National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Chattahoochee River National Recreation Area

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2470

ON THE COVER
Photograph of shoals at Chattahoochee River National Recreation Area. Photograph by Georgia Hybels (Colorado State University) taken in spring 2012.

THIS PAGE
Photograph of the rocks along Sope Creek at Chattahoochee River National Recreation Area. Flashes of light in the rock are reflections off the flaky, mica minerals characteristic of some of the park rocks. The alignment of the minerals is a result of metamorphism and deformation. These characteristics influence the location of the Chattahoochee River channel and its famous shoals. Photograph by Georgia Hybels (Colorado State University) taken in spring 2012.

Chattahoochee River National Recreation Area

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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, this Geologic Resources Inventory (GRI) report for Chattahoochee River National Recreation Area (herein referred to as the "park") provides information and resources intended to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in this GRI report may also be useful for interpretation.

Islands of knobby bedrock rise from the misty surface of the Chattahoochee River. These islands or shoals are characteristic of this stretch of the river below Buford Dam, which impounds Lake Sidney Lanier northeast of the major urban center of Atlanta, Georgia. The shoals form where the river preferentially weathers away adjacent softer, less resistant rocks. The river is confined in part by the ancient Brevard Zone—a major geological structure in the southern Appalachians. Its course is one of the oldest in the United States, flowing between and over rocks that collected in ancient sea basins and volcanoes before being squeezed, heated, shoved, and deformed during multiple mountain-building orogenies. The geologic history of the park records the construction of eastern North America. For more than 200 million years, the rocks beneath the park have weathered deeply producing a layer of clay-rich soils. Earth surface processes continue to change the landscape, eroding the highest points, and reworking sediments along the river and its tributary stream channels. Today, the park is a green oasis between Atlanta's urban center and its suburbs. Resource managers face challenges due to the proximity of the park to the city of Atlanta, including wastewater and freshwater demands, transportation corridors (e.g., interstate), encroaching suburban development, and water management associated with the Buford Dam.

This report is supported by GRI GIS data compiled from maps of the bedrock and shoals and underwater hazards of Chattahoochee River National Recreation Area that were originally produced by the US Geological Survey, Geocorps of America, and the University of West Georgia. The GRI GIS data was 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. The GRI GIS data for the recreation area consists of four maps: a northern portion (map code "chtn"), southern portion map ("chts"), a map of part of the Sandy Springs 7.5x7.5-minute quadrangle ("sasp"), and a shoals and water hazard areas map ("chsh"). Collectively, the maps cover the extent of the park and surrounding area. The data includes geologic information such as geologic units, contacts, faults, linear dikes, cross section lines, folds, geologic attitude observations, geologic observations, underwater hazard areas, and shoal areas. Surficial geologic mapping is a data need at the park.

Given the park's long, linear nature, many geologic units are mapped along the course of the Chattahoochee River. The regional trend of folds, faults, valleys, and ridges is northeast to southwest. This report provides descriptions of the Brevard Zone, faults, folds, valleys, and geologic map units that are applicable to the entire park. Two tables break out the geologic features, processes, and resource management issues per geologic map unit presented in the GRI GIS data.

The GRI report consists of the following seven chapters:

Introduction to the Geologic Resources Inventory—This chapter provides background information about the GRI, highlights the GRI process and products, and recognizes GRI collaborators. A geologic map in GIS format is the principal deliverable of the GRI. This chapter identifies the four source maps used by the GRI team in compiling the GRI GIS data for the park and provides specific information about the use of these data. It also calls attention to the poster that illustrates these data.

Geologic Heritage of Chattahoochee River National Recreation Area—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 Setting and History—This chapter describes the geologic setting and chronology of geologic events that formed the present landscape.

Geologic Features and Processes—This chapter describes the geologic features and processes of significance for the park and highlights them in a context of geologic time. The features and processes are discussed in order, from oldest to youngest: metamorphic and igneous bedrock; Brevard Zone; faults and folds; type localities and type sections (stratotypes); rock shelters; fluvial features and processes; shoals; and paleontological resources.

Geologic Resource Management Issues—This chapter discusses management issues related to the park's geologic resources (features and processes). Issues that relate to geologic resources are included: anthropogenic effects on the fluvial system; adjacent development, overuse, disturbed lands, and illegal mining; rock shelter management; geologic hazards; paleontological resource inventory, monitoring, and protection; climate change; and additional geologic information needs.

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.

Literature Cited—This chapter is a bibliography of references cited in this GRI report. Many of the cited references are available online, as indicated by an Internet address included as part of the reference citation. If park managers are interested in other investigations and/or a broader search of the scientific literature, the NPS Geologic Resources Division has collaborated with—and funded—the NPS Technical Information Center (TIC) to maintain a subscription to GEOREF (the premier online geologic citation database). Multiple portals are available for NPS staff to access this database. Park staff may contact the GRI team or the NPS Geologic Resources Division for instructions to access GEOREF.

Introduction to the Geologic Resources Inventory

The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division of the 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 one of 12 inventories funded by the NPS Inventory and Monitoring Program.

GRI Products

The GRI team—which is a collaboration between NPS staff at the Geologic Resources Division and research associates at Colorado State University, Department of Geosciences, and University of Alaska Museum of the North—completed the following tasks as part of the GRI process for Chattahoochee River National Recreation Area (herein referred to as "the park"): (1) conducted a scoping meeting and provided a scoping summary, (2) provided digital geologic map data in a geographic information system (GIS) format, (3) created a poster to display the GIS data, and (4) provided a GRI report (this document).

GRI products are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov. Enter "GRI" as the search text and select a park from the unit list. Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.

Information provided in GRI products is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided in GRI products. Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the poster. Based on the source map scales (1:24,000, 1:100,000 and 1:500,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 12 m (40 ft), 51 m (167 ft) and 256 m (834 ft), respectively of their true locations.

Scoping Meeting

On 22 March 2012, the National Park Service held a scoping meeting at the park in Sandy Springs, Georgia. 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 (KellerLynn 2012) documents the findings of that meeting.

GRI GIS Data

Following the scoping meeting, the GRI team compiled the GRI GIS data for the park from four source maps. The data was compiled by the GRI in 2022 and may be updated if new, more accurate geologic maps become available or if software advances require an update to the digital format. The completion of the GRI GIS data satisfies a medium priority data need identified in the park's foundation document (National Park Service 2017). The GRI team did not conduct original geologic mapping but compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data. Scoping participants and the GRI team identified the best available source maps based on coverage (area mapped), map scale, date of mapping, and compatibility of the mapping to the current geologic interpretation of an area.

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for Chattahoochee River National Recreation Area was compiled using data model version 2.3, which is available 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.

More information about the GRI GIS data can be found in the files accompanying the data accessed via the NPS IRMA portal. The "GIS Readme Document" explains the available file formats for the GRI GIS data, how to use the different file formats, and where to find more information about the GIS data model. The "Ancillary Map Information Document" lists the geologic maps or GIS data used to produce the GRI GIS data, the map units and map unit descriptions (including descriptions from all source maps), and additional information about the source maps.

The GRI team may compile multiple source maps into a single map product to cover a park seamlessly or provide a greater extent as needed for resource management. For Chattahoochee River National Recreation Area, four source maps were selected but not compiled into a single product because of their vastly different scales and extents. The GRI GIS data for the recreation area therefore consists of four separate map products: a northern portion (GRI map code "chtn"), southern portion map ("chts"), a map of part of the Sandy Springs 7.5x7.5-minute quadrangle ("sasp"), and a shoals and water hazard areas map ("chsh"). Each map has a unique extent, although there is some overlap. The sasp map overlaps a portion of the chts map and the chsh map covers the entire length of the park, overlapping the three other maps (fig. 1).

The following four source maps were used to produce the GRI GIS data for Chattahoochee River National Recreation Area. For GRI maps chtn and chts, the source maps' extent vastly exceeds the area of the park, thus only a portion of the source publication is presented in the GRI GIS data:

- Geologic map of the Atlanta 30'x60' quadrangle, Georgia by Higgins et al. (2003); GRI map code: chtn.
- Preliminary integrated geologic map databases for the United States: Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina by Dicken et al. (2005); GRI map code: chts.
- Geologic map illustrating the tectonostratigraphy and structural geology of part of the Brevard Zone in Georgia: results from detailed surface geologic mapping in the Chattahoochee River National Recreation area, Sandy Springs Quadrangle, Georgia by Harden et al. (2013); GRI map code: sasp.
- Shoals map of Chattahoochee River National Recreation area, Georgia by Hundley (2014); GRI map code: chsh.

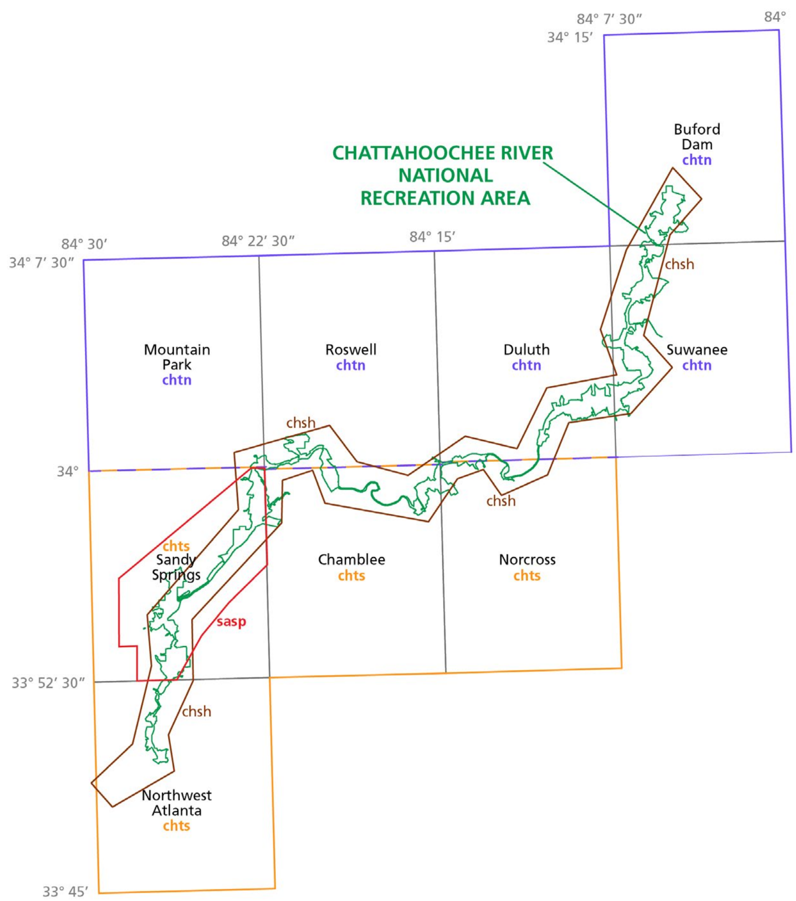

Figure 1. Index map of the GRI GIS data.
The map shows the extent of the four GRI GIS maps (chtn, chts, sasp, and chsh) and the boundary of Chattahoochee River National Recreation Area. The extent of the GRI digital geologic map of the northern portion of the park (chtn) is outlined in blue, whereas the extent of the GRI digital geologic map of the southern portion of the park (chts) is outlined in orange. The extent of the GRI digital shoals and underwater hazards-GIS map of the park (chch) is displayed in reddish-brown. GRI digital geologic map data also exist for part of the Sandy Spring 7.5' quadrangle, outlined in red. The boundary for Chattahoochee River National Recreation Area (as of September 2021) is green. The extents and names of relevant 7.5' quadrangles are also displayed, as are longitude and latitude coordinates that define these quadrangles. Graphic by Stephanie O'Meara, Kajsa Holland-Goon, and Trista L. Thornberry-Ehrlich (Colorado State University).

GRI Poster

The GRI team created a poster displaying the GRI GIS data for the sasp map draped over a shaded relief image of the park and surrounding area. The poster is not a substitute for the GIS data but is 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. Geographic information and selected park features have been added to the poster. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

GRI Report

On 24 August 2021, the GRI team hosted a follow-up conference call for park staff and interested geologic experts. The call provided an opportunity to get back in touch with park staff, introduce "new" (since the 2012 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 conference call in 2021, and additional geologic research. The selection of geologic features was guided by the previously completed GRI GIS data, and writing reflects the data and interpretation of the source map authors. Information from the park's foundation document (National Park Service 2017) was also included as applicable to the park's geologic resources and resource management.

The GRI report links the GRI GIS data to the geologic features and processed discussed in the report by referencing map unit symbols. Usually, a map unit symbol consists of an uppercase letter indicating age (e.g., **PZ** for Paleozoic, **PC** for Precambrian, and **UNK** for age not given) followed by lowercase letters indicating the rock formation's name or the type of deposit (e.g., **a** for amphibolite). Thus, **PZPCa** is the map unit symbol for a Precambrian to Paleozoic age amphibolite and **UNKm** is the symbol for a mylonite and ultramylonite unit of unknown age (see map chtn).

Acknowledgements

The GRI team thanks the participants of the 2012 scoping meeting and 2021 follow-up conference call for their assistance in this inventory. The lists of participants (below) reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the US Geological Survey, Geocorps of America, and University of West Georgia for their maps of the area. This report and accompanying GIS data could not have been completed without them. Additional thanks go to subject experts Timothy Henderson (NPS Geologic Resources Division) and Jacob Bateman McDonald (University of North Georgia) for their contributions.

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Geologic Heritage of Chattahoochee River National Recreation Area

Shoals of knobby bedrock characterize the ancient course of the Chattahoochee River northeast of Atlanta, Georgia. The park's landscape is riverine with steep riverside bluffs or cliffs and rolling forested uplands—a green oasis. The history of the park and its natural features are part of the local and national heritage. This chapter highlights the significant geologic heritage of the park and draws connections between geologic resources and other park resources and stories.

Park Background and Establishment

Misty vistas and churning rapids abound along the length of the river in Chattahoochee River National Recreation Area. About 77 km (48 mi) of the 698-km (434-mi) Chattahoochee River flows through the park between Buford Dam (at Lake Sidney Lanier) and Peachtree Creek, which flows through the city of Atlanta (fig. 2; Georgia River Network 2018; National Park Service 2022). Established on 15 August 1978, Chattahoochee River National Recreation Area is composed of 15 noncontiguous management units, rather than a single corridor, covering about 2,630 ha (6,500 ac) in Cobb, Forsyth, Fulton, and Gwinnett Counties. The units from north to south are:

- Bowmans Island
- Orrs Ferry
- Settles Bridge
- McGinnis Ferry
- Suwanee Creek
- Abbotts Bridge
- Medlock Bridge
- Jones Bridge
- Holcomb Bridge
- Island Ford
- Vickery Creek
- Gold Branch
- Johnson Ferry
- Cochran Shoals
- Palisades

Private land exists within the park's authorized boundary (fig. 2). Assuming future land acquisitions are possible, the maximum potential area of Chattahoochee River National Recreation Area is approximately 4,050 ha (10,000 ac) (National Park Service 2017). In 2011, the park added an 18-ha (44-ac) tract of land near Rogers Bridge, around river mile 337 (between the Suwanee Creek and Abbotts Bridge management units; see fig. 2) (KellerLynn 2012).

The Chattahoochee River is vitally important to the greater Atlanta metropolitan area as a water source—the primary source of drinking water—and public green space (Atlanta Regional Commission 2021). The Chattahoochee River corridor provides 70% of the public green space in the greater Atlanta area and Kennesaw Mountain National Battlefield Park (see GRI report about Kennesaw Mountain National Battlefield Park by Barthelmes 2021) provides most of the remaining 30% (Kunkle and Vana-Miller 2000). More than 3 million people visit the park annually and more than one-third of these visitors engage in river-based recreation (National Park Service 2018).

The river begins in the mountains of northern Georgia near Brasstown Bald. It flows southwestward until impounded by Buford Dam. Below the dam it continues to flow southwest until reaching Norcross, Georgia where it turns nearly west for several miles until Roswell where it turns southwestward again. Morgan Falls Dam impounds Bull Sluice Lake here. Beyond Peachtree Creek and Atlanta, the river enters West Point Lake below West Point Dam where it forms the border between Georgia and Alabama. Near the town of Chattahoochee, Florida (on the Georgia-Florida border) the Chattahoochee and Flint Rivers merge to form the Apalachicola River which flows into the Gulf of Mexico (Brown 1980). The segment of the Chattahoochee River within the park is the most intensely used segment in the state of Georgia (Burkholder et al. 2010; KellerLynn 2012).

Geoheritage Values of Park Resources

This section identifies the most significant geologic resources in the park and describes their value in terms of America's geoheritage. Geologic heritage (or "geoheritage") encompasses the significant geologic features, landforms, and landscapes characteristic of our Nation which are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values. The NPS also identifies geologic heritage aspects of museum collections, soils, and scientific data sets.

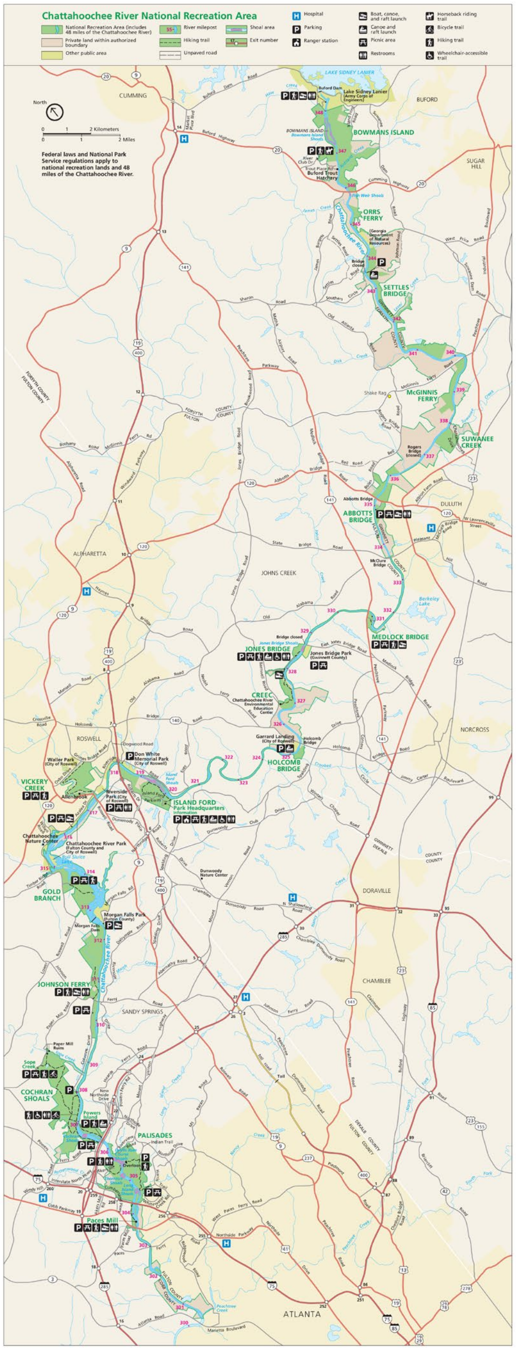

Figure 2. Map of Chattahoochee River National Recreation Area.
The park consists of 15 units, from north to south: Bowmans Island, Orrs Ferry, Settles Bridge, McGinnis Ferry, Suwanee Creek, Abbotts Bridge, Medlock Bridge, Jones Bridge, Holcomb Bridge, Island Ford, Vickery Creek, Gold Branch, Johnson Ferry, Cochran Shoals, and Palisades, strung along a stretch of the Chattahoochee River. In some areas, the park barely extends beyond the river channel itself. The park is north of Atlanta, Georgia and provides a green oasis in an increasingly urban to suburban environment. National Park Service maps are available at www.nps.gov/carto.

Geoheritage sites are locales that play a key role in developing our understanding of the history of the Earth. Though not formally designated, sites that would qualify as geoheritage sites in the National Park System 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. Currently, there is no comprehensive national registry that includes all geoheritage sites in the United States. For more information about geoheritage sites, see the "Additional References, Resources, and Websites" section of this report and "America's Geologic Heritage: An Invitation to Leadership". This booklet introduces the American experience with geoheritage, geodiversity, and geoconservation (National Park Service and American Geosciences Institute 2015). This publication introduces key principles and concepts of America's geoheritage which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States.

Though park units are not currently established specifically for "geoheritage" values, any geologic component of a park's enabling legislation or planning and management documents can be considered a part of America's geoheritage. The foundation document for Chattahoochee River National Recreation Area describes the park's purpose, significance, fundamental resources and values, and interpretive themes (National Park Service 2017). Fundamental resources and values are those features, systems, processes, experiences, stories, scenes, or other attributes determined to warrant primary consideration during planning and management processes because they are essential to achieving the purpose of the park and maintaining its significance. Fundamental resources and values are closely related to a park's legislative purpose. Geology is listed as a fundamental resource and value for the park, including the Brevard Fault, crystalline rocks, the river channel, palisades, cliffs, and ridges. The foundation document for the park identifies the following significance statements with geoheritage connections:

- Chattahoochee River runs along the Brevard Fault Zone and is one of the oldest and most stable river channels in North America, the park's 77-km (48-mile) river corridor features steep, rugged palisades, rocky shoals, sheer rock faces, and exposed geologic features that provide remarkable visual scenery.
- The park's location at the intersection of the southern Piedmont and mountain habitats, provides the geological foundation for an ecological oasis within a densely populated region and contains more

than 950 species of plants and a diverse assemblage of wildlife.

- Cultural resources along the Chattahoochee River represent the continuum of human interaction with the landscape over the past 10,000 years that is reflected in archeological sites, historic structures, and cultural landscapes that owe their locations to the natural (geological) features of the river corridor.
- The park constitutes an important outdoor recreation resource to an urban population numbering over 6 million people (ca. 2020) in the Atlanta metropolitan area. Its waters and lands provide a diverse and abundant variety of outdoor recreation opportunities. These experiences are further enhanced by the park's scenic qualities, of which geology features prominently, as well as opportunities for natural solitude and seclusion within relatively undisturbed forests, wetlands, bluffs, ravines, and open water areas.

Geology and Human Stories

Geology is the foundation of the landscape at Chattahoochee River National Recreation Area. It has influenced the human history of the area as well as modern landforms and ecosystems. The park's foundation document (National Park Service 2017) stated that archeological sites, historic structures, and cultural landscapes owed their locations to the natural (geological) features of the river corridor. The river is constrained in part by regional geologic features such as faults, folds, and rock units (see "Geologic Features and Processes" section). Its unique setting determined how and where humans interacted with the riverine landscape, such as harnessing the power of its flow, and determining river crossing locations. This report will present a brief overview of the human history with emphasis on the connections with geology. Park history is thoroughly detailed in Gerdes and Messer (2007).

Native American History

Compared to the geologic record, the human history of Chattahoochee River National Recreation Area is quite short. According to Higgins et al. (2003), the first humans to use the natural resources of the area were Native Americans from the Archaic period and later Woodland culture. Their occupation sites and rock shelters are among the archeological resources at the park. Soapstone within the Stonewall Gneiss (geologic map unit **OZs**) coincides with archeological sites. Soapstone was a favored material because of the ease with which it could be sculpted into bowls, cooking utensils, and heat-retaining devices thought to have been used as warmers for beds, shelters, and food (Higgins et al. 2003). Bowl fragments, chips, and occasionally in-situ partially excavated bowls are present in the park area (Higgins et al. 2003). Rock shelters and associated archeological sites are considered sensitive sites; therefore, these features are not interpreted for the public. While park staff are aware of some of these sites, a formal and comprehensive inventory of rock shelters with archeological sites is a data need. (see "Guidance for Resource Management"; National Park Service 2017; Beth Wheeler, Chattahoochee River National Recreation Area, chief of Planning, Resources and Education, conference call, 24 August 2021).

The Chattahoochee River was a transportation corridor and territorial boundary for the Creek and Cherokee Indians playing a large role in their cultures and lifestyles (National Park Service 2017). Following initial contact during the DeSoto expedition (1539-1542), contact with European settlers had profound impacts on the local Creek and Cherokee populations. Some groups moved closer to trading posts, whereas others moved to more advantageous hunting grounds because the fur trade was lucrative. Other groups took European tools and changed from subsistence (hunting and gathering) to agricultural ways of living using fertile soils along major rivers.

Prior to 1800, the Hightower Trail (named for the Creek word "Etowah", meaning town) was a primary travel route linking Creeks and Cherokees in northwest Georgia to the trade center of Augusta on the Savannah River (Brown 1980; Georgia Historical Society 2015). The trail was at least 400 km (250 mi) long from the east and crossed the Chattahoochee River at a shallow ford (known locally as Shallowford) near mile marker 317 (see fig. 2 for mile marker location, trail is not included). The trail is underlain by mica schist, gneiss, and amphibolite (**PZPCms**), and proceeded downstream about 2 km (1 mi) until heading west near present day Willeo Road at mile marker 316 (Brown 1980). The Hightower Trail formed an early boundary between the Cherokee and Creek Nations. The trail was later used as a dividing line between Indian cessions of 1819 and 1821 and remains today as part of the Gwinnett–Dekalb Counties boundary (Georgia Historical Society 2015).

Trade with European settlers prompted entrepreneurial opportunities for Cherokee that were linked with the river. Along the Chattahoochee River, Cherokee families operated four ferries (Orrs, Gilberts, Rogers, and Waters Ferries) and created a well settled area of cultivated farmlands, small mills, towns (e.g., Suwanee), and a road system linking this part of Georgia to the west (Brown 1980). Initially, trade was primarily an exchange of manufactured goods (e.g., guns, knives, traps, metal utensils, etc.) for food and furs. Because of the demand for furs, some lands became depleted in wild game and people moved west or southwest to find more animals. Beginning in the early 1800s, European settlers moved in ultimately displacing Cherokee families. As settlement of the area continued, trails such as the Hightower Trail became roads used by settlers (Brown 1980) and many built their homes along it (Georgia Historical Society 2015). By 1821, all land on the east side of the Chattahoochee River was granted to the State of Georgia (Brown 1980). The discovery of gold near Dahlonega, Georgia in 1828 (see the Dahlonega gold belt in fig. 3) exacerbated the drive to own land ultimately resulting in the "Trail of Tears" to remove the Cherokee from Georgia— during which a quarter of their population perished (Brown 1980).

