National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Little River Canyon National Preserve

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2469

ON THE COVER
Photograph of Mushroom Rock. The Pennsylvanian Pottsville Formation, which is composed of sandstone, has been long exposed to erosion. The wearing away of the rock along cracks and fractures may leave pinnacles isolated in place, anchored from the top by an erosion resistant layer. Pinnacles in various stages of weathering create interesting shapes and forms throughout the preserve. NPS photograph courtesy of Little River Canyon National Preserve.

THIS PAGE
Photograph of Graces High waterfall. An unnamed creek (sometimes referred to as Graces Creek for reference) plunges over erosion-resistant sandstone ledges in the Pennsylvanian Pottsville Formation to create the highest waterfall in Alabama. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

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Executive Summary

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

The Little River flows through one of the most extensive canyon and gorge systems in the southeastern United States. Slicing through the backbone of Lookout Mountain, the Little River is the country's longest mountain-top river. Little River Canyon National Preserve (referred to as the "preserve" throughout this report) encompasses forested rolling uplands, narrow river bottoms, forking tributaries, sandstone glades, vegetated ravines, imposing cliffs, and cascading waterfalls in Cherokee and DeKalb Counties, Alabama. Little River Canyon National Preserve was established in 1992 to protect and provide for the enjoyment of its scenery, ecology, and history. Annually, about 400,000 visitors enjoy the natural and cultural resources the preserve has to offer.

Geologic features and processes affect nearly every facet of the natural environment of the preserve as well as its long and rich human history. The Little River and its tributaries have cut into mid-to-late Paleozoic sedimentary bedrock of Lookout Mountain for millions of years. The preserve's bedrock records a geologic history beginning more than 320 million years ago when much of Alabama was flooded by a shallow epicontinental sea. The sea transgressed (rose) and regressed (fell) many times with accompanying rivers and nearshore environments. This resulted in the deposition of the mix of limestone, clay, silt, sand, and gravel that compose the preserve's stack of bedrock. The bedrock was deformed (uplifted, folded, and faulted) during the orogenies (mountain-building events) that culminated in the Appalachian Mountains and the formation of a supercontinent more than 250 million years ago. Since that time, the supercontinent broke apart, and weathering and erosion have beveled the mountains. River incision, slope movements, and weathering and erosional processes continue to modify and affect the Little River Canyon National Preserve landscape.

This report is supported by a GRI-compiled digital map (GIS data) and poster of the geology of Little River Canyon National Preserve. The GRI GIS data were compiled in 2020. The GRI GIS data may be updated if new, more accurate geologic maps become available or if software advances require an update to the digital format.

To create a geologic map with coverage of the entirety of the preserve lands, the GRI team compiled six separate quadrangle maps published by the Geological Survey of Alabama and Auburn University. A poster (printable PDF document) illustrates the GRI GIS data draped over shaded relief imagery of the area.

Geologic units will be referenced in this report using map unit symbols. Individual bedrock and surficial units are included in the poster's legend and in the GRI GIS data. For example, the Pottsville Formation is map unit **PNpv**. The GRI GIS data and poster are available for download on the GRI publications website (see "Access to GRI Products").

The GRI report consists of the following six chapters:

Introduction to the Geologic Resources Inventory—This chapter provides background information about the Geologic Resources Inventory (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 highlights the six source maps used by the GRI team in compiling the GRI GIS data for the preserve and provides specific information about the use of these data. It also calls attention to the poster that illustrates these data.

Geologic Heritage of Little River Canyon National Preserve—This chapter highlights the significant geologic features, landforms, landscapes, and stories of the preserve protected for their heritage values. It describes the geologic setting and chronology of geologic events that formed the present landscape. It also draws connections between geologic resources and other preserve resources and stories.

Geologic Features and Processes—This chapter describes the geologic features and processes of significance for the preserve and highlights them in a context of geologic time. The features and processes are discussed whenever feasible in order of geologic time, oldest to youngest. Following general descriptions of these features and processes, a table provides a detailed look at which features and/or processes pertain to each geologic map unit included in the GRI GIS data. The table presents the units in stratigraphic order with the oldest bedrock on the bottom and the youngest surficial units on the top.

Geologic Resource Management Issues—This chapter discusses management issues related to the preserve's geologic resources (features and processes). Issues are discussed in order of management priority (when such ranking exists) and related to geologic map units in the GRI GIS data.

Guidance for Resource Management—This chapter follows and is a follow up to the "Geologic Resource Management Issues" chapter. It provides resource managers with relevant references and links to data and resources that provide guidance in making science-based decisions.

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 preserve 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. Preserve 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. Most inventories were point-in-time surveys to learn about the location or condition of resources, including the presence, distribution, or status of plants and animals, air, water, soils, landforms, and climate, and were completed by 2010, but several of the more extensive or complex inventories, such as vegetation and geology, are still in progress in some parks.

GRI Products

Starting in 2009, the GRI team—which is primarily a collaboration between staff at the National Park Service, Geologic Resources Division, and Colorado State University, Department of Geosciences—completed the following tasks as part of the GRI for Little River Canyon National Preserve (referred to as the "preserve" throughout this report): (1) conduct a scoping meeting and provide a scoping summary, (2) provide digital geologic map data in a geographic information system (GIS), (3) create a poster to display the GRI GIS data, and (4) provide a GRI report (this document). GRI products—GIS data, map posters, scoping summaries, and reports—are available on the "Geologic Resources Inventory—Products" website and through the NPS Integrated Resource Management Applications (IRMA) portal (see "Access to GRI Products").

GRI Scoping Meeting

On 25–26 March 2009, the National Park Service held a scoping meeting at Fort Oglethorpe, Georgia, followed by a site visit to the preserve. The scoping meeting brought together preserve staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report. A scoping summary (Thornberry-Ehrlich 2009) summarizes the findings of that meeting.

GRI GIS Data and Poster

Following the scoping meeting, the GRI team compiled the GRI GIS data for the preserve. The data was compiled by the GRI in 2020. 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 team compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data from six source maps (see "Geologic Map Data"). A geologic map poster illustrates these data. Because these data are the principal deliverable of the GRI, a more detailed description of the product is provided in the "Geologic Map Data" section.

GRI Report

On 5 May 2020, the GRI team hosted a follow-up conference call for preserve staff and interested geologic experts. The call provided an opportunity to get back in touch with preserve 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 2020, and additional geologic research. Selection of geologic features discussed in the report was guided by the previously completed GRI map data, and writing reflects the data and interpretation of the source map authors. In addition, the preserve's foundation document (National Park Service 2016b) helped guide the writing of the GRI report; applicable information, as related to the preserve's geologic resources and resource management, was included.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here.

Geologic Map Data

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

Introduction to Geologic Maps

Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). The colors on a geologic map indicate the rocks or deposits. In addition to color, map unit symbols delineate rocks and their ages on geologic maps. Usually, a map unit symbol consists of an uppercase letter indicating age (e.g., **C** for Cambrian, **OC** for Ordovician and Cambrian, **O** for Ordovician, **S** for Silurian, **D** for Devonian, **M** for Mississippian, **PN** for Pennsylvanian, **T** for Tertiary, and **Q** for Quaternary) and lowercase letters indicating the rock formation's name or the type of deposit (e.g., **pv** for Pottsville Formation). In geologic terminology, a formation is the fundamental rock-stratigraphic unit, meaning it is mappable (at a particular scale), lithologically distinct (with respect to rock type and other characteristics such as color, mineral composition, and grain size) from adjoining strata, and has a definable upper and lower contact (surface between two types or ages of rocks). A formation can be divided into "members" or combined into a "group." Other symbols on geologic maps depict the contacts between map units or structures such as faults or folds (see "Faults, Folds, and Joints" section with explanatory figures). Some map units, such as landslide deposits, delineate locations of past geologic hazards, which may be susceptible to future activity. Geologic maps also may show human-made features, such as wells or mines.

Geologic maps are generally one of two types: bedrock or surficial. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, or igneous rocks. Bedrock map units are generally differentiated based on age and rock type. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (Quaternary Period). Geomorphic surfaces, geologic processes, or depositional environments differentiate surficial geologic map units. The digital geologic map for the preserve includes bedrock geologic data but only alluvium (**Qal**) for surficial geologic units.

Source Maps

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

The GRI team compiled the following six maps into the GRI GIS data for the preserve (fig. 1):

- Geologic map of the Dugout Valley 7.5' quadrangle, Dekalb County, Alabama, by Irvin et al. (2018c).
- Geologic map of the Fort Payne 7.5' quadrangle, DeKalb and Cherokee Counties, Alabama, and Chattanooga and Walker Counties, Georgia, by Irvin et al. (2018a).
- Geology of the Gaylesville 7.5' quadrangle, Cherokee County, Alabama, by Cook et al. (2019).
- Bedrock geologic map of the Jamestown 7.5' quadrangle, DeKalb and Cherokee Counties, Alabama, and Chattanooga and Walker Counties, Georgia, by Ma and Steltenpohl (2018a).
- Bedrock geologic map of the Little River 7.5' quadrangle, DeKalb and Cherokee Counties, Alabama, by Ma and Steltenpohl (2018b).
- Geologic map of the Valley Head 7.5' quadrangle, DeKalb and Cherokee Counties, Alabama, and Chattanooga and Walker Counties, Georgia, by Irvin et al. (2018b).
- The data was compiled by the GRI in 2020. The compiled GRI GIS data of the entire preserve have the four-letter code, liri. The GRI team also compiled data for the six individual quadrangle maps: Dugout Valley (duva), Valley Head (vahe), Fort Payne (fopa), Jamestown (jmst), Little River (lirv), and Gaylesville (gayl), north to south, respectively (see fig. 1). 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.

GRI Geodatabase Model and Data Set

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for the preserve were compiled using data model version 2.3, which is available online (see "Access to GRI Products"). 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 on IRMA (see "Access to GRI Products"). 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.

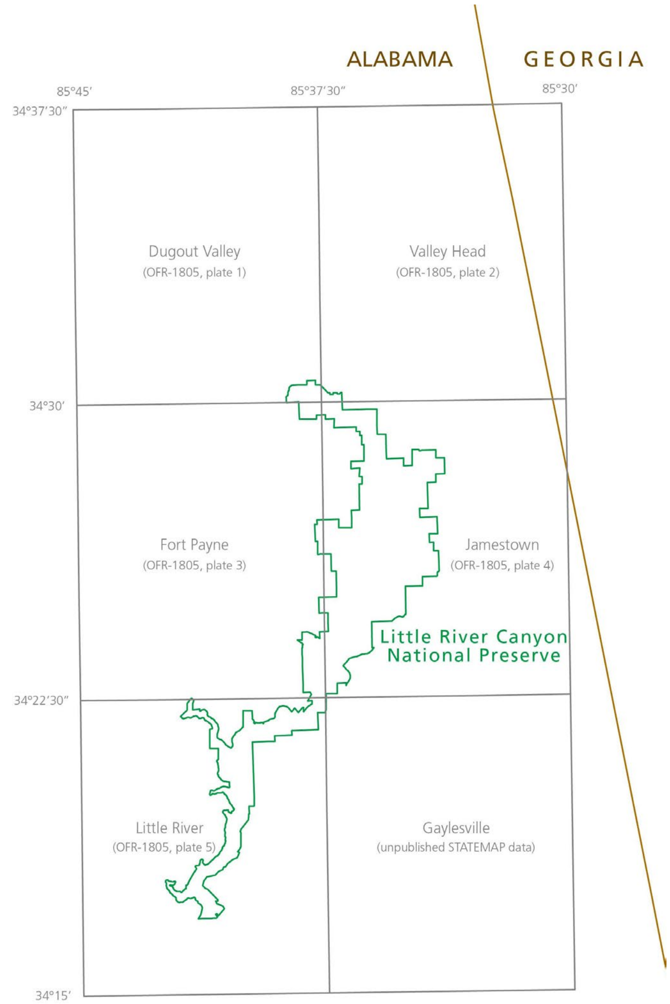

Figure 1. Index map of the GRI GIS data. Green outline is the preserve boundary. Brown line is the Alabama–Georgia state line. The compiled map for the preserve contains data from six source maps: Dugout Valley, Valley Head, Fort Payne, Jamestown, Little River, and Gaylesville 7.5' quadrangles. These source maps encompass the entire preserve and some surrounding area. Quadrangle names correspond to individual source maps for the GRI GIS data and are referenced in this report. Graphic by James Winter and Stephanie O'Meara (Colorado State University).

GRI Geologic Map Poster

A poster of the GRI GIS data draped over a shaded relief image of the preserve and surrounding area are the primary figures referenced throughout this GRI report. 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 poster (table 1). Geographic information and selected preserve 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.

Use Constraints

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

Acknowledgements

The GRI team thanks the participants of the 2012 scoping meeting and 2020 follow-up conference call for their assistance in this inventory. The lists of participants reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the Geological Survey of Alabama and Auburn University for their maps of the area. This report and accompanying GIS data could not have been completed without them. Thanks also to Mary Shew, Steve Black, Johnathan Jernigan, Ed Osborne, Dan Irvin, and Steve Thomas for their local knowledge contributions. Johnathan Jernigan, Justin Tweet, Patricia Seiser, Mike Martin, Timothy Henderson, and Jack Wood also provided subject matter review contributions.

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Table 1. GRI GIS data layers for Little River Canyon National Preserve.

Data Layer	On Poster?
Geologic Cross Section Lines	No
Geologic Attitude Observation Localities	No
Geologic Observation Localities	No
Folds	Yes
Faults	Yes
Linear Geologic Units	Yes
Geologic Contacts	Yes
Geologic Units	Yes

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Geologic Heritage of Little River Canyon National Preserve

Forested rolling uplands, narrow river bottoms, sandstone glades, leafy ravines, imposing cliffs, and cascading waterfalls make Little River Canyon National Preserve a natural gem and one of the most extensive canyon and gorge systems in the eastern United States. This chapter highlights the significant geologic features, landforms, landscapes, and stories of Little River Canyon National Preserve protected for their heritage values. It also draws connections between geologic resources and other preserve resources and stories.

Preserve Establishment

Little River Canyon, carved by the nation's longest mountain-top river, is the highlight of some of the most rugged scenery in the southeastern United States (National Park Service 2016a). Managed in partnership with the Alabama State Parks system, Little River Canyon National Preserve was established on 21 October 1992 (Public Law 102-427) to protect and preserve the canyon for the enjoyment of its scenery, ecology, and history (National Park Service 2016b). The preserve encompasses about 6,100 ha (15,000 ac) of Cherokee and DeKalb Counties in northeastern Alabama (fig. 2). The preserve is in a semi-rural area; the closest large cities are Chattanooga, Tennessee, 32 km (20 mi) northeast, and Huntsville, Alabama, 32 km (20 mi) northwest. Annual visitation to the park is about 400,000 people.

