitoring and ventilation. Higher radon concentrations are more common in areas underlain by granitic or metamorphic rock, such as Five Forks Battlefield (Dinwiddie County). Radon levels typically decrease in Virginia to the east of the fall line. However, radon levels above 4pCi/L can be found anywhere, and testing within structures is the best way to determine the exposure of building occupants.

In wells tested near the park boundaries to the southwest, radon was detected. Dinwiddie County has high radon concentrations in the soil in some locations. This is likely due to naturally occurring uranium-bearing minerals in the Petersburg Granite (**PNMpg**). Southeast of the park, near

Williamsburg, homes built in or slightly above shelly layers in the Yorktown Formation (**Ty**) have high radon (Rick Berquist, Virginia Energy, geologist, written communication, 5 November 2023; Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023). These issues must be addressed when potential new park lands are assessed, and geologists recommend having radon testing performed for park buildings, particularly those that overlie the Petersburg Granite and those with basements (Rick Berquist, Virginia Energy, geologist, GRI follow-up meeting, 18 August 2022).

### Active Faults and Earthquakes

Geologic map units: Petersburg Granite (**PNMpg**), Potomac Formation (**Kp**), Aquia Formation (**Ta**), Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty)**, Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**)

Earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensity ranges from imperceptible to total destruction of developed areas and alteration of the landscape. The "magnitude" of an earthquake refers to the amount of energy released. A variety of scales measure magnitude, including the Richter scale. Earthquakes can directly damage park infrastructure or trigger other hazards, such as slope movements, which may impact park resources, infrastructure, or visitor safety.

Shaking from the magnitude 5.8 earthquake that occurred in central Virginia, about 70 km (42 mi) northwest of the park, in August 2011 was felt along the eastern seaboard from Canada to Florida and as far west as Denver, Colorado (Horton et al. 2015). This event caused no documented damage in the park, but it is a reminder that earthquakes, although rare, can shake this region. The National Center for Earthquake Engineering Research catalog contains records of a magnitude 4.5 earthquake with an epicenter just southwest of Petersburg in 1774 (Tuttle et al. 2020; 2021).

The Dutch Gap fault is mapped in the GRI GIS data (Dischinger 1987; Occhi et al. 2018). This fault runs directly through the Eastern Front unit of the park (see "Dutch Gap and Unnamed Faults" and the GRI geologic map poster). Coring and map data concluded the fault trace is obscured or covered by younger (Pleistocene) sediments (e.g., Bacons Castle Formation [**Qbc**]; Occhi et al. 2018). This indicates that any activity or displacement along the fault occurred before those Pleistocene sediments were deposited, more than 10,000 years ago. However, the fault is still a discontinuity or local zone of weakness.

Any moderate earthquake has the potential to damage park infrastructure, trigger slope movements, and/or cause liquefaction, which is the conversion of unconsolidated sediments and soil into an unstable, fluid-like mass during an earthquake. As indicated by its occurrence in the USGS Quaternary faults database (https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf), a historically active seismic area exists northwest of Richmond called the central Virginia seismic zone. Seismicity is associated with the zone, with most earthquakes occurring within 60 km (36 mi) of the James River between Richmond and Charlottesville (Figure 38; Tuttle et al. 2020;

2021). This area is visible as a bullseye on the national seismic hazards map (Figure 39), which shows the likelihood of a moderate earthquake (i.e., Richter magnitude 5) over the next 100 years.