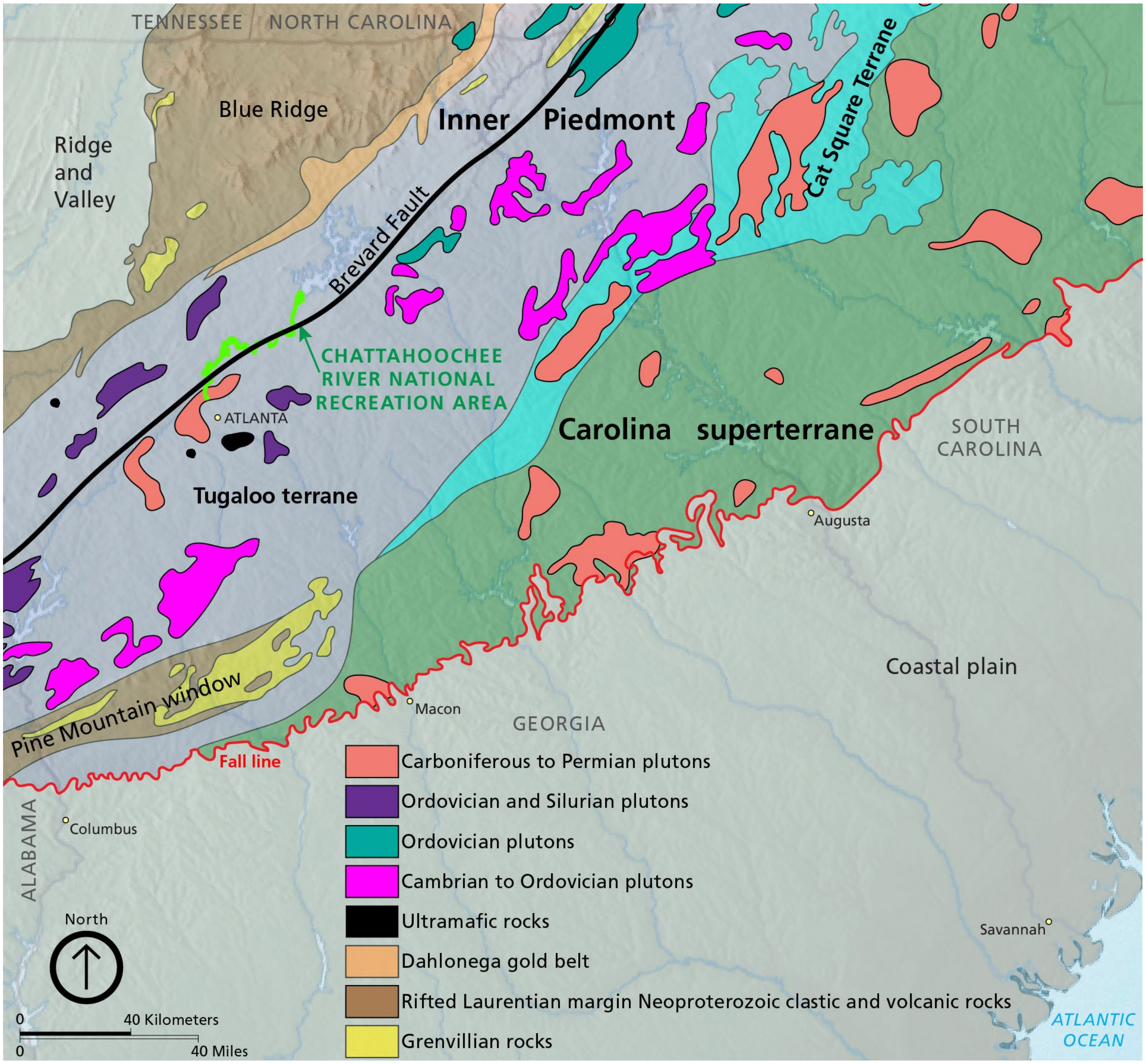

Figure 3. Map of the geologic regions in northern Georgia.
Chattahoochee River National Recreation Area runs along the Brevard Zone (fault), which transverses the Tugaloo terrane. Together with the Cat Square terrane, the Tugaloo terrane is a major part of the Inner Piedmont province. Several different phases of igneous plutons intruded the Tugaloo terrane: Cambrian to Ordovician plutons, Carboniferous to Permian plutons, and Ordovician plutons. Graphic is redrafted after figure 3 in Hatcher (2005) by Trista L. Thornberry-Ehrlich (Colorado State University). Some features from the original figure were not included for graphic clarity. Shaded relief basemap by Tom Patterson (National Park Service) available at http://www.shadedrelief.com/physical/index.html (accessed 31 March 2020).

Land Use

Prior to intensive human land use, the Chattahoochee River had clear water and a gravel bed with very little suspended sediment beyond that released during seasonal floods. When significant agriculture and forest clearing began with human occupation and settlement in the 1700s and 1800s, erosion of upland areas was severe and caused extensive deposition in the bottom lands. Chattahoochee River became "brown water" full of suspended sediment (Jacob Bateman McDonald, University of North Georgia, assistant professor and Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021). The introduction of soil conservation efforts in the mid-to-late-1930s slowed the overall erosion (Georgia Soil and Water Conservation Commission 2022).

Impoundments of the river changed its course and sedimentation patterns forever. Construction began on Morgan Falls Dam in 1902 and took two years; it was the first hydroelectric dam to provide electricity to Atlanta. In the late 1950s the sediment cycle was interrupted altogether by further impoundments of the river (Buford Dam was built in 1957). Now, sediment is stored behind the dams and the water runs clear immediately downstream from the dams and slowly becomes "muddy" as tributaries carry sediment to the Chattahoochee River (Jacob Bateman McDonald, University of North Georgia, assistant professor, conference call, 24 August 2021).

Transportation and Industry

While much of the river was heavily traveled, the stretch of the Chattahoochee River in north-central Georgia above Peachtree Creek (now the park) never became a major transportation corridor due to the geologically controlled topography, dangerous shoals, and rapids (Brown 1980; Hundley 2014). The river is in a distinctive geologic location, along the Brevard Zone (see "Brevard Zone" section), which confines portions of its length, making its course very stable and old (KellerLynn 2012; National Park Service 2017). It was a natural barrier with unpredictable flows necessitating the use of fords, ferry sites, and eventually bridges to cross (National Park Service 2017). In the 1830s, railroads led to Atlanta's prominence as a strategic transportation hub and major rail center. The initial railroad crossing location had to be carefully planned because of the geologic obstacles along the river. Originally, the crossing was to be at Pittmans Ferry near Norcross, but the topographic setting there, where Stonewall Gneiss, Powers Ferry Member (**OZsp**) and Long Island Creek Gneiss (**PYl**) crop out, presented difficulties and the site was abandoned for Montgomerys Ferry near Peachtree Creek, underlain by button schist (**POb**) and mylonitized granitoid (**PSm**), which are less resistant to erosion and therefore presented less obstacles (Brown 1980; Dicken et al. 2005). Three rail lines from the east, south, and north would eventually meet at the future site of Atlanta. By 1864, a bridge spanned the river at Roswell near the Hightower Trail crossing. Until more bridges were constructed in the early 1900s, ferries continued to be the major means of crossing the river (Brown 1980). Some of the earliest bridges were Paces, Powers Ferry, Medlock, Settles, Jones, Rogers, and Johnson Ferry Bridges (Brown 1980; National Park Service 2017).

In addition to its history of use as a transportation corridor, humans have used the power of flowing water in the Chattahoochee River and its tributaries for centuries. Along the length of the park, the 77 km (48 mi) of the Chattahoochee River descends 45 m (150 ft), most of which occurs in the lower half, below Nesbitts Ferry (near Holcomb Bridge, see fig. 2) where the elevation drops from 263 m (863 ft) to 228 (748 ft) over just 29 km (24 mi). The steepness of the river is due, in part, to resistant gneisses and granites (e.g., **OZmg** and **OZsg**; see GRI poster which shows the river downstream from Holcomb Bridge) underlying the river channel and the pattern of high-angle faults characteristic of the region. Where the river encounters resistant rocks (shoals) its erosive power is limited, however, upon encountering a fault trace (zone of weakness in the rocks) the river is able to incise deeply and rapidly resulting in a river channel and tributaries punctuated by steep drops between resistant shoals (fig. 4; see "Faults and Folds" section; Dicken et al. 2005). The steep slopes of the Chattahoochee River's tributaries allowed for the development of small grist mills and eventually bigger industry of the area (KellerLynn 2012). Textile and paper mills harnessed the water's power for industrial purposes; two major 19th-century industrial complexes included the Roswell Manufacturing Company on Vickery (Big) Creek and the Marietta Paper Manufacturing Company on Sope Creek (Brown 1980; National Park Service 2017).

At Vickery Creek, a dam and mills constructed in the 1830s accompanied a planned upland community, named Roswell. Industries included cotton and woolen mills, flour mills, and a tannery. One of the original mill buildings and the dam (fig. 5) are still standing. The dam and building foundations were constructed of local rocks from biotitic gneiss, mica schist, and amphibolite

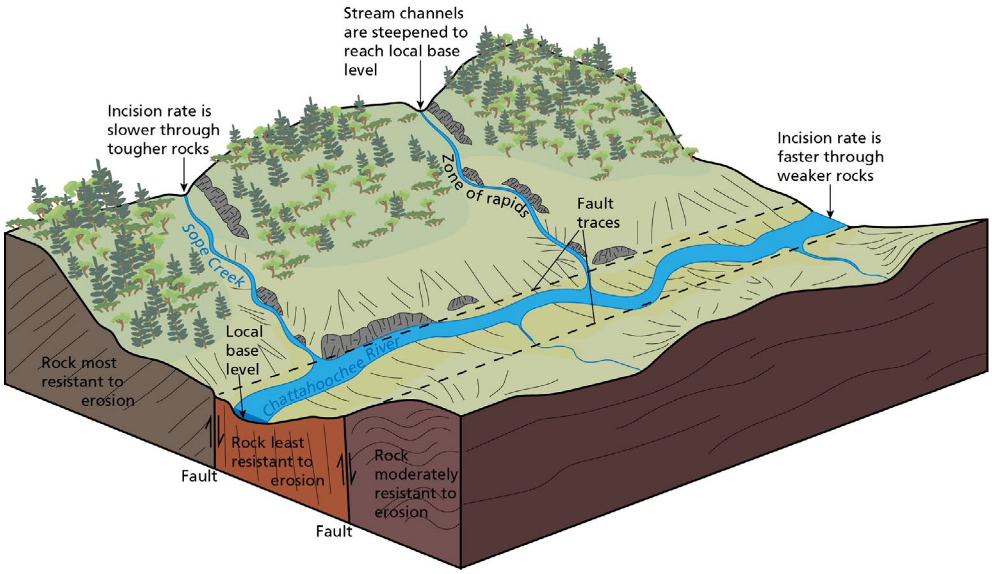

Figure 4. Schematic diagram showing uneven stream incision.
In areas where faults have juxtaposed erosion resistant rocks against less erosion-resistant rocks, incision rates of streams and rivers are different. In places, the Chattahoochee River is incising relatively quickly through weaker rocks, which lowers the baselevel that tributary streams and creeks must reach. If the tributary is incising relatively slowly through resistant rocks, their channel is naturally steepened to reach the base level. Such a situation exists along Sope Creek creating a high-energy situation that humans used to build mills and take advantage of the hydraulic gradient for mill power. Graphic is not to scale and idealized to illustrate the setting. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

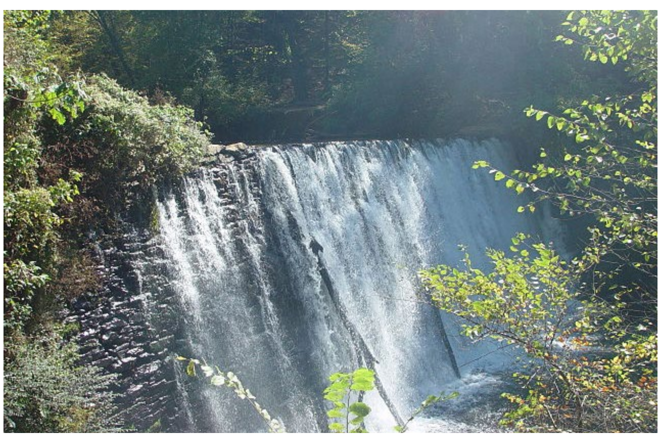

Figure 5. Photograph of Roswell Mill dam on Vickery Creek.
The dam, constructed of local gneiss, schist, and amphibolite still impounds Vickery Creek. In this setting, the drainage for Vickery Creek is higher than that of Chattahoochee River; this forms a high energy environment that many mills along the river's tributaries took advantage of historically. Today, popular trails lead to the dam and reservoir. Photograph by R. T. taken in 2003 available at https://commons.wikimedia.org/wiki/File:RoswellMillDam1.JPG (accessed 9 March 2022). Unmodified and used under license, CC BY-SA 2.5 (https://creativecommons.org/licenses/by-sa/2.5/deed.en).

(geologic map units **PZPCbg2** and **PZPCms** among possible others). Due to their importance as a supplier of cotton and woolen goods to the Confederate army, the mills at Roswell were destroyed by Union forces during the Civil War (Brown 1980). Upon rebuilding after the war, the mills would go on to produce goods for the World War I effort (Brown 1980). The paper manufacturing industrial complex on Sope Creek started about a decade after Roswell (fig. 6). This mill complex produced a large portion of the South's paper as well as much of the stock on which the Confederate currency and bonds were printed (Brown 1980). The paper mill was also destroyed during the Civil War, but later rebuilt.

The American Civil War on the Chattahoochee

The American Civil War has history in Chattahoochee River National Recreation Area in addition to the fates of the mill complexes. Encampments, earthworks, and river crossings from that time are among the park's cultural resources. After the Battle of Chattanooga, in the spring of 1864, Union forces were in a position to advance on Atlanta—a strategic location with railroads reaching it from four directions and manufacturing capabilities. Fighting at Kennesaw Mountain (Wiss et al. 2013; see GRI report about Kennesaw Mountain National Battlefield Park by Barthelmes 2021) resulted in the Union position being able to destroy the Western

Figure 6. Photographs of the Paper Mill ruins.
The mill ruins were once part of a larger 19th-century industrial complex that closed in 1902. (A) Mills such as the Paper Mill were constructed out of local materials to take advantage of the flowing energy of water along tributaries of the Chattahoochee River, (B) view across Sope Creek to the ruins, (C) local rocks made up the walls and foundation of the mill, (D) view across Sope Creek from the mill,(E) local springs flow through some of the walls, and (F) close up of the gneisses, quartzites, and schists that compose the walls of the mill. Photographs by Georgia Hybels (Colorado State University) taken in spring 2012.

and Atlantic Railroad, cutting off necessary supplies to Confederate troops. The next natural barrier between the Union army and Atlanta was the Chattahoochee River, already fortified by Confederates (Brown 1980). Fortifications included double-walled redoubts, log palisades, timber revetments, log retaining walls, abatis (entanglements), and sharpened stakes. Fortifications were concentrated near river crossings (fords, ferries, and bridges) and many are visible today (fig 7; Brown 1980; National Park Service 2017).

The settlement of Vinings, near Peachtree Creek and underlain by button schist (**POb**) and mylonitized granitoid (**PSm**), became a major Union staging area during the first half of July 1864. Deep weathering of the geologic units contributed to unconsolidated material vital for trenches and other earthworks. Ultimately the Confederate fortifications were outflanked by Union troops. The Roswell Bridge was destroyed before it could be used by the Union forces, the original railroad bridge was burned, and many of the industrial complexes were also destroyed at this time. Troops crossed the river at Shallowford (site of the Hightower Trail crossing near mile marker 317, not labeled on park map) and other fords such as Island Ford (Brown 1980). A pivotal crossing was planned for the Sope Creek area. Here, the terrain contributed to the element of surprise. Union forces were able to remain under cover in thick woods, assemble and load pontoon boats (see fig. 7) behind a high ridge, advance across the fish dam, and quickly enter the river. The trend of the ridge, composed of Stonewall Gneiss, Powers Ferry Member (**OZsp**) and garnet-rich schist (**OZmgs**) is parallel to the Morgan Falls fault and other, unnamed faults (Dicken et al. 2005). The crossing and subsequent construction of a pontoon bridge took less than half a day (Brown 1980). The Chattahoochee was breached. Two bridges, hastily constructed at Roswell would allow the entire Army of Tennessee totaling some 30,000 men plus accompanying wagons and artillery to cross the river by mid-July (Brown 1980). The Battle of Peachtree Creek on July 20 was the beginning of the end for Confederate Atlanta. Today, remnants of Civil War fortifications and activities are visible on the park landscape, but not identified nor interpreted for visitors (Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021).

Geologic Connections to Ecosystems

In addition to the historical connections briefly presented here, geologic features and processes are fundamentally connected with vegetation patterns, many animal habitats, soils, and water resources. Chattahoochee River National Recreation Area is located at the intersection of the southern Piedmont and mountain habitats; the park sustains species from both habitats. Features of the mountain habitat including deep, fertile soils, trees, and shrubs combine with characteristics from the southern Piedmont habitat including red clay soils, scattered rock outcrops, lakes and rivers, pine trees and hardwood forests (Richmond County Board of Education date unknown). Such a setting supports more than 950 species of plants (National Park Service 2017) including the federally listed dwarf sumac (Rhus michauxii) and many other state-listed species of concern including the Georgia aster (Symphiothrichum georgianum) (Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021).

Geology gives rise to soil formation, which in turn support the biota of the park. The dwarf sumac grows in soils developed over amphibolite rocks (fig. 8). Soil

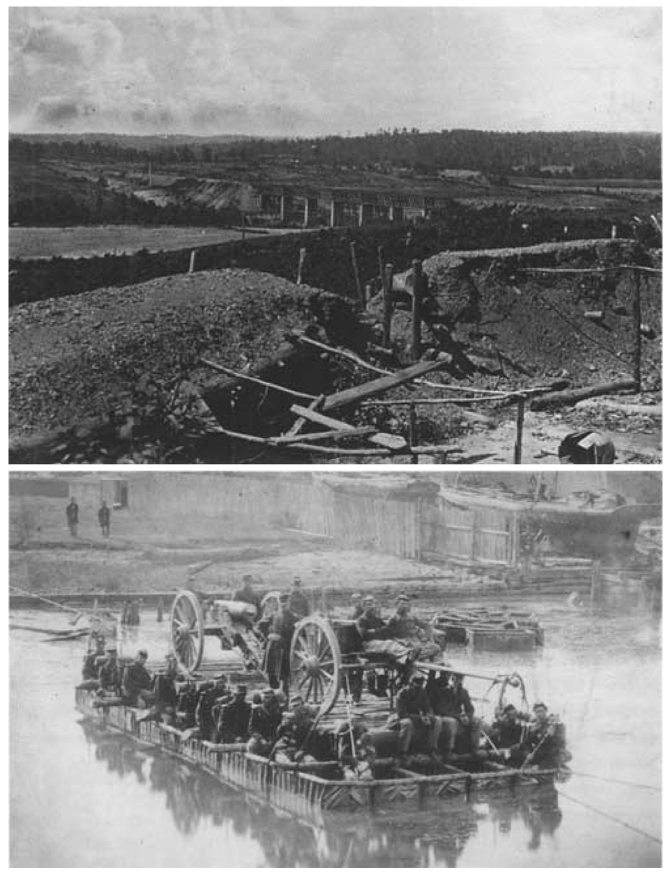

Figure 7. Historical photographs of Confederate earthworks and pontoon boats.
Top image is the south bank of the Chattahoochee River, fortified against attack near a bridge site. Bottom image shows a representative image of pontoon boats employed by Union forces to ferry troops and equipment across the Chattahoochee River. NPS photographs hosted at http://npshistory.com/publications/civil_war_series/7/sec6.htm (accessed 8 March 2022).

resources are beyond the scope of this report and the subject of another natural resource inventory in the National Park Service. Soil resources inventory products for Chattahoochee River National Recreation Area were updated in 2012 and are available on the NPS IRMA portal.

The park's foundation document (National Park Service 2017) lists ecology, the critical terrestrial and aquatic habitats for flora and fauna preserved in the park as a fundamental resource and value. For being so close to a major urban setting, the park fosters significant biodiversity within its boundaries such as a cold-water fishery, migratory bird flyway, and wetland and botanical habitats for many species of butterflies, salamanders, frogs, birds, and turtles. Because the river corridor is a natural refuge for so many species, accurate natural inventories are imperative to the successful management and preservation of park resources. As of 2021, the park was in the midst of acquiring funding (anticipated for work in 2023) for a seeps and springs inventory to count and understand the herpetofauna (reptiles and amphibians) associated with those areas in the park (Ann Couch, Chattahoochee River National Recreation Area, hydrologist and Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call 24 August 2021).

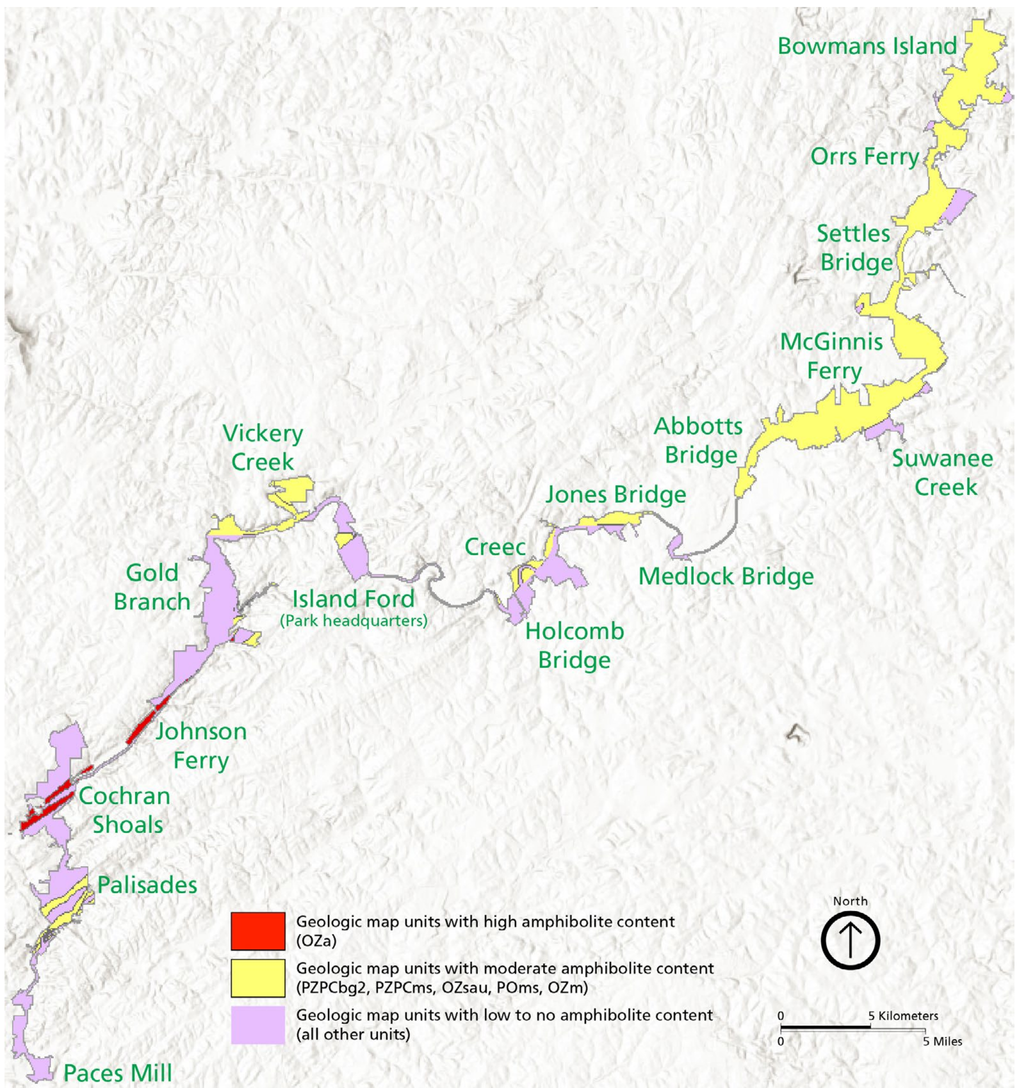

Figure 8. Map of areas with amphibolite-bearing rocks.
In Chattahoochee River National Recreation Area, the federally listed species, dwarf sumac (Rhus michauxii), depends on soils developed from amphibolite bedrock. Amphibolite typically weathers to produce soils rich in magnesium, calcium, and trace elements. The map shows areas within the park with bedrock mapped as amphibolite (red areas), areas mapped as having some amphibolite mixed with other rock types (yellow areas), and areas with no mappable amphibolite content (blue areas). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Hillshade basemap.

Geologic and Physiographic Setting, and History

This chapter describes the physiographic setting of the park and geologic events that formed the present landscape as recorded in the park's mapped bedrock. A geologic time scale (table 1) shows the chronology of geologic events (bottom to top) that led to the park's present-day landscape; this story covers a time interval of more than 1 billion years.

Table 1. Geologic time scale.

The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses. Age ranges are millions of years ago (MYA). For a full description of the geologic map units see the GRI GIS data. The Paleogene and Neogene Periods are collectively referred to as the Tertiary, a widely used but no longer formally recognized term for the geologic period from 66.0 million–2.6 million years ago. Ages follow the International Commission on Stratigraphy (ICS 2022). *JTRd is not mapped within park boundaries.

Era	Period	MYA	Geologic Map Units	Geologic Events
Cenozoic (CZ)	Quaternary (Q)	2.6–today	None mapped	Human history; fluvial meandering, incision, and deposition locally Ice age glaciations; weathering and incision accelerated
Cenozoic (CZ)	Tertiary (T); Neogene (N)	23.0–2.6	None mapped	Ongoing erosion and weathering locally
Cenozoic (CZ)	Tertiary (T); Paleogene (PG)	66.0–23.0	None mapped	Ongoing erosion and weathering locally
Mesozoic (MZ)	Cretaceous (K)	145.0–66.0	None mapped	Global mass extinction at end of Cretaceous (dinosaurs extinct)
Mesozoic (MZ)	Jurassic (J)	201.3–145.0	**JTRd*** intrusions end	Ongoing erosion and weathering locally
Mesozoic (MZ)	Triassic (TR)	251.9–201.3	**JTRd*** begins to intrude the local bedrock	Global mass extinction at end of Triassic Breakup of Pangea begins; Atlantic Ocean opened
Paleozoic (PZ)	Permian (P)	298.9–251.9	End of PPNM, PO, PY, PNM, PS units' formation	Global mass extinction at end of Permian. Supercontinent Pangea intact.
Paleozoic (PZ)	Carboniferous; Pennsylvanian (PN)	323.2–298.9	All existing units deformed and/or metamorphosed	Alleghany (Appalachian) Orogeny
Paleozoic (PZ)	Carboniferous; Mississippian (M)	358.9–323.2	None mapped	Erosion and weathering of overlying sediments locally
Paleozoic (PZ)	Devonian (D)	419.2–358.9	None mapped	Global mass extinction at end of Devonian
Paleozoic (PZ)	Silurian (S)	443.8–419.2	**PSm** begins to form; all other existing units deformed and/or metamorphosed	Ongoing marine sedimentation Neoacadian Orogeny
Paleozoic (PZ)	Ordovician (O)	485.4–443.8	OZ units end accumulation; PO units begin to form; all units deformed and/or metamorphosed	Global mass extinction at end of Ordovician; deeper marine settings Sea level fluctuations; marine and nearshore settings locally Taconic Orogeny; open marine settings

Table 1, continued. Geologic time scale.