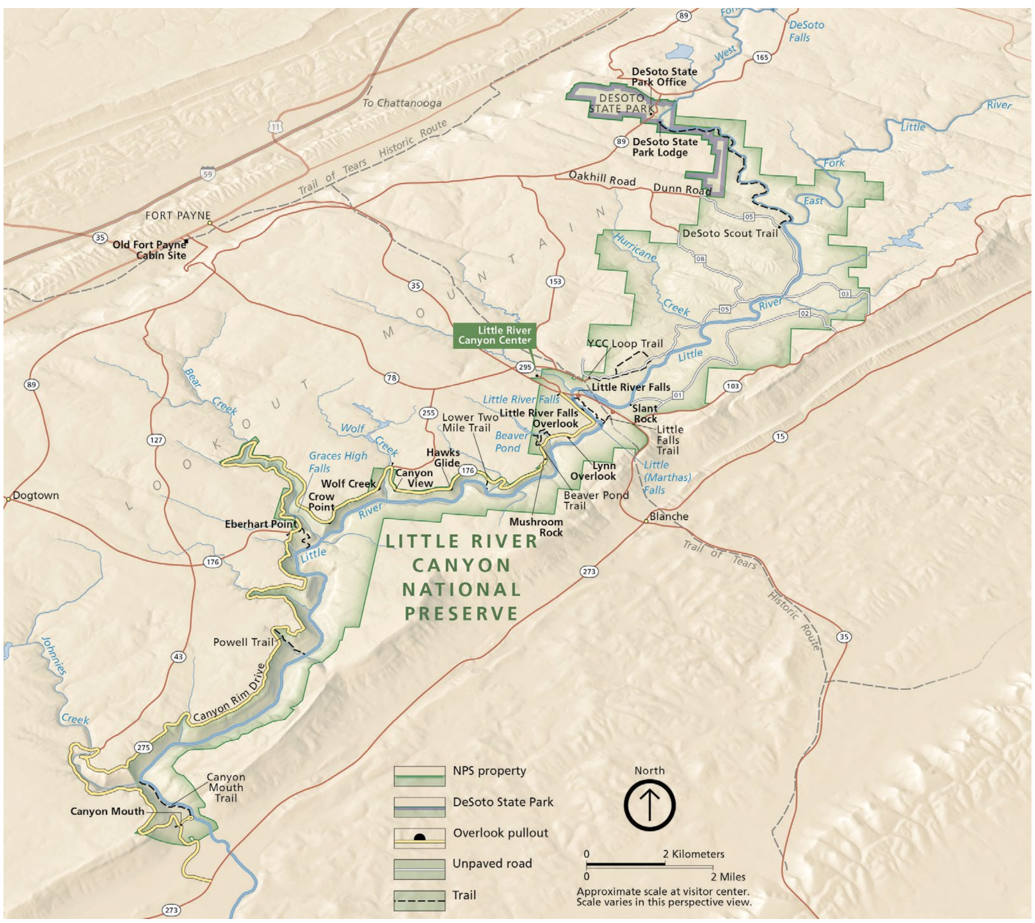


Figure 2. Map of Little River Canyon National Preserve.
The preserve is located in northeastern Alabama along the spine of Lookout Mountain. The preserve has an elongated shape flanking the Little River, its canyon, and a few tributaries such as Bear and Hurricane Creeks. Regional topography strongly follows the northeast to southwest regional trend of the Valley and Ridge Province. The Little River has incised through the erosion-resistant Pottsville Formation (PNpv; see GRI poster) that caps Lookout Mountain. NPS map available at https://www.nps.gov/carto (accessed 8 August 2022). Graphic modified by Trista L. Thornberry-Ehrlich (Colorado State University).

As its name suggests, the preserve's focus is the Little River. The preserve encompasses a 43-km (27-mi) stretch of the Little River and its largest tributaries: Hurricane Creek, Bear Creek, Johnnies Creek, and Yellow Creek. As the river flows, it drains more than 500 km^2 (200 mi^2) of surrounding land while incising the sedimentary bedrock of Lookout Mountain (Rinehart et al. 2011). Because the river is eroding though different types of bedrock, creating steep cliffs through sandstones and carbonates and slopes where more easily eroded shales (soft finely layered rock that formed from consolidated mud and can be split easily into fragile plates) are present, the result is dramatic topography from gently rolling upland areas atop Lookout Mountain to near vertical sandstone cliffs of Little River Canyon.

The river begins where the 40-km- (25-mi-) long West Fork Little River and 27-km- (17-mi-) long East Fork Little River meet (see fig. 2) near the start of the DeSoto Scout Trail that follows the West Fork Little River upstream. From there it flows southwest as a meandering channel until reaching Little River Falls where it cascades through a narrow, steep canyon. After flowing 37 km (23 mi), the Little River emerges from its canyon at Canyon Mouth, having descended 380 m (1,250 ft) from its source to where it joins Weiss Lake reservoir, which is impounded by a dam on the Coosa River at Leesburg, Alabama (Rinehart et al. 2011).

Geologic Setting and History

The preserve's landscape is a function of its geologic history (table 2). The preserve and surrounding area's geologic record spans approximately 500 million years. Beginning in the Cambrian Period and continuing through the Pennsylvanian Period, myriad depositional settings left a complex geologic record that geologists continue to study (fig. 3). Then, hundreds of millions of years ago, Earth's tectonic forces pushed these Paleozoic rocks northwestward during the construction of the Appalachian Mountains, creating folds and faults in the process.

Table 2. 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). National Park Service graphic using dates from International Commission of Stratigraphy (2022).

Era	Period	MYA	Geologic Map Units	Geologic Events
Cenozoic (CZ)	Quaternary (Q)	2.58–today	**Qal** deposited and reworked by the Little River and local tributaries	Fluvial meandering, incision, and deposition. Ice age glaciations. Ongoing erosion and weathering.
Cenozoic (CZ)	Tertiary (T)	66.0–2.58	**Tal** deposited and reworked on the flanks of Lookout Mountain; valley incised by the proto-Little River	Fluctuating sea levels. Meandering rivers. Ongoing erosion and weathering.
Mesozoic (MZ)	Cretaceous (K)	145.0–66.0	Any units deposited during this time were eroded away.	Global mass extinction at end of Cretaceous Period (dinosaurs extinct)
Mesozoic (MZ)	Jurassic (J)	201.3–145.0	Any units deposited during this time were eroded away.	Continued rifting and weathering
Mesozoic (MZ)	Triassic (TR)	251.9–201.3	Any units deposited during this time were eroded away.	Global mass extinction at end of the Triassic Period. Breakup of Pangea began. Atlantic Ocean opened. Sediments began building out the coastal plain.
Paleozoic (PZ)	Permian (P)	298.9–251.9	Any units deposited during this time were eroded away.	Global mass extinction at end of the Permian Period. Supercontinent Pangea intact. Increased sedimentation in the Appalachian basin. The Appalachian Mountains may have rivaled height of modern-day Himalayas.
Paleozoic (PZ)	Carboniferous; Pennsylvanian (PN)	323.2–298.9	**PNpv** deposited in fluvial and coal swamp settings. **PNMpwp** deposited in nearshore to fluvial settings.	Alleghany (Appalachian) Orogeny

Table 2, continued. Geologic time scale.

Era	Period	MYA	Geologic Map Units	Geologic Events
Paleozoic (PZ)	Carboniferous; Mississippian (M)	358.9–323.2	**Mbmt** and **Mfpm** deposited in marine settings	Appalachian basin collects sediment and subsides.
Paleozoic (PZ)	Devonian (D)	419.2–358.9	**Dc** deposited in Appalachian basin	Global mass extinction at end of the Devonian Period. Appalachian basin collected sediment and subsided.
Paleozoic (PZ)	Silurian (S)	443.8–419.2	**Sm** deposited in Appalachian basin	Appalachian basin collected sediment and subsided. Acadian-Neoacadian Orogeny.
Paleozoic (PZ)	Ordovician (O)	485.4–443.8	**Os**, **Oc**, **Oca**, **On**, **Olv** deposited in Appalachian basin	Global mass extinction at end of the Ordovician Period. Uplift and erosion. Taconic Orogeny.
Paleozoic (PZ)	Cambrian (C)	538.8–485.4	**OCk** and **OCchcr** deposited. **Cc** deposited on carbonate platform.	Extensive oceans covered most of proto-North America (Laurentia).
Proterozoic Eon; Neoproterozoic (Z)	n/a	1,000–538.8	None mapped	Supercontinent Rodinia rifted apart.
Proterozoic Eon; Mesoproterozoic (Y)	n/a	1,600–1,000	None mapped	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

The preserve is in the Cumberland Plateau physiographic province of northeastern Alabama—part of the Appalachian Mountain belt, just northwest of the Alabama Valley and Ridge province (fig. 4). The Little River cuts its canyon into Lookout Mountain, which is bordered to the west by Wills Valley and to the east by Shinbone and Broomtown Valleys (Rinehart et al. 2011). Regionally, Lookout Mountain is part of a series of northeast to southwest trending sandstone and shale mountains (e.g., Sand and Blount) with limestone valleys (e.g., Murphrees, Wills, and Sequatchie). Its eastern escarpment marks the eastern boundary of the Cumberland Plateau physiographic province in Alabama with the Valley and Ridge province (see fig. 4; Rinehart et al. 2011).

Paleozoic Era (538.8 million to 251.9 million years ago)—Seas and Mountain Building

At the dawn of the Paleozoic Era, Alabama was covered by a shallow sea (fig. 5). Limestone accumulated in this setting and eventually became the Conasauga Formation (geologic map unit **Cc**), the oldest geologic map unit in the preserve area but buried beneath the rocks in the preserve itself (see figs. 3 and 6; Ma and Steltenpohl 2018). Most of the bedrock layers exposed within the preserve and surrounding area are Paleozoic sedimentary rocks that originated in the Appalachian basin. The Appalachian basin was created when a volcanic arc (a curved chain of volcanoes that develops on the overriding tectonic plate of a subduction zone, formed by magma that rises from the melting of the subducting plate) collided with the eastern edge of North America during the first of three orogenies (the Taconic Orogeny) to construct the Appalachian Mountains (fig. 7) during the Ordovician Period (485.4 million to 443.8 million years ago). As the mountains rose along the collision zone, Earth's crust bowed downwards farther inland (to the west) creating the deep Appalachian basin that would persist for hundreds of millions of years (fig. 7). A warm, shallow sea filled the basin and collected the vast amount of sediment that eroded from the new mountains to the east. With respect to the GRI GIS data (see GRI poster), these sediments became the Knox Group (**OCk**), Chepultepec and Copper Ridge Dolomites (**OCchcr**), Longview Limestone (**Olv**), Newala Limestone (**On**), Chickamauga Limestone (**Oca** and **Oc**), and Sequatchie Formation (**Os**). Alabama was host to a longstanding epicontinental

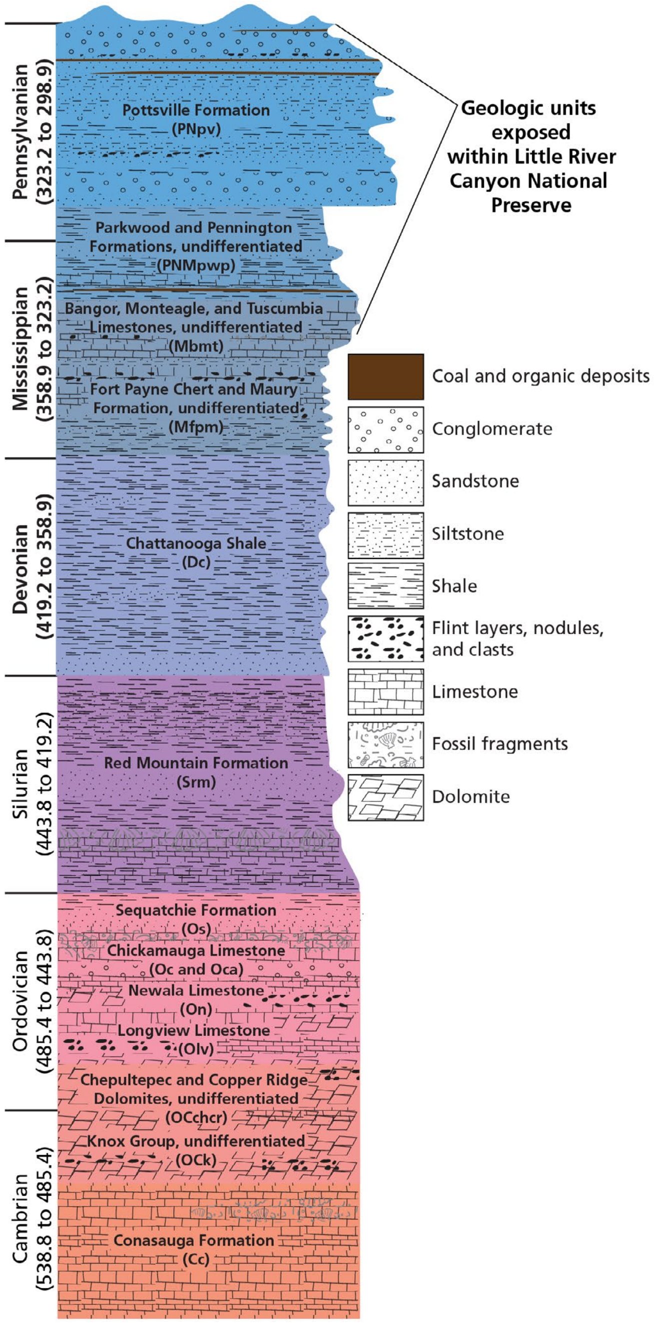


Figure 3. Stratigraphic section of Lookout Mountain. Mississippian and Pennsylvanian sedimentary bedrock underlies much more recent Quaternary surficial deposits. Vertical placement and scale are representative of age only and not spatial proximity or actual unit thickness. Units are from the GRI GIS data (see "Geologic Map Data"). Unit colors are according to US Geological Survey standards for geologic time periods. Numbers refer to age in millions of years. Section is not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from the GRI GIS data.