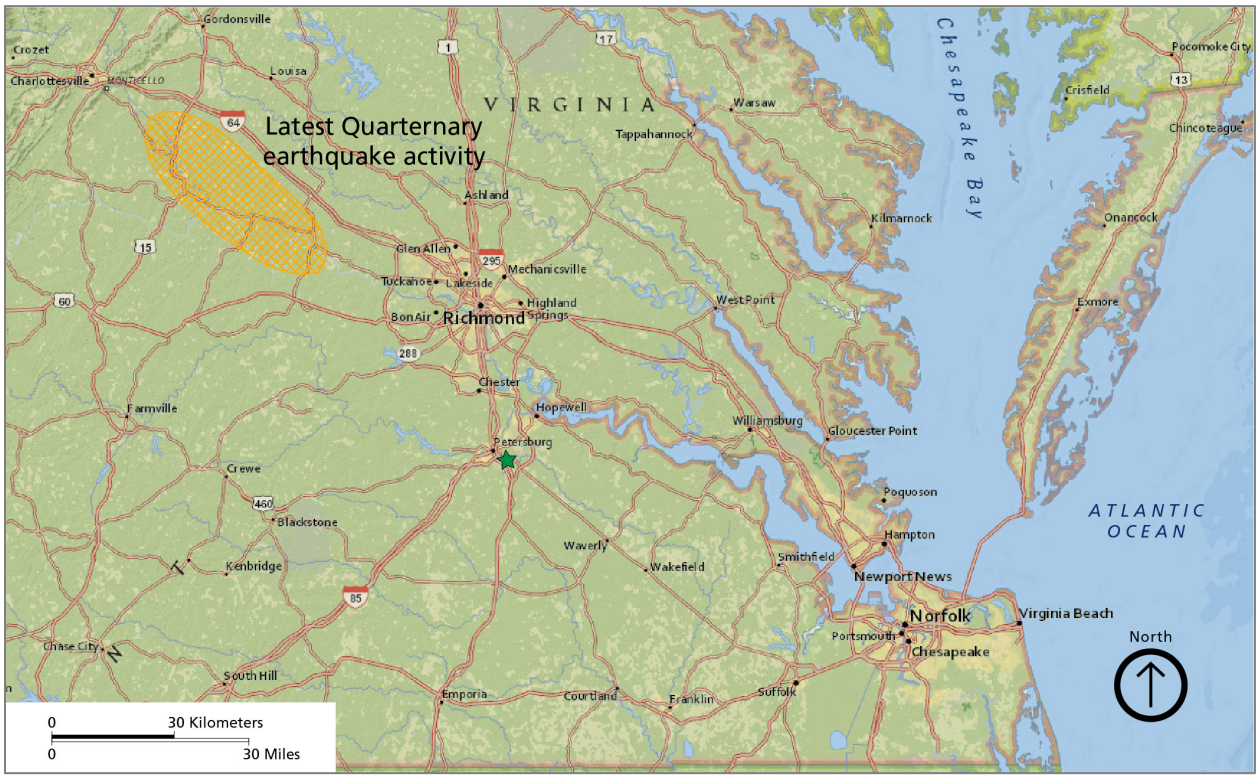



**Figure 38.** Map of eastern Virginia Quaternary faults. The orange hatched area northwest of Richmond and Petersburg indicates an area of latest Quaternary (<15,000 years) seismic activity in a well-constrained location. This area was the epicenter of the 2011 earthquake that shook the eastern US. Fault map courtesy of the US Geological Survey; available at https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf.

The USGS and others are conducting paleoliquefaction research on features in the central Virginia seismic zone, near Richmond National Battlefield Park (Tuttle et al. 2020; 2021) and the park (Mark Carter, US Geological Survey, geologist, GRI follow-up meeting, 18 August 2022). Paleoliquefaction features are those attributed to seismic events occurring before seismic measurements or written records were kept. These can include dikes (intrusions of a lower liquefied sand that penetrate strata or open cracks of an upper, non-liquefied soil) and sand boils (areas where a dike completely penetrates the non-liquefied layer above it and reaches/erupts onto the ground surface). Their initial findings reveal a history of seismic events in the area, with liquefaction features formed during the past 2800 years or so (Tuttle et al. 2020; 2021).