Era	Period	MYA	Geologic Map Units	Geologic Events
Paleozoic (PZ)	Cambrian (C)	538.8–485.4	**Caq**, **Ccp**, and **Cas** accumulate or are emplaced	Extensive oceans covered most of proto-North America (Laurentia); sediments accumulated in ocean basin; erosion and weathering
Proterozoic Eon; Neoproterozoic (Z)	n/a	1,000–538.8	PZPC and OZ units begin to form	Supercontinent Rodinia rifted apart; erosion and uplift
Proterozoic Eon; Mesoproterozoic (Y)	n/a	1,600–1,000	Sediments of **PYl** begin to accumulate	Formation of early supercontinent; Grenville Orogeny
Proterozoic Eon; Paleoproterozoic (X)	n/a	2,500–1,600	None mapped	None reported
Archean Eon	n/a	~4,000–2,500	None mapped	Oldest known Earth rocks
Hadean Eon	n/a	4,600–4,000	None mapped	Formation of Earth approximately 4,600 million years ago

Geologic and Physiographic Setting

Georgia contains five distinct physiographic provinces. From northwest to southeast they are: Appalachian Plateau, Ridge and Valley, Southern Blue Ridge Mountains, Appalachian Piedmont, and Coastal Plain (fig. 9). Chattahoochee River National Recreation Area is in the Appalachian Piedmont province, which may be characterized as a hilly plateau of igneous and metamorphic rocks which slopes gradually southeastward until it is covered by sedimentary rocks of the Coastal Plain. The Piedmont province is more than 1,600 km (1,000 mi) long, extending from Alabama northeastward to New York. The Piedmont is made up of complexly deformed metamorphic and igneous rocks that have been weathered and eroded for millions of years to produce a rolling, hilly, landscape compared to the more rugged topography of the Southern Blue Ridge Mountains, Ridge and Valley, and Appalachian Plateau provinces to the northwest or to the nearly flat Coastal Plain to the south and east.

The "fall line" refers to the boundary between the Piedmont and Coastal Plain provinces. At this boundary, erosion-resistant igneous and metamorphic Proterozoic (2500 billion–538.8 million years ago) and Paleozoic (538.8 million–251.9 million years ago) rocks of the Piedmont are overlain by less erosion-resistant gently dipping, Mesozoic (251 million–65.5 million years ago) and Cenozoic (65.5 million–present) sedimentary rocks and unconsolidated sediments of the Coastal Plain (refer to table 1 for geologic time scale). Because of the extreme difference in erosion resistance of the rocks juxtaposed at this boundary, many waterfalls and rapids occur here that enabled flume- and waterwheel-powered industries in colonial times; thus, the term "fall line." Along most major rivers in Georgia, this boundary is the upper limit of river transportation and therefore, where early settlements were established which later developed into major cities: Augusta, Macon, and Columbus (US Geological Survey 2004).

Chattahoochee River National Recreation Area is located in an area of the Appalachian Piedmont—the Brevard Zone— with distinctively different structure and topography than the rest of the province. The strikingly different character of the Brevard Zone strongly influenced development of the Chattahoochee River as it established its course across Georgia. The zone channels the location of the river within the park, making its course very stable and old (KellerLynn 2012; National Park Service 2017). The Brevard Zone is a major structural and topographic feature (see "Brevard Zone" section) cutting across the Appalachian Piedmont from Alabama through Georgia, North Carolina, South Carolina, and into Virginia over 510 km (320 mi). In a general way, the surface exposure of the Brevard Zone in Georgia serves as the boundary between the Appalachian Piedmont and the Appalachian Mountains (Southern Blue Ridge Mountains). The Brevard Zone extends to the southwest into Alabama where it is covered by sediments of the Coastal Plain. To the north of the Brevard Zone are the Southern Blue Ridge Mountains. The Blue Ridge Mountains can be considered the "backbone" of the Appalachian Mountains and are one of the principal drainage divides in eastern North America. Because of this divide and the channeling nature of the Brevard Zone the Chattahoochee River drains southwest to the Gulf of Mexico instead of east to the Atlantic Ocean.

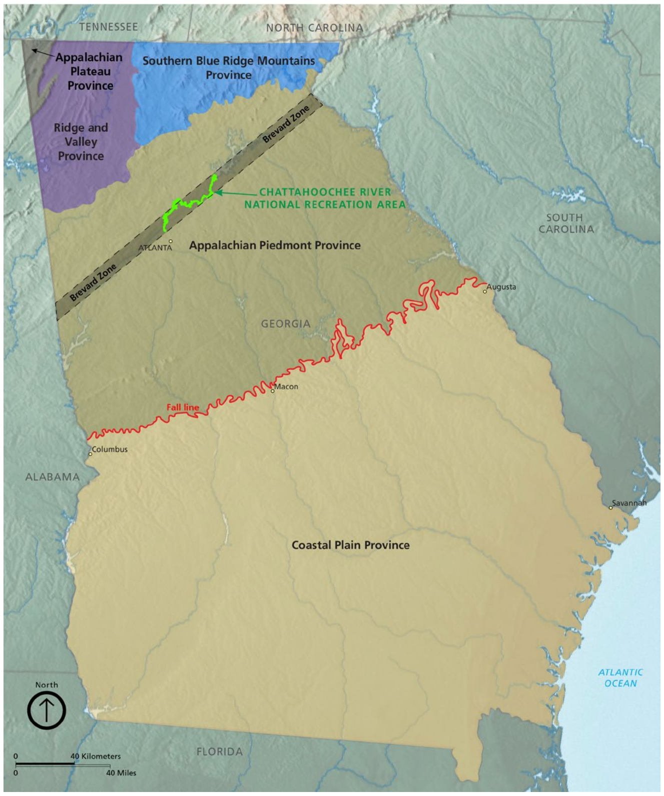

Figure 9. Map showing the physiographic provinces of Georgia.
Chattahoochee River National Recreation Area (bright green area) is located along the Brevard Zone (gray band), a major structural feature of the Appalachian Piedmont province. A bold red line denotes the fall line, which separates the Appalachian Piedmont from the Coastal Plain. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with input from Tom Crawford and Jacob Bateman McDonald, using map data from the Georgia Geological Survey, available at https://epd.georgia.gov/outreach/publications/georgia-geologic-survey-maps (accessed 25 July 2022). Basemap by Tom Patterson (National Park Service) available at http://www.shadedrelief.com/physical/index.html (accessed 31 March 2020).

Geologic History

At the dawn of the Paleozoic Era, some 541 million years ago (fig. 10), the sediment, magma, and volcanic material that would eventually form the rocks of the Appalachian Piedmont province were accumulating in an ancient ocean basin (Iapetus). The Iapetus Ocean was created during the rifting (breaking) apart of the Precambrian supercontinent, Rodinia (fig. 11). As the Earth's crust extended and was pulled apart along a great rift, the ocean basin widened.

More than 450 million years ago, plate tectonic processes reversed crustal extension, or rifting, leading to compression as land, volcanic arcs, and subcontinents collided with and accreted onto what would become the North American continent (fig. 11). The Appalachian Piedmont of Georgia, according to some interpretations, is broadly divisible into terranes that accreted to the growing edge of the ancient North American continent (see fig. 3). A terrane is a group of rocks with similar characteristics and geologic history that differ from those around it, which formed somewhere other than its present location. Terranes are associated with continent-scale plate tectonics, forces that can displace, squeeze, or rip apart large bodies of rock and move them great distances. Examples of terranes include fragments of continents, volcanic arcs, and oceanic basin accumulations. The land underlying the park forms part of the Tugaloo terrane (oceanic and arc assemblages), which collided with North America about 450 million years ago during the Taconic Orogeny (fig. 11; Hooper and Hatcher 1990; Hanley et al. 1997; Hatcher 2001; Hatcher 2005; Hanley 2018).

Over the next 200 million years, rocks in the accreted terranes were intruded by granitic magmas, metamorphosed, deformed, and thrust westward during Paleozoic mountain-building that culminated in the formation of a supercontinent, Pangea, that stretched from pole to pole and included creation of the Appalachian Mountains (fig. 12; Harris 1997; Boland 2006). Pangea incorporated all of the major continents at the time including, proto-North America, called "Laurentia," and Africa and South America, called "Gondwanaland." The Appalachian Mountains were in the interior of the supercontinent and may have rivaled the modern Himalayas in magnitude with elevations exceeding 6,100 m (20,000 ft) (Harris et al. 1997; Southworth et al. 2009). Pangea endured for about 80 million years.

During the Late Triassic Epoch, approximately 185 million years ago, and after the Allegany Orogeny (Southworth et al. 2009), the supercontinent Pangea began breaking into landmasses that would become the modern continents (fig. 12). Because compressional tectonic forces were replaced by tensional forces during rifting, the Appalachian Mountains were no longer rising. Thereafter, weathering, erosion, and deposition became the dominant processes shaping the Appalachian Piedmont (fig. 12). Large rivers transported vast amounts of sediment from the mountains, depositing them to build the Coastal Plain seaward.

The Coastal Plain is essentially a large, wedge-shaped mass of sediment, which is thickest, reaching depths of

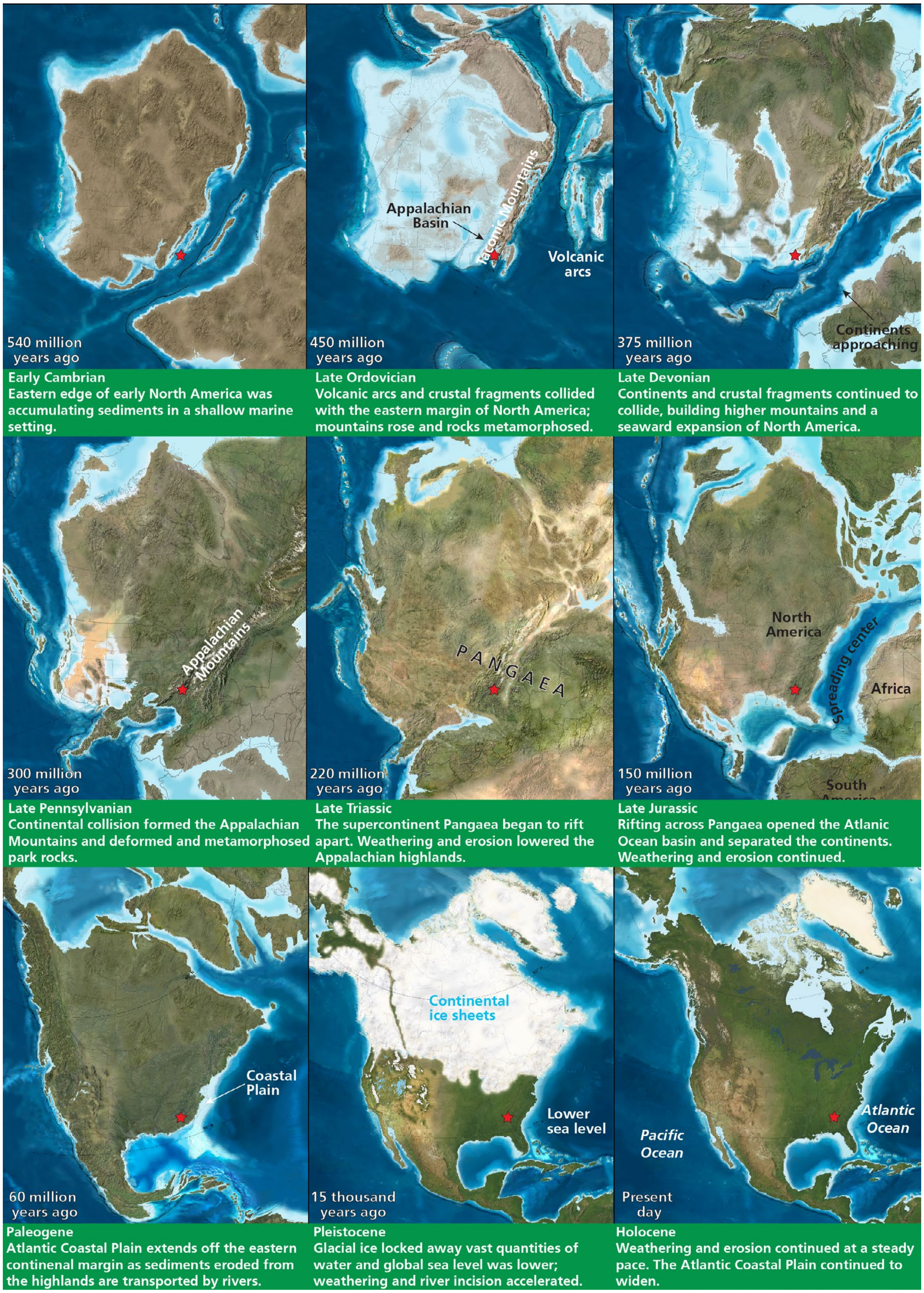

Figure 10. Paleogeographic maps of North America.
The red star indicates the approximate location of Chattahoochee River National Recreation Area. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc.), additional information is available at http://deeptimemaps.com.

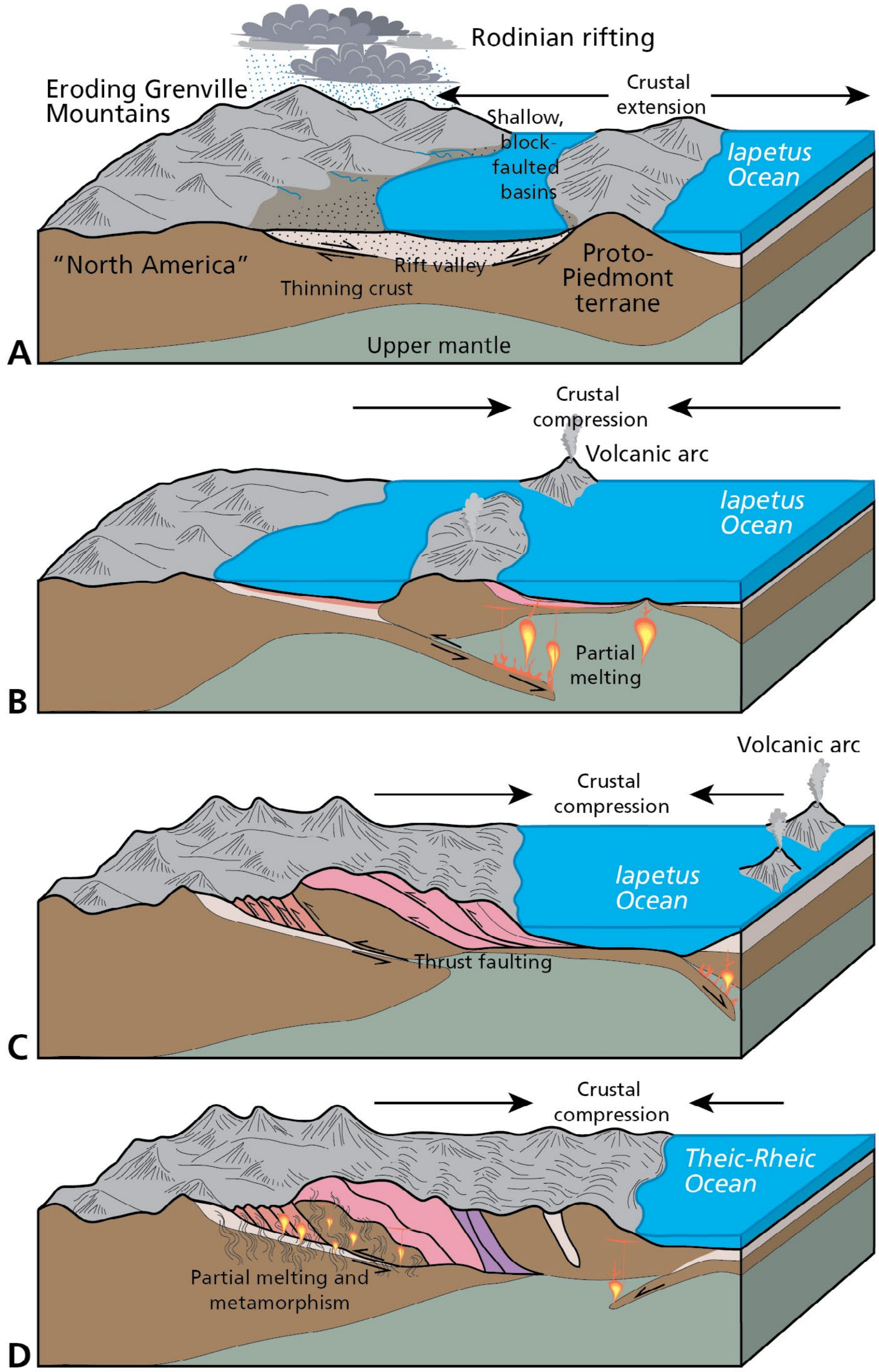

Figure 11. Illustration of the evolution of the Iapetus Ocean and development of the geologic setting for Chattahoochee River National Recreation Area.
(A) In the Neoproterozoic, more than one billion years ago, the supercontinent was rifting apart. The Iapetus Ocean formed in a rift valley. This ocean basin collected mixed sediments from eroding landmasses mixed with volcanic ejecta. (B and C) By Cambrian and Ordovician time (541 to 443.8 million years ago), crustal extension and rifting in this area changed to compression and thrusting as a subduction zone developed. The rocks of the proto-Piedmont continued to develop at this time and volcanic arcs were moving westward toward the eastern edge of Laurentia (proto-North America). (D) The Iapetus Ocean closed as another landmass accreted onto the edge of the continent. Graphics are not to scale. Colors are standard colors approved by the US Geological Survey on geologic maps to indicate different time periods on geologic maps and correspond to the colors on the geologic time scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Hatcher (1987; 2005), and GRI GIS source data.

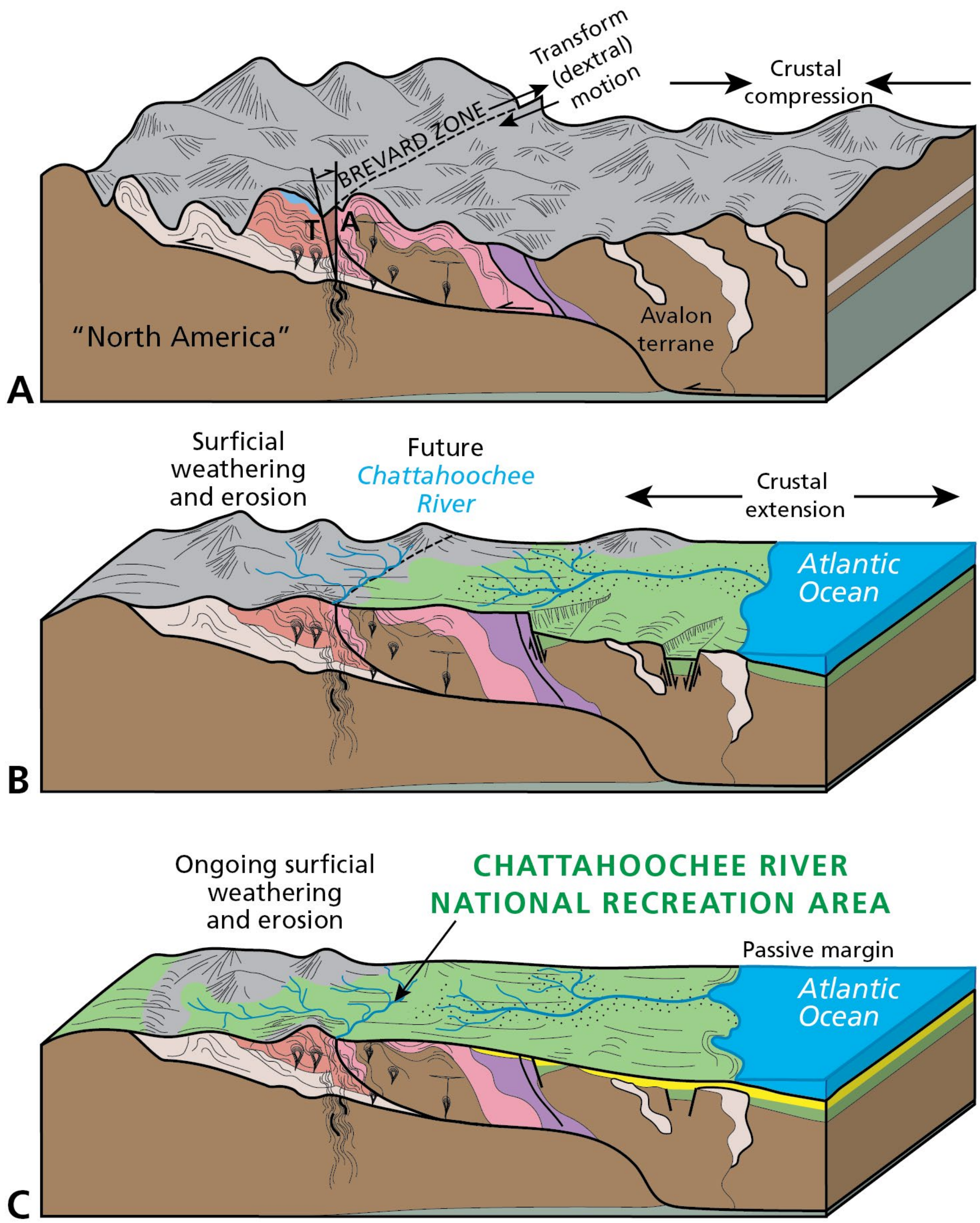

Figure 12. Illustration of the evolution of the Brevard Zone and development of the geologic setting for Chattahoochee River National Recreation Area.
(A) By Pennsylvanian time about 300 million years ago, major continental collision pushed the proto-Appalachians up to their highest elevations and all the accreted landmasses and thrust sheets were deformed and metamorphosed. (B) Since Triassic time (252.2 to 201.3 million years ago), when the landmasses began to break apart, the part of North American where Chattahoochee River National Recreation Area is located has been continuously weathered and eroded. Surface processes (e.g., flowing water) transported the derived sediments eastward and southward to become part of the Coastal Plain. (C) Surficial weathering and erosion continue today as the Chattahoochee River cuts and shifts its channel along the Brevard Zone through north-central Georgia. Graphics are not to scale, and interpretations of fault locations and timing are limited to the source material used and do not necessarily represent consensus within the geological community. Colors are standard colors approved by the US Geological Survey on geologic maps to indicate different time periods and correspond to the colors on the geologic time scale (table 1). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Hatcher (1987; 2005), and GRI GIS source data.

up to 3,050 m (10,000 ft) or more, along the present-day coast and thinnest along the fall line. Because these layers dip towards the sea in most cases, the oldest sediments are exposed at the fall line (e.g., in the vicinity of Ocmulgee Mounds National Historical Park near Macon; fig. 13). Here, the oldest sedimentary rocks are at least 65 million years old (LeGrand 1962; Hetrick and Friddell 1990; Frazier 2019). These sediment layers collected in mainly shelf (marine) to coastal estuarine (nonmarine) settings during sea-level fluctuations (Richards 1956; Schwimmer 1986; Savrda and Nanson 2003; Frazier 2019).

Younger sediments occur at Chattahoochee River National Recreation Area; however, these are not included in the GRI GIS data because they are surficial deposits and the GRI GIS data is limited to bedrock. They present a record of fluvial and slope processes during the Quaternary Period, approximately the last 2.6 million years. These unconsolidated surficial deposits accumulated and are being reworked by surface processes (see "Fluvial Features and Processes" section). Examples include the boulders of slope deposits and unsorted clay, silt, sand, and gravel deposited along the channel and floodplain of the Chattahoochee River and its tributaries.

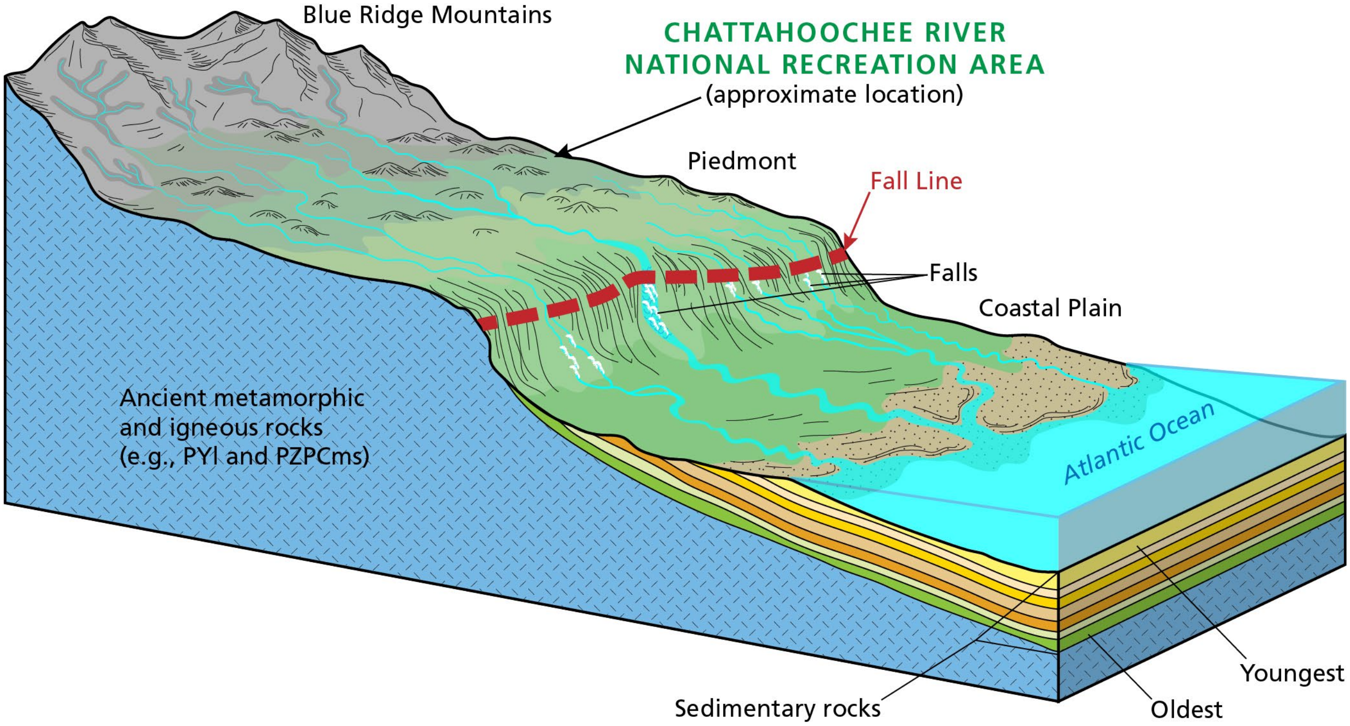

Figure 13. Cross section diagram of the geologic setting for the fall line.
The fall line developed where the soft sedimentary rocks of the Coastal Plain lapped onto the hard crystalline bedrock of the Appalachian Piedmont. The sedimentary rock layers are inclined toward the sea and become progressively thicker toward the east and south. The oldest sedimentary layers are exposed at the fall line. Chattahoochee River National Recreation Area, which is within the Appalachian Piedmont province, is underlain by and the river is cutting into ancient metamorphic rocks. The eroded remnants of these rocks is continuing to contribute sediment to the Coastal Plain. Note graphic is not to scale and the fall line's topography was greatly exaggerated for illustrative purposes. Graphic by Trista L. Thornberry-Ehrlich (Colorado State Univeristy) after Britannica, The Editors of Encyclopaedia (2022).