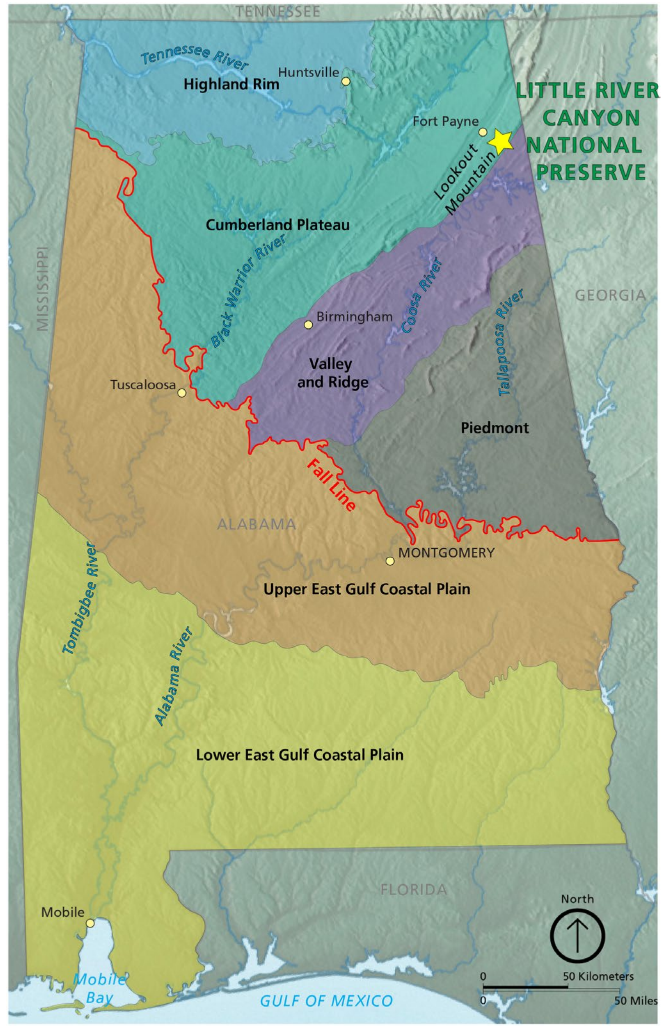


Figure 4. Map of physiographic provinces of Alabama.
Little River Canyon National Preserve (yellow star) is located on the boundary between the Valley and Ridge province and Cumberland Plateau province. The Fall Line (red line) is the low escarpment that parallels the Atlantic coastline from New Jersey to Alabama. This erosional boundary formed along and is juxtaposed between the hard, resistant Paleozoic rocks of the Piedmont, Valley and Ridge, Cumberland Plateau, and Highland Rim provinces and the softer, gently dipping Mesozoic and Cenozoic sedimentary rocks and unconsolidated sediments of the Atlantic and Gulf Coastal Plain province. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after University of Alabama (2007) and Carr (no date). Shaded relief base map by Tom Patterson (National Park Service).

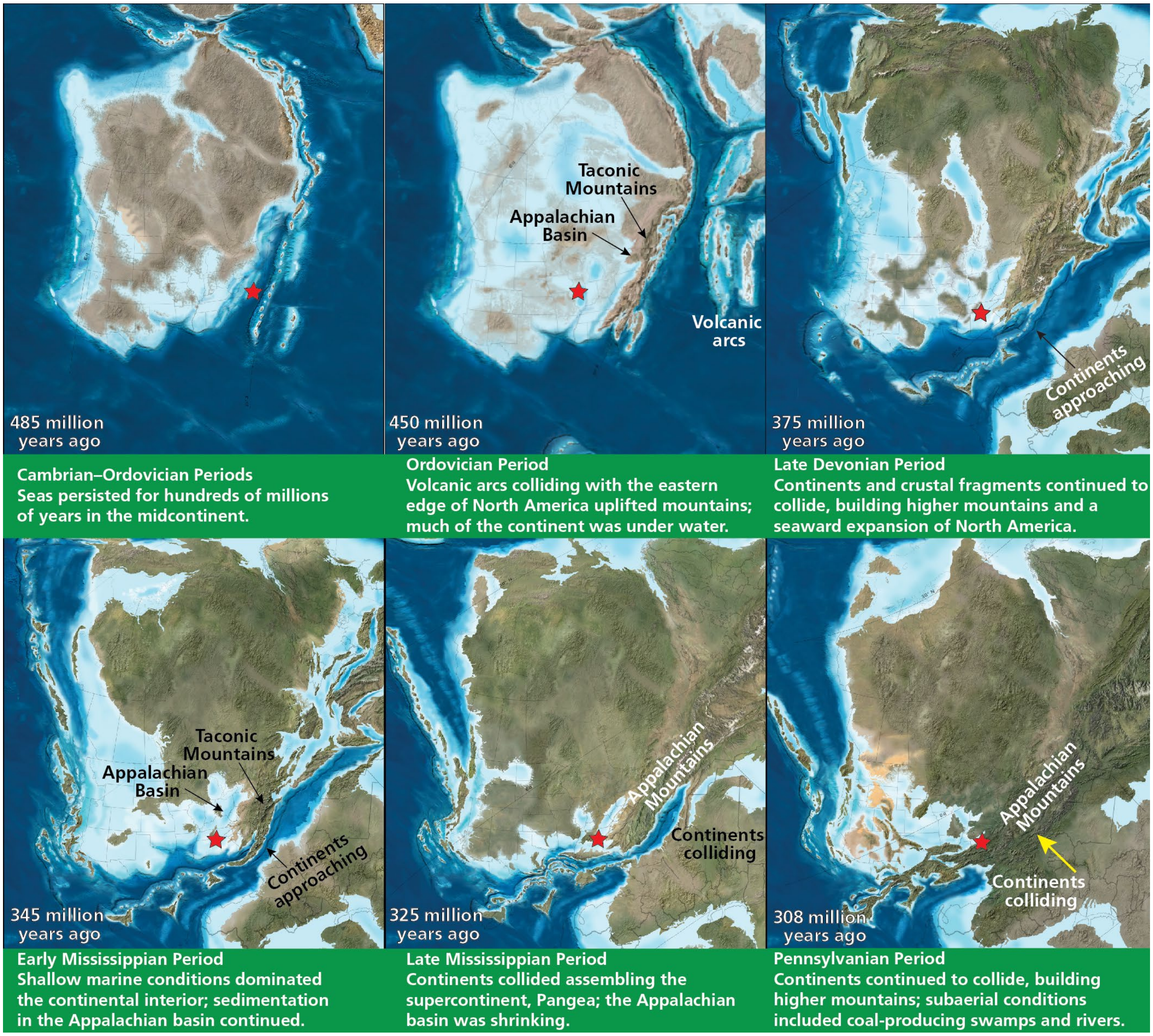


Figure 5. Cambrian–Pennsylvanian paleogeographic maps of North America.
A paleogeographic map represents geographic conditions of Earth's past, including the distribution of land and sea. The red star indicates the approximate location of the preserve. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc.); additional information available at https://deeptimemaps.com/ (accessed 8 August 2022).

sea, southeast of a basement arch—the Nashville dome (uplifted area), which was intermittently exposed and flooded. During the Silurian Period (443.8 million to 419.2 million years ago), mixtures of limy sediment and fine sand collected in the basin to become the Red Mountain Formation (**Srm**). The Little River area was a sheltered bay-like setting with periodically restricted circulation because of its position between the highlands to the east (lifted higher by the second major mountain building event, the Acadian-Neocadian Orogeny 340 million years ago), the ancient Canadian shield (the exposed portion of continental crust at least 1 billion years old) to the north, and the Nashville dome to the west. By the end of the Devonian Period (419.2 million to 358.9 million years ago), the seas had become stagnant and anoxic and accumulated large amounts of black, organic rich mud, eventually lithifying to form the Chattanooga Shale (**Dc**).

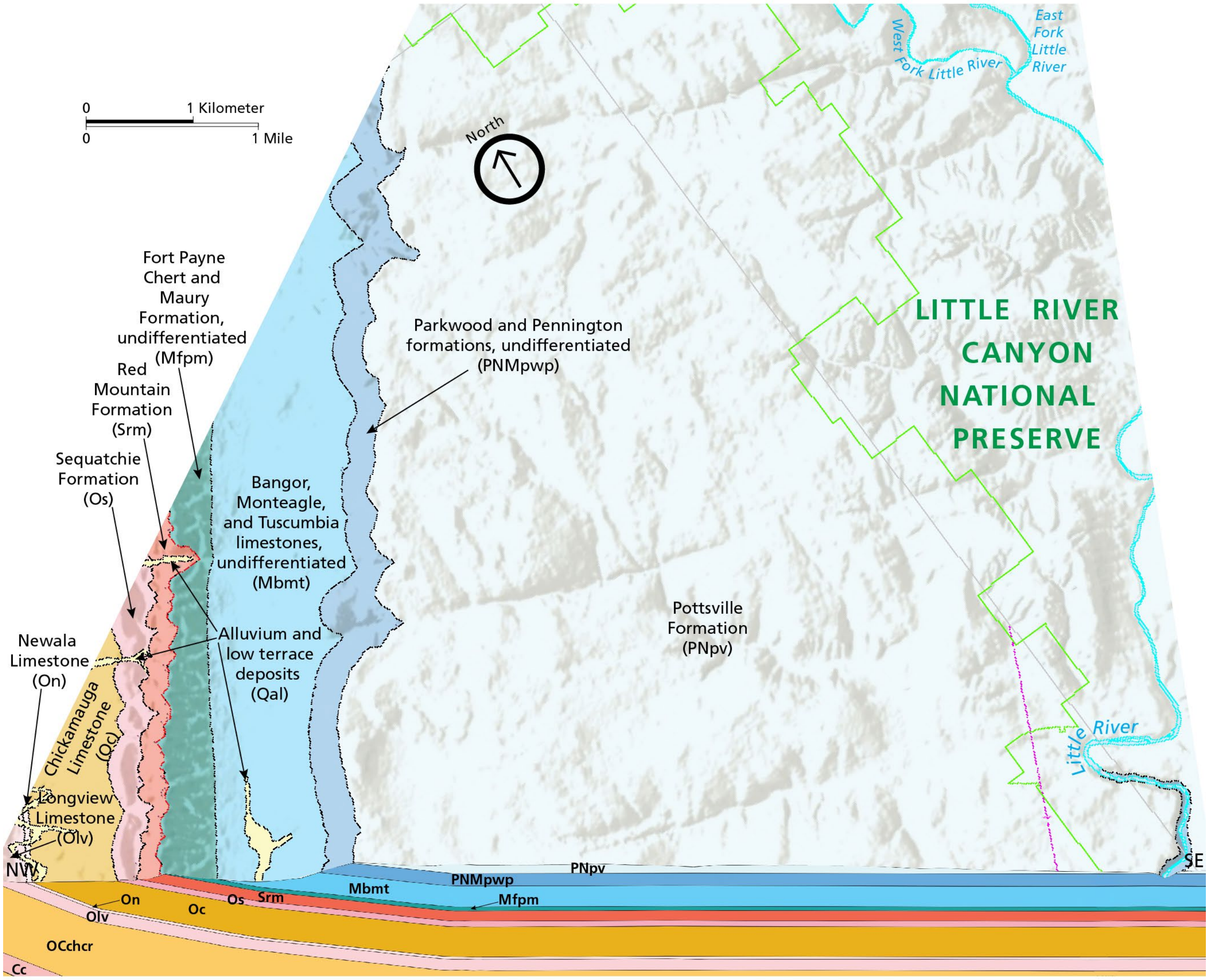


Figure 6. Cross section of the Lookout Mountain landscape.
Only three geologic map units occur within the preserve: PNpv, PNMpwp, and Mbmt. The remaining units crop out nearby or are buried beneath Lookout Mountain and adjacent valleys. Preserve boundary is indicated by green line. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using the GRI GIS data and cross section A-A' in Irvin et al. (2018a). Shaded relief base layer is from ESRI World Terrain Base.

Shallowing conditions in the inland sea during the latest Devonian and early Mississippian Periods (382.7 million to 346.7 million years ago) caused the deposition of dark, organic rich muds to give way to shallow marine limestone accumulation (e.g., the Fort Payne Chert and Maury Formation, undifferentiated **Mfpm**). The oldest bedrock within the preserve is the Mississippian Bangor, Monteagle, and Tuscumbia Limestones (mapped together [or "undifferentiated"] as geologic map unit **Mbmt**). These rocks are present, though poorly exposed, in the lowermost elevations of the preserve near the mouth of the Little River as it flows into Weiss Lake of the Coosa River system. The marine setting gradually gave way to nearshore, barrier, back barrier, and fluvial and deltaic systems, preserved as the mudstone, limestone, and siltstone of the Parkwood and Pennington Formations (**PNMpwp**). During the late Mississippian into the Pennsylvanian Period (330.9 million to 298.9 million years ago), mountain building to the east uplifted what is now Alabama into a rolling coastal plain with fluvial systems and coal swamps (fig. 7). The sediments that were deposited coarsened from mud to the sandstone, coal beds, and pebbly conglomerate of the Pottsville Formation (**PNpv**), which is the youngest and most prevalent bedrock unit within the preserve (Causey 1965).

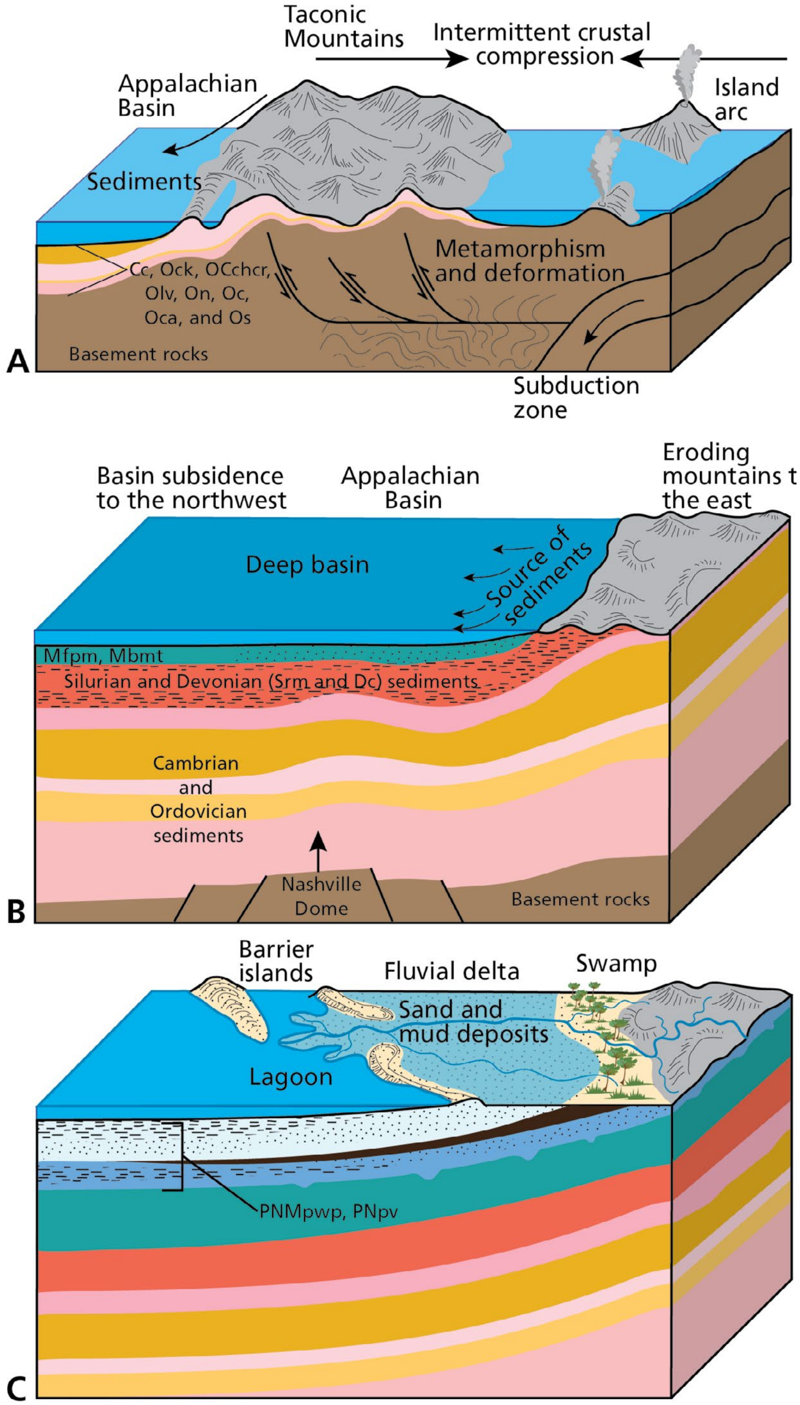


Figure 7. Schematic illustration of landscape evolution, starting 450 million years ago. (A) 450 million to 420 million years ago, the Taconic Orogeny to the east provided a source of sediment and caused metamorphism and deformation. The Appalachian basin subsided in response to crustal loading during the orogeny and began accumulating sediments. (B) 340 million years ago, the Acadian-Neoacadian Orogeny to the northeast provided a source of sediment to the Appalachian basin, which continued to subside and deepen. Quiet marine conditions dominated the depositional settings of mixed sand, silt, mud, and carbonate sediments in the preserve area. (C) 310 million years ago, the Alleghany Orogeny was beginning to uplift the Appalachian Mountains to the east causing folding and faulting in the Valley and Ridge province. Mixed fluvial and swamp depositional environments accumulated sand, silt, mud, and thick coal beds in the basin. Sea level was relatively low. Graphics are not to scale. Colors represent geologic map units in the GRI GIS data. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), with information from the GRI GIS data.