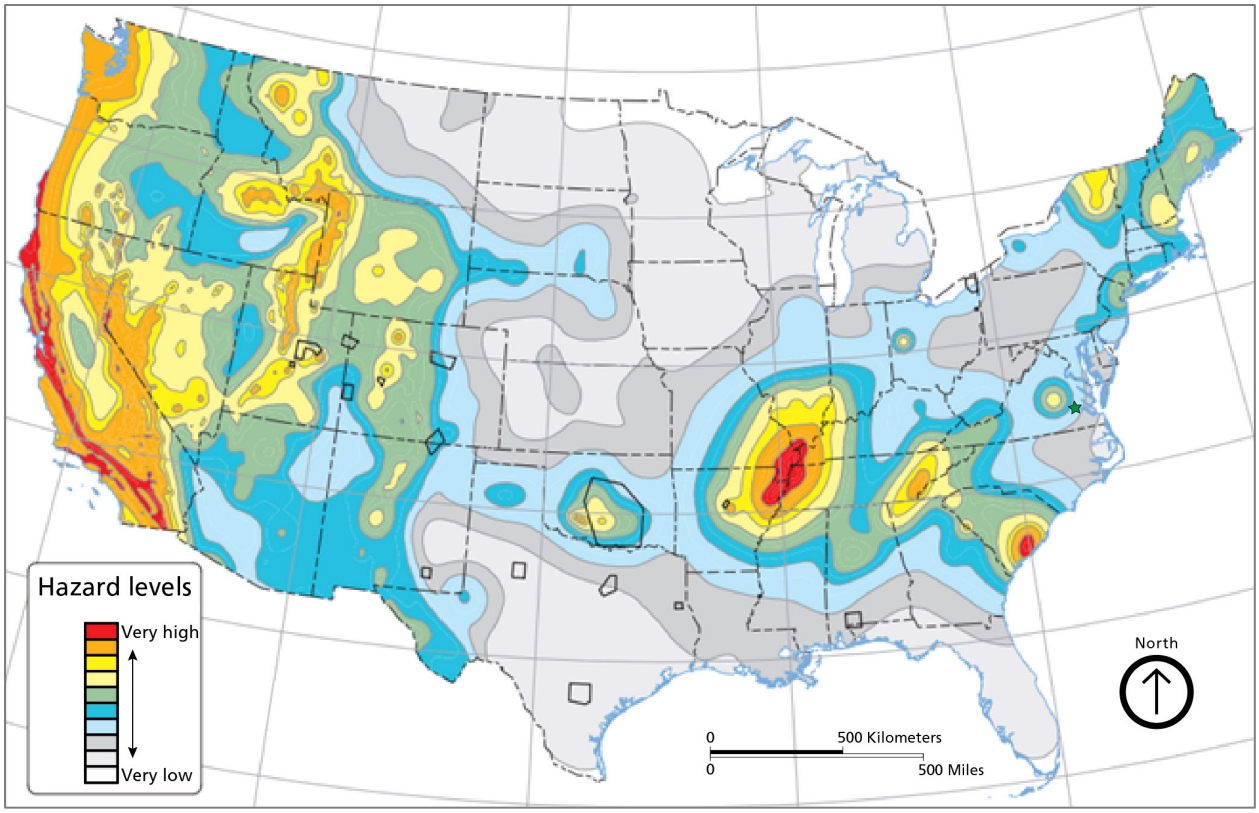



**Figure 39.** National seismic hazard map. The map shows the relative hazard associated with potential earthquakes in different areas. The map is based on USGS models that calculate the probability of an earthquake within 50 years for a firm rock site based on seismicity and fault-slip rates and consider the frequency of earthquakes of various magnitudes. 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 a moderate probability of seismicity. The park location is at the green star. Public domain graphic courtesy of the US Geological Survey; available at https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map.

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. The GRD Seismic Monitoring website (https://go.nps.gov/geomonitoring) and the USGS Earthquake Hazards website (http://earthquake.usgs.gov/) provide more information.

### Swelling Clays and Sulfide-Rich Units

Swelling clays expand when wet and shrink when dry. Expansion happens when water is soaked into the crystalline structure of the clay. In extreme cases, these soils can buckle roads, undermine buildings, and damage other structures. In less extreme ways, they can affect trails and other visitor facilities (Thornberry-Ehrlich 2005).