Geologic Features and Processes

The geologic features and processes highlighted in this chapter are significant to the park's landscape and history. At the beginning of each of the following sections, relevant geologic map units and features from the GRI GIS data and poster are listed. Map units are referenced directly in the text as well. Some sections may not be directly related to a map unit or feature, in which case no unit is listed at the start of the section. The geologic map units and features can also be viewed in the GRI GIS data. Tables 2 and 3 describe the mapped geologic (rock) units in the park.

The selection of geologic features and processes in this chapter 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 discussed, more-or-less, in order of geologic age (oldest to youngest). Based on these information sources, the following geologic features and processes are discussed in this chapter:

- Metamorphic and Igneous Bedrock
- Brevard Zone
- Faults and Folds
- Type Localities and Type Sections
- Rock Shelters
- Fluvial Features and Processes
- Shoals
- Paleontological Resources

Table 2. Geologic map units in Chattahoochee River National Recreation Area.

Units listed from north to south as the river meanders around bends; units mapped more than once along the course are not repeated in this table. Colors per map unit follow the US Geological Survey's color chart for different periods of geologic time. Only units mapped within park boundaries are included. Information about specific minerals is available at: https://www.nps.gov/subjects/geology/rocks-and-minerals.htm. This table includes map units from the chtn and chts GRI GIS maps; see table 3 for map units from the sasp GRI GIS map. Detailed descriptions of each unit per source-map are in the GRI GIS data.

Map Unit (map code) (symbol)	Description	Mapped Locations in Park
Biotitic gneiss, mica schist and amphibolite (chtn) (**PZPCbg2**)	**PZPCbg2** is a mixed unit containing foliated (banded) gneiss, flaky mica schist, and dark mineral-rich amphibolite.	Bowmans Island Shoals, Richland Creek, Fish Weir Shoals, Orrs Ferry, downstream to Jones Bridge area, Vickery Creek
Quartzite (chtn) (**PZPCq**)	**PZPCq** is predominately metamorphosed quartz sand. Bands of accessory minerals may appear as dark layers.	West of Fish Weir Shoals
Granitic gneiss, undifferentiated (chtn) (**PZPCgg**)	**PZPCgg** is metamorphosed granite, containing a mixture of plagioclase and potassium feldspar, quartz, and micaceous minerals such as biotite and muscovite. As a gneiss, it is characteristically foliated in light and dark mineral-rich bands.	Between Orrs Ferry and Settles Bridge
Metagraywacke and mica schist (chtn) (**PZPCmr**)	**PZPCmr** consists of metagraywacke (originally a sedimentary mix of quartz, feldspar, and dark minerals) and flaky mica schist.	Suwanee Creek and McGinnis Ferry
Stonewall Gneiss, Powers Ferry Member (chts) (**OZsp**)	**OZsp** is biotite gneiss with schistose and pegmatitic layers. Characteristically and commonly contains small pods and lenses of altered ultramafic rocks, now mostly weathered soapstone and serpentinite. Some scattered amphibolite is characteristic of **OZsp**.	Medlock Bridge, east side of river at Jones Bridge, Holcomb Bridge, just upstream from Island Ford, Gold Branch, Cochran Shoals, Powers Island
Informal mixed unit (chts) (**OZm**)	**OZm** is a mixture of lustrous schist (containing garnet, sillimanite, biotite, muscovite), gneiss with mineral assemblages such as biotite-quartz plagioclase and biotite-quartz-potassium feldspar-plagioclase, and amphibolites. Pods and lenses of chlorite, hornblende, and actinolite schists are present locally. Characteristic of **OZm** are thin beds of quartzite, schist, and amphibolite.	Downstream from Holcomb Bridge to near milemarker 323, Cochran Shoals, Palisades

Table 2, continued. Geologic map units in Chattahoochee River National Recreation Area.

Map Unit (map code) (symbol)	Description	Mapped Locations in Park
Aluminous schist unit (chts) (**Cas**)	**Cas** consists of light gray to silvery gray kyanite or staurolite-garnet-biotite-plagioclase-muscovite-quartz-schist. Some layers are garnet rich. Quartzite-rich layers are also present as are pegmatite layers.	Island Ford, Palisades
Long Island Creek Gneiss (chts) (**PYl**)	**PYl** is epidote-biotite-plagioclase-quartz gneiss with some sheared mylonites layers. In outcrop, **PYl** is light to dark gray and may have tiny crystals of sphene; it commonly crops out in bare pavement outcrops. Quartz veins and sills, as well as aplite dikes and sills are characteristic of **PYl**.	Small areas at Holcomb Bridge, Palisades to Paces Mill
Crider Gneiss (chts) (**OZcr**)	**OZcr** is gray to nearly white, muscovite-quartz-plagioclase gneiss.	Island Ford, Gold Branch, Morgan Falls Road
Aluminous schist (chtn) (**PZPCs**)	**PZPCs** is a metamorphic rock rich in aluminum-bearing minerals. Its parent material was likely a fine-grained mud (shale) rock.	Island Ford, Don White Memorial Park
Mica schist, gneiss, and amphibolite (chtn) (**PZPCms**)	**PZPCms** is a mixed unit of flaky mica schist, foliated (banded) gneiss, and amphibolite characterized by granules of hornblende (dark green to black) and plagioclase (white).	Vickery Creek, Chattahoochee Nature Center
Garnet-rich schist (chts) (**OZmgs**)	**OZmgs** contains garnet-rich muscovite-biotite schist. Kyanite is locally present as an accessory mineral.	Gold Branch, between Gold Branch and Cochran Shoals
Ropes Creek Metabasalt (chts) (**OZr**)	**OZr** is mainly hornblende and plagioclase amphibolite with some granofels. **OZr** has some magnetite quartzite layers. Pillow structures attest to its igneous origin. Fresh exposures are dark green to greenish black.	Between Gold Branch and Cochran Shoals
Chattahoochee Palisades Quartzite (chts) (**Ccp**)	**Ccp** is nearly pure quartz with some muscovite, garnet, and feldspar as accessory minerals in layers.	Cochran Shoals, Palisades
Thin (<2m thick) mappable units of muscovite quartzite (chts) (**Caq**)	**Caq** is inferred to be fault slices of **Ccp**. Please see **Ccp** description.	Palisades and Paces Mill
Button schist and sheared amphibolite (chts) (**POms**)	**POms** contains gray to silvery quartz-sericite button schist with lenses of amphibolite and some spessartine (garnet) quartzite. **POms** exhibits "fish flash" as a result of its coarse grained micaceous layers Similar to **POb**, **POms** likely formed as layers of **OZm** (parent rock) were sheared during mountain building.	Palisades and Paces Mill
Button schist (chts) (**POb**)	**POb** is gray to silvery in fresh exposures. **POb** consists primarily of plagioclase-quartz-sericite schist. Locally, manganese-rich layers, as well as lenses and slivers of amphibolite appear as black bands. **POb** exhibits "fish flash" as a result of its coarse-grained micaceous layers. Similar to **POms**, **POb** likely formed as layers of **OZm** (parent rock) were sheared during mountain building.	Peachtree Creek
Mylonitized granitoid (chts) (**PSm**)	**PSm** is mylonites and/or mylonites gneiss. The parent rock was likely granite. In outcrop, **PSm** is light gray to nearly white. Deformation (faulting) resulting in mylonitic texture was synmetamorphic—occurred during mountain building (Permian or older).	Peachtree Creek

Table 3. Geologic map units in the Sandy Springs Quadrangle.

Units listed from north to south as the river meanders around bends; units mapped more than once along the course are not repeated in this table. This table includes map units from the sasp GRI GIS map; see table 2 for map units from the chtn and chts GRI GIS maps. Detailed descriptions of each unit per source-map are in the GRI GIS data.

Map Unit (map code) (symbol)	Description and Spatial Distribution	Mapped Locations in Park
Orange Gneiss (sasp) (**OZog**)	**OZog** is primarily biotite-quartz-feldspar gneiss with some schistose and amphibolite layers. Interspersed in the unit are some muscovite-quartz-feldspar pegmatites and ultramafic bodies. The ultramafic component is present in ovoid masses up to 100 ft (30 m) in the long dimension and contain pyroxene and amphibole.	Bull Sluice Lake, Timber Ridge Road, Gold Branch
Mixed schist/gniess (sasp) (**OZmu**)	**OZmu** consists of garnet-muscovite-biotite-quartz-feldspar gneiss with some garnet locally abundant. Pegmatite and coarse-grained schist are interlayered. The unit is very non-uniform, but its texture creates a "tough" rock that resists breaking.	Gold Branch, Johnson Ferry, Cochran Shoals, Morgan Falls Park, Sope Creek
Pappasito Schist (sasp) (**OZps**)	**OZps** is garnet-biotite-muscovite-quartz schist with fine black opaque minerals throughout. OZps is mostly coarse grained, sheared, and has a button texture.	Morgan Falls Dam to Cochran Shoals, Sope Creek
Amphibolite (sasp) (**OZa**)	**OZa** is mostly amphibole and hornblende (dark minerals). Layering is thin. Some layers of chlorite-actinolite schist appear as flaky layers in **OZa**.	Morgan Falls Dam to Cochran Shoals, Sope Creek
Muscovite schist (sasp) (**OZsh**)	**OZsh** is garnet-biotite-quartz-muscovite schist. The unit is coarse grained with tourmaline and black opaque minerals with a "button" texture.	Morgan Falls Dam to Cochran Shoals, Sope Creek
Migmatitic gneiss (sasp) (**OZmg**)	**OZmg** is mostly muscovite-biotite-quartz-feldspar gneiss with scattered garnets and some pegmatites in layers. Quartz veins are scattered throughout.	Cochran Shoals, Powers Island
Quartzite (sasp) (**OZq**)	**OZq** is nearly all quartz with some micaceous layers and scant fine-grained opaque (dark) mineral grains.	Powers Island, Cochran Shoals
Garnet schist (sasp) (**OZgs**)	**OZgs** contains kyanite-garnet-biotite-quartz-muscovite schist. The rock mostly coarse-grained and sheared with abundant pegmatite pods and lenses.	Powers Island, Cochran Shoals
Biotite gneiss (sasp) (**OZbg**)	**OZbg** is muscovite-biotite-quartz-feldspar gneiss. Some layers are schistose, and some layers are rich in garnet. The layering (foliation) wraps around pegmatite pods, lenses, and layers.	Powers Island, Palisades
Palisades Quartzite (sasp) (**OZpq**)	**OZpq** is almost entirely massive to weakly foliated cherty quartz. Some areas are so fine-grained as to be glassy (vitreous).	Palisades
Rottenwood Creek Mixed Unit (sasp) (**OZsg**)	**OZsg** is mostly biotite-muscovite-quartz-feldspar gneiss with some scant garnets. In some places the micaceous minerals are dominant, and the layers are schistose rather than gneissic.	Palisades
Schist, amphibolite, and ultramafic (sasp) (**OZsau**)	**OZsau** consists of quartzose-rich garnet-kyanite-feldspar-muscocite-biotite-quartz schist. Schist is lumped with gneiss, quartzite, and some ultramafic bodies. The ultramafic component is in ovoid masses up to 100 ft (30 m) in the long dimension and contain pyroxene and amphibole.	Palisades
Granitic gneiss (sasp) (**OZgg**)	**OZgg** contains primarily biotite, quartz, and feldspar in banded rocks. The lighter minerals (i.e., quartz and feldspar) are coarser grained than the darker minerals. Some sheared (deformed) bands are rich in muscovite mica.	Palisades
Long Island Creek Gneiss (sasp) (**OZli**)	**OZli** contains sphene, epidote, biotite, quartz, and feldspar grains. Crystals are readily recognizable in outcrops and the foliation (compositional banding) is moderately well developed.	Palisades

Metamorphic and Igneous Bedrock

Geologic map units relevant to this section: all

Bedrock is the very old, solid rock that underlies the younger unconsolidated surficial deposits of the park. Bedrock can be sedimentary, igneous, or metamorphic. Sedimentary rocks are formed from fragments of pre-existing rocks or chemical precipitation from solution. Igneous rocks form by the cooling of molten material (magma or lava). Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids. Metamorphic rocks are the primary rock type at the park. The parent rock or original, unmetamorphosed rock can usually be determined. Metamorphism can occur in two distinctly different settings: regional or contact. Regional metamorphism is associated with large-scale tectonic events, such as orogenesis (mountain building) where deep burial, high confining pressure, and high temperature are present. Contact metamorphism is associated with the intrusion of molten material where rocks adjacent to the intrusion are "baked" by the high temperatures. The two main types of metamorphic rocks are foliated (minerals are aligned in "stripes") and non-foliated. Metamorphic rocks are further classified by degree of foliation, grain size, and parent rock. The prefix "meta" is commonly added to the original rock type to signify its origin (e.g., metagranite or metasandstone). Certain minerals, for example, biotite, garnet, kyanite, and sillimanite, are used to determine the conditions or "grade" (i.e., pressure, temperature, or presence of fluids) of metamorphism (fig. 14) and are listed as part of the geologic map unit name and/or description. Schist and gneiss, medium to high grade metamorphic rocks are the most prevalent at the park.

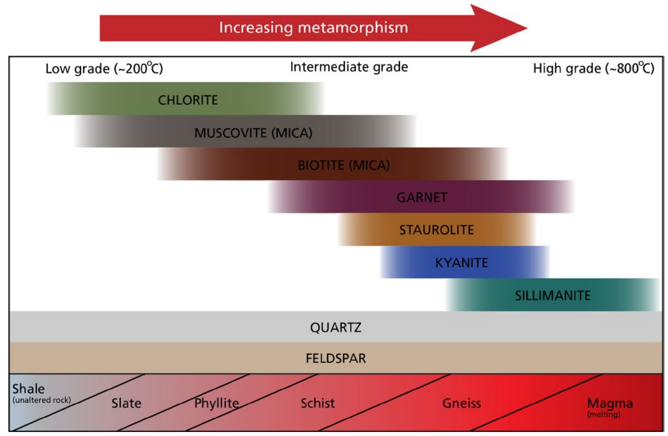

Figure 14. Chart of index minerals in metamorphic rocks.
The presence of these minerals indicates the metamorphic grade of a rock. At different temperatures, pressures, and fluid content, different minerals form during metamorphism. Quartz and feldspar are not index minerals because they may occur in rocks of every grade. The parent rock for this diagram is a clay-rich shale. Other parent rocks may have other index minerals. The metamorphic geologic map units in the park contain most of these minerals and schist and gneiss are most prevalent reflecting intermediate to high grade metamorphism. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Philpotts and Ague (2022).

At Chattahoochee River National Recreation Area, the bedrock consists of 250-million- to 1.6-billion-year-old, metamorphic crystalline rocks: schist, gneiss, mylonite, metabasalt, granite, granitic gneiss, and quartzite (tables 2 and 3, fig. 15; Higgins 1968; Higgins et al. 2003). Schist is a strongly foliated, crystalline rock formed by metamorphism. The major minerals in schist are sheet-like or platy and have a parallel arrangement. Gneiss is generally a foliated metamorphic rock with alternating bands of dark and light minerals. Varieties are distinguished by texture (e.g., augen "eye" gneiss), characteristic minerals (e.g., biotite gneiss), or general composition (e.g., granitic gneiss). Geologic texture is the relationship between the materials of which a rock is compose, creating the physical appearance or character of a rock, such as grain size, shape, arrangement, and other properties, at both the visible and microscopic scale. Mylonite is a fine-grained metamorphic rock formed when the original grains in a rock are crushed to a very fine particle size and recrystallized during deformation at high temperatures and high confining pressure. The term mylonite refers to texture and origin of the rock (often in multicolored bands) rather than its mineralogical composition. Metabasalt and granitic gneiss are terms referring to metamorphosed igneous rocks (intrusive and/or volcanic). Basalt is an igneous rock that is relatively poor in silica and rich in iron and magnesium. Granite and granitic gneiss indicate a specific mineral composition: rich in quartz and feldspar with minor dark or flaky minerals. Quartzite is a rock that is almost entirely made of quartz, commonly a metamorphosed "pure" sandstone.

The bedrock in the park includes some of the oldest rocks in the southeastern United States, and some of the most complicated in their composition, texture, and history. The Long Island Creek gneiss (geologic map unit **OZli** and **PYl**; named for Long Island Creek, which flows into Chattahoochee River at the Palisades unit) is among the oldest rocks in the park, possibly as much as 1.6 billion–1.0 billion years old (Higgins et al. 2003). Even the youngest crystalline rock is still quite old. The button schist (**POms** and **POb**) mapped by Higgins et al. (2003) is of possible Upper Ordovician to Permian

Figure 15. Photographs of rocks characteristic of the park's bedrock.
All bedrock in the park is metamorphic, meaning that it started as a sedimentary, igneous, or other metamorphic rock and changed its mineralogical, chemical, and/or structural composition under changing temperature and/or pressure conditions. Mylonite forms when the rock is strongly deformed in high temperature and pressure conditions. Schist is a metamorphic rock with abundant platy minerals, usually mica. Gneiss is the term for color-banded metamorphic rocks with alternating dark and light layers. Ultramafic rocks, characterized by darker minerals high in iron and magnesium, are present as pods and lenses in some park bedrock units. Quartzites are rich in quartz but may also contain layers of feldspar or mica minerals (e.g., muscovite or biotite). Photographs were presented on 22 March 2012 at the GRI scoping meeting by R. L. Kath and T. J. Crawford (University of West Georgia).

age (460 million to 251 million years ago). Since their forming, these rocks have undergone repeated cycles of igneous intrusions and extrusions, metamorphism, folding, faulting, shearing, and silicification (Kath and Crawford 2001).

Boudinage and pegmatite are two distinctive features of the crystalline bedrock at Chattahoochee River National Recreation Area (fig. 16). "Boudinage," a structural term, is derived from the French word for sausages, "boudins." Boudinage structures, or "links" of quartz, can be seen in the crystalline rocks at Island Ford Shoals (KellerLynn 2012). Pegmatite is an exceptionally coarse-grained rock, sometimes containing rare minerals and gemstones, usually igneous in origin, stemming from element-laden fluids moving from a magma chamber deep in the Earth's crust. However, the pegmatite at Chattahoochee River National Recreation Area, is metamorphic. During metamorphism, rock begins to "sweat," mobilizing lower-melting-temperature elements, which, as they cool, precipitate crystals of quartz, feldspar, muscovite, and other minerals. Pegmatite can be seen at Sope Creek (KellerLynn 2012).

Metamorphic Rock References

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

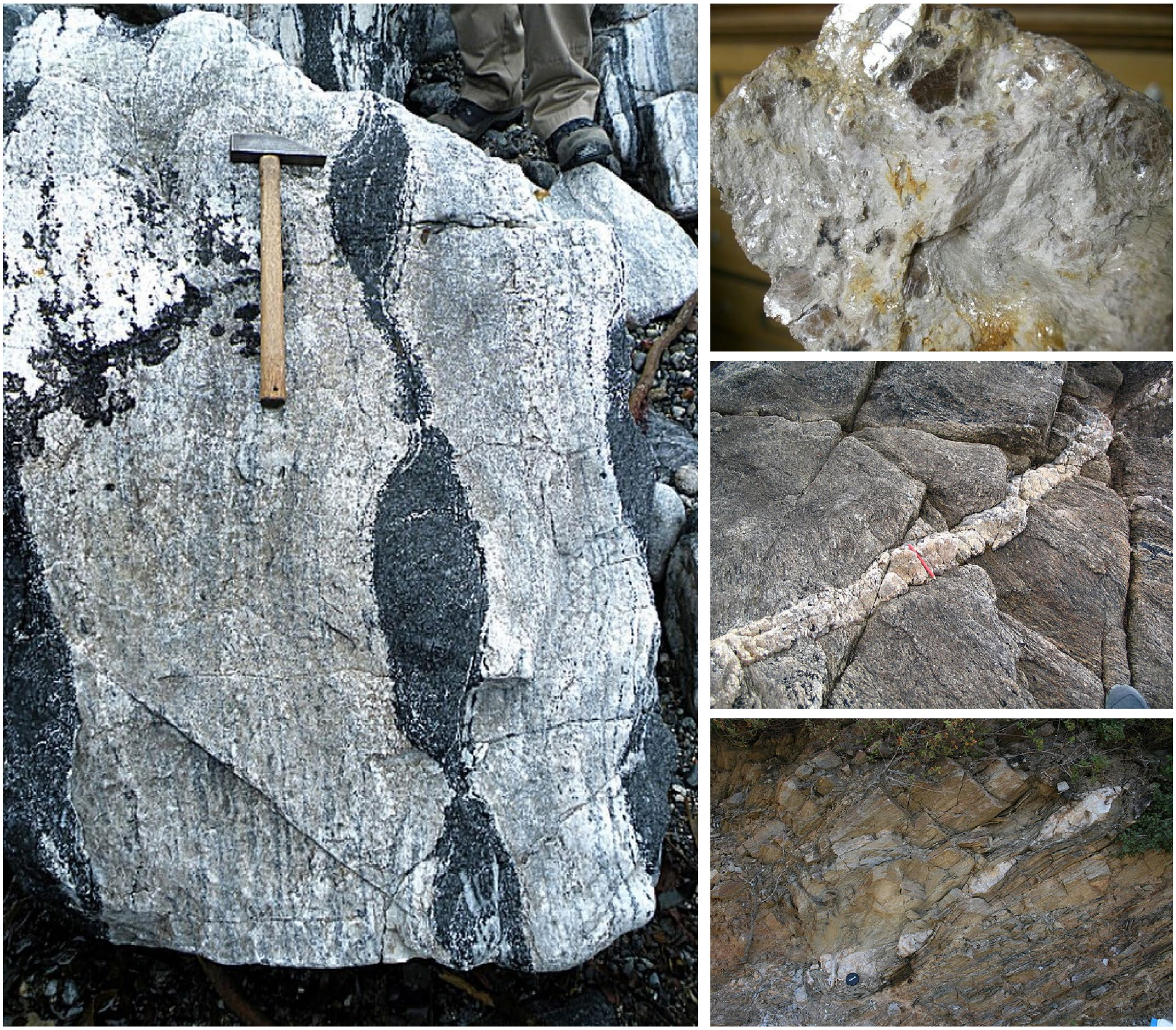

Figure 16. Photographs of boudinage structure and pegmatites.
Large photograph on the left shows dark "boudins" within a light-colored gneissic matrix. Top and middle right photographs show coarse-grained, mica-, feldspar-, and quartz-rich pegmatites in hand specimen and outcrop, respectively. Pegmatites are found as veins cutting across other rock types. They are, by definition, coarse grained. Bottom right photograph shows boudins of a white-colored mineral within a tan-colored rock. Photographs were not taken in the park but are representative of the geologic features found there. Pegmatites and boudins are present in park rocks at Sope Creek and Island Ford Shoals, respectively. Photograph of pegmatite hand sample by Chmee2 taken in 2007 available at https://commons.wikimedia.org/wiki/File:Pegmatite23.jpg (accessed 9 March 2022). Unmodified and used under license, CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/deed.en). Photograph of pegmatite outcrop by arlette1 taken in 2007 available at https://commons.wikimedia.org/wiki/File:Filon_de_pegmatite.jpg (accessed 15 March 2022). Unmodified and used under license, CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/deed.en). Photograph of small, white boudins in outcrop by Seb Turner in 2008 available at https://commons.wikimedia.org/wiki/File:Samos_boudins.JPG (accessed 16 March 2022). Unmodified and used under public domain, released by its author. Photograph of boudinage in a boulder by Anne Burgess taken in 2009 available at https://commons.wikimedia.org/wiki/File:Boudinage_-_geograph.org.uk_-_1370886.jpg (accessed 16 March 2022). Unmodified and used under license, CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0/deed.en).

Brevard Zone

Geologic map units relevant to this section: biotite gneiss, mica schist and amphibolite (**PZPCbg2**); granitic gneiss, undifferentiated (**PZPCgg**); metagraywacke and mica schist (**PZPCmr**); mica schist, gneiss and amphibolite (**PZPCms**); quartzite (**PZPCq**); aluminous schist (**PZPCs**); Orange Gneiss (**OZog**); mixed schist/ gneiss (**OZmu**); Pappasito Schist (**OZps**); amphibolite (**OZa**); muscovite schist (**OZsh**); migmatitic gneiss (**OZmg**); quartzite (**OZq**); garnet schist (**OZgs**); biotite gneiss (**OZbg**); Palisades Quartzite (**OZpq**); Rottenwood Creek mixed unit (**OZsg**); schist, amphibolite, and ultramafic (**OZsau**); granitic gneiss (**OZgg**); Long Island Creek Gneiss (**OZli**); Stonewall Gneiss, Powers Ferry Member (**OZsp**); informal mixed unit (**OZm**); aluminous schist unit (**Cas**); Long Island Creek Gneiss (**PYl**); Crider Gneiss (**OZcr**); garnet-rich schist (**OZmgs**); Ropes Creek metabasalt (**OZr**); Chattahoochee Palisades Quartzite (**Ccp**); thin (<2m thick) mappable units of muscovite quartzite (**Caq**); button schist and sheared amphibolite (**POms**); button schist (**POb**); mylonitized granitoid (**PSm**)

The Brevard Zone is a major, somewhat enigmatic, structural feature that extends across the southern Appalachians for 510 km (320 mi) (Bobyarchick et al. 1988). Near Chattahoochee River National Recreation Area in Georgia, the Brevard Zone extends northeastward from Heard County to Habersham County (see figs. 9 and 3; Higgins 1968; KellerLynn 2012). First described as the Brevard Schist by Keith (1905), the Brevard Zone and its geologic origins are still being studied today, with still much disagreement about its nature and origin. Every term used to describe deformation in geology can be and probably has been used to describe the Brevard Zone: folding, faulting, jointing, shearing, crushing, and fracturing (KellerLynn 2012).

The zone has long been recognized as a major break in Earth's crust, but the exact nature of the zone and its evolution through time are still debated and geologists have interpreted it as a variety of different kinds of faults or discontinuities (Hatcher 1987; Bobyarchick 1999). Bobyarchick et al. (1988) noted 31 different interpretations published between 1905 and 1987, and more have been added since. The Brevard Zone's long and complex history records several overprinting deformation and metamorphic events. Possibly, deformation during the earliest mountain building events of the southern Appalachians (Taconic orogeny) caused the formation of mylonite—fine-grained, foliated metamorphic rock formed in localized zones of ductile deformation, at great depths under high temperature and confining pressure (Hatcher 1987). Later, probably during the last major Appalachian Mountain building event (Alleghanian orogeny), at much lower temperatures and confining pressures, the Brevard Zone was deformed again in a brittle regime involving fracturing (forming cataclasite rock) instead of recrystallization (Hatcher 1987).