At about 265 million years ago, the Appalachian Mountains were rising again to the east during the Alleghany Orogeny (the third major orogeny; fig. 8). This orogeny was the result of continental collision. The compression involved in the collision caused extensive thrust faulting and associated folding (see "Faults, Folds, and Joints" section for descriptions and graphics). The Valley and Ridge province in Alabama sits above a large-scale thrust fault, also referred to as "detachment fault" or "decollement," along which Paleozoic folded and faulted rocks were shoved many kilometers westward. This was the last of the major Paleozoic mountain-building events that ultimately sutured together all of Earth's continents forming the supercontinent Pangea (see fig. 5). The orogeny uplifted the southern Appalachians and caused major structural changes in the preserve's bedrock. The broad Lookout Mountain syncline (a trough or fold of rock in which the layers slope upwards from the fold axis; see fig. 6), which plunges gently towards the southwest, formed at this time. It is possible that a precursor to the Little River would have begun carving its course through the Lookout Mountain sediments around this time. Permian (298.9 million to 251.9 million years ago) rocks are not mapped in the preserve area. They were either never deposited or have since eroded away.

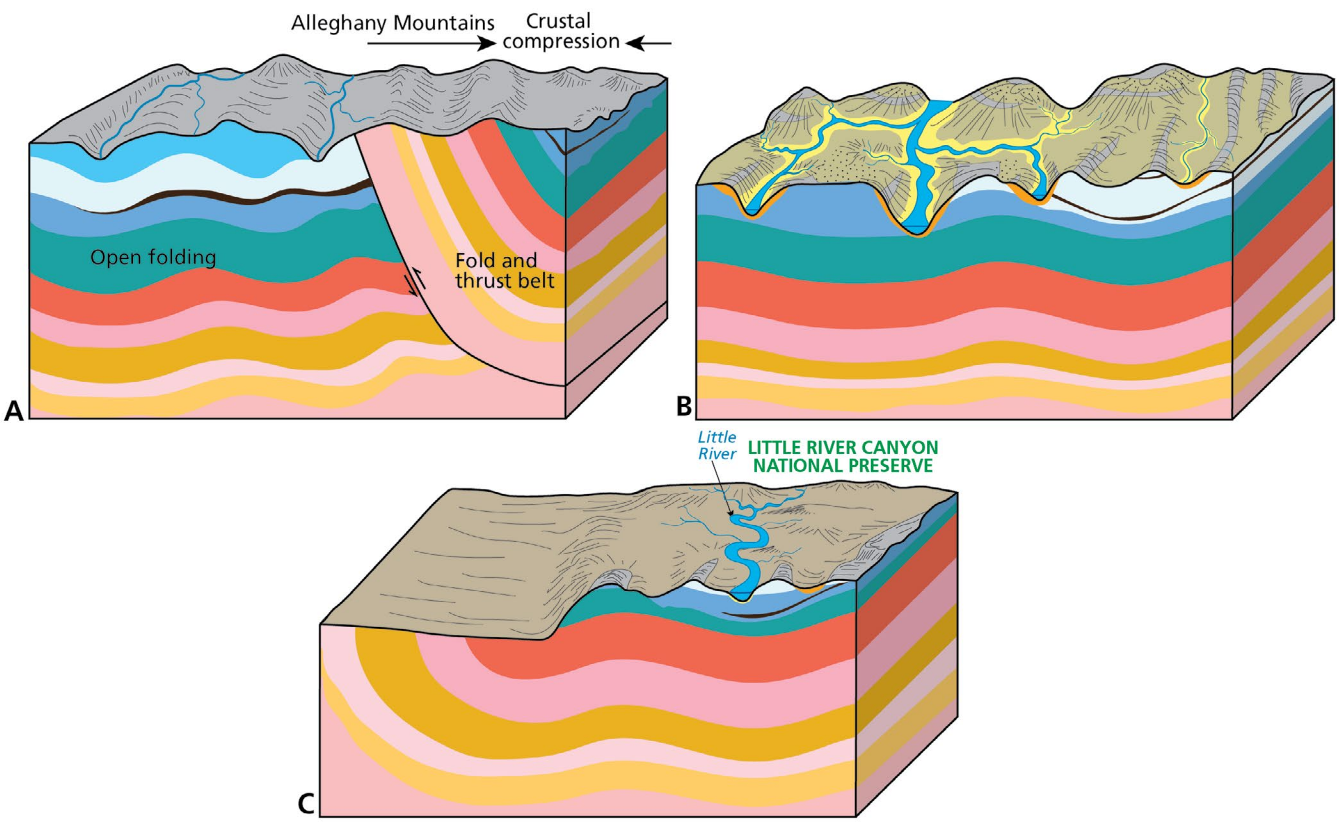


Figure 8. Schematic illustration of landscape evolution, starting 265 million years ago. (A) 265 million years ago, the Alleghany Orogeny resulted in the formation of Pangea; extensive thrust faulting shoved older rocks atop younger rocks to the west. Faulting and folding formed long, linear ridges separated by narrow valleys in the preserve area. In the Appalachian basin, deformation was limited to broad, open folds and very minor faulting. Rivers continued to cut through any Permian and Pennsylvanian sediments. (B) 150 million years ago, Pangea rifted apart, and the Atlantic Ocean opened. Erosion and weathering continued to wear away the Appalachian highlands. Residuum (the material derived from the in-place weathering of bedrock) formed via deep weathering, and slope deposits accumulated. Rivers and streams incised bedrock, deposited terraces, and reworked alluvium mixed with colluvium. (C) Past 15,000 years, earth surface processes continued to carve river valleys and canyons. Sediments are continually eroded from the uplands, transported downslope, and reworked as alluvium (Qal and Tal geologic map units) along the river channels. Graphics are not to scale. Colors represent geologic map units in the GRI GIS data. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), with information from the GRI GIS data.

Mesozoic Era (251.9 million to 66.0 million years ago)—Weathering and Erosion

Pangea was not to last, and by the beginning of the Mesozoic Era about 252 million years ago, it began to rift, (break apart) opening the Atlantic Ocean basin and many pull-apart basins along the eastern edge of North America (fig. 9). Throughout the early Mesozoic Era, the modern configuration of continents began to take shape and major drainages of eastern North America were established. Whatever rocks may have been deposited atop the Pennsylvanian Pottsville Formation were worn away by millennia of weathering and erosion across northern Alabama (see fig. 8). The Pottsville Formation (**PNpv**) caps Lookout Mountain (see fig. 2 and GRI poster). Streams erode most easily along of zones of weakness such as joints (see "Faults, Folds, and Joints" section for descriptions and graphics) and faults to incise steep-sided valleys into the erosion-resistant layers, where layers are less resistant to erosion, wider valleys with gentler slopes may form (Rinehart et al. 2011).

Millions of years of weathering and erosion have resulted in the Lookout Mountain syncline (see GRI poster) being a topographical high point in the region. The youngest rocks of the syncline occur at heights (fig. 10) of 728 m (2,388 ft) above sea level, more than 540 m (1,770 ft) above the valley floor at Canyon Mouth. The Little River began incising Lookout Mountain many millions of years ago, carving a channel and forming Little River Canyon. These processes continue today.

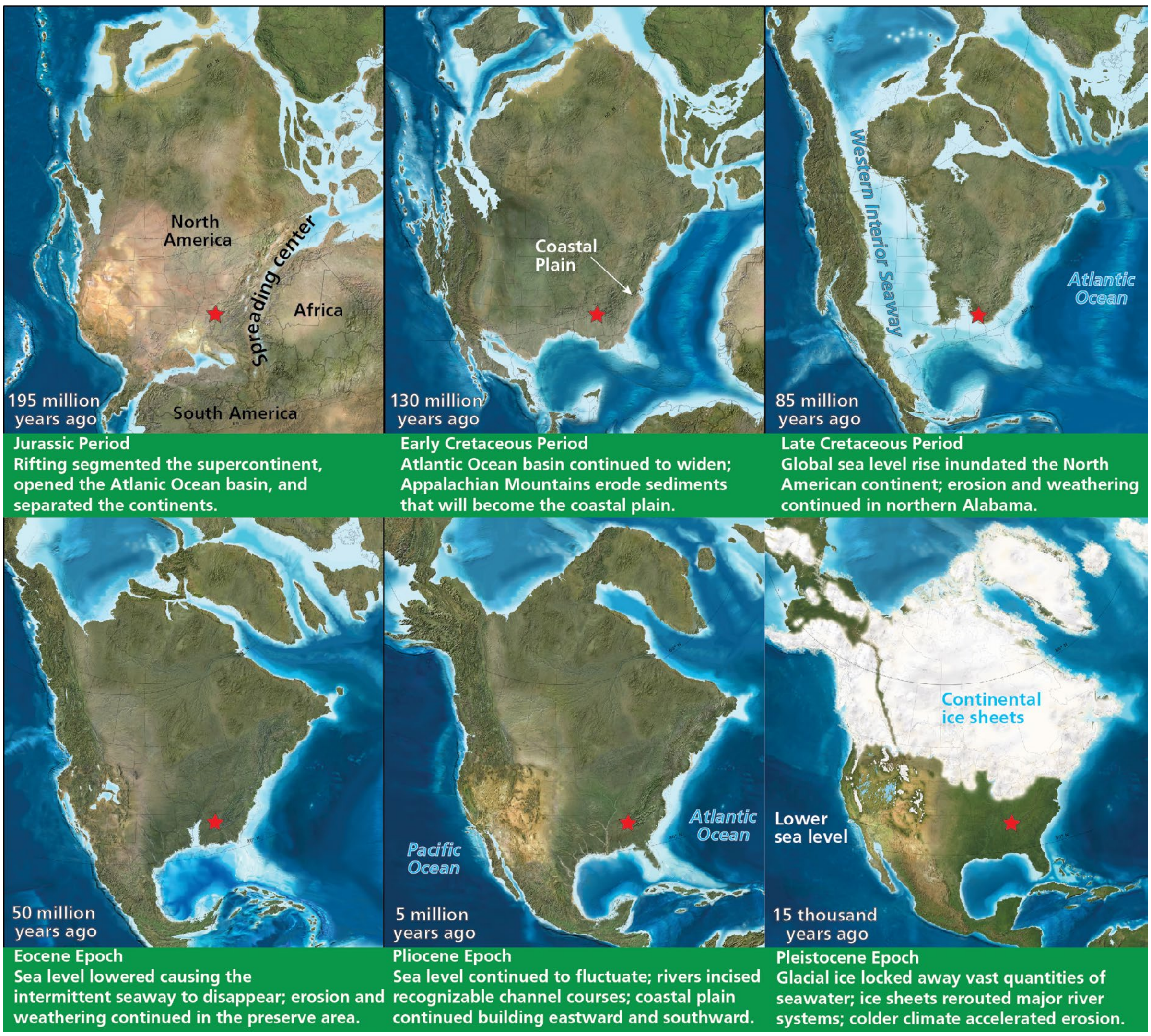


Figure 9. Jurassic–Pleistocene paleogeographic maps of North America.
The red star indicates the approximate location of the preserve. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey (North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc.); additional information available at https://deeptimemaps.com/ (accessed 8 August 2022).