Swelling clays are mapped within the soils and geologic map units of the park. The Eastover Formation (part of geologic map unit **Tcl**) contains swelling clays, as does the fossiliferous clayey silt of the Yorktown Formation (**Ty**) (Rick Berquist, Virginia Energy, geologist, GRI follow-up meeting, 18 August 2022; Mark Carter, US Geological Survey, geologist, written communication, 14 November 2023). Soils maps provide information regarding the swelling (or linear extensibility) potential of soils. The park is part of two Natural Resources Conservation Service (NRCS) soil survey areas: Dinwiddie County (Five Forks Battlefield) and Prince George County (all other park areas). According to the NRCS, linear extensibility (a measure of the change in volume between moist and dry soils) is used to determine the shrink-swell potential of soils. The shrink-swell potential is low if the soil has a linear extensibility of less than 3%; moderate if 3 to 6%; high if 6 to 9%; and very high if greater than 9%. If the linear extensibility is greater than 3%, shrinking and swelling can cause damage to buildings, roads, and other structures, as well as to plant roots. Special designs are commonly needed. Within the park, about 13% of park acres are mapped as soils rated moderate or higher for swelling. The highest values are in small areas of Five Forks Battlefield (Natural Resources Conservation Service 2023a).

The marine clayey silt of the Yorktown Formation (**Ty**), Eastover Formation (**Tcl**), and other Miocene-age units also contain layers of high iron sulfide mineral concentrations (Mark Carter, US Geological Survey, geologist, GRI follow-up meeting, 18 August 2022). Chemical reactions associated with the in-situ weathering of the iron sulfide minerals create corrosive conditions. This can lead to acidic drainage from these layers. Acidic drainage can negatively impact concrete infrastructure by dissolving the lime cement. Detailed mapping of layers containing iron sulfide would provide valuable information for siting future facilities by allowing planners to avoid such areas when using concrete as construction materials. Soils maps also provide an interpretation for the corrosion of concrete. According to the NRCS, the risk of corrosion pertains to the potential soil-induced electrochemical or chemical action that corrodes or weakens concrete. The rate of corrosion of concrete is based on the sulfate and sodium content, texture, moisture content, and acidity of the soil (Natural Resources Conservation Service 2023b). A special site examination and design may be needed if the combination of factors results in a severe hazard of corrosion. The concrete in installations that intersect soil boundaries or soil layers is more susceptible to corrosion than the concrete in installations that are entirely within one kind of soil or within one soil layer. All soils within the park are mapped as moderate or high for risk of corrosion, and about 45% are mapped as high (Natural Resources Conservation Service 2023b).

### Urban Development and Utility Corridors

External development and habitat fragmentation were identified as key issues, stressors, and threats to the park's resources (National Park Service 2020). Within park boundaries, forests make up 82% of the landscape, with agriculture and developed lands at 8% and 6%, respectively; however, much of the upstream areas and adjacent landscape are developed for agriculture or suburban/urban purposes (National Park Service 2017b). Urbanization is a primary threat to aquatic habitats and stream conditions in the park; inherent impermeable surfaces such as roads, sidewalks, buildings, and parking lots increase storm runoff and decrease groundwater infiltration, in addition to removing stabilizing vegetation (Gregory et al. 1991; National Park Service 2017b). Urbanization can affect

stream flow (and thus erosion potential) and water quality. These factors are also affected by the changing climate.

The park's foundation document (National Park Service 2017b) notes a high priority need for a survey and legal title search of utility rights-of-way in the park. Such an effort would clarify jurisdictional responsibilities and inform decision-making related to replacing or repairing these utility lines in the future. The GRD (contact a regional energy specialist) can assist with these inquiries. In August 2023, the GRD queried the Enverus database (https://www.enverus.com/) and identified two 18-inch natural gas pipelines that cross beneath the Eastern Front unit of the park. The Enverus database only includes hydrocarbon lines and does not include electric transmission lines above or below grade.