The geology of the park and other natural features that characterize it are influenced by the Brevard Zone in both large ways and small, from the river course, topography, and landforms, to texture, grain size, and shape in rocks (KellerLynn 2012). Digital elevation models or shaded relief maps show the influence of the Brevard Zone on the park's landscape (fig. 17). Within the park, the Chattahoochee River flows subparallel to the Brevard Zone, its channel essentially "locked in place" as one of the oldest and most stable river channels in the US (Higgins 1968; O'Grady and Poe 1980; Harden et al. 2013). Excellent exposures of bedrock of the Brevard Zone are located along the Chattahoochee River as it flows through the park. Because of the influence of the Brevard Zone, many of the reaches of the Chattahoochee River and its watershed are long and linear, such as the reach from Morgan Falls Dam downstream to just north of Interstate 285. The long, straight reach north of Gainesville, Georgia, made it suitable for the 1996 Summer Olympics rowing and flat-water canoe venues (KellerLynn 2012).

The Brevard Zone includes closely spaced, parallel ridges that align with the zone's northeast strike or orientation (see fig. 17). Flowing among these ridges, the Chattahoochee River cut its northeast-to-southwest course across northern Georgia. Drainages that might otherwise have flowed southeast toward the Atlantic Ocean intersect the river to flow southwest into the Gulf of Mexico (Higgins 1968; KellerLynn 2012). The mineral composition and texture of the bedrock within the Brevard Zone control the type of channel lending, in places, to a stair-step pattern visible from a birds-eye view in the park area (see GRI poster). Where the river flows almost parallel to the Brevard Zone it cuts through rocks that are relatively less resistant to erosion (e.g., Button Schist; **POb**). Fault traces (e.g., Morgan Falls fault and Seven fault) within the Brevard Zone may also funnel parallel or subparallel flows. The river cuts across the regional pattern of parallel ridges in some areas. This is controlled by a local weakness (e.g., cross cutting major joints or faults) that focused the flow or perhaps that portion of the river was incised at a higher level through less resistant rocks, then as incision proceeded into more resistant rocks, the course was already set. In areas where the river cuts across the Brevard Zone and the underlying rocks are more resistant to erosion (e.g., Stonewall Gneiss, Powers Ferry Member; **OZsp**); shoals develop (see "Shoals"). In places where the river

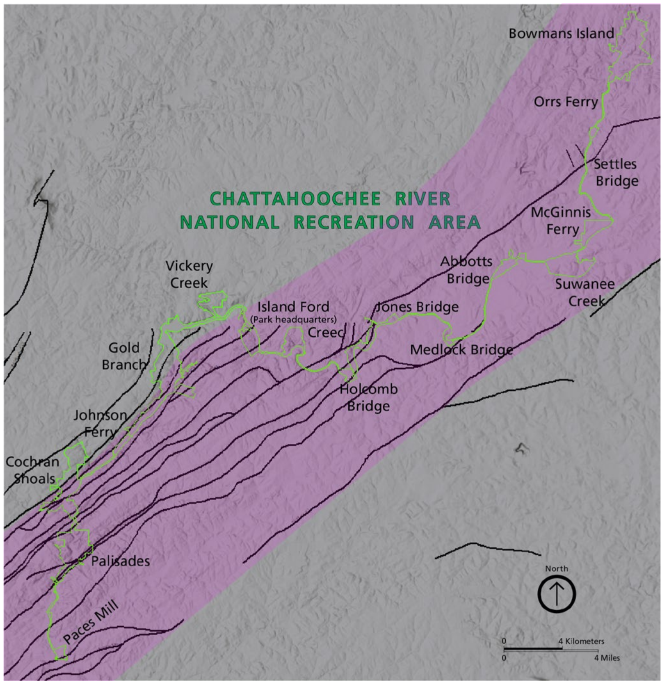

Figure 17. The Brevard Zone on a shaded relief image.
Parallel faults, folds, and ridges are characteristic of the Brevard Zone in the vicinity of Chattahoochee River National Recreation Area. The Brevard Zone confines the course of the river and played a major role in diverting its drainage to the southwest toward the Gulf of Mexico. Bold black lines are fault traces. The purple area represents the Brevard Zone. The green outline is the park boundary, inside of which the Chattahoochee River flows. Individual units of the park are labeled in black. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap.

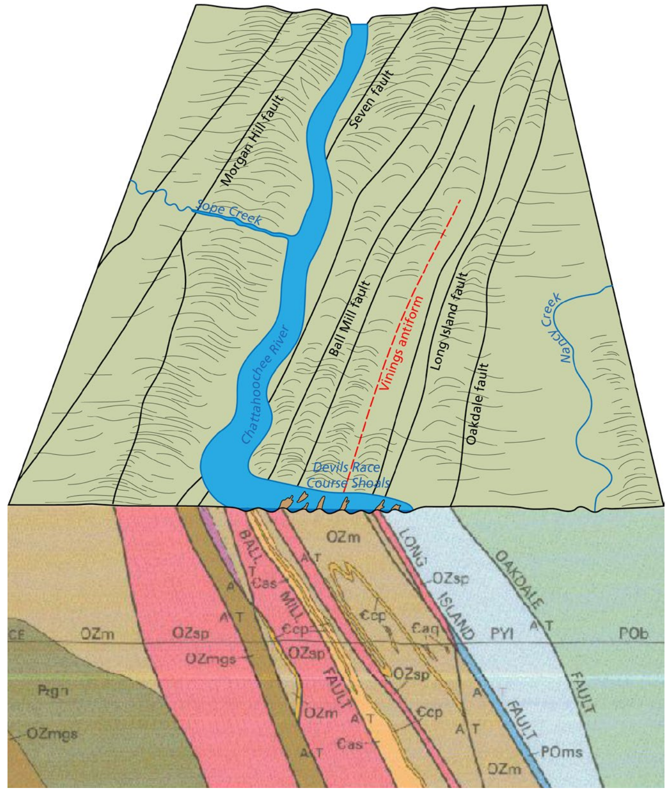

Figure 18. Cross section and block diagram illustrating the influence of faults and folds on the Chattahoochee River.
Along the Brevard Zone, the Chattahoochee River flows parallel or subparallel to the regional fault and fold orientation. The river cuts preferentially through zones of weakness such as smaller, local joints and faults, which cut across the larger regional faults of the Brevard Zone. In areas where the river cuts perpendicular to the trend of these features, rapids and shoals form. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using cross section A-A' from the GRI GIS data. Cross section originally created by Higgins et al. (2003).

cuts across this regional fabric (e.g., Vinings antiform, Long Island fault and Ball Mill fault), the course has shoals and rapids. The high energy tributaries such as Big Creek, Vickery Creek, Sope Creek, and Rottenwood Creek, located between mile markers 319 and 304, cut across faults and folds (see figs. 2 and 18).

Faults and Folds

> Geologic map units relevant to this section: overturned antiforms (in sasp and chts), right-lateral strike-slip faults (in sasp and chts), high-angle faults (in sasp and chts), thrust faults (in sasp and chts), faults of unknown displacement (in chtn), and shear/mylonite zones (in chtn)

Faults form where rocks have been compressed, stretched, sheared, or fractured and rocks on either side of the break have moved relative to each other. They are common structural features in areas where mountain building has occurred, such as the southern Appalachian Mountains. The three primary types of faults are normal faults, reverse faults, and strike-slip faults (fig. 19). A thrust fault is a low angle variety of a reverse fault. Faults are classified based on motion of rocks (displacement) on either side of the fault plane as shown in fig. 19.

Strike-slip and thrust faults have been mapped within the Chattahoochee River National Recreation Area as shown by GRI GIS data. Some of the mapped faults are of unknown displacement and therefore are not assigned a fault type. The GRI GIS data within park boundaries include 13 major, named faults: Olley

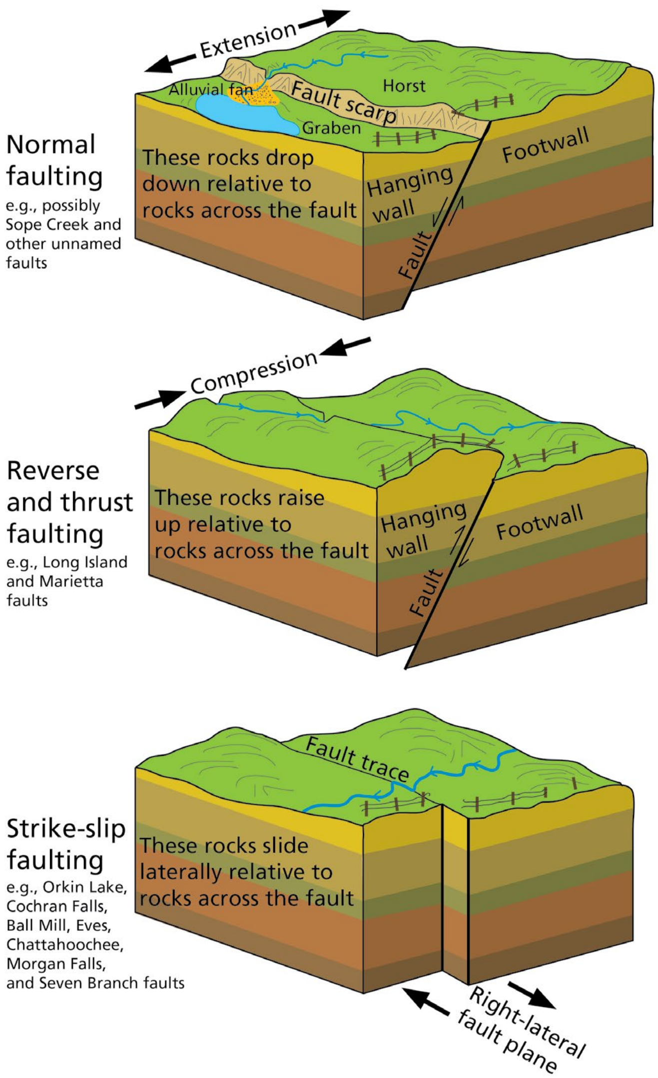

Figure 19. Block diagrams illustrating fault types. In faulting there is movement along a fault plane. The footwall is below the fault plane, and hanging wall is above. In a normal fault, crustal extension (pulling apart) allows the hanging wall to move down relative to the footwall. In a reverse fault, crustal compression causes the hanging wall to move up relative to the footwall. A thrust fault is a reverse fault which has a dip angle of less than 45°. In a strike-slip fault, the relative direction of movement along the fault is lateral. When movement across the fault is to the right, it is a right-lateral (dextral) fault, as illustrated above. When movement is to the left, it is a left-lateral (sinistral) fault. Two of the three major fault types are included in the GRI GIS data for Chattahoochee River National Recreation Area. Fault types may be combined (oblique-slip) where there is evidence for more than one direction of displacement. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Creek, Marietta, Cochran Shoals, Orkin Lake, Sope Creek, Long Island, Ball Mill, Eves, Morgan Falls, Seven Branch, Oakdale, Rivertown, and Seven faults (Higgins et al. 2003; Dicken et al. 2005; Harden et al. 2013). Myriad small-scale faults (not necessarily mapped) are visible in rocks along the river. Faults are commonly zones of weakness which may be preferentially weathered and eroded by rivers and streams flowing along fault traces (Higgins et al. 2003). Included in the GRI GIS data for faults are shear/mylonite zones associated with deformation at great depths under high confining pressure and/or great temperature (see "Brevard Zone" section; Dicken et al. 2005).

Folds are curves or bends in originally flat structures, such as rock strata, bedding planes, or foliation. The two primary types of folds, where relative ages of rocks are known, are anticlines which are "A-shaped" (convex upward) and synclines which are "U-shaped" (concave upward) (fig. 20). If relative ages of the folded rock layers is not known, the terms antiform and synform are used. Monocline, another type of fold, is a step-like structure consisting of a steeply dipping zone within otherwise relatively horizontal rock layers. All types of folds can be "overturned"—tilted past vertical—by unequal compressional components. Folds frequently "plunge," meaning the fold axis tilts or is not horizontal. As the Earth's crust is compressed, a pattern of alternating anticlines and synclines may form, as is demonstrated by the linear folds of the Ridge and Valley province northwest of the park. At least six sets of overlapping, multi-scale folds are known in the region covered by the GRI GIS data, recording a long, complex history of deformation (Higgins et al. 2003). Major folds are in the GRI GIS data within park boundaries, including named folds such as the Vinings antiform (see GRI poster; Higgins et al. 2003; Dicken et al. 2005; Harden et al. 2013). However, additional folds exist in the park at scales too small to be mapped. Small folds are visible in bedrock exposures along the river (see fig. 20).

Type Localities and Type Sections (Stratotypes)

Geologic map units relevant to this section: Long Island Creek Gneiss (**OZli** in sasp and **PYl** in chts), Palisades Quartzite (**OZpq** in sasp) and Chattahoochee Palisades Quartzite (**Ccp** in chts), Rottenwood Creek (**OZsg** in sasp), Pappasito Schist (**OZps** in sasp), Orange Gneiss (**OZog** in sasp), Powers Ferry Member (**OZsp** in chts), Crider Gneiss (**OZcr** in chts), and Ropes Creek metabasalt (**OZr** in chts)

Geologic formations are commonly named after a geographic feature, such as a stream, river, or town near its "type locality"—a geographic location where a rock formation is best displayed or first described. More

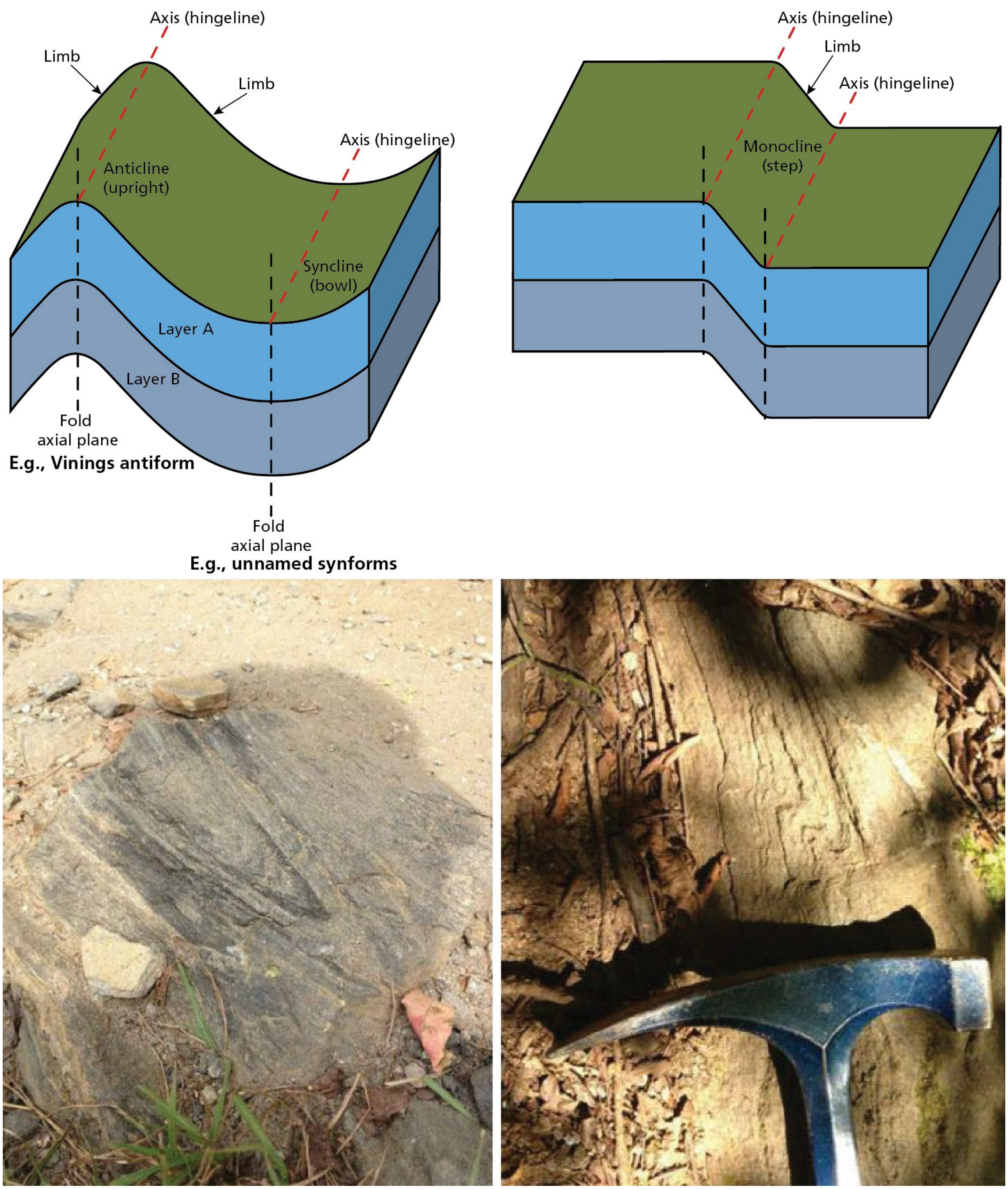

Figure 20. Illustrations of fold types and photographs of small-scale folds.
Folds accommodate stress within the rocks without pervasive fracture (faulting). Two of the three major fold types are included in the GRI GIS data for Chattahoochee River National Recreation Area: synforms and antiforms. No monoclines are mapped in the GRI GIS data. In addition to the large-scale regional folds, small-scale folds are visible in the park bedrock. Left image shows tight folding within an amphibolite (e.g., geologic map unit OZa). Right image shows crenulation in bedrock of the Brevard Zone (e.g., OZmg). Photographs are figure 1 and 3, respectively from Harden et al. (2013). Folds illustrations by Trista Thornberry-Ehrlich (Colorado State University).

particularly, an outcrop may show the formation so well that it is designated as the "type section" (North American Commission on Stratigraphic Nomenclature 2021). Because type localities and type sections are commonly where a formation was originally described and named, they also may have historical significance. Many of the geologic map-unit names in the GRI GIS data refer to local geographic features (most of which are along Chattahoochee River), and many are very well exposed in the park. Examples of local features and corresponding geologic map unit names include Long Island Creek Gneiss (**OZli** in sasp and **PYl** in chts), Palisades Quartzite (**OZpq** in sasp) and Chattahoochee Palisades Quartzite (**Ccp** in chts), Rottenwood Creek Mixed Unit (**OZsg** in sasp), Pappasito Schist (**OZps** in sasp), Orange Gneiss (**OZog** in sasp), Powers Ferry Member (**OZsp** in chts), Crider Gneiss (**OZcr** in chts), and Ropes Creek Metabasalt (**OZr** in chts) (Higgins et al. 2003; Dicken et al. 2005; Harden et al. 2013). The USGS Geolex service, available at https://ngmdb.usgs.gov/Geolex/search is a national compilation of names and descriptions of geologic units. Within the park boundary, formally designated type localities are present for the Chattahoochee Palisades Quartzite (**Ccp**) and the Powers Ferry Member of the Stonewall Gneiss (**OZsp**) (Higgins and McConnell 1978). The Crider Gneiss (**OZcr**) type section, Ropes Creek Metabasalt (**OZr**) type locality, and Long Island Creek Gneiss (**OZli**) type area are just outside of the park. The NPS Geologic Resources Division (contact at http://go.nps.gov/geology) can provide the locations for these sites.

Rock Shelters

Geologic map units relevant to this section: Crider Gneiss (**OZcr** in chts), Powers Ferry Member (**OZsp** in chts)

At Chattahoochee River National Recreation Area, rock shelters have formed in overhanging bedrock near the river (fig. 21). Similar to the formation of shoals, rock shelters develop as a result of differential weathering of the bedrock, which is dependent on mineral composition and rock texture. For example, the roof lines of the rock shelters at Island Ford Shoal follow the metamorphic foliation (banding) of the biotite gneiss in which the shelters formed. Over time, weathering preferentially broke down the biotite-rich layers within the gneiss, thus providing a means for a cavity to develop. The overall shape or morphology of a shelter is dependent on the rock in which it formed, with compositional layering and foliation (such as at Island Ford Shoal) being the primary controlling factor (KellerLynn 2012).

Figure 21. Photographs of rock shelters at Chattahoochee River National Recreation Area. Left image shows rock shelters and overhangs developed on the low bluff above the river at the confluence with Vickery Creek. Right image shows a rock shelter formed in an outcrop at Island Ford. Social trails from the river up to the shelter areas indicate that they are frequented by visitors. Loose slope deposits (colluvium) litter the slopes below the outcrops. Photographs by Georgia Hybels (Colorado State University) taken in March 2012.

Rock shelters are geologic features; however, they locally have archeological connections as well. When Chattahoochee River National Recreation Area was established in 1978, investigators from the NPS Southeast Archeological Center completed archeological surveys and overviews of several of the larger shelters; evidence was found that the rock shelters along the Chattahoochee River were used by prehistoric peoples (Byrd 2009; KellerLynn 2012). Shelters in the Sope Creek area were used as temporary hunting camps (Byrd 2009). A geologic survey of the rock shelter locations would help target areas for protection and archeological research. Strategies to help protect all unique geologic features remains a resource management need at Chattahoochee River National Recreation Area (National Park Service 2017).

Fluvial Features and Processes

Fluvial features are those which are formed by flowing water. Fluvial processes both construct (deposit sediments or alluvium) and erode landforms (e.g., the local streams and river channels). Chattahoochee River and its tributaries are the primary fluvial features at the park. The Chattahoochee River watershed within Chattahoochee River National Recreation Area below Buford Dam covers about 1,077 km^2 (416 mi^2) as it flows southwest through Georgia. Its headwaters are north of the park in the mountains at the Tennessee border near Brasstown Bald, the highest peak in Georgia at 1,455 m (4,774 ft) elevation (Kunkle and Vana-Miller 2000; Byrd 2009). In the park, the Chattahoochee River flows through an entrenched channel from Buford Dam southwest to the confluence with Peachtree Creek. It flows through steep rugged palisades, over rocky shoals, and past sheer rock faces. Fifteen major tributaries (a major tributary is defined as having at least two tributaries of their own; e.g., Big Creek and Suwanee Creek) and many minor tributaries (has less than two tributaries of their own) of the Chattahoochee River also flow within the park, commonly running through steep, rugged terrain. For example, Sope Creek drops nearly 90 m (300 ft) along its 19 km (12 mi) length (National Park Service 2004; Byrd 2009). Beyond the southern end of the park, the Chattahoochee flows south-southwestward, serving as the state line between Alabama and Georgia. Where the Chattahoochee River joins with the Flint River near the Florida-Georgia boundary, they form the Apalachicola River, eventually emptying into the Gulf of Mexico (Byrd 2009).

Fluvial features within the Chattahoochee River and its tributaries in the park include channels, palisades, and bedrock shoals (fig. 22). A river's channel is the relatively linear landform through which it flows (Bierman and Montgomery 2014). Fluvial channels exist in a variety of shapes as their development is controlled by flowing water, sediment movement, stream gradient or slope, and the material through which the channel is cutting (Bierman and Montgomery 2014). Palisades are rock cliffs or lines of bold cliffs rising precipitously from the edge of a stream or lake (fig. 23; Neuendorf et al. 2005). Locally, palisades are associated with shoals, which are submerged rock ridges, boulders, or bars that may or may not rise above the stream surface (see "Shoals" section; Neuendorf et al. 2005).

Other important fluvial features at the park include point bar deposits, gravel bars, meanders, floodplains, and riparian zones (see fig. 22). As a river flows around curves (meanders) in its channel, the flow velocity (and thus erosive or transport energy) is greatest on the outside of the bend, therefore, the river erodes into its bank on the outside of a meander (see fig. 22) 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. Gravel bars are within the channel and contain coarse, rounded rock fragments and small stones. As the erosive process continues, the outside bend typically erodes, while deposition typically occurs on the inside bend, thus creating laterally migrating meanders. The Chattahoochee River is primarily flowing within entrenched meanders, meaning the meanders have incised directly into the underlying bedrock. Because of this, their lateral migration is limited compared to classic meandering streams which flow through unconsolidated surficial deposits. Adjacent to the rivers and streams are narrow, relatively flat floodplains. Many local floodplains contain mixtures of alluvium and colluvium, shed from uphill areas. Tributary streams flowing toward the main river through these up-gradient areas may form entrenched channels in slope deposits. Where they intersect the larger valley floor or floodplain, they may deposit alluvial fans. Floodplains may also contain terraces, surfaces that reflect former, higher river levels above the modern floodplain. Riparian zone refers to the strip of land on the bank of a body of water. Riparian zones support hydrophilic species of plants and animals, some of which are species of concern (National Park Service 2017; Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021).