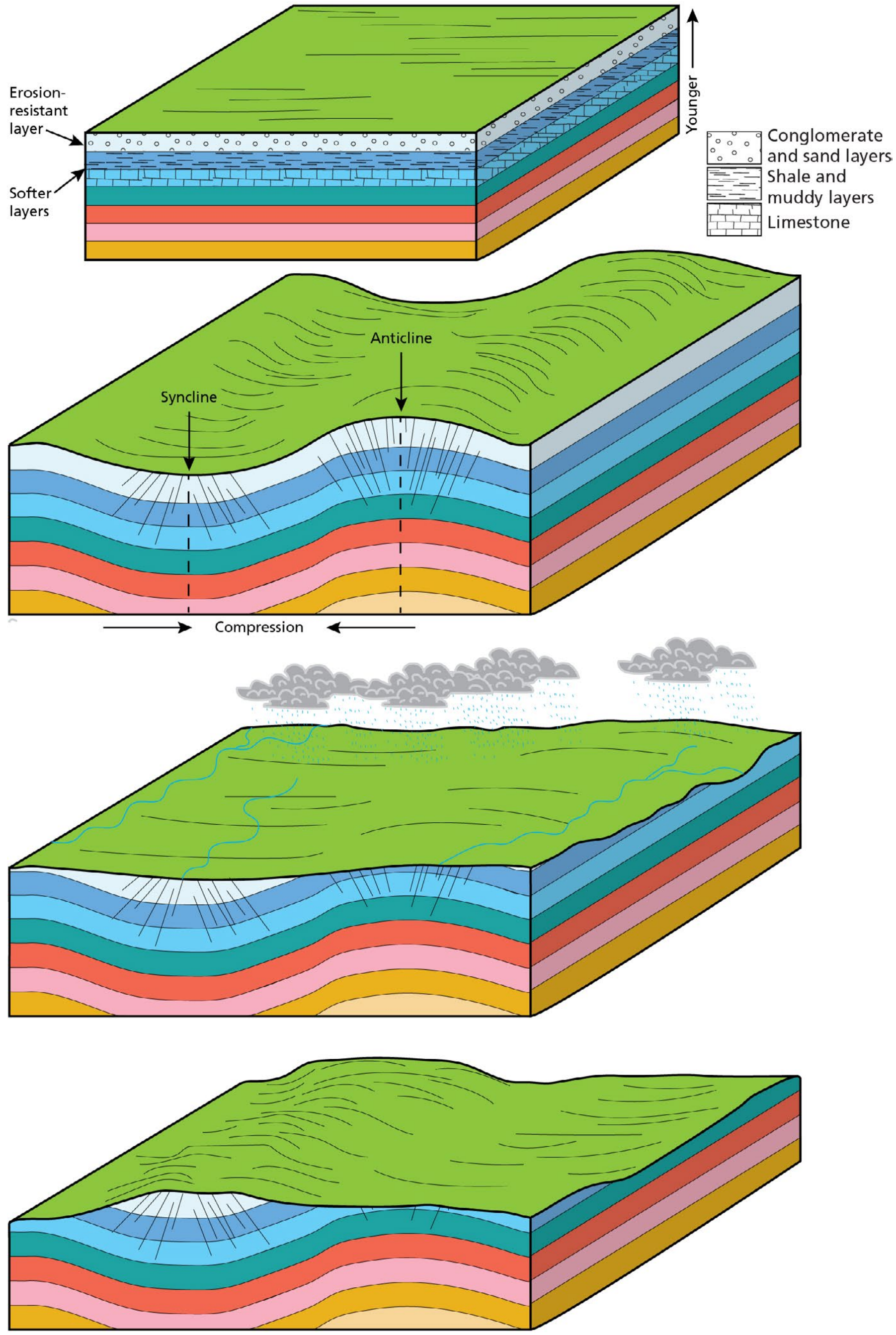


Figure 10. Schematic illustration showing the weathering of a syncline to produce a ridge. A syncline forms the axis of the prominent Lookout Mountain ridge. Millenia of erosion and weathering have worn away the flanks of the syncline. The Little River is incising into the core of the syncline. (A) Undeformed layers: the accumulation of sedimentary layers beneath the preserve was more-or-less continuous for hundreds of millions of years resulting in a thick stack of roughly parallel, flat geologic units. (B) Deformed layers: compression in Earth's crust caused the layers to buckle, fault, and fold into alternating synclines and anticlines. Initially, the anticlines would have been the high ground and the synclines were the valleys. Deformation is typically greatest near the hinge lines (dashed lines) of the fold axis. (C) Beveled land surface: when compression subsided, earth surface processes began wearing away the landforms, preferentially eroding along bedding planes, softer layers, deformed zones, and fractures. (D) Synclinal ridge: when the resistant layer atop the anticline is breached, weathering and erosion move faster through the softer underlying units. Eventually, the adjacent anticlines are left as valleys next to a ridge supported by the resistant layer. Colors represent map units in the GRI GIS data. Graphic not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Cenozoic Era (Past 66 million years)—Modern Landscape Development and the Little River

Throughout the Mesozoic and into the Cenozoic Eras, the primary geologic processes in the preserve area were river incision, slope movements, and weathering and erosion (see figs. 8 and 9). Tertiary (66.0 million to 2.6 million years ago) fluvial deposits (**Tal**) record a former reach of the river system more than 23 million years ago (Irvin et al. 2018c).

During the Pleistocene Epoch, about 2 million years ago, thick continental glaciers descended from the north in repeated advances. The glaciers stored vast amounts of water, lowering global sea level and, thereby, exposing surfaces to erosion. Moreover, glaciers were effective agents of landscape change, eroding, transporting, and depositing rock and sediment across glaciated terrains. Even though glacial ice never reached farther south than central Missouri (see fig. 9), the glaciations affected temperature and vegetation globally and were the single most significant geologic process to affect the modern geomorphology and geologic history of the lower Mississippi River system (Saucier 1994). At Little River Canyon, colder temperatures and less vegetation facilitated weathering and erosion, and slope movements; the accumulation of slope deposits, such as colluvium (unconsolidated, commonly angular debris that collects at the base of a slope), attests to this activity.

The Little River and its tributaries are constantly undercutting the base of slopes. Slope deposits such as colluvium accumulate at the base of local slopes through a process called mass wasting. These deposits are not mapped in the GRI GIS data, but slope deposits are visible throughout the preserve.

Rivers are powerful agents of landscape change and have their associated surficial units, including alluvium (**Qal**). At the preserve, clay, sand, and gravel with abundant quartz (a hard, colorless, silica-rich mineral) and chert grains (see table 3 for descriptions) compose the alluvium and low terrace deposits (**Qal**) that flank the river channels. Terraces form as remnants of a previous river level; after the river level becomes lower, terraces are left perched on the flanking valley sides.

Geologic Heritage

Geologic heritage (also referred to as "geoheritage") encompasses the significant geologic features, landforms, and landscapes characteristic of the nation that are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, and economic. The NPS also identifies geologic heritage aspects of museum collections, soils, and scientific data sets.

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

The landscape at the preserve varies from gently undulating upland areas to sheer vertical cliffs with a narrow canyon floor. For resource management purposes, the preserve is subdivided into three units: riverine, canyon, and upland plateau forest (Rinehart et al. 2011). The riverine unit contains the area defined by the 100-year floodplain of the Little River and its large tributaries. The canyon unit encompasses the rim and the 19-km (12-mi) length of the canyon but not the river and associated floodplain, which are part of the riverine unit. The upland plateau forest unit covers the majority of the preserve's land, from the vicinity of Highway 35 northward, but not the canyon or floodplain (Rinehart et al. 2011).

Significance statements, which express why the preserve's resources and values merit national park designation (National Park Service 2016a, 2016b), emphasize the interplay of geology, biology, and human experience at the preserve. These significance statements also are expressions of geologic heritage.

- Little River Canyon is the deepest canyon in Alabama, and it is one of the deepest in the southeast United States. It contains the highest waterfall in the state, and is resplendent with sheer rock walls, cascading waters, and ever-changing seasonal views.
- With exceptional recreational opportunities, Little River Canyon provides world-class whitewater paddling, internationally renowned climbing, and public lands open to hunting, fishing, and trapping.
- The Little River is the only river in the United States that forms on—and flows almost its entire length along—a mountain top. The Little River's high water quality supports biological diversity, exceptional aquatic riparian communities, and rare endemic species. This mountain-top river is designated as an Alabama Outstanding National Resource Water.

Table 3. Sedimentary rock classification and characteristics.

Note: Claystone and siltstone may also be called "mudstone," or if they break into thin layers, "shale." Carbonate classification is based on Dunham's textural classification scheme (Dunham 1962).

Rock Type	Rock Name	Texture and Process of Formation	Little River Canyon National Preserve Geologic Map Unit Examples
INORGANIC CLASTIC SEDIMENTARY ROCKS	Conglomerate (rounded clasts) and breccia (angular clasts)	Cementation of clasts >2 mm (0.08 in) in size. Higher energy environment (e.g., rivers).	Conglomerate: Layers in **PNpv** Breccia: Layers in **Oc**, **Oca**
	Sandstone	Cementation of clasts 1/16–2 mm (0.0025–0.08 in) in size.	Layers in **PNpv**, **PNMpwp**
	Siltstone	Cementation of clasts 1/256–1/16 mm (0.00015–0.0025 in) in size.	None identified in mapping
	Claystone	Cementation of clasts <1/256 mm (0.00015 in) in size. Lower energy environment (e.g., floodplains).	Layers in **PNMpwp**
CARBONATE CLASTIC SEDIMENTARY ROCKS	Fossiliferous limestone	Carbonate rock containing fossils.	Layers in **Mbmt** and **PNMpwp**
	Boundstone	Fossils, fossil fragments, or carbonate mud fragments cemented together during deposition (e.g., reefs).	None identified in mapping
	Grainstone	Grain (e.g., fossil fragments) supported with no carbonate mud. High energy environment. Components cemented together following deposition.	None identified in mapping
	Packstone	Grain (e.g., fossil fragments) supported with some carbonate mud. Lower energy than grainstone. Components cemented together following deposition.	None identified in mapping
	Wackestone	Carbonate mud supported with more than 10% grains and less than 90% carbonate mud. Lower energy than packstone. Components cemented together following deposition.	None identified in mapping
	Mudstone	Carbonate mud supported with less than 10% grains and more than 90% carbonate mud. Lower energy than wackestone. Components cemented together following deposition.	Layers in **PNMpwp**, **Mfpm**, **Dc**, **Oc**
CHEMICAL SEDIMENTARY ROCKS	Limestone	"Carbonate mud." Precipitation of calcium (Ca) and carbonate (CO_3^{2-}) ions from water (e.g., lakes or marine environments).	Layers in **PNMpwp**, **Mbmt**, **Mfpm**, **Srm**, **Os**, **Oc**, **Oca**, **On**, **Olv**, **Occhcr**, **Cc**
	Travertine	Precipitation of calcium (Ca) and carbonate (CO_3^{2-}) ions from freshwater (e.g., terrestrial springs).	None identified in mapping
	Dolomite	Precipitation of calcium (Ca), magnesium (Mg), and carbonate (CO_3^{2-}) ions from water. Direct precipitation in shallow marine environments or post-depositional alteration by Mg-rich groundwater.	Layers in **Olv**, **Occhcr**, **Ock**, **Oc**, **On**
	Chert	Dissolution of siliceous marine skeletons (e.g., sponge spicules) followed by precipitation of microcrystalline silica (SiO_2). Biochemical chert typically forms from marine invertebrates.	None identified in mapping
	Evaporites (i.e., gypsum)	Precipitation of salts to form evaporite minerals. Typical of hot, dry environments.	None identified in mapping
	Oolite	Precipitation of calcium carbonate in thin spherical layers around an original particle (e.g., fossil fragment) that is rolled back and forth by tides or waves. Typical of warm, shallow marine environments.	Layers in **Mbmt**
ORGANIC SEDIMENTARY ROCKS	Coal	Peat (partly decomposed plant matter) is buried, heated, and altered over time. Typical of lagoon, swamp, and marsh environments.	Layers in **PNpv**, **PNMpwp**

- The location of the preserve along the southern limits of the Cumberland Plateau contributes to a rare assemblage of plants and animals, including the endangered green pitcher plant [(*Sarracenia oreophila*), which is a carnivorous perennial herb].

Geologic Impacts on Human History

The human story at Little River Canyon is connected to geologic resources. Overhanging rock shelters are among the earliest documented archeological resources within the preserve and contain lithic and ceramic artifacts that range from about 10,000–9,200 BCE to 1540–1670 CE (National Park Service 2016a). The raw materials for the artifacts were sourced from local chert layers (e.g., Fort Payne chert, geologic map unit **Mfpm**). Those rock shelters would later harbor moonshine distillers who used local coal veins (coal is present in the Pottsville Formation [**PNpv**]; and Parkwood and Pennington Formations, undifferentiated [**PNMpwp**]) to fuel their stills (Thornberry-Ehrlich 2009; GRI conference call participants, 5 May 2020). Some 165 archeological sites are within and adjacent to preserve boundaries (Cornelison 1991; Rinehart et al. 2011). Earth surface processes have largely obscured or obliterated most of these sites, and much of the preserve has yet to be surveyed by archeologists (National Park Service 2016a).

Trails crisscross the valley and, along with roads and farmsteads, are among the cultural resources at the preserve. A trace of the unpaved 1830s road, the Trail of Tears, was identified near preserve headquarters (fig. 11; National Park Service 2016a). National Park Service (2016a) listed Cherokee (and other Native groups) heritage, African American stories, and southern Appalachian family histories among their cultural resources. How these groups interacted with their natural environment is an ongoing research need.

Figure 11. Photograph of a portion of the Trail of Tears path.
In the 1830s, Cherokee were forcibly removed from their ancestral lands and relocated to lands deemed "Indian Territory" via the "Trail of Tears." Historians estimate more than 5,000 Cherokee perished along this 1,900-km (1,200-mi) march. This trace is located near preserve headquarters in dense forest. Neighboring Fort Payne was built as a temporary fort to support military forces during the removal of Cherokee and other tribes. NPS photograph from National Park Service (2016a, p. 32).

In the late 1930s, before the preserve had been designated, the Civilian Conservation Corps (CCC) constructed culverts, bridges, roads, and trails (Cornelison 1991; Rinehart 2008; Rinehart et al. 2011). Stone materials for these projects were likely locally sourced from bedrock units such as the Pottsville Formation (**PNpv**).

Geologic Ecosystem Connections

In addition to the historical connections, geologic features and processes are fundamentally connected with vegetation patterns, animal habitats, soils, and water resources. At the southern limits of the Cumberland Plateau near the Gulf Coastal Plain physiographic province, the preserve protects significant biodiversity including habitats for several rare flora and fauna, for example, green pitcher plant with half of the known plant patches in the world, Kral's water plantain (*Sagittaria secundifolia*), and the blue shiner fish (*Cyprinella caerulea*) (Rinehart et al. 2011; National Park Service 2016b). Ecological diversity includes a variety of habitants such as those in the upland sandstone glades (see "Sandstone Glades" section) and dry pine hardwood forests, as well as some in the cliffs, floodplain forests, and rocky shoals of the bottomlands (National Park Service 2016a, 2016b).

The Little River ecosystem, which is connected to the Coosa River ecosystem (Rinehart et al. 2011), is a fundamental resource. Its river, streams, canyon, gorges, floodplains, and wetlands support biodiversity and provide a buffer against impacts of development in the area surrounding the preserve.

Soil 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 the preserve were completed in 2012. These data are available via the Web Soil Survey (WSS), which is maintained by the Natural Resources Conservation Service (see "Guidance for Resource Management").

Predicted climate change trends will impact the ecosystem at the preserve. The current ecosystem relies on four distinct seasons, average annual temperature of about 17°C (62°F), and average annual precipitation of 137 cm (54 in) (Rinehart et al. 2011). Climate models indicate that both temperature and heavy precipitation events are projected to increase in frequency and severity by 2100 (National Park Service 2016b). Climate change scenario planning is among the planning and data needs (medium priority) identified in the preserve's foundation document (National Park Service 2016b; Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020).

Geologic Features and Processes

The geologic features and processes highlighted in this chapter are significant to the preserve's landscape and history. Selection 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). Each is briefly introduced and, if applicable, map units corresponding to the GRI GIS data and poster are listed. Table 4 correlates these topics with individual GRI GIS geologic map units.

Bedrock Exposures and Type Localities

Map units: All except for alluvium (**Qal**) and fluvial deposits (**Tal**)

"Bedrock" is the older solid foundation rock that underlies the younger unconsolidated surficial deposits of the preserve. Bedrock is dramatically exposed in most areas of the preserve, most notably on the walls of Little River Canyon. Bedrock can be sedimentary, igneous, or metamorphic, though only sedimentary rocks are present in bedrock exposures (or "outcrops") in the preserve. Sedimentary rocks form from fragments of other rocks or chemical precipitation (table 3). Igneous rocks form by the cooling of molten material. Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids.

The bedrock within the preserve includes layers of all three major sedimentary rock types: clastic, chemical, and organic. Clastic sedimentary rocks are the products of weathering, erosion, transportation, and deposition of rock fragments called "clasts." Chemical sedimentary rocks form when ions (microscopic particles of rock dissolved during chemical weathering) precipitate out of water. Organic sedimentary rocks are composed of organic remains (e.g., coal) or were produced by the physiological activities of an organism (e.g., secretion of calcium carbonate to form limestones of coral reefs).