During the 2022 follow-up meeting, relatively shallow (~1.5 m or 5 ft below the surface) gas, water, and sewer lines were noted as items of concern. Expansion of the water lines for Fort Lee (at the time of this writing, the Virginia American Water Company is the managing utility) could leave lines abandoned in place as new lines are built. Leaking water and sewer systems are thought to contribute to erosion at City Point and potentially other areas of the park. According to the NRCS Web Soil Survey ratings for "Subsurface Water Management, System Performance," about 69% of the acres in the park are rated as "very limited," which means that most of the soils in the park possess at least one limiting or unfavorable characteristic (e.g., depth to a water table, salinity, flooding, sodicity, sand content, soil reaction, hydraulic conductivity, soil density, gypsum content, and subsidence). An accurate inventory of abandoned, active, and proposed utilities within the park would support park resource managers.

### Abandoned Mineral Lands

Abandoned mineral lands (AML) features pose a variety of resource management issues, such as visitor and staff safety and the environmental quality of air, water, and soil. AML features can also provide habitat for bats and other animals, some of which may be protected under the Endangered Species Act or state species listings. Resource management of AML features requires accurate inventory and reporting. All AML features should be recorded in the Servicewide AML Database (see "Guidance for Resource Management"), and any newly acquired lands will need to be inventoried; the GRD can provide assistance. An accurate inventory identifies human safety hazards and contamination issues, as well as facilitates the closure, reclamation, and restoration of AML features. When appropriate for resource management and visitor safety, AML features can also present opportunities for interpretation as cultural resources (Burghardt et al. 2014).

Small-scale abandoned sand and gravel pits, boreholes, and wells dot the landscape within the units at the park, some of which are part of the GRI GIS geologic map data (in GRI GIS sensitive map layers: mine point features for CIPO and PETE). Since 1933, the park has filled many of these features to restore a Civil War-era appearance (Thornberry-Ehrlich 2005). New lands being considered for park acquisition (authorization for expansion in 2016) are near a sand quarry and a Petersburg Granite (geologic map unit **PNMpg**) quarry. The state of Virginia 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.

### Monuments

Unlike other parks associated with the Civil War, this park has limited memorials, monuments, and commemorative markers within it. They are considered important resources and values by park staff, as noted in the park foundation document (NPS 2016). Park memorials and commemorative markers include the Pennsylvania Monument, the Gowen Monument (both located along US Highway 201), a memorial at Five Forks Battlefield, and those in and around the Battle of the Crater landscape (see "Geologic Heritage"; National Park Service 2016). Most of the monuments are made of granite, some of which is locally sourced (e.g., Petersburg Granite [**PNMpg**]). The granite is mostly resistant, but where blocks of granite are held together by more soluble mortar, this can lead to instability. Natural weathering and acid rain can impact historic monuments, characterized by heavy chipping along the edges, cracking, and weathering with eroded edges and sugared surfaces. Climate change, social trails, and vandalism are among the threats to historic monuments listed in the foundation document.

Over the past few decades, the park has compiled GIS data for historical features such as (1) batteries, crater locations, and other earthen features at Fort Morton; (2) data from other military tunnels; and (3) GPR data at Taylor House and Fort Morton, (Bevan 1979; 2004; 2009). Compiling the GIS data of the historical features into a single database with LiDAR, geology, and soil layers as basemaps would provide a powerful tool for resource managers to manage and protect historic earthworks and better understand the subsurface at the park. This would be an ideal Scientists in Parks project (see "Guidance for Resource Management").

### Paleontological Resource Inventory, Monitoring, and Protection

Geologic map units: Potomac Formation (**Kp**), Aquia Formation (**Ta**), Lower Chesapeake Group (**Tcl**), Yorktown Formation (**Ty)**, Cold Harbor formation (**Tch**), Bacons Castle Formation (**Qbc**), Shirley alloformation (**Qsh**), and alluvium (**Qal**)

All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act.

Kenworthy et al. (2006) prepared a paleontological resource summary for the parks of the Mid-Atlantic Network, including the park ("see Cretaceous, Paleocene, Miocene, Pliocene, and Pleistocene Fossils"). The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists, but no field-based investigations. An on-the-ground paleontological survey would be an ideal SIP project. Resource-management recommendations from Kenworthy et al. (2006) for the park included:

- Monitor the fossil-bearing bluffs near the river at City Point for exposure of paleontological resources.