Floods and seasonal runoff drive geomorphological change, shaping the fluvial environment, and have an important role in controlling the pattern of riparian vegetation along channels and floodplains. During high flows or floods, a stream deposits natural levees of sand and silt along its banks. These deposits represent the relatively coarse-grained component

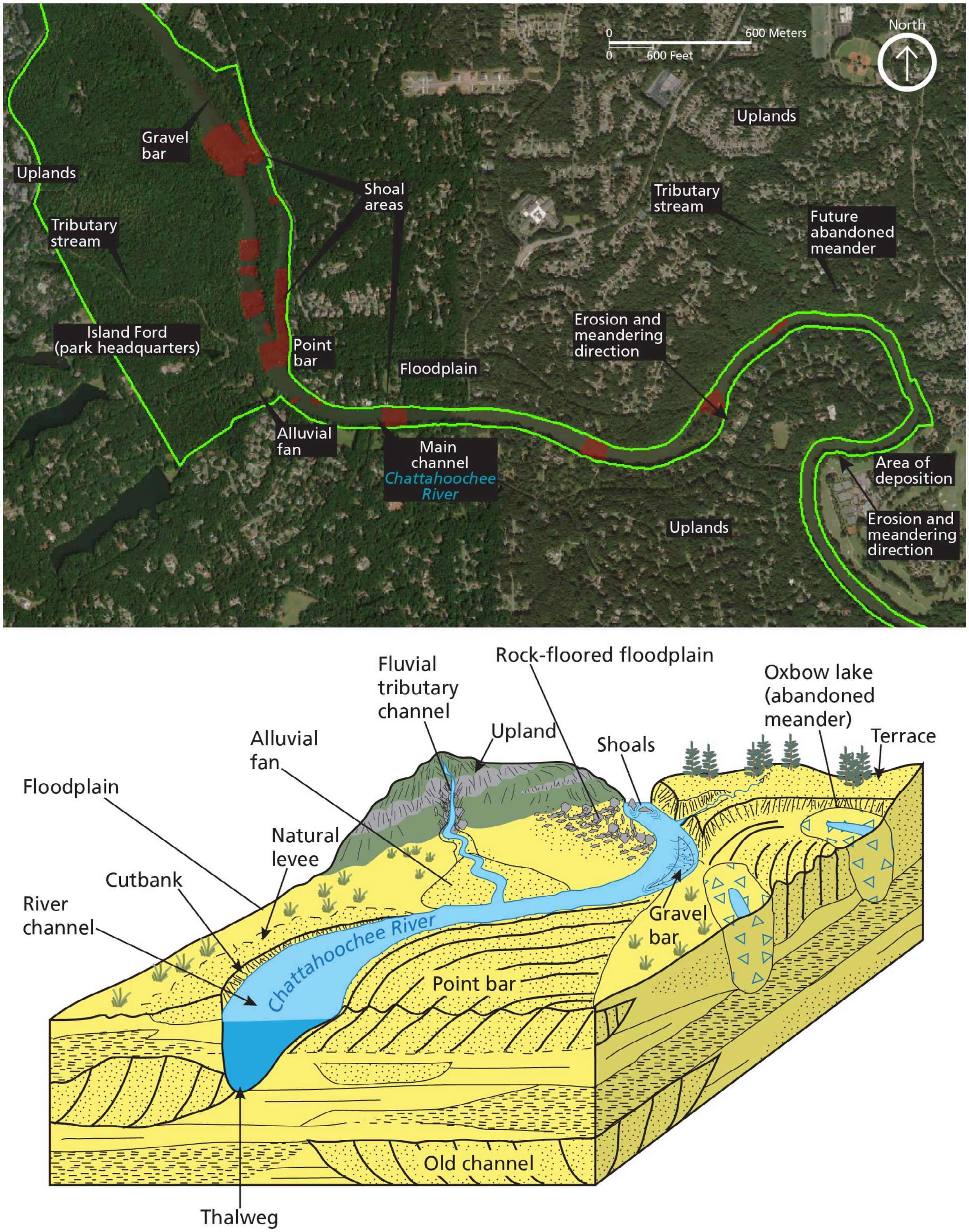

Figure 22. Satellite image and block diagram illustrating fluvial features.
Both erosional and depositional are shown. Diagram is not to scale. The Chattahoochee River cuts down through weathered bedrock to incise its channel. Along its length are myriad fluvial features formed as the river meanders across its floodplain depositing alluvium in some areas and eroding the valley floor in others. In the satellite image, areas of shoal development are translucent dark red, and the park boundary is in green. Block diagram and annotations on satellite image by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap.

Figure 23. Photograph of palisades along the Chattahoochee River.
The palisades are marked by visually striking, sharply angular rock slabs that rise steeply from the river. This outcrop is at Bull Sluice Lake above Morgan Falls Dam, near Roswell. Photograph by Thomson200 taken in 2018 available at https://commons.wikimedia.org/wiki/File:Huntcliff,_Chattahooche_River,_May_2018_2.jpg (accessed 16 March 2022). Unmodified and used under license, CC0 1.0 (https://creativecommons.org/publicdomain/zero/1.0/deed.en).

of a river's suspended sediment load and can form a high area on an alluvial region's land surface. Flooding is a natural process, but it can become a resource management concern if significant cultural or natural resources are threatened. Flooding and seasonal runoff are exacerbated by increased storm intensity and fluctuating water availability (see "Demand for Freshwater" section) associated with climate change (National Park Service 2017).

Shoals

Geologic map units relevant to this section: shoal area features (in chsh); Long Island Creek Gneiss (**OZli** in sasp and **PYl** in chts); Palisades Quartzite (**OZpq** in sasp) and Chattahoochee Palisades Quartzite (**Ccp** in chts); Rottenwood Creek mixed unit (**OZsg** in sasp); Powers Ferry Member (**OZsp** in chts); Crider Gneiss (**OZcr** in chts); biotitic gneiss, mica schist and amphibolite (**PZPCbg2** in chtn); mixed schist/gneiss (**OZmu** in sasp); schist, amphibolite, and ultramafic (**OZsau** in sasp); muscovite schist (**OZsh** in sasp); migmatitic gneiss (**OZmg** in sasp); quartzite (**OZq** in sasp); garnet schist (**OZgs** in sasp); biotite gneiss (**OZbg** in sasp); button schist (**POb** in chts); informal mixed unit (**OZm** in chts); button schist and sheared amphibolite (**POms** in chts); garnet-rich schist (**OZmgs** in chts); aluminous schist (**Cas** in chts)

Shoals are a distinctive geologic feature in Chattahoochee River National Recreation Area (National Park Service 2012; KellerLynn 2012). A shoal is a relatively shallow place in a stream, lake, sea, or other body of water (Neuendorf et al. 2005). The shoals in the Chattahoochee River are just barely submerged areas of bedrock within the river channel that may be exposed during low flows (fig. 24). Eight shoals are named within the park, from north to south: Bowmans Island Shoals, Fish Weir Shoals, Jones Bridge Shoals, Island Ford Shoals, Cochran Shoals, Devils Race Course Shoals, Thornton Shoals, and Long Island Shoals (see GRI poster). These shoals formed where more resistant bedrock has withstood the weathering processes of the river better than the adjacent rocks or where the river is cutting across geologic structures (e.g., faults or ridges) (figs. 25 and 26; KellerLynn 2012).

Rates of bedrock weathering and erosion depend on many factors. Mineralogy is particularly significant for the rocks along the Chattahoochee River, and strongly influences the location of shoals. In general, if the rocks are rich in quartz—such as quartzites (e.g., **PZPCq** and **OZq**), they are more resistant to weathering (KellerLynn 2012). Topographic ridges in the area are often held up by rocks rich in quartz. By contrast, where rocks are rich in feldspar (e.g., **OZbg** and **OZsg**) more rapid weathering and erosion are likely to occur (KellerLynn 2012). Many of the rocks in the park contain mica. Mica occurs most commonly in two varieties, a clear or lighter colored muscovite, and a darker color, biotite. Muscovite is more resistant to weathering than biotite. The overall degree of weathering, from least to most weathered, in the Chattahoochee River area, is: quartzite (e.g., near Fish Wier shoals or the Palisades), then quartzose muscovite schist (e.g, near Powers Island), then muscovite schist (e.g., near Cochran Shoals), followed by ultramafic rocks (parts of **OZsau** near Long Island Shoals), amphibolite hornblende gneiss (e.g., near Johnson Ferry), and biotite gneiss (e.g., by Powers Ferry Road; see fig. 15 for rock types; Kath and Crawford 2001).

Shoals are also part of the human story at Chattahoochee River. The abundance of bedrock shoals, and associated waterfalls on creeks feeding into the Chattahoochee River, supported the proliferation of sawmills, paper mills, grist mills, and textile mills in the region well before the Civil War (Brown 1980; Byrd 2009). Mills harnessed the waterpower. Local mills focused industrial development along the river in northern Georgia and it became a lucrative business location (e.g., along Sope Creek; see fig. 6; Byrd 2009). Today, the shoals create rapids which are used for water-

Figure 24. Photographs of shoals in Chattahoochee River National Recreation Area.
In the park, shoals range in size from broad areas of exposed rock (A), to more localized bedrock islands (B), to areas of shallowly submerged bedrock knobs (C), to shallowly submerged gravel bars (D), to planar, submerged bedrock surfaces (E and F). Photograph locations are included in the GRI GIS data, map chsh (DSC00154, DSC00027, DSC00031, DSC00041, DSC00063, DSC0006, respectively) taken by Hundley (2014).

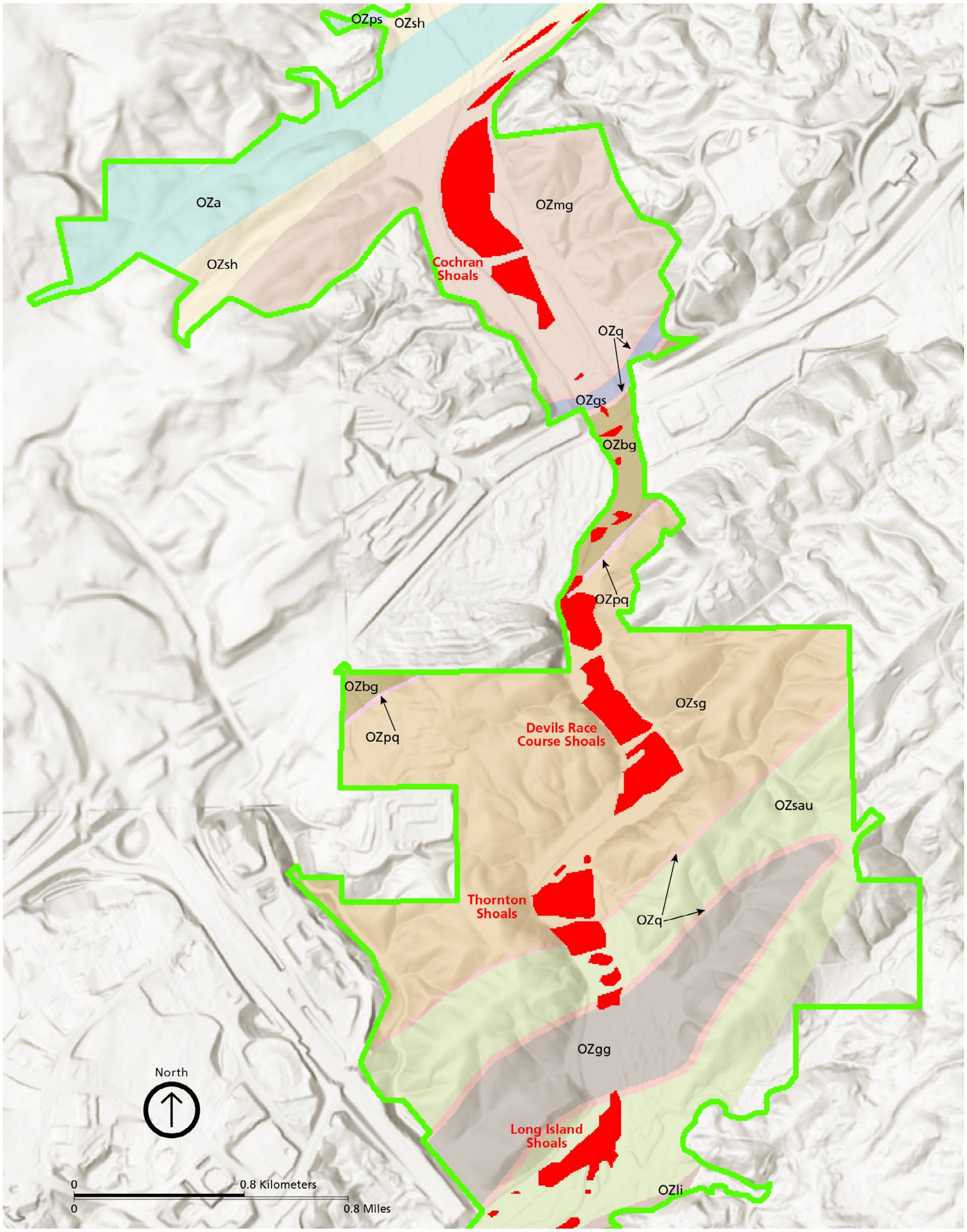

Figure 25. Map showing location of shoals in and near the Palisades park unit.
The map includes geologic map units draped over a terrain basemap. The bright green line is the park boundary. Red areas are mapped shoal areas along the Chattahoochee River in and near the Palisades unit of the park. Units' resistance to erosion is a dominant factor in the formation of shoals. Geologic structures such as joints and faults are also controlling factors providing localized zones of weakness. Map by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Terrain Base as a basemap.

Figure 26. Photographs of shoals aligned with bedrock and structure.
At Chattahoochee River National Recreation Area, shoals typically form where some bedrock is more resistant to erosion than adjacent bedrock. This is generally a function of mineralogical composition, and/or geologic structures. Some structures such as faults and joints may provide zones of weakness that preferentially weather away. (A) Palisades Shoals looking downstream, (B) Palisades Shoals looking across the flow, (C) Palisade Shoals with gravel bar deposit, (D) Sope Creek Shoals looking across the flow, (E) Sope Creek Shoals aligned with bedrock layering, visible on far bank, (F) Sope Creek Shoals, and (G) submerged Vickery Creek Shoals. Photographs by Georgia Hybels (Colorado State University) taken in spring 2012.

based recreation. The resistant bedrock that forms shoals and cliffs through which large tributaries flow enhances visitors' experiences with scenic focal points and creates rapids for recreation at Chattahoochee River National Recreation area (KellerLynn 2012).

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are nonrenewable. Body fossils are any remains of the actual organism such as bones, teeth, shells, or leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, or coprolites (fossilized feces). Fossils in NPS areas are present in rocks or unconsolidated deposits, in museum collections, and in cultural contexts such as building stones or archeological resources. As of May 2022, 283 parks had documented paleontological resources in at least one of these contexts (Vincent Santucci, NPS Geologic Resources Division, paleontologist, email communication to Rebecca Port, NPS Geologic Resources Division, geologist, 16 May 2022). Fossils have not yet been documented in any of these contexts at Chattahoochee River National Recreation Area.

Tweet et al. (2009) completed a baseline paleontological inventory for the Southeast Coast Inventory & Monitoring Network, including Chattahoochee River National Recreation Area. Within the rocks and deposits in the park, only unconsolidated (surficial), Quaternary, river deposits have the potential to contain fossils; surficial deposits, however, are not part of the GRI GIS data for the park. Examples of potential fossils include algal cysts, pollen, leaves, and wood (Tweet et al. 2009). Such fossils are known from marshy areas at nearby Congaree National Park. If present, fossils could be useful for determining past climate and/or ecological conditions (Tweet et al. 2009).

Fossil discovery potential also exists at Chattahoochee River National Recreation Area in conjunction with archeological resources, though as of August 2021 none have been documented (KellerLynn 2012; GRI conference call participants, conference call, 24 August 2021). Kenworthy and Santucci (2006) presented an overview and detailed selected examples of National Park Service fossils found in cultural resource contexts. Remains of plants and animals contemporaneous with archeological resources, if documented, may be considered paleontological resources. Over 300 archeological sites are identified within Chattahoochee River National Recreation Area, with at least 47 of these pertaining to prehistoric Indians and 23 being historic (Ehernhard 1982; Beth Wheeler, Chattahoochee River National Recreation Area, chief of Planning, Resources and Education, written communication, 11 April 2022). These early inhabitants left behind traces of their occupation in rock shelters, camp sites, village sites, fish weirs, and special-use areas (Ehernhard 1982). Further research and archeological surveys could locate unidentified paleontological resources.

Geologic Resource Management Issues

This chapter highlights issues (geologic features, processes, or human activities) that may require management for human safety, protection of infrastructure, or preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues (see "Guidance for Resource Management"). The issues are ordered with respect to management priority. Tables 4 and 5 break out resource management information per mapped geologic unit.

Geologic resources, including the Chattahoochee River, small streams, ridges, palisades, cliffs, rock shelters, wetlands, and shoals at Chattahoochee River National Recreation Area are fundamental to its history and modern preservation and interpretation. The foundation document for the park lists geology, ecology, recreation, cultural resource complexes, ethnographic and archeological resources, museum and archival collections, the Chattahoochee River, and scenic qualities as fundamental resources (National Park Service 2017). Conditions of these fundamental resources may warrant management.

Table 4. Resource management information by map unit for Chattahoochee River National Recreation Area.

This table includes map units from the chtn and chts GRI GIS maps; see table 5 for issues from map units from the sasp GRI GIS map. Units listed from north to south as the river meanders around bends; units mapped more than once along the course are not repeated in this table. Only units mapped within park boundaries are included. Detailed descriptions of each unit per source-map are in the GRI GIS map data.

Map Unit (map code) (symbol)	Noteworthy Information for Resource Management
Biotitic gneiss, mica schist and amphibolite (chtn) (**PZPCbg2**)	**PZPCbg2** weathers to produce a variety of soil types. Shoals form along the Chattahoochee River within **PZPCbg2**.
Quartzite (chtn) (**PZPCq**)	**PZPCq** weathers to produce a nearly pure quartz sand and acidic soils. **PZPCq** is resistant to erosion and commonly underlies ridges.
Granitic gneiss, undifferentiated (chtn) (**PZPCgg**)	**PZPCgg** is resistant to erosion and commonly underlies ridges.
Metagraywacke and mica schist (chtn) (**PZPCmr**)	Graywacke is resistant to erosion and commonly underlies ridges.
Stonewall Gneiss, Powers Ferry Member (chts) (**OZsp**)	**OZsp** weathers deeply to produce a dark red saprolite and clayey, dark red soil. If **OZsp** contains ultramafic bodies, these may harbor archaeological sites because of the ease in sculpting bowls, cooking utensils, and heat-retaining devices thought to have been used as bed/shelter/food warmers. Bowl fragments can be found at many sites; occasionally abandoned bowl blanks can be found still attached to the rock. **OZsp** has a type locality at Stonewall, Fulton County, Georgia. Shoals form along the Chattahoochee River within **OZsp**.
Informal mixed unit (chts) (**OZm**)	**OZm** weathers to produce a variety of soil types. Shoals form along the Chattahoochee River within **OZm**.
Aluminous schist unit (chts) (**Cas**)	**Cas** typically weathers to produce a reddish soil. Shoals form along the Chattahoochee River within **Cas**.
Long Island Creek Gneiss (chts) (**PYl**)	**PYl** weathers to produce a characteristic yellowish soil. Long Island Creek Gneiss has a type locality at the mouth of Long Island Creek. Shoals form along the Chattahoochee River within **PYl**.
Crider Gneiss (chts) (**OZcr**)	**OZcr** weathers to produce a light tan to dark yellowish tan soil with gneiss cobbles. Boulders of residual gneiss of **OZcr** are common. **OZcr** has a type locality at Crider Creek. Shoals form along the Chattahoochee River within **OZcr**.
Aluminous schist (chtn) (**PZPCs**)	**PZPCs** weathers to produce a very clay-rich soil that may act as an aquitard to groundwater.

Table 4, continued. Resource management information by map unit for Chattahoochee River National Recreation Area.

Map Unit (map code) (symbol)	Noteworthy Information for Resource Management
Mica schist, gneiss, and amphibolite (chtn) (**PZPCms**)	**PZPCms** weathers to produce a variety of soil types.
Garnet-rich schist (chts) (**OZmgs**)	Garnets (some as large as 1.5 cm) weather out of **OZmgs** and cover the ground at outcrops. **OZmgs** weathers to yellowish soils. Shoals form along the Chattahoochee River within **OZmgs**.
Ropes Creek Metabasalt (chts) (**OZr**)	**OZr** weathers to dark-red, clayey soil (ocher). **OZr** soils may be rich in iron and magnesium. **OZr** has a type locality at Ropes Creek, Lee County, Alabama.
Chattahoochee Palisades Quartzite (chts) (**Ccp**)	**Ccp** is resistant to erosion and underlies low ridges that stand 30 to 60 m above adjacent valleys. **Ccp** typically weathers to produce quartz sand and saprolitic soil. Locally, **Ccp** contains some mineable quartz sand. **Ccp** is massive, glassy (vitreous) and white to bluish in color. Chattahoochee Palisades is the type locality for **Ccp**. Shoals form along the Chattahoochee River within **Ccp**.
Thin (<2m thick) mappable units of muscovite quartzite (chts) (**Caq**)	Please see **Ccp** description.
Button schist and sheared amphibolite (chts) (**POms**)	**POms** weathers to create a red soil with "buttons" of mica scattered on the ground surface. Shoals form along the Chattahoochee River within **POms**.
Button schist (chts) (**POb**)	**POb** weathers to create a red soil with "buttons" of mica scattered on the ground surface. Shoals form along the Chattahoochee River within **POb**.
Mylonitized granitoid (chts) (**PSm**)	Weathering of **PSm** tends to create light-colored soils rich in quartz and clay (derived from feldspar).

Table 5. Resource management information by map unit for the Sandy Springs Quadrangle.

This table includes map units from the sasp GRI GIS map; see table 4 for issues from map units from the chtn and chts GRI GIS maps. Units listed from north to south as the river meanders around bends; units mapped more than once along the course are not repeated in this table. Detailed descriptions of each unit per source-map are in the GRI GIS map data.

Map Unit (map code) (symbol)	Noteworthy Information for Resource Management
Orange Gneiss (sasp) (**OZog**)	**OZog** weathers deeply to a soft, feldspathic soil, except for the coarse-grained mafic and ultramafic bodies and the pegmatites. The coarse-grained mafics yield a hard, tough saprolite, and pegmatites remain in residuum as resistant boulders.
Mixed schist/gniess (sasp) (**OZmu**)	**OZmu** weathers unevenly. Where layering is well developed, slabby outcrops form when weathered. Weathering can be deep or shallow depending on the composition and texture. Shoals form along the Chattahoochee River within **OZmu**.
Pappasito Schist (sasp) (**OZps**)	**OZps** is shallow weathering.
Amphibolite (sasp) (**OZa**)	**OZa** soils may be rich in iron and magnesium.
Muscovite schist (sasp) (**OZsh**)	**OZsh** weathers to create a red soil with "buttons" of mica scattered on the ground surface. Shoals form along the Chattahoochee River within **OZsh**.
Migmatitic gneiss (sasp) (**OZmg**)	Migmatitie gneiss underwent extreme shearing during deformation along the Brevard Zone. Shoals form along the Chattahoochee River within OZmg.

Table 5, continued. Resource management information by map unit for Sandy Springs Quadrangle.

Map Unit (map code) (symbol)	Noteworthy Information for Resource Management
Quartzite (sasp) (**OZq**)	**OZq** weathers to produce a nearly pure quartz sand and acidic soil. Shoals form along the Chattahoochee River within **OZq**.
Garnet schist (sasp) (**OZgs**)	**OZgs** weathers to produce platy soils with garnet and quartz clasts.
Biotite gneiss (sasp) (**OZbg**)	Weathering of **OZbg** tends to create light-colored soils rich in quartz and clay (derived from feldspar). Shoals form along the Chattahoochee River within **OZbg**.
Palisades Quartzite (sasp) (**OZpq**)	Chert was a common tool material for Native Americans using the area. **OZpq** weathers to produce a nearly pure quartz sand and acidic soils. **OZpq** has a type locality at the Chattahoochee River palisades. Shoals form along the Chattahoochee River within **OZpq**.
Rottenwood Creek Mixed Unit (sasp) (**OZsg**)	Weathering of **OZsg** tends to create light-colored soils rich in quartz and clay (derived from feldspar). **OZsg** has a type locality at Rottenwood Creek, Fulton County, Georgia. Shoals form along the Chattahoochee River within **OZsg**.
Schist, amphibolite, and ultramafic (sasp) (**OZsau**)	**OZsau** weathers to produce a variety of soil types. Shoals form along the Chattahoochee River within **OZsau**.
Granitic gneiss (sasp) (**OZgg**)	Weathering of **OZgg** tends to create light-colored soils rich in quartz and clay (derived from feldspar).
Long Island Creek Gneiss (sasp) (**OZli**)	Weathering of **OZli** tends to create light-colored soils rich in quartz and clay (derived from feldspar). Long Island Creek Gneiss has a type locality at the mouth of Long Island Creek.

Anthropogenic Effects on the Fluvial System

Human activities have profoundly impacted the fluvial system at Chattahoochee River National Recreation Area from dam releases with flooding, erosion, and stream channel widening, to runoff, water supply demands, and impacts to stream habitats (fig. 27). Overall, National Park Service (2017) described the current river channel as stable; however, the river channel is widening and becoming shallower in some locations due to dam operations and sedimentation resulting from overall urbanization throughout the watershed.

Dam Releases

On the Chattahoochee River within the park, the Buford Dam and the Morgan Falls Dam have altered natural flows of surface water. Buford Dam and its impoundment, Lake Sidney Lanier, form the upstream (northern) boundary of the national recreation area at river mile 348.3. Originally built by the US Army Corps of Engineers (ACOE) in 1957 for hydroelectric power production and flood control, Buford Dam and Lake Sidney Lanier now (since 1989) have an additional purpose—for water supply and increasingly, recreational uses of the impounded reservoirs (Burkholder et al. 2010; KellerLynn 2012). The much smaller, Morgan Falls Dam, was constructed in 1903 at river mile 312.6 to provide electricity for Atlanta's streetcars. This dam now serves to help regulate flow and soften or lessen pulses of sediment and water released from Buford Dam. After more than 110 years, sediment has largely filled the Morgan Falls Dam impoundment, called Bull Sluice Lake, which has significantly reduced water-storage capacity (Kunkle and Vana-Miller 2000; KellerLynn 2012). Bull Sluice "Lake" has largely become a mudflat, which supports a thriving water-bird population.

Before dams, the river flow was relatively stable, only picking up during natural seasonal floods. After the construction of dams, the river flow is highly variable, meaning it is both artificially low and then artificially high which is unnatural and therefore creates a lot of problems within the downstream portion of the river that the park is trying to manage. Prior to the completion of Buford Dam in 1957, floods in the winter and early spring were common. Larger floods (e.g., greater than 30,000 cfs) occurred once or twice most decades (Kunkle and Vana-Miller 2000; Burkholder et al. 2010; KellerLynn 2012). Now, due to Atlanta's water intake at river mile 299.6, releases from Lake Sidney Lanier (Buford Dam) 40 miles upstream, which is large enough to hold the volume of a 500-year flood, and other upstream dams are required to provide a minimum flow of 750 cfs between May to

Figure 27. Photographs of stream-channel widening and streambank erosion. Park staff have noted the channel of the Chattahoochee River widening, particularly in areas underlain by unconsolidated (more easily eroded) materials such as alluvium. (A) Palisade Shoals, (B) Island Ford, (C) Sope Creek, (D) Vickery Creek, and (E) Vickery Creek Shoals. Photographs by Georgia Hybels (Colorado State University) taken in spring 2012.

October and 650 cfs between November to April (US ACOE 1998; US ACOE 2016). The amount of water needed to be released from Buford Dam varies; river discharge below Buford Dam can be less than 500 cfs up to more than 12,000 cfs (Kunkle and Vana-Miller 2000; US Geological Survey 2022). The outlet sluice at Buford Dam has a maximum flow capacity of 11,600 cfs, but the dam can release up to 22,600 cfs without using the emergency spillway (US ACOE 1998; KellerLynn 2012). While flow rates are quite variable, they are at least predictable. Until 2012, the cycle of dam releases and subsequent increased flow typically followed a schedule, with weekday releases once per day at approximately 3:30 pm ET, corresponding to peak energy demand in the surrounding communities (KellerLynn 2012). This has since increased to commonly twice per day, once in the morning and once in the evening (Ann Couch, Chattahoochee River National Recreation Area, ranger, written communication, 28 April 2022). Stream gage data for the Buford Dam releases is available through the US Geological Survey (2022).