Bedrock exposures at Little River Canyon are abundant within sandstone glades, steep rocky trails, and sheer cliffs (fig. 12); bedrock exposures within the canyon are listed among the preserve's fundamental resources (National Park Service 2016b). Bedrock vistas can be seen from places such as Canyon View, Lynn, Hawks Glide, Powell Trail, Chinkapin Creek, Crow Point, Eberhart Point, and other overlooks along Canyon Rim Drive (Thornberry-Ehrlich 2009; Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May

Table 4. Geologic map unit descriptions, features, processes, and associated resource management issues in Little River Canyon National Preserve.

Units are presented in approximate order of their age with youngest at the top of the table. Colors represent the map unit colors in the GRI GIS data. Definitions of some terms are provided in the table; many terms are described in table 3 (e.g., mud and mudstone, sand and sandstone, limestone, and dolomite); a few (i.e., quartz, gravel, and shale) are defined elsewhere in the text. In addition, figures illustrate some terms.

Map Unit (symbol)	Description and Little River Canyon National Preserve Occurrence	Geologic Features, Processes, and Potential Resource Management Issues
Alluvium and low terrace deposits (**Qal**)	**Qal** consists of dark brown to reddish brown clay, sand, and gravel. Rich in quartz and chert. **Qal** occurs in Dugout Valley, Valley Head, and Fort Payne quadrangles (see fig. 1). Alluvium lines most river valleys but is not mapped within preserve boundaries.	**Fluvial Features and Processes** **Qal** accumulates along active stream channels throughout the preserve area. **Abandoned Mineral Lands and Disturbed Lands** **Qal** may be a source of gravel regionally. No known pits occur within the preserve.
Fluvial deposits (**Tal**)	**Tal** includes yellowish orange to white, chert and quartz cobbles and pebbles in conglomeratic beds overlying white to pale yellowish orange, medium-grained quartz sand. **Tal** is mapped in the Dugout Valley quadrangle beyond preserve boundaries.	**Fluvial Features and Processes** **Tal** accumulated along former stream channels throughout the preserve area. **Tal** now occurs as perched deposits above modern floodplains. **Abandoned Mineral Lands and Disturbed Lands** **Tal** may be a source of gravel regionally. No known pits occur within the preserve.
None	Unconformity	An unconformity represents a gap in the rock record. During this time deposition did not occur and/or erosion removed the deposits.

Table 4, continued. Geologic map unit descriptions, features, processes, and associated resource management issues in Little River Canyon National Preserve.

Map Unit (symbol)	Description and Little River Canyon National Preserve Occurrence	Geologic Features, Processes, and Potential Resource Management Issues
Pottsville Formation (**PNpv**)	**PNpv** is light gray, conglomeratic sandstone in its upper and lower reaches, divided by a dark gray, shale-dominated layer. Coal beds and associated clay layers occur in the shale layer as well. **PNpv** is mapped throughout the preserve making up 92.9% of the area within preserve boundaries. It is in Dugout Valley, Valley Head, Fort Payne, Jamestown, Little River, and Gaylesville quadrangles.	**Bedrock Exposures** Exposures of **PNpv** are prevalent in the higher reaches of the preserve, characterized by rapid horizontal and vertical rock-type changes. The unit is named from exposures near Pottsville, Pennsylvania, including outcrops in the Allegheny River valley and along a railroad cut on the east side of the water gap through Sharp Mountain, Schuylkill County, Pennsylvania. **Paleontological Resource Inventory, Monitoring, and Protection** **PNpv** includes carbonized plant fragments, including specimens of the primitive tree *Lepidodendron* and horsetail *Calamites*. Crinoids, bryozoans, brachiopods, mollusks, echinoderms, and amphibian tracks are also part of **PNpv**. **Faults, Folds, and Joints** The Lookout Mountain syncline axis trends through **PNpv** across preserve boundaries. **Fluvial Features and Processes** Many waterfalls form where the resistant beds of **PNpv** are undercut by streams eroding underlying, less resistant layers of **PNMpwp**. **Geologic Hazards** As resistant cap rock throughout the area, **PNpv** is prone to blockfall when undercut by erosion of softer underlying units. **Upland Bogs and Other Wetlands** **PNpv** underlies the upland bogs in the preserve. **Abandoned Mineral Lands and Disturbed Lands** **PNpv** has coal beds. A sand pit is mapped within **PNpv** outside preserve boundaries.
Parkwood and Pennington formations, undifferentiated (**PNMpwp**)	As part of **PNMsb**, the Parkwood Formation is gray shale and mudstone with some sandstone interbedded. In the lower parts of the combined unit, layers of limestone and maroon and green shale occur. Shale with interlayers of fossiliferous limestone, sandstone, claystone, and coal dominate the Pennington Formation in this unit. **PNMsb** occurs in the extreme northern end of the preserve and along the course of the Little River below Little River Falls. **PNMsb** is 4.3% of the mapped preserve area. It is mapped in Dugout Valley, Valley Head, Fort Payne, Jamestown, and Little River quadrangles.	**Fluvial Features and Processes** Where the Little River cuts through **PNpv** and begins to incise the softer, less resistant **PNMpwp** at Little River Falls marks the start of Little River Canyon. **Karst Features and Processes** Carbonate dissolution is likely happening in the limestone beds of **PNMpwp**. **Paleontological Resource Inventory, Monitoring, and Protection** **PNMpwp** has fossiliferous limestone.
Bangor, Monteagle, and Tuscumbia limestones, undifferentiated (**Mbmt**)	The Bangor Limestone in the combined unit, **Mbmt**, is gray limestone with ooliths, and dark gray chert. The Monteagle Limestone is light gray, limestone with interlayers of shaly limestone and shale. The Tuscumbia Limestone contains bioclastic (pieces derived from organisms) fragments and some chert nodules. **Mbmt** is mapped in the most downstream reach within preserve boundaries, at the southern end of the preserve. It is 1.7% of the mapped preserve area.	**Fluvial Features and Processes** Little River Canyon opens (and ends) downstream where the river cuts into Mbmt. **Paleontological Resource Inventory, Monitoring, and Protection** **Mbmt** has bioclastic limestone.

Table 4, continued. Geologic map unit descriptions, features, processes, and associated resource management issues in Little River Canyon National Preserve.

Map Unit (symbol)	Description and Little River Canyon National Preserve Occurrence	Geologic Features, Processes, and Potential Resource Management Issues
Fort Payne Chert and Maury Formation, undifferentiated (**Mfpm**)	The Fort Payne Chert of **Mfpm** is gray, silica-rich limestone with interbeds and nodules of chert. The Maury Formation of **Mfpm** is shale and mudstone with phosphatic concretions which are phosphorus-rich, hard solid masses formed by the local accumulation of material within sediments. **Mfpm** is mapped in Dugout Valley, Fort Payne, Jamestown, and Little River quadrangles. **Mfpm** is mapped outside preserve boundaries.	**Abandoned Mineral Lands and Disturbed Lands** Two gravel pits are mapped within **Mfpm** beyond preserve boundaries. **Paleontological Resource Inventory, Monitoring, and Protection** **Mfpm** has fossiliferous chert.
None	Unconformity	An unconformity represents a gap in the rock record. During this time deposition did not occur and/or erosion removed the deposits.
Chattanooga Shale (**Dc**)	**Dc** is dark gray to black, carbon-rich shale and mudstone with some pebbly sandstone beds interlayered. **Dc** is mapped beyond preserve boundaries in Dugout Valley, Valley Head, Fort Payne, Jamestown, and Little River quadrangles.	**Geologic Hazards** **Dc** is a regionally weak geologic unit prone to slumping and sliding.
None	Unconformity	An unconformity represents a gap in the rock record. During this time deposition did not occur and/or erosion removed the deposits.
Red Mountain Formation (**Sm**)	**Sm** is olive gray silty shale interbedded with brownish sandstone and some fossiliferous limestone. **Sm** is mapped in Dugout Valley, Valley Head, Fort Payne, Jamestown, and Little River quadrangles. **Sm** is mapped outside preserve boundaries.	**Abandoned Mineral Lands and Disturbed Lands** Hematitic (hematite is a black or blackish red to brick-red mineral, essentially Fe_2O_3) limestone layers in Sm have been mined as iron ore in the past. **Paleontological Resource Inventory, Monitoring, and Protection** **Sm** has fossiliferous limestone.
None	Unconformity	An unconformity represents a gap in the rock record. During this time deposition did not occur and/or erosion removed the deposits.
Sequatchie Formation (**Os**)	**Os** appears as multicolored shale layers with some brown sandstone and gray, fossiliferous limestone interlayers. **Os** is mapped beyond preserve boundaries in Dugout Valley, Valley Head, Fort Payne, Jamestown, and Little River quadrangles.	**Paleontological Resource Inventory, Monitoring, and Protection** **Os** has fossiliferous limestone.
Chickamauga Limestone (**Oc**)	**Oc** contains gray, fossiliferous limestone, with some dolomite and bentonite layers in the upper part. Bentonite is a kind of absorbent clay, commonly formed by breakdown of volcanic ash. Dolomite and shale increase in the lower beds. **Oc** is mapped in Dugout Valley, Valley Head, Fort Payne, Jamestown, and Little River quadrangles. **Oc** is mapped outside preserve boundaries.	**Geologic Hazards** Bentonite layers are prone to shrink-and-swell action and can undermine infrastructure and roadbeds. **Paleontological Resource Inventory, Monitoring, and Protection** **Oc** has fossiliferous limestone.

Table 4, continued. Geologic map unit descriptions, features, processes, and associated resource management issues in Little River Canyon National Preserve.

Map Unit (symbol)	Description and Little River Canyon National Preserve Occurrence	Geologic Features, Processes, and Potential Resource Management Issues
Chickamauga Limestone, Attalla Chert Conglomerate Member (**Oca**)	**Oca** is grayish orange, chert-pebble conglomerate and breccia. **Oca** is mapped in the Little River quadrangle beyond preserve boundaries.	None noted during mapping
None	Unconformity	An unconformity represents a gap in the rock record. During this time deposition did not occur and/or erosion removed the deposits.
Newala Limestone (**On**)	**On** consists of light gray limestone interbedded with dolomite with some chert nodules and stringers. Nodules are small, rounded lumps of material distinct from its surrounding materials. Stringers are mineral veinlets or filaments resembling ribbons. On is mapped in Dugout Valley, Valley Head, and Fort Payne quadrangle outside preserve boundaries.	None noted during mapping
Longview Limestone (**Olv**)	**Olv** is gray limestone with dolomite and chert nodules and stringers. **Olv** weathers to produce a clay-rich regolith (a blanket of unconsolidated, loose, heterogeneous superficial deposits covering solid bedrock) with residual chert. Olv is mapped in Dugout Valley, Valley Head, and **Fort** Payne quadrangles beyond preserve boundaries.	**Geologic Hazards** Weathered layers of **Olv** may be prone to slumping on slopes. **Abandoned Mineral Lands and Disturbed Lands** One gravel pit is mapped within Olv beyond preserve boundaries.
Chepultepec and Copper Ridge dolomites, undifferentiated (**OCchcr**)	**OCchcr** consists of gray dolomite with interbedded limestone. **OCchcr** weathers to produce a clay-rich regolith with residual chert. **OCchcr** is mapped outside preserve boundaries in the Dugout Valley, Valley Head, and Fort Payne quadrangles.	**Geologic Hazards** Weathered layers of **OCchcr** may be prone to slumping on slopes. **Abandoned Mineral Lands and Disturbed Lands** Five gravel pits are mapped within **OCchcr** beyond preserve boundaries. **Paleontological Resource Inventory, Monitoring, and Protection** **OCchcr** contains stromatolite (fossilized algae mats) fragments.
Knox Group, undifferentiated (**OCk**)	**OCk** includes gray dolomite with oolitic chert as **z**, stingers, and thin beds. **OCk** weathers to produce a clay-rich regolith with residual chert. **OCk** is mapped in the Jamestown and Little River quadrangles beyond preserve boundaries.	**Geologic Hazards** Weathered layers of **OCk** may be prone to slumping on slopes. **Abandoned Mineral Lands and Disturbed Lands** One gravel pit is mapped within Ock beyond preserve boundaries.
Conasauga Formation (**Cc**)	**Cc** is dark gray, fossiliferous limestone. **Cc** is only mapped in the Jamestown quadrangle outside the preserve.	**Paleontological Resource Inventory, Monitoring, and Protection** **Cc** contains trilobite (creatures recognized by their distinctive three-lobed, three-segmented form) fossil fragments.

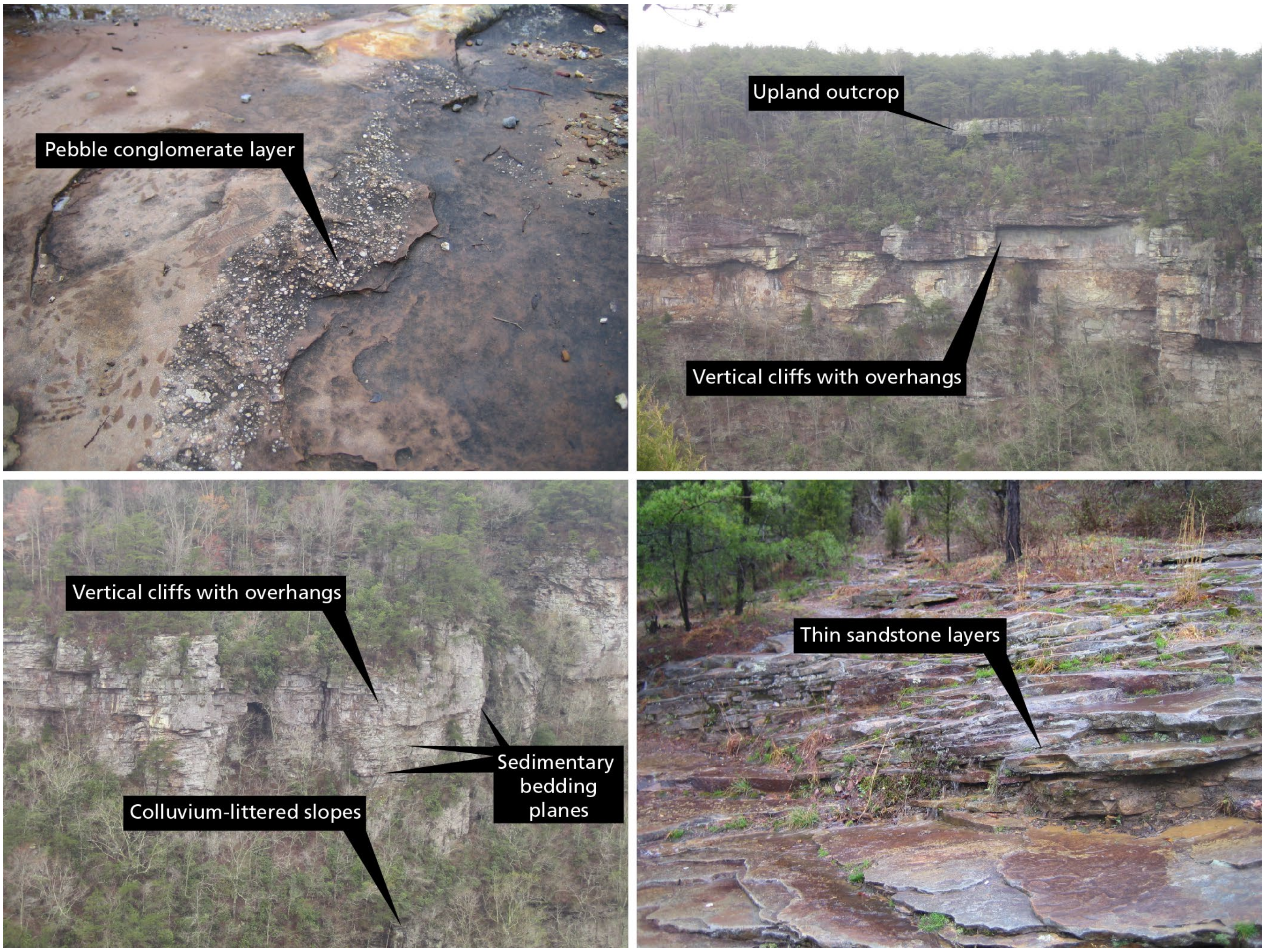


Figure 12. Photographs of bedrock exposures at Little River Canyon National Preserve. **Bedrock is exposed throughout the preserve cropping out as flat layers, vertical cliffs, overhangs, slopes, glades, and small outcrops. Top left photograph shows coarse pebble conglomerate layers in the Pottsville Formation (PNpv). Top right photograph shows vertical cliffs and overhangs along the canyon walls in the Pottsville Formation. Lower left photograph shows vertical cliffs in the Pottsville Formation, clear sedimentary bedding planes, and blocks of the bedrock that have fallen to collect as colluvium on the slopes below. Lower right photograph shows thin sandstone layers in upland areas typical of the sandstone glades in the preserve in the Pottsville Formation. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.**

2020). The bedrock exposures within the preserve provide geologists with invaluable study areas in a region that is highly obscured by forests and covered by unconsolidated surficial deposits (Thornberry-Ehrlich 2009). The canyon system provides the opportunity to observe the “belly” of Lookout Mountain as the river scours ever deeper through layers of rock (National Park Service 2016b).