- Encourage park staff to observe exposed gullies and eroding streams for fossil material while conducting their usual duties.
- Photodocument and potentially monitor any occurrences of paleontological resources that may be observed in situ.
- Consider long-term monitoring of paleontological sites.
- Contact the GRD for paleontological resource management assistance.

### Climate Change

Climate change was identified as a key issue, stressor, and threat for the park's resources in that it may increase erosion to earthworks, rifle pits, and streambanks in the park, as well as the bluff at City Point (National Park Service 2020). Climate models suggest that recent climatic conditions are already shifting beyond the historical range of variability for temperature and precipitation, with increased average temperatures and more frequent extreme weather events such as storms, associated flooding, and drought (Monahan and Fisichelli 2014; Wofford 2018, 2020). The changing climate scenarios and overall increase in visitation across the service suggest that visitation will continue to increase at the park (e.g., Fisichelli and Ziesler 2015). Additional visitors would, in turn, increase the potential for trail development and associated erosion (Monahan and Fisichelli 2014).

The NPS Mid-Atlantic Network monitors weather and climate at the park (https://www.nps.gov/im/midn/pete.htm). Park managers are directed to the NPS Climate Change Response Program (https://www.nps.gov/orgs/ccrp/index.htm) to address climate change planning, which helps park managers develop plausible science-based scenarios that inform strategies and adaptive management activities that allow mitigation or adjustment to climate realities. The park's Resource Stewardship Strategy (National Park Service 2020) prominently features climate change vulnerability assessments and adaptation plans as long-term goals for natural and cultural resource management planning. The NPS has also produced a cultural resources plan for climate change mitigation, providing 1) a concept framework for cultural resources and climate change, 2) information for understanding climate change impacts on cultural resources, 3) practices for resources management, and 4) connection possibilities with global cultural heritage partners (Rockman et al. 2016). Petersburg National Battlefield is one of over 30 parks that have completed a coastal facilities vulnerability assessment (Peek et al. 2022). Nine assets in the City Point area of the park have high or moderate exposure to the evaluated coastal hazards (flooding potential, shoreline change, sea level rise inundation, extreme event flooding, and reported coastal hazards) and sea level rise. Two features/areas, the seawalls and shore protection and the James River waterfront pier, are within all evaluated exposure zones (Peek et al. 2022).

Finishing the process to become a "Climate Friendly Park" with an action plan was noted as a high-priority stewardship activity for priority resources (National Park Service 2020; https://www.nps.gov/subjects/climatechange/cfpprogram.htm). This program's goals include the following: (1) measure park-based greenhouse gas (GHG) emissions; (2) educate staff, partners, stakeholders, and the public about climate change and demonstrate ways individuals and groups can take action to address the issue (e.g., at City Point); and (3) assist parks in developing strategies and

specific actions to address sustainability challenges, reduce GHG emissions, and anticipate the impacts of climate change on park resources.

# Guidance for Resource Management

These references, resources, and websites may be of use to resource managers. The laws, regulations, and policies apply to NPS geologic resources. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), National Park Service 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 through the NPS Integrated Resource Management Applications (IRMA) DataStore 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).

### Assistance with Water-Related Issues

Although water is a geologic agent, some water-related issues are best addressed by the NPS Water Resources Division rather than the GRD. Such issues include groundwater hydrology, water quality, water supply, floodplains, wetlands, and water rights. Park managers are directed to the Water Resources Division webpages for program specifics (https://home.nps.gov/orgs/1439/index.htm) and contact information (https://home.nps.gov/orgs/1439/contactus.htm). Park managers can formally request assistance from the Water Resources Division via https://irma.nps.gov/Star/ (available on the DOI network only).