The surges of water released from Buford Dam cause severe bank and bed erosion along the Chattahoochee River for about 32 km (20 mi) downstream, which is a stretch of river that is fully within Chattahoochee River National Recreation Area (KellerLynn 2012). Shoreline (bank) erosion is a key resource management issue (National Park Service 2017). Bank erosion contributes to tree fall along the river's banks due to the unnaturally sudden rise and fall of the water level (Kunkle and Vana-Miller 2000; National Park Service 2017). Features such as the "bathtub ring" below "Jumping Rock" near Devils Race Course Shoals (fig. 28), are evidence of a drop in water level of about 1.2 m (4 ft) (KellerLynn 2012). This effect, however, is much more dramatic closer to the dam; peak flow attenuates further away from the dam (Ann Couch, Chattahoochee River National Recreation Area, ranger, written communication, 28 April 2022).

Buford Dam interrupts net sediment transport from upstream by trapping sediment behind it in Lake Sidney Lanier. The surges of water released from the dam lack sediment and are therefore considered "hungry water" because they have excessive stream power available to transport sediment. As a result, hungry water has the potential to severely erode the riverbed and banks. The sediment-poor water coupled with the frequent dam releases have caused the Chattahoochee River to scour to a lower base level, which in some locations is bedrock. Tributaries then incise more rapidly to reach the same base level at the confluence with the main river (Jacob Bateman McDonald, University of North Georgia, assistant professor, conference call, 24 August 2021). In the park, tributaries have become deeply incised at their confluence with the Chattahoochee River. Park staff observed incisions up to 5 m (15 ft) deep running as far as 45 m (150 ft) upstream into tributaries (KellerLynn 2012). Dam releases also cause water to back up in tributaries.

The excessive erosion resulting from dam releases affects visitor safety, park infrastructure, and other park resources. Rapid fluctuations in water levels cause exacerbated scouring and undercutting of the riverbanks, releasing local pulses of increased suspended sediment, which in turn negatively impact fisheries and macroinvertebrate communities (National Park Service 2017). Visitor safety is also threatened by unstable riverbanks and rapidly variable flows (National Park Service 2017). Unfortunately, fatalities have occurred nearly every year and many other visitors required rescue after being stranded on shoals or gravel bars mid-river and unable to swim to shore after water was released from the dam (Foster 2011; GRI conference call participants, conference call, 24 August 2021). Significant bank erosion impacts park infrastructure, as well as private property (KellerLynn 2012). Erosion is notable around steps (e.g., river access points) built into riverbanks. These rock steps are losing underlying and/or adjacent support. For example, undercutting is happening at the step-down ramp at Sandy Point and Powers Island (KellerLynn 2012). Even more severe riverbank erosion is proceeding in other locations, such as at the step-down ramp at Settles Bridge (KellerLynn 2012).

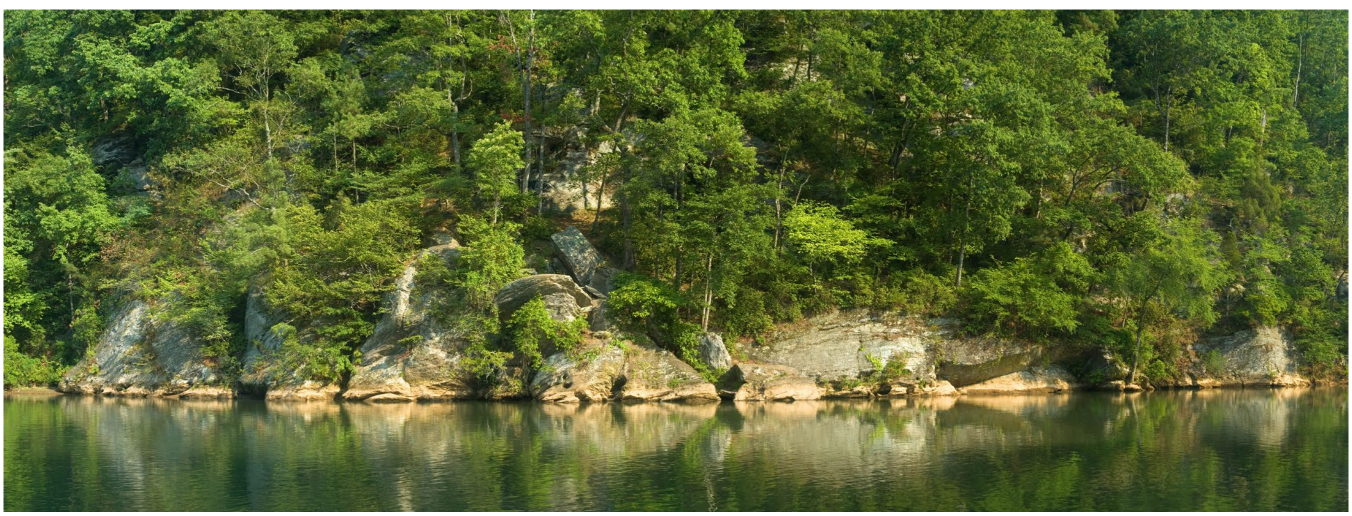

Figure 28. Photograph of the bathtub ring below jumping rock.
A "bathtub ring" is a strip of conspicuously colored rock immediately above the modern river level. These rings are evidence of a drop in water level. The ring in the photograph shows the river level has dropped about 1.2 m (4 ft) (KellerLynn 2012). NPS photograph provided by Allyson Read (Chattahoochee River National Recreation Area).

Stormwater Runoff

Major storms and accompanying runoff can strongly impact the Chattahoochee River's hydrograph (graph showing the rate of flow (discharge) versus time past a specific point in the river) and water quality (US ACOE 1998). Impervious surfaces are surfaces such as streets, roofs, or parking lots that allow little or no stormwater infiltration. Urban and suburban areas, like those surrounding the park, are covered in more impervious surfaces than undeveloped areas. Therefore, when it rains, a high percentage of stormwater is forced to flow as surface runoff which quickly funnels to nearby waterways, thus increasing scouring and streambank erosion rates (Burkholder et al. 2017; National Park Service 2017). Point sources of pollution and damaging runoff are directed right at the boundary along the length of the park creating gullies, washes, and localized excess sedimentation (Allyson Read, Chattahoochee River National Recreation Area, biologist and Beth Wheeler, Chattahoochee River National Recreation Area, chief of Planning, Resources and Education, conference call, 24 August 2021). For example, a sloped, private driveway at Sope Creek became a spillway for storm-water runoff (KellerLynn 2012). During and after heavy rainfall, manholes have overflowed and released raw sewage and debris into the river, tributaries, and surrounding park units (Lester 2020). Park managers noted they are consistently occupied with stormwater runoff and associated issues made worse by continual adjacent urbanization along the entire length of the park (Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021). Bank undercutting and slumping were observed at all 14 streams chosen for a baseline inventory report (see "Wadeable Stream Habitat"; McDonald et al. 2019).

Hurricanes and tropical storms can cause mass precipitation that overwhelms the fluvial system. In 1994, Tropical Storm Alberto dropped 58 cm (23 in) of rainfall in Atlanta. Local rivers flooded and deposited 1.7 m (5.5 ft) of silt on their floodplains (Hooke et al. 1995; KellerLynn 2013). When flooding occurs, park infrastructure located on floodplains such as rest rooms, parking lots, and trails are threatened, as well as the historic steel-truss bridges (KellerLynn 2012). In September 2009, after 30 cm (12 in) of rain fell in three days, the rest room and boardwalk at Paces Mill sustained damage as a result of flooding- and runoff-related erosion (KellerLynn 2012). Storm-water runoff commonly causes large pulses of sediment in the river and tributaries.

An analysis of US Geological Survey gage stations on tributaries, comparing baseflow to stormflow ratios and how those have changed through time, would be a valuable resource management tool (Ann Couch, Chattahoochee River National Recreation Area, ranger, conference call, 24 August 2021). These data needed to perform this analysis are served at https://waterdata.usgs.gov/nwis. This could be a project for a technical assistance request (see "Guidance for Resource Management").

Demand for Freshwater

Beginning in 1885, the Chattahoochee River began to be seen as a source of water for the growing city of Atlanta instead of just a natural force to be harnessed for industry or used for transportation (Brown 1980). Prior to this time, citizens drew their water from public or private wells. Dams impounding reservoirs, pumping stations, sewage treatment plants, and hydroelectric power production accompanied the effort to supply the Atlanta area with reliable, clean water (Brown 1980). The Atlanta Regional Commission Metropolitan River Protection Act of 1972 dictates that the river corridor is managed regionally to regulate intakes and outtakes along the river. Water quality and quantity are key resource management issues (National Park Service 2017). Given freshwater flow demands, releases are increasingly a subject of interest and potential conflict among the various downstream entities (KellerLynn 2012). Downriver from Chattahoochee River National Recreation Area, the urban area of Atlanta and its suburbs are placing increasing demands on supplies of freshwater. Impervious surfaces associated with urbanization cause increases in the frequency and magnitude of peak discharges. Groundwater recharge is also reduced because less infiltration of rainwater can occur which causes lower-than-normal base flow during dry periods (McDonald et al. 2019). Pressure to impound headwater streams and create reservoirs has the potential to reduce the amount of water that flows through the park, which will inevitably continue to change the fluvial system there. It is becoming increasingly necessary to balance the various uses of the river to assure that impoundments and consumption/sewage treatment demands do not degrade the fluvial system in the park (Brown 1980).

Wadeable Stream Habitat

To give park resource managers insight into the conditions and trends of stream and near-channel habitats, the Southeast Coast Inventory & Monitoring Network is monitoring wadeable streams at Chattahoochee River National Recreation Area. Fourteen stream reaches in the park were selected to compile a baseline report (McDonald et al. 2019). Goals of this monitoring as listed in the report are to:

- Determine status of upstream watershed characteristics (basin morphology) and trends in land cover that may affect stream habitat.
- Determine the status of and trends in benthic and near-channel habitat in selected wadeable stream reaches (e.g., bed sediment, geomorphic channel units, and large woody debris).
- Determine the status of and trends in cross-sectional morphology, longitudinal gradient, and sinuosity of selected wadeable stream reaches.

The watersheds draining to the monitored streams ranged from small, mostly forested, first-order watersheds to large, mostly developed, third-order watersheds. Watersheds with higher slope/relief and/or higher amounts of suburban development tended to be more prone to flash flood events. Large woody debris present in the channel contributed to overall diversification of stream habitat by supporting the formation of steps and pools along the streams. Habitats for the streams of the baseline study were classified as good (four streams), fair (seven streams), and poor (three streams). Habitat quality may improve if non-mobile (stable) large woody debris increases, the amount of fine sediment reaching the stream is reduced, and/or the diversity of geomorphic channel units of the channel increases (McDonald et al. 2019).

Cabin Creek and Long Island Creek are eroding into park trails (fig. 29). The bank along Long Island Creek is more than 1.5 m (4.9 ft) above the eroding channel. Bank failure will create hazardous conditions for trail users. Erosion rates for these streams and determination of flow regimes with stream gages remain resource management needs (McDonald et al. 2019). Park resource managers seek to understand the extent and severity of erosion along all of the Chattahoochee River in the park, as well as its tributaries. Techniques could include comparing aerial images from year to year and measuring the amount of change (GRI conference call participants, conference call, 24 August 2021).

Figure 29. Photographs of tributary streams eroding near trails.
Top photograph shows erosion and meandering along Cabin Creek encroaching on a park trail. Exposed roots and overhanging banks occur along the creek. Middle photograph shows erosion along a high bank flanking Red Tail Creek. Woody debris in the creek channel may anchor some sediment in place and support habitat diversity. Bottom photograph shows a 1.5-m- (4.9-ft-) high bank eroding towards a park trail along Long Island Creek. If this bank fails, it may create a hazardous situation for trail users. Photographs are top to bottom: F-8, I-2, and O-8 from McDonald et al. (2019).

Resource Management for Fluvial Issues

The park's foundation document identified the need for a river management plan as a high priority (National Park Service 2017). A shoreline stabilization plan and flows assessment were identified as high-priority data management needs (National Park Service 2017). A geomorphic assessment (i.e., how the bed or channel and the bank of the river are changing through time with associated monitoring) remains a data management need of medium priority (National Park Service 2017). The park's foundation document listed the following opportunities with regards to fluvial issues: (1) work with the US ACOE on a sustainable flow regime, (2) work with local landowners/municipalities on watershed management, (3) provide education outreach on hydrology and geology, (4) encourage construction of green infrastructure in the watershed, using projects in the park as an example, and (5) pursue climate change mitigation through adaptive management (National Park Service 2017).

References and resources related to management of the fluvial system at the park include:

- Information regarding the park's water resources is available from the NPS Water Resources Division (http://go.nps.gov/waterresources).
- Information regarding shoreline monitoring is available from the Southeast Coast Network (2017).
- Hydrographic and impairment statistics for Chattahoochee River are available from Tucker and Ling (2020).
- Wadable stream habitat monitoring protocols are available by McDonald et al. (2018).
- The Southeast Coast Inventory & Monitoring Network monitors wadeable streams among other vital signs at the park: https://www.nps.gov/im/secn/monitoring.htm. The baseline report for this monitoring is by McDonald et al. (2019).
- Groundwater monitoring reports and data are available from Rasmussen et al. (2009).
- Lord et al. (2009) offered monitoring guidance for fluvial systems in response to changing conditions.
- Starkey (2015) provided stream flow conditions for Chattahoochee River.
- Burkholder et al. (2010) provided an assessment of water resources and watershed conditions.

Adjacent Development, Overuse, Disturbed Lands, and Illegal Mining

The suburbs and land adjacent to the park are experiencing rapid development and growth. Population forecasts predicted that between 2015 and 2050, the metro Atlanta region's total population will increase by 51% (Atlanta Regional Commission 2021). Since the creation of the park, adjacent land development, including installation of new infrastructure or renovation of existing infrastructure, has increasingly become the source of resource management problems including stormwater runoff, soil impairment, overuse, and inappropriate use.

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by human activities such as urbanization; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered disturbed lands appropriate for restoration unless influenced by human activities. Restoration activities attempt to return a site, watershed, or landscape to a previous condition, commonly some desirable historic baseline. At Chattahoochee River National Recreation Area, many of the disturbed lands are also considered historic (e.g., mill ruins, Civil War encampments, and historic bridges; see fig. 6). Historic sites like these are fundamental to the purpose of the park and therefore managed as cultural resources rather than disturbed lands.

Other disturbed lands include social trails (informal, unmaintained pathways created by repeated human use), bike trails, and overused areas near river access points (fig. 30; KellerLynn 2012). Foot traffic causes soil compaction, trail widening, and vegetation disturbances, especially in sloped areas, which in turn threaten the ecological resources of the park (National Park Service 2017). The Sope Creek area is prone to social trail use; the bike trail in the Sope Creek area and the one in the Cochran Shoals unit both cross soils that are likely not stable enough to sustain long-term use (KellerLynn 2012; Allyson Read, Chattahoochee River National Recreation Area, biologist, conference call, 24 August 2021). Riverbank disturbances due to construction (e.g., installation of stairs and steps to access the river) result in erosion, increased sediment loading in the river, and threats to archeological resources (National Park Service 2017). As of 2022, the park was finalizing a comprehensive trails management plan to address trail sustainability in all units of the park (Beth Wheeler, Chattahoochee River National Recreation Area, chief of Planning, Resources and Education, written communication, 11 April 2022).

Tunnels and chat piles (gravel-like waste leftover from mining) hint at the history of hydrologic mining in the park. One of the park's larger units is named Gold Branch, a likely reference to the gold deposits that were historically mapped in the area (fig. 31). Gold mining is not allowed in the park today but may be happening illegally. These disturbances could threaten ethnographic and archeological resources (National Park Service 2017). The gold rush story is not formally interpreted for the public by park staff; contacting a local historian may yield more information for interpretation purposes or to determine specific areas to monitor for illegal activity (Allyson Read, biologist, Chattahoochee River National Recreation Area, conference call, 24 August 2021).

Dredging

Chattahoochee River National Recreation Area's dam releases and water levels are managed by the US Army Corps of Engineers as part of the Apalachicola-Chattahoochee-Flint River system (US ACOE 2022).

Figure 30. Photographs of overuse and mitigation measures.
Social trails and overuse at some areas in the park exacerbate erosion problems. (A) erosion adjacent to a boulder along the river at Palisades Shoals, (B) social trail use and vegetation damage at Paper Mill area, (C) trail closure measures at Sope Creek, (D) erosion and overuse near a river access point at Palisades Shoals, and (E) boardwalk trail to protect vegetation at Palisade Shoals. Photographs by Georgia Hybels (Colorado State University) taken in spring 2012.

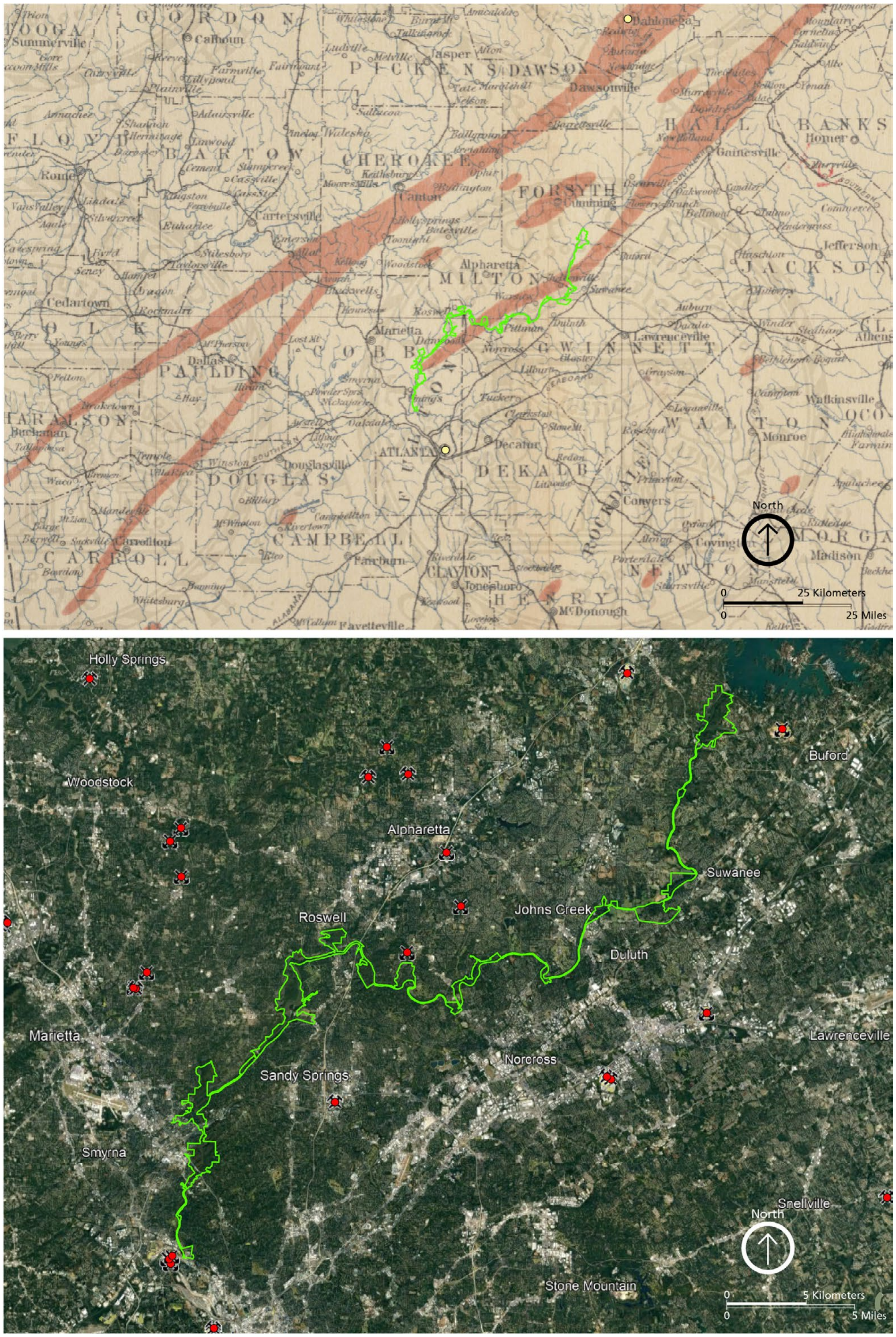

Figure 31. Historic map of gold deposits and modern mining features over aerial imagery. Chattahoochee River National Recreation Area (bright green boundary) contains gold-bearing rocks and is adjacent to know mining areas. Top image: map from 1909 of gold-bearing rocks (orange-colored areas) present locally in belts that parallel the regional trend of geologic map units, fault traces, and fold axes. Bottom image: mine features captured including borrow pits, gravel/borrow pits, and open pits mine or quarry. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using Georgia mine data from the US Geological Survey (https://mrdata.usgs.gov/usmin/), ESRI World Imagery basemap, and mapping from Jones (1909).

Part of this management involves dredging to maintain navigation channels and/or for sand and gravel extraction. According to an environmental impact statement prepared in 1991, the US ACOE issued permits to six different commercial interests, predating the 1972 establishment of the park, to allow dredging (sand and gravel mining) within the park (mostly in the upper, northern reaches) (US ACOE 1991). As of 2000, instream sand and gravel dredging was permitted along eight percent of the total river length within the park, mostly near the McGinnis Ferry, Abbotts Bridge, and Island Ford units (fig. 32; Kunkle and Vana-Miller 2000). Dredged material is desirable for construction materials in the growing Atlanta urban area because natural stream abrasion produces durable, rounded, more chemically inert, and well-sorted gravel (Kunkle and Vana-Miller 2000).

All active and proposed sand mining operations require Department of the Army permits under Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403). Some operations may also require approval under section 404 of the Clean Water Act of 1977 (33 U.S.C. 1344). Additionally, the park issues special use permits for sand and gravel operations with conditions allowing for NPS advice on any aspect of the mining that might impact natural resources of the park (Kunkle and Vana-Miller 2000; Honious 2021). Dredging removes sand and gravel from the riverbed, increases suspended solids in the water, reduces woody debris and other fish "cover," and changes the depth and water velocity in dredged sections. Potential benefits to dredging can include the creation of sediment basins or pools, creation of ledges for resting fish, and removal of smothering sand (Kunkle and Vana-Miller 2000). Potential damages include terrestrial vegetation disturbances, safety risks to recreational activities, and visual and noise impacts on the immediate area (US ACOE 1991). The US ACOE website for the Apalachicola-Chattahoochee-Flint River system contains more information: https://www.sam.usace.army.mil/Missions/Civil-Works/Navigation/Apalachicola-Chattahoochee-Flint/.

Overall, dredging results in deeper, wide channels, slower water velocities, and potentially richer fish assemblies. Instream dredging should be based on technical guidelines to control the size, extent, and pattern or distribution of the dredging sites with the end goal of attaining a more natural pool and riffle mix. Removal of sand should be emphasized over removal of gravel and fall trees, while other cover should be promoted (Kunkle and Vana-Miller 2000). Additional information on sand and gravel mining impacts is needed to develop a good set of guidelines, goals, and desirable restrictions for sand and gravel mining

Figure 32. Photographs of dredging operations within Chattahoochee River National Recreation Area.
Top photograph is an undated image of a dredge near McGinnis Ferry. Bottom photograph is also an undated image of another dredging operation near Abbotts Bridge. Dredging has potential benefits to fish diversity at the park. Potential negative impacts include increased water turbidity, changed flow velocity, and disturbed visitor experiences. Photographs top to bottom: figures 6.10 and 6.2 in Honious (2021).

operations within the park (Kunkle and Vana-Miller 2000; Honious 2021).

Chattahoochee Tunnel

The Chattahoochee Tunnel, started in 2000, was intended to relieve the existing wastewater sewer system in metropolitan Atlanta, in particular the Rottenwood Creek, Sope Creek, and Chattahoochee interceptors which were near capacity and had the potential to impact the park if overwhelmed (Cobb County Government 2018). Over the next four and a half years, engineers excavated the 15-km- (9.5-mi-) long tunnel (Cobb County Government 2018). Its diameter is approximately 5.5 m (18 ft) and it crosses depths between 30 and 115 m (100 and 375 ft) underground. At the northern end of the tunnel, sewage from the Sope Creek and Sewell Mill Creek interceptors drop into the tunnel through the Indian Hills intake structure. Other intakes are at Rottenwood Creek, Little Nancy Creek, and Chattahoochee interceptors. The tunnel conveys wastewater to the R. L. Sutton Water Reclamation Facility where it is treated and ultimately discharged to the Chattahoochee River south of Vinings (Cobb County Government 2018). The alignment of the tunnel is subparallel to the Chattahoochee River channel and crosses numerous surface drainages as well as the Brevard Zone (KellerLynn 2012). The tunneling project provided opportunities to map and understand the subsurface geology in the vicinity of Chattahoochee River National Recreation Area (KellerLynn 2012). Compared to previous work by the US Geological Survey, which mapped nine geologic map units, the tunnel project described at least 16 lithologic (compositional) units, several subunits, and mixed units. The project also detailed foliation and joint orientations in a wedge analysis for stability calculations for the tunnel (Kath and Crawford 2001). The Cobb County Government website (https://www.cobbcounty.org/water/projects/major-projects) provides more information.

Rock Shelter Management

Because rock shelters may preserve intact and potential archeological resources, they are considered cultural and natural resources in Chattahoochee River National Recreation Area. Resource management issues related to rock shelters include vandalism, inappropriate use, and impacts such as climbing (chalk/bolt installation) on the rock surfaces (KellerLynn 2012). Some shelters have been sites of graffiti that then require remediation (Ann Couch, Chattahoochee River National Recreation Area, ranger, conference call, 24 August 2021). An inventory of the rock shelters within the park would be a valuable data set for resource managers. Such an inventory might be an appropriate Scientists in Parks (SIP) project (see "Guidance for Resource Management").

Geologic Hazards

A geologic hazard ("geohazard") is a natural or human-caused geologic condition or process capable of causing damage, loss of property, and/or injury and loss of life. Geologic hazard processes can happen slowly over days or years or have a sudden onset occurring in seconds or minutes. The risk associated with a geologic hazard may be exacerbated by human activities (e.g., building trails beneath unstable slopes). Risk is the probability of occurrence combined with the expected degree of damage or loss that may result from exposure to a hazard, or the likelihood of a hazard causing losses (see also Holmes et al. 2013). The primary geologic hazards for Chattahoochee River National Recreation Area are slope movements, shoals, and seismicity.

Slope Movements

Slope movements are the downslope transfer of soil, regolith, and/or rock under the influence of gravity. Soil creep, rockfalls, debris flows, and avalanches are common types of slope movements. These processes and the resultant deposits are also known as "mass wasting" and commonly grouped as "landslides." Slope movements happen on time scales ranging from seconds to years (see fig. 33). These processes are natural elements of landscape change which become hazards when they undermine the integrity of the roadway or other infrastructure, or when visitors hike near the base of cliffs, along debris flows, across stone streams, or beneath overhanging rock. Particularly hazardous areas are those with visible cracks on cliffs, wedging root growth, loose material on slopes or overhangs, as well as settings where geologic features such as foliation, cleavage, bedding, and jointing are sloping steeply toward a road or trail surface (Carter et al. 2016).