When a geologic formation is first introduced or proposed, it is usually assigned a formal name taken from a nearby geographic feature, such as a stream or town. The geographic location where a formation is best displayed or first described is called its “type locality.” Located within the type locality is a “type section,” a specific measured surface exposure that displays the diagnostic characteristics of the formation. Type localities and type sections have scientific, educational, and geologic heritage significance. Because type localities and type sections commonly occur 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 and some were named for locations in the preserve, as summarized on table 4. Information about named geologic units may be found at the US Geologic Names Lexicon ("Geolex"), which is a national compilation of names and descriptions of geologic units maintained by the US Geological Survey (see "Additional References, Resources, and Websites").

The type locality for the Mississippian Fort Payne Chert (geologic map unit **Mfpm**) is nearby (less than 50 km [30 mi] from the preserve). Proposed around the turn of the 20th century by Smith (1890), the formation was named for exposures around Fort Payne, Alabama. At Little River Canyon, hundreds of rock shelters (see "Karst Features and Processes") with archeological material, including stone implements and arrowheads composed of the Fort Payne Chert, are beneath the prominent sandstone ledges and overhangs of the Pottsville Formation (**PNpv**) (see fig. 3). Other nearby stratotypes include the Cambrian Rome Formation (type locality), Ordovician Chickamauga Supergroup (type area), Pond Spring Formation (type section), Mississippian Lavender Shale Member of the Fort Payne Formation (type locality), Pennsylvanian Flat Rock Member of the Raccoon Mountain Formation (type section), and Norwood Cove Member of the Raccoon Mountain Formation (type section) (Timothy Henderson, NPS Geologic Resources Division, geologist, written communication, 7 November 2021). More research is needed to sort the intricacies of the complex depositional history of the Devonian, Mississippian, and Pennsylvanian rocks in the Little River Canyon region. These rocks record a shift from ancient shallow seas to deep marine conditions then coastal fluvial-deltaic and terrestrial braided streams, and back again. Geologists continue to refine the geologic history of these rocks throughout the region.

Paleontological Resources

Map units: Conasauga Formation (**Cc**); Chickamauga Limestone (**Oc**); Sequatchie Formation (**Os**); Red Mountain Formation (**Sm**); Fort Payne Chert and Maury Formation, undifferentiated (**Mfpm**); Bangor, Monteagle, and Tuscumbia limestones, undifferentiated (**Mbmt**); Parkwood and Pennington formations, undifferentiated (**PNMpwp**); Pottsville Formation (**PNpv**)

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 (fossil dung). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. As of August 2022, 283 parks had documented paleontological resources in at least one of these contexts (Vince Santucci, NPS Geologic Resources Division, paleontologist, email communication, 10 August 2022).

According to the NPS paleontological resource summary for the Cumberland Piedmont Network (which includes Little River Canyon National Preserve; Hunt-Foster et al. 2009), fossils occur within the canyon bedrock, presenting opportunities for resource management including field surveys, inventory, monitoring, education, and interpretation (fig. 13). Documented fossils include carbonized fragments of *Lepidodendron* (fig. 14), horsetails, bark impressions, ferns, crinoid remains, and sea stars (fig. 15). Other fossilized remains regionally include invertebrate fossils and amphibian footprints, though none have been documented in the preserve. Coal seams within the preserve contain Pennsylvanian peat-swamp flora (Hunt-Foster et al. 2009; Thornberry-Ehrlich 2009).

The Canyon View site may present a good opportunity to interpret the paleontological resources in the preserve for visitors. Mississippian fossils such as crinoids, Archimedes bryozoan frond parts, and corals may be present in float blocks, boulders, and cobbles on the canyon floor (see fig. 37; Hunt-Foster et al. 2009; Thornberry-Ehrlich 2009). Float blocks are large, loose pieces of rock that are not connected to an exposure or outcrop. Boulders are rock fragments with size greater than 25.6 cm (10.1 in) in diameter. Smaller pieces are called cobbles (size range 64–256 mm [2.5–10 in]) and pebbles (size range 2–4 mm [0.079–0.157 in]). In common usage, a boulder is too large for a person to move.

Faults, Folds, and Joints

Map units: All except for alluvium (**Qal**) and fluvial deposits (**Tal**)

Faults, folds, and joints occur where rocks have been compressed, stretched, sheared, or fractured. They are common structural features in areas where mountain building has occurred. As displayed in the strata at the preserve, compressive forces buckled the rocks in a regional northeast to southwest trend when the southern Appalachian Mountains were built. A fault is a fracture or planar surface in rocks along which movement of one side opposite the other has happened. The three primary types of faults are normal faults, reverse faults, and strike-slip faults (fig. 16). Faults are classified based on motion of rocks on either side of the fault plane as described in figure 16. Thrust faults are mapped within the GRI GIS data for the preserve. Thrust faults are reverse faults with a low angle (<45°) fault plane. Décollements, or detachment faults, are very low angle (nearly horizontal) reverse faults with

Figure 13. Photographs of fossil specimens from Little River Canyon National Preserve.
The preserve's geologic collection includes a variety of fossil types, including, from left to right (top row), invertebrate shell casts (brachiopods and possible snails), Calamites (extinct tree-like horsetails), gastropods, Calamites, (middle row) leaves, ferns, variety of plant fragments, (lower row) Sigillaria (extinct tree-like plant), Calamites, and Calamites. NPS photographs provided by Mary Shew (Little River Canyon National Preserve).

large displacement (kilometers to tens of kilometers). The GRI GIS data within preserve boundaries include at least three major, named thrust faults: Harmony Grove, Wills Valley, and Kingston (see GRI poster). Myriad small-scale faults (not necessarily mapped) are visible in rocks all along the river.

Folds are curves or bends in originally flat geologic structures, such as rock strata, bedding planes, or foliation. The two primary types of folds are anticlines which are "A-shaped" (convex) and synclines which are "U-shaped" (concave) (fig. 17). A monocline, another type of fold, is a step-like structure consisting of a steeply dipping zone within otherwise relatively horizontal rock layers. As bedrock is compressed by tectonic forces, anticlines and synclines form adjacent to each other, as is characteristic in the linear folds of the Valley and Ridge province. All types of folds can be overturned—tilted past vertical—by continued or future tectonic forces. Folds frequently "plunge" meaning the fold axis tilts. Folds were identified in the GRI GIS data within preserve boundaries, including named folds such as the Lookout Mountain syncline (see GRI poster). Folds exist in the preserve bedrock at many scales ranging from regional (10s of kilometers) to microscopic. Small scale folds on the order of a few

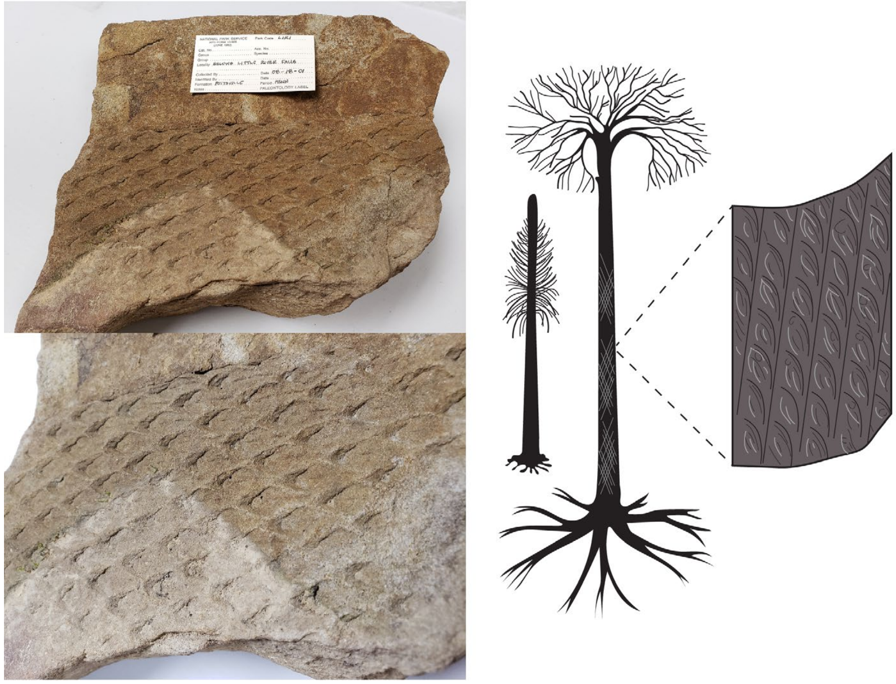


Figure 14. Photographs and sketch of *Lepidodendron* fossils.
***Lepidodendron* are the fossilized remains of a tree-like plant from the Pennsylvanian Period. Bedrock outcrops host in situ fossils; float (displaced fragments of rock, especially on a hillslope) also may contain *Lepidodendron* fossils. NPS photographs provided by Mary Shew (Little River Canyon National Preserve). Sketch by Trista L. Thornberry-Ehrlich (Colorado State University).**

Figure 15. Photographs of sea star fossils from Little River Canyon National Preserve.
Photographs depict two specimens with a zoomed in image (note scale bars). Star patterns are outlined to enhance visibility in the zoomed-out images. Left images show an internal mold, whereas the right images show an external mold. Sea starts may also leave trace fossils. All fossils are protected by law and require diligence to monitor their condition and status. NPS photographs by Larry Beane (Little River National Preserve) taken in 2010.

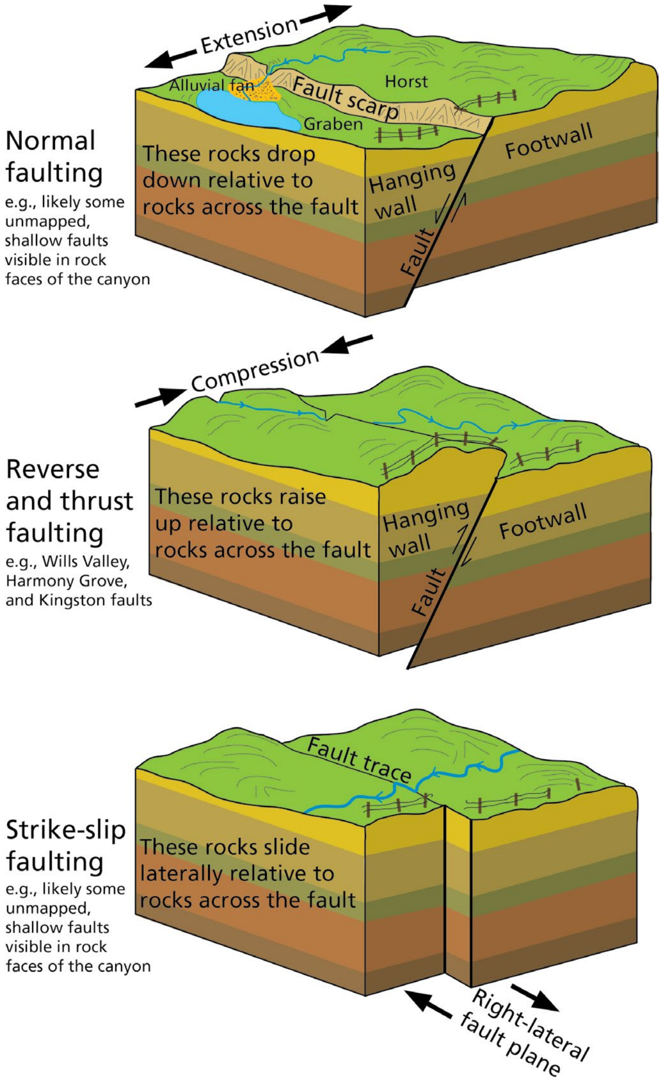


Figure 16. Illustrations of fault types. Movement occurs along a fault plane.
Footwalls are the blocks of rock below the fault plane and hanging walls are the blocks of rock above the fault plane. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging wall up relative to the footwall. A thrust fault is like a reverse fault but has a dip angle of less than 45°. In a strike-slip fault, the relative direction of movement of the opposing plate 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. Thrust faults occur in the GRI GIS data for the preserve. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

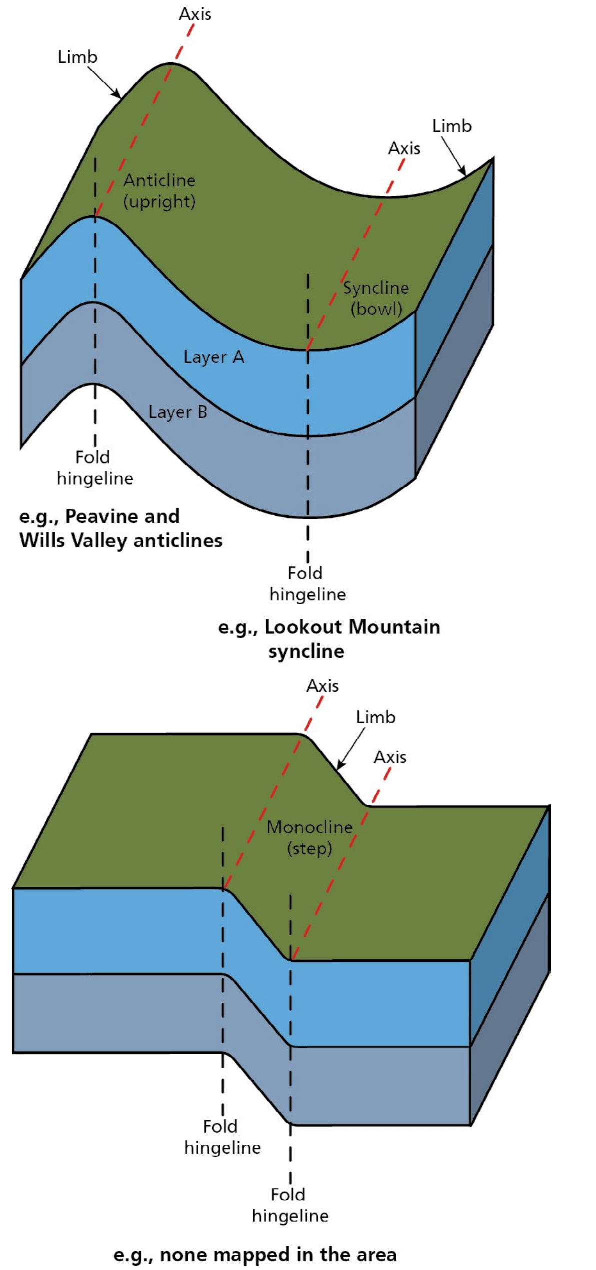


Figure 17. Illustrations of fold types.
Folds accommodate stress within the rocks without fracture (faulting). Where the rock layers bow upward, an anticline forms. Where the layers bow downward, a syncline forms. Erosion through the layers of a syncline or anticline may have younger layers topographically higher than older layers (see fig. 10). Syncline and anticline fold types are recorded in the GRI GIS data for the preserve. Folds are typically oriented perpendicular to the tectonic stress that is forcing the rock layers to buckle. The Little River cuts through folded strata at the preserve giving some outcrops a tilted appearance. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

meters across are visible in bedrock exposures along the river's length.