### Petersburg National Battlefield Documents

The park's foundation document (National Park Service 2016), resource stewardship strategy (National Park Service 2020), natural resource condition assessment (Lookingbill et al. 2013), vital signs monitoring plan (Comiskey and Callahan 2008), and general management plan (National Park Service 1994) are primary sources of information for natural resource management within the park. A resource stewardship strategy was noted as a high-priority resource for planning needs in the foundation document. Several cultural landscape and resource documents exist for the park, including Auwaerter (2009), Layton et al. (2017), Layton and Foulds (2017), National Park Service (2009a, 2009b), and Wallace and Conway (1983).

### 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 10 3–169** 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. 2879 3–28800 (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 §§210 1–2108, 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. 9 7–382, 96 Stat. 1938 (codified at 25 USC §§ 210 1–2108).
- **30 CFR §§ 1202.10 0–1202.101** governs royalties on oil produced from Indian leases.
- **30 CFR §§ 1202.55 0–1202.558** governs royalties on gas production from Indian leases.
- **30 CFR §§ 1206.5 0–1206.62 and §§ 1206.17 0–1206.176** 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.

<u>Recreational Collection of Rocks and Minerals</u>

*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. 10 7–223—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 1 5–01** (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 §§ 2001–2009** 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).

<u>Upland and Fluvial Processes</u>

*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. 7 7–2**).
- **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 7 7–1**).

*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 Servicewide AML Database: http://go.nps.gov/aml
- NPS AML, reclamation and restoration: https://www.nps.gov/subjects/abandonedminerallands/reclamation-and-restoration.htm

### *Bedrock References*

- NPS GRD 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 1 2–02—Applying NPS Management Policies in the Context of Climate Change: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Policy Memorandum 1 5–01—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

### *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/

#### *Energy Development and Mining*

- NPS Energy and Mineral Development: https://www.nps.gov/subjects/energyminerals/index.htm
- GRD completed an oil, gas, and minerals management handbook in 2017 that provides guidance for implementing existing NPS policy. Contact the 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

#### *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/index.shtml

### *Geology of National Park Service Areas*

- NPS GRD: http://go.nps.gov/geology
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm *Note*: Geodiversity refers to the full variety of natural geologic (rocks, minerals, sediments, fossils, landforms, and physical processes) and soil resources and processes that occur in the park. The atlas delivers information in support of education, geoconservation, and integrated management of living (biotic) and non-living (abiotic) components of the ecosystem.
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscience Concepts: https://www.nps.gov/subjects/geology/geology-concepts.htm

### *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 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/2194567
- "Monitoring in situ Paleontological Resources" (Santucci et al. 2009) in *Geological Monitoring* (Young and Norby 2009) details 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 (2003)
- NPS Fossils and Paleontology website, http://go.nps.gov/paleo
- Santucci et al. (2009) details paleontological resource monitoring strategies.

### *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/

### *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) describes five vital signs for understanding and monitoring slope movements: (1) types of landslides, (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 GRD Geohazards: http://go.nps.gov/geohazards
- NPS GRD Slope Movement Monitoring: https://www.nps.gov/subjects/geology/geological-monitoring.htm
- US Geological Survey, landslide hazards: https://www.usgs.gov/programs/landslide-hazards

### *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 and Cultural Resource Information*

- Geology and Mineral Resources: Virginia Department of Energy: https://www.virginia.gov/services/environment/mines-minerals-energy/
- Virginia Department of Energy Mineral Resources Database: https://www.energy.virginia.gov/geology/MineralResources.shtml
- Description of geologic map units of Virginia (Virginia Division of Mineral Resources 2003)
- Virginia Cultural Resource Information System: https://vcris.dhr.virginia.gov/VCRIS/Mapviewer/

### *Water Resources*

- NPS Water Resources Division provides 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 the park (https://www.nps.gov/im/midn/pete.htm).

# Literature Cited

These references are cited in this report. Contact the GRD for assistance in obtaining them.


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Bevan, B. W. 2007. A radar survey between Fort Morton and Battery 13. Internal, unpublished report prepared for Petersburg National Battlefield. Geosight, Weems, Virginia.

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