Shoals

Shoals, described in the "Shoals" section of the "Geologic Features and Processes" chapter, become a geohazard at Chattahoochee River National Recreation Area where they threaten visitor safety in hidden shallow areas unpassable by watercraft. Boats may hit an underwater obstacle, sustain damage, and capsize, throwing people overboard into the turbulent water associated with rapids and shoals. In areas where shoals are shallow enough to walk on, visitors falling into the water becomes a potential issue. Concentrated shoal areas and areas of shallow water hazard (e.g., point bar, mid-channel bar, shallow sand or gravel bar) are included in the GRI GIS data (map chsh; see GRI poster) along the length of the park (Hundley 2014). The park's website (https://www.nps.gov/chat/planyourvisit/conditions.htm) has current information for planning a visit, including water release schedules, river flow rates, flooding, and weather.

Seismicity

Seismicity or earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensities range from being imperceptible by humans to complete destruction of developed

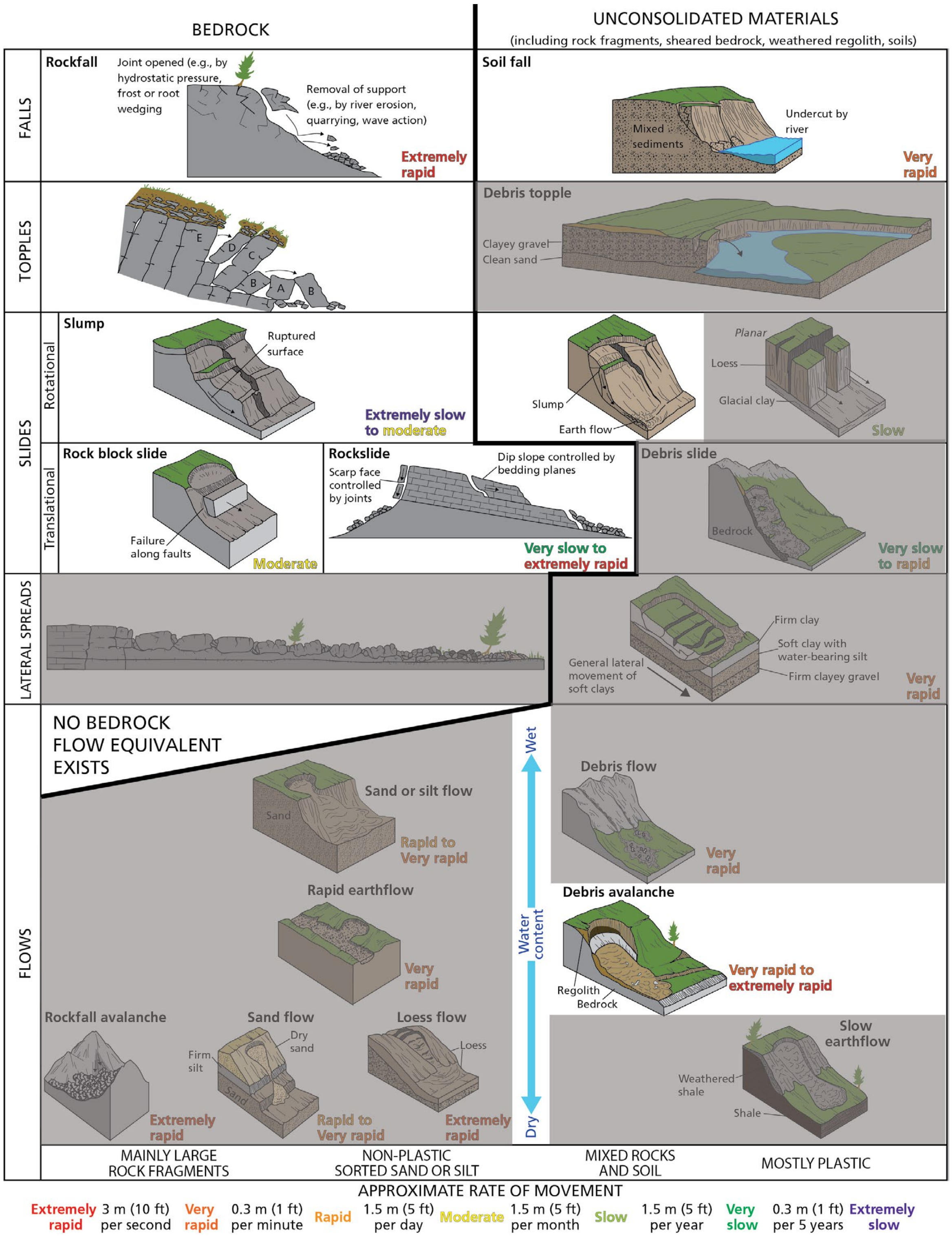

Figure 33. Illustrations of varieties of slope movements.
Categories of slope movements are defined by material type, nature of the movement, rate of movement, and moisture content. Bedrock falls, topples, slides, as well as soil falls, unconsolidated slumps, and debris avalanches are possible at the park. Grayed areas depict conditions unlikely to exist at Chattahoochee River National Recreation Area. 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 and climate change. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

areas and alteration of the landscape. The "Richter magnitude" is a measure of the energy released by an earthquake; another way to measure earthquake intensity is via the Mercalli scale, which notes the types of damage an earthquake may cause. Earthquakes can directly damage park infrastructure or trigger other hazards, such as slope movements, that may impact park resources, infrastructure, or visitor safety.

Based on the National Seismic Hazard Model (Petersen et al. 2019), the park is in an area of moderate seismic hazard (see fig. 34). According to the US Geological Survey's earthquake hazard catalog for Georgia, (https://www.usgs.gov/programs/earthquake-hazards/science/information-region-georgia), since 1983, about 10 earthquakes have occurred within a 60 km (40 mi) radius around the park (see fig. 35). These range in magnitude from 2.0 to 2.7. Earthquakes with magnitudes between 2 and 3 are common as "microseismicity" when crustal adjustments happen on very old faults (Robby Morrow, South Carolina Geological Survey, field geologist, conference call, 18 December 2019).

The Chattahoochee River flows along the Brevard Zone in the park. Many individual faults splay from or trend along (parallel) the Brevard Zone. Near Chattahoochee River National Recreation Area, geologists mapped the Oakdale, Long Island, Rivertown, and Ball Mill faults (Higgins et al 2003). Kath and Crawford (2001) described the Frolona and Long Island faults during bedrock mapping associated with the Chattahoochee Tunnel project (see "Chattahoochee Tunnel" section). Because the Brevard Zone transects portions of both the Appalachian Piedmont and Southern Blue Ridge Mountains physiographic provinces, some tectonic activity is still occurring in the park area. The Earth & Atmospheric Sciences Department at Georgia Tech in Atlanta monitors earthquake activity in Georgia. Earthquakes are occasionally felt in the national recreation area but have not been sources of structural damage or particular hazards to people (KellerLynn 2012).

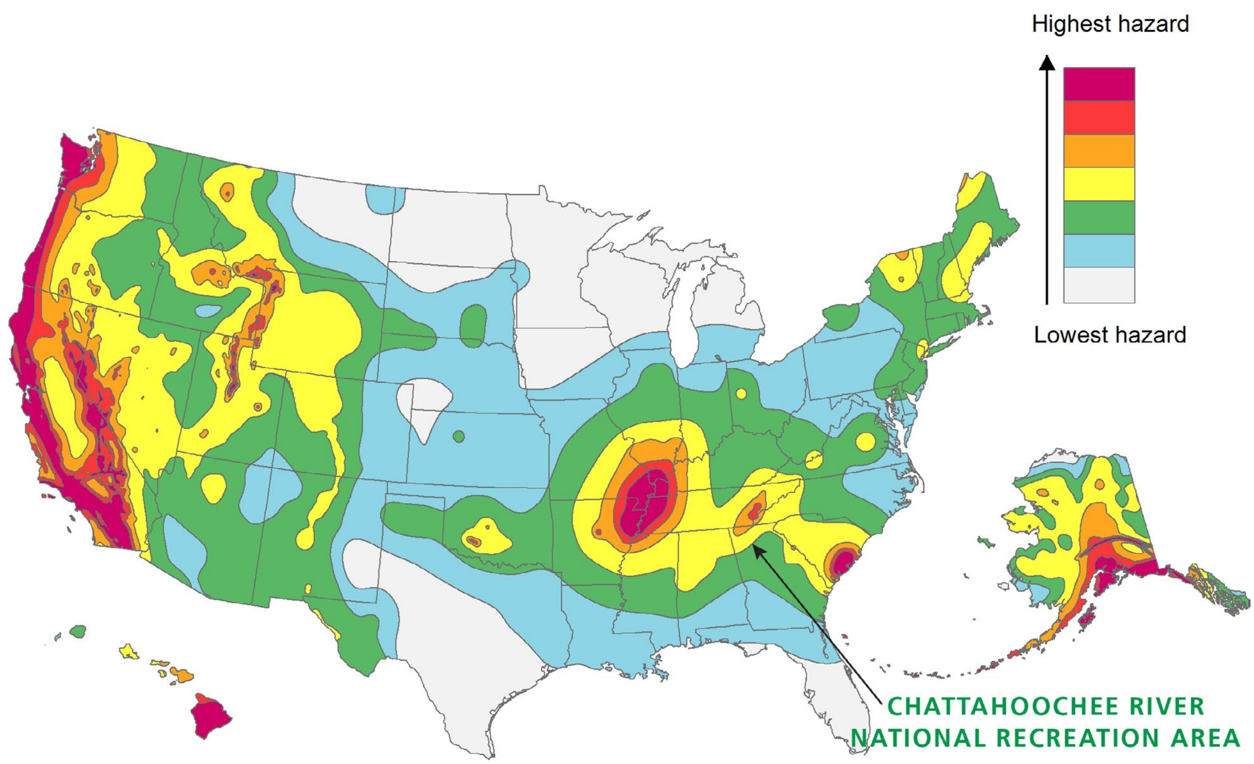

Figure 34. National seismic hazard map.
Maps of earthquake shaking hazards provide information essential to creating and updating the seismic design provisions of building codes and insurance rates used in the United States. The map shows predicted earthquake hazards across the United States for the next 50 years based on the most recent National Seismic Hazard Models (2018 for the conterminous US, 2007 for Alaska, and 1998 for Hawaii). The models are 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 (particularly unconsolidated sediment) may amplify ground motion. Northern Georgia is near the East Tennessee Seismic Zone and has low to moderate probability of seismicity in the yellow-colored band. US Geological Survey map (public domain).

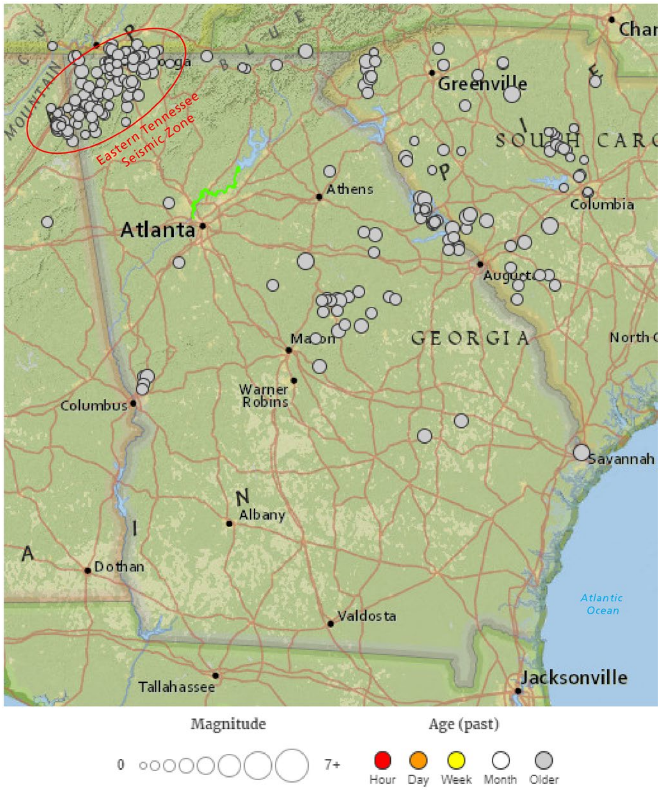

Figure 35. Map of Georgia showing earthquake epicenters since 1990.
Seismicity occurs along a fault where stored energy is released suddenly as the fault slips and the two blocks of the Earth's crust on either side of the fault, slide past each other. Chattahoochee River National Recreation Area (bright green line) is about 150 km (90 mi) southeast of the very active Eastern Tennessee Seismic Zone, which spans the northwestern corner of Georgia and the edges of Alabama and Tennessee. Graphic is courtesy of the US Geological Survey (https://www.usgs.gov/programs/earthquake-hazards/science/information-region-georgia; accessed 2 August 2022; click on "All Earthquakes 1900-Present" under the "Seismicity and Hazard" heading) with labels added by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Hazards Management

Slope movements create geologic hazards and associated risk in many parks, including Chattahoochee River National Recreation Area. A slope-movement assessment has not yet been conducted for the park. Potential information to gather might include data associated with slope-movement material and mechanism, movement date, activity level, hazard rating, slope elevations, slope geomorphology, deposit dimensions, damage or impacts, associated geologic map unit, associated geologic structures (e.g., faults or bedding), slope vegetation, and movement history (North Carolina Geological Survey 2008). If funding permits, resource managers could consider obtaining quantitative information to assess the frequency and magnitude of rockfall (and other slope movements) in high visitation areas. A photomonitoring program is one possibility. The SIP program is an option to support such a project. The NPS Geologic Resources Division Photogrammetry website (http://go.nps.gov/grd_photogrammetry) provides examples of how photographic techniques support structural analysis of rockfall areas. The Unstable Slope Management Program—a cooperative effort among the National Park Service, Federal Highways, University of Montana, and others—created and is populating a central database of unstable slopes with ranking. This database will support an unstable slope management tool to allow prioritization of mitigation to reduce slope hazard risks (see Bilderback et al. 2017). The slopes of Chattahoochee River National Recreation Area are ideal candidates for inclusion in the effort. In the *Geological Monitoring* chapter about slope movements (Wieczorek and Snyder 2009) described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks. Park managers can contact the Geologic Resources Division to discuss these options and determine if submitting a technical request is appropriate. Further information about slope movements is provided in "Guidance for Resource Management."

The Brevard Zone and associated faults mapped in the park have not been active for many millions of years; however, they are discontinuities in Earth's crust and reactivation during the crustal adjustments is possible. The Brevard fault (Zone) warranted notice in a recent environmental assessment (Lester 2020) wherein alternatives for a sewer diversion proposal were discussed with regards to potential blasting or drilling through the fault. The assessment treated the fault as a single structure rather than a zone of many parallel to subparallel faults. As urban and suburban developments associated with the population center of Atlanta continue, ground disturbing activities (e.g., drilling, blasting, deep injection) should always consider the location of geologic features such as the Brevard Zone and other faults.

Slope movements and earthquakes may be monitoring targets. In the *Geological Monitoring* chapter about slope movements, Wieczorek and Snyder (2009) described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks. In the Geological Monitoring chapter about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

Additional Geologic Hazards Information

- NPS Geologic Resources Division Geohazards website (http://go.nps.gov/geohazards).
- US Geological Survey Earthquakes Hazards website (http://earthquake.usgs.gov/)
- Natural hazards science strategy: Holmes et al. (2013).
- Landslide hazards and climate change: Coe (2016).
- US Geological Survey Landslides website (http://landslides.usgs.gov/).

Paleontological Resource Inventory, Monitoring, and Protection

Fossils in NPS areas are found in situ in rocks or unconsolidated deposits, in museum collections, and in cultural contexts such as building stones or archeological resources. All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (see "Geologic Resource Laws, Regulations, and Policies").

A variety of publications and resources provide park-specific or servicewide information and paleontological resource management guidance. For example, in the *Geological Monitoring* chapter about paleontological resources, Santucci et al. (2009) described 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. The NPS Geologic Resources Division has a website devoted to paleontological resources: https://www.nps.gov/subjects/fossils/index.htm. Kenworthy and Santucci (2006) presented a summary of National Park Service fossils in a cultural resource context. The literature-based network paleontological inventory prepared by Tweet et al. (2009) recommended: (1) park staff be encouraged to observe surface deposits for fossil material and document any discoveries with photographs; (2) fossils found in a cultural context be documented but also seek input from archeologists; (3) contact the NPS Geologic Resources Division for assistance regarding paleontological resource management or interpretation.

A field-based paleontological resource survey has not been completed for Chattahoochee River National Recreation Area but could provide detailed, site-specific descriptions and resource management recommendations. Field work could be accomplished by establishing a cooperative agreement with one or more of the local natural history museums with paleontological/archeological expertise, such as the Georgia Museum of Natural History at University of Georgia, Athens, Georgia. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions or potentially use the SIP program (see "Guidance for Resource Management").

Climate Change

Although climate change planning is beyond the scope of this GRI report, a discussion of climate change is included because of the potential disruption it may cause to the park's resources, including geologic resources. 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 climate is warm, humid, and temperate. Predicted climate change trends will impact the ecosystem at Chattahoochee River National Recreation Area. The Intergovernmental Panel on Climate Change (IPCC) has projected that temperature in the southeastern US will increase 2.2 to 5.0°C (4 to 9°F) by 2080 (Karl et al. 2009; Burkholder et al. 2017). Since 1970, average annual temperatures in the southeast, including the Atlanta area, have increased by 1.1°C (2°F) (Karl et al. 2009, Fisichelli 2013, Kunkle et al. 2013; Burkholder et al. 2017). Climate change models suggest that there will be heavier downpours interspersed with increased droughts between storm events—conditions apt to increase the risk of flooding, stormwater runoff problems, and drought (Karl et al. 2009, GRI conference call participants, conference call, 24 August 2021). According to Monahan and Fisichelli (2014), ongoing and future changes in climate will affect all aspects of park management including natural resource protection, park operations, and visitor experience. Understanding the triggers and outcomes of these changes is crucial to protecting the natural and cultural resources at the park.

Chattahoochee River National Recreation Area is not yet part of the "Climate Friendly Park" Program (see https://www.nps.gov/subjects/climatechange/cfpprogram.htm). This program's goals are: (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; 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.

Additional Climate Change Information

- Climate change trends for the United States and U.S. national parks by Gonzalez et al. (2018).
- Warming and effects on visitation to Chattahoochee River National Recreation Area by Fisichelli and Ziesler (2015).
- Recent climate change exposure and stressors in eastern national park forests by Fisichelli et al. (2015).
- The NPS Southeast Coast Inventory & Monitoring Network currently inventories and monitors natural resources such as climate, species, wadeable streams, vegetation communities, amphibians, and land birds (https://www.nps.gov/im/secn/index.htm).

Additional Geologic Information Needs

Some features, though cultural in origin, are now part of the surficial landscape at Chattahoochee River National Recreation Area. They are important for understanding the history of the park, as well as landform change through time. These features include Civil War earthworks (trenches, forts, redoubts, batteries, etc.), family (gold) mining prospects, and prime and unique farmlands (GRI conference call participants, conference call, 24 August 2021). Detailed surficial geologic mapping in targeted areas may reveal previously unknown cultural resources and would provide a foundation for a cultural and natural resources geodatabase. The park also fields questions regarding dredging operations and permitting but sparse data about the impacts of these operations exist for the park resource managers (see "Dredging" section; Allyson Reed, Chattahoochee River National Recreation Area, biologist, written communication, 13 April 2022).

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) portal: https://irma.nps.gov/. Enter "GRI" as the search text and select a park from the unit list.
- Additional information regarding the GRI, including contact information: https://www.nps.gov/subjects/geology/gri.htm

Four Ways to Receive Geologic Resource Management Assistance

- Contact the NPS Geologic Resources Division (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. Park managers can formally request assistance via https://irma.nps.gov/Star/.
- 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 (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 Geologic Resources Division 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.
- Refer to *Geological Monitoring* (Young and Norby 2009), which provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Chapters are available online at https://www.nps.gov/subjects/geology/geological-monitoring.htm.

Park Documents

The park's foundation document (National Park Service 2017), an assessment of water resources and watershed conditions (Burkholder et al. 2010), and a wadeable stream habitat monitoring guide (McDonald et al. 2019) are primary sources of information for resource management within the park. Cultural landscape restoration, administration, and management are addressed in a number of publications including Brown (1980), Byrd (2009), Wheeler-Byrd (2011), Gerdes and Messer (2007). A cultural resource management plan for each cultural resource complex was noted as a planning need by National Park Service (2017).

Geologic information specific to the park area is available from the following sources:

- Hatcher (2005) discussed the geologic history of the southern Appalachians.
- Higgins et al. (1988) discussed southern Appalachian structure, stratigraphy, and geologic history.
- The Environmental Protection Division of Georgia hosts the Georgia Geological Survey (no longer active) publications at https://epd.georgia.gov/outreach/publications.

- The New Georgia Encyclopedia website has detailed descriptions of the geologic provinces across the state and the geologic history at https://www.georgiaencyclopedia.org/topics/geology.
- DeVivo (2008) summarized natural resource issues for all the NPS units in the Southeast Coastal Network.
- The NPS Southeast Coast Inventory & Monitoring Network currently inventories and monitors natural resources such as climate, species, wadeable streams, vegetation communities, amphibians, and land birds (https://www.nps.gov/im/secn/index.htm).

NPS Natural Resource Management Guidance and Documents

- NPS Management Policies 2006 (Chapter 4: Natural Resource Management): https://www.nps.gov/policy/index.cfm
- National Parks Omnibus Management Act of 1998: https://www.congress.gov/bill/105th-congress/senate-bill/1693
- Natural Resources Inventory and Monitoring Guideline (NPS-75): https://irma.nps.gov/DataStore/Reference/Profile/622933
- Natural Resource Management Reference Manual #77 (NPS-77): https://irma.nps.gov/DataStore/Reference/Profile/572379
- Resist-Accept-Direct (RAD)—A Framework for the 21st-Century Natural Resource Manager: https://doi.org/10.36967/nrr-2283597

Geologic Resource Laws, Regulations, and Policies

The following table (table 6), which was developed by the NPS Geologic Resources Division, summarizes laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

Table 6. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims (Locatable Minerals)	**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.	**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.	**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.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Caves and Karst Systems	**Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/ Agriculture to identify "significant caves" on Federal lands, regulate/ restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources. **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.	**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.	**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 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.
Recreational Collection of Rocks Minerals	**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).	**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. **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.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq.** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**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.	**Section 4.8.2.4** requires NPS to -prevent unnatural erosion, removal, and contamination; -conduct soil surveys; -minimize unavoidable excavation; and -develop/follow written prescriptions (instructions).
Geothermal	**Geothermal Steam Act of 1970, 30 USC. § 1001 et seq.** as amended in 1988, states -No geothermal leasing is allowed in parks. -"Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead). -NPS is required to monitor those features. -Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects. **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.		**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.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	None Applicable.	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change. **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.
Nonfederal Oil and Gas	**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.)	**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 outside of Alaska to -demonstrate bona fide title to mineral rights; -submit an Operations Permit Application to NPS describing where, when, how they intend to conduct operations; -prepare/submit a reclamation plan; and -submit a bond 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.	**Section 8.7.3** requires operators to comply with 9B regulations.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil, Gas, and Solid Minerals)	**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 GLCA, which is the only park unit that contains a STSA. **Exceptions**: Glen Canyon NRA (**16 USC § 460dd et seq.**), Lake Mead NRA (**16 USC § 460n et seq.**), and Whiskeytown-Shasta-Trinity NRA (**16 USC § 460q et seq.**) authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. **American Indian Lands Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108,** all minerals on American Indian trust lands within NPS units are subject to leasing. **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.	**36 CFR § 5.14** states prospecting, mining, and… leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing. **Regulations re: Native American Lands within NPS Units:** **25 CFR Part 211** governs leasing of tribal lands for mineral development. **25 CFR Part 212** governs leasing of allotted lands for mineral development. **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development. **25 CFR Part 224** governs tribal energy resource agreements. **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**). **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases. **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases. **30 CFR §§ 1206.50-1206.62** and **§§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases. **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases. **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.	**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.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**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.	**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.	**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.
Nonfederal minerals other than oil and gas	**NPS Organic Act, 54 USC §§ 100101 and 100751**	**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 **§ 5.3** business operation, and **§ 5.7** – Construction of buildings or other facilities, and to comply with the solid waste regulations at **Part 6**.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1** and **5**.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coal	**Surface Mining Control and Reclamation Act 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.	**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.	None Applicable.
Uranium	**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.	None Applicable.	None Applicable.
Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)	**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.	None applicable.	**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 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.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1)**	None applicable.	**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.

Table 6, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coastal Features and Processes	**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.	**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.	**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.

Additional References, Resources, and Websites

Georgia Geology

- Georgia Geological Society: https://www.westga.edu/~ggsweb/

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- NPS Sea Level Rise Map Viewer: https://maps.nps.gov/slr/
- NPS Climate Change, Sea Level Change website: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- NPS Policy Memorandum 12-02 Applying NPS Management Policies in the Context of Climate Change: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Policy Memorandum 15-01 Addressing Climate Change and Natural Hazards for Facilities: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm

- US Global Change Research Program: http://www.globalchange.gov/home

Earthquakes

- ShakeAlert: An Earthquake Early Warning System for the West Coast of the United States (USGS sponsored): https://www.shakealert.org/
- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/

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
- UNESCO Global Geoparks: https://en.unesco.org/global-geoparks
- U.S. Geoheritage & Geoparks Advisory Group: https://www.americasgeoheritage.com/

Geologic Maps

- The 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)
- National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geological Surveys and Societies

- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

Geology of National Park Service Areas

- NPS Geologic Resources Division (Lakewood, Colorado) Energy and Minerals; Active Processes and Hazards; Geologic Heritage: http://go.nps.gov/geology
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscience Concepts website: https://www.nps.gov/subjects/geology/geology-concepts.htm

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 Landslide*s (Highland and Bobrowsky 2008): http://pubs.usgs.gov/circ/1325/
- Unstable Slope Management Program for transportation corridor risk reduction: https://usmp.info/client/credits.php

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) portal: https://irma.nps.gov/. *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.

Relevancy, Diversity, and Inclusion

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

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/2190427. Note: The PDF is contained within SRI_Detailed_Soils.zip, which also contains an index map of parks where SRIs have been completed. Download and extract all files.

US Geological Survey Reference Tools

- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- Geographic Names Information System (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- US Geological Survey Store (find maps by location or by purpose): http://store.usgs.gov
- USGS Publications Warehouse: http://pubs.er.usgs.gov
- Tapestry of Time and Terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

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These references are cited in this report. Contact the Geologic Resources Division for assistance in obtaining them.

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