Joints are the most prominent geologic structures in Little River Canyon; they occur in rocks throughout the preserve (Ed Osborne, Geological Survey of Alabama, geologist, written communication, 9 March 2022). Joints are defined as planar fractures, cracks, or parting in a body of rock without shear displacement or relative movement of one side to the other. Joints commonly form in parallel sets. In the preserve, many joints intersect as orthogonal joint sets, commonly intersecting at nearly 90° angles (though not formally measured; Ed Osborne, Geological Survey of Alabama, geologist, GRI conference call, 5 May 2020). As described in other sections of this report, joints have significant correlations with the fluvial features and processes and karst features and processes, as well as slope movements at the preserve.

Fluvial Features and Processes: Little River Canyon

Map units: alluvium and low terrace deposits (**Qal**) and fluvial deposits (**Tal**)

Fluvial features are formed by flowing water. Fluvial processes both construct (deposit alluvium **Qal**) and erode landforms (e.g., valleys or ravines). The Little River and its tributaries, including Bear Creek, Wolf Creek, Johnnies Creek, Straight Creek, Hurricane Creek, and Yellow Creek, form the fluvial features at the preserve (fig. 18). Examples of the preserve's fluvial features include meandering river channels, point bars, terraces, floodplains, and canyons (fig. 19).

The flow of a river itself provides energy to the system to alter the landscape. As a river flows around curves, the flow velocity (and thus erosive energy) is greatest on the outside of the bend. The river erodes into its bank on the outside of a curve and deposits sediment, known as point bars deposits, on the inside of the bend. Point bars are crescent-shaped ridges of sand, silt, and clay deposited on the inside of meander loops where the water's velocity is slowest. As the process continues, the outside bend retreats farther, while the inside bend migrates laterally, thus creating migrating meanders. When meandering reaches an extreme, the narrow neck of land between two bends is breached leaving an oxbow lake. Notably, deposition of point bars may only be happening to a limited extent, if at all, within the deeply incised bedrock canyon of the preserve (Mike Martin, NPS Water Resources Division, hydrologist, written communication, 16 November 2021).

Terraces are markers of former river levels, commonly left perched above the modern floodplain. As the river incises down at a lower level, a terrace deposit is left commonly as a series of benches, each representing a different level. In some areas of a channel, these deposits are not preserved, having been eroded or washed away by floods. At the preserve, terrace deposits are not common, but low benches cut into the bedrock, called strath terraces, may represent former river levels (Mike Martin, NPS Water Resources Division, hydrologist, written communication, 16 November 2021).

Floodplains are areas of flat or gently undulating land alongside a river which periodically convey water when

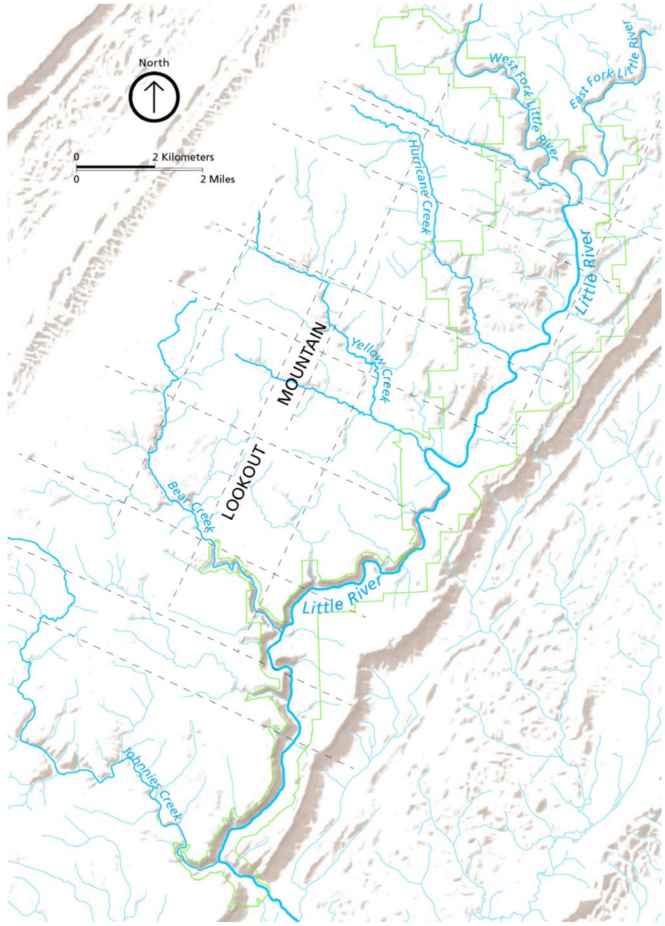


Figure 18. Map of the Little River and its major tributaries atop Lookout Mountain.
Lookout Mountain syncline underlies a topographic high. Creeks and streams flow into the Little River, resembling "ribs of a fish" intersecting the "backbone" (Little River). Local joints, faults, and fractures (orientations approximately indicated by dashed lines) likely channel river incision through the resistant layers of the Pottsville Formation (PNpv). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using the GRI GIS data and base map imagery from ESRI.

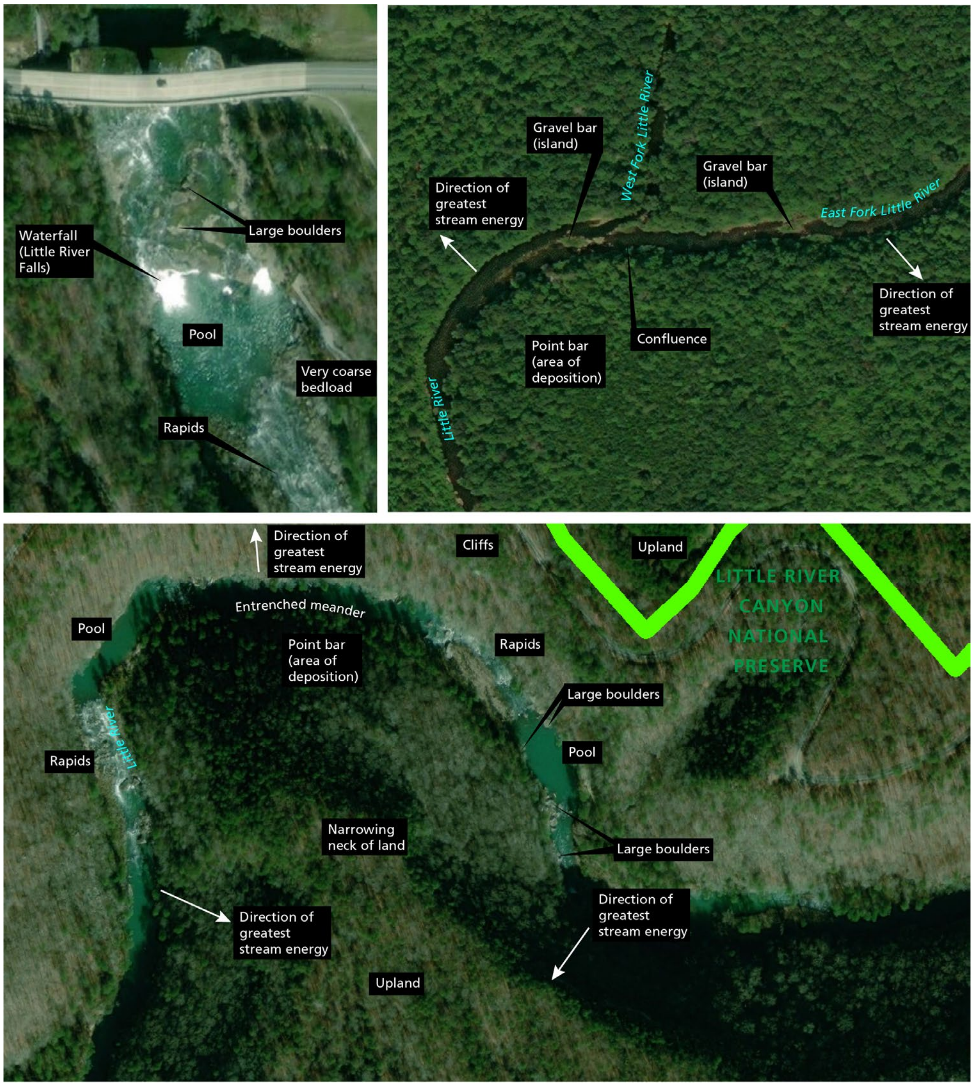


Figure 19. Annotated aerial images of fluvial features typical of Little River Canyon.
Much of the river's course in the preserve is a bedrock channel. Typically, rivers hemmed by bedrock do not experience as much meandering as those with broad floodplains composed of unconsolidated deposits. Upper left image is located at Little River Falls and the river is flowing from top to bottom. Upper right image shows the confluence of the West Fork Little River and the East Fork Little River to form the Little River near the beginning of the DeSoto Scout Trail and flow is from the right side of the image to the left. Lower image is located near Lower Two Mile Trail and Hawks Glide and the river is flowing from right to left. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

the river floods. Floodplain dominated fluvial systems, characterized by broad flanking floodplains, experience more lateral meandering through unconsolidated alluvium and terrace deposits than a channel controlled by more erosion resistant bedrock. Bedrock channels tend to be narrower and straighter with the incised meanders constraining the river course. They may have little to no floodplain development. Most of Little River Canyon is a scoured bedrock channel with a low quantity of fine-grained sediment.

The canyon is more than 180 m (600 ft) deep and approximately 19 km (12 mi) long. The Little River is considered the only river in the country whose entire course flows atop a mountain (Rinehart et al. 2011). At the top of Lookout Mountain, the West Fork Little River begins at 626 m (2,054 ft) above sea level and descends to 174 m (570 ft) above sea level at Weiss Lake (Mary Shew, Little River Canyon National Preserve, resources management specialist, written communication, 8 November 2021). The most dramatic plunge is Little River Falls, a 14 m (45 ft) waterfall that marks the beginning of the canyon and where the river has breached the base of a thick sandstone ledge in the Pottsville Formation (geologic map unit **PNpv**) to incise into the softer undifferentiated Parkwood and Pennington Formations (**PNMpwp**).

Little River Falls is formally recognized by the US Board on Geographic Names and named in the Geographic Names Information System (GNIS; see "Guidance for Resource Management"), which is the official listing of US place names and geographic features. The US Board on Geographic Names is a federal body designed to maintain uniform geographic name usage throughout the federal government. The Secretary of the Interior has joint authority with the board as well as final approval or review of the board's actions. Other waterfalls in the preserve include DeSoto Falls (spelled "DeSoto Falls" and formally recognized in GNIS) as well as the informally named Indian, Lodge, Greggs Two, Johnnies Creek, and Graces High (fig. 20; Rinehart 2008; National Park Service 2016b). Oddly, Graces High, which is the highest waterfall in Alabama, is not formally recognized in GNIS.

Figure 20. Photographs of waterfalls at Little River Canyon National Preserve.
Waterfalls of all scales occur throughout the preserve. Top left, plunging 41 m (133 ft), is Graces High waterfall, the highest in Alabama. Top right is a tumbling cascade of more than 45 m (150 ft) down the canyon's steep slopes. Bottom left is an unnamed falls, on the scale of less than 15 m (50 ft), that formed as runoff after a heavy rain. Bottom right is Little River Falls, which is 14 m (45 ft) high. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

The river above Little River Falls, which is recognized in GNIS, features pool areas with sandy bottoms, riffles, and rapids, and is surrounded by wooded hills. Riffles are a rocky or shallow parts of a stream or river where the water flows brokenly. Rapids are a fast-flowing and turbulent part of the course of a river. The river in the canyon itself features high-energy flow environments, numerous rapids, and debris-laden floodplains as the river channel constricts and gradient increases. It is among the deepest and most extensive canyon and gorge systems east of the Mississippi River (Rinehart et al. 2011).

The rugged canyon of the river resembles the backbone of a fish or a trellis; it is characterized by steep-sided valley walls with short tributaries lying nearly perpendicular to the river. A direct spatial relationship exists between geologic faults and joints and the orientation of stream drainages; streams are parallel to subparallel with the regional joint and fault orientations (Thornberry-Ehrlich 2009; Mike Martin, NPS Water Resources Division, hydrologist, written communication, 16 November 2021). Most of the streams in the preserve are characterized by a "youthful" form consisting of steep walls and narrow V-shaped valleys as opposed to a mature valley consisting of a broad, shallow floor with a wide floodplain. This immaturity is also characterized by rapids and waterfalls along their courses (Thornberry-Ehrlich 2009). Resistant layers in the rock form ledges as the limestone and shale weather away from below leaving the sandstone perched along stream courses.

Karst Features and Processes

Map units: Bangor, Monteagle, and Tuscumbia Limestones, undifferentiated (**Mbmt**); Parkwood and Pennington Formations, undifferentiated (**PNMpwp**); Pottsville Formation (**PNpv**)

Karst is a landscape that forms through the dissolution of soluble bedrock, most commonly carbonates limestone or dolomite. Karst is characterized by surface features, such as the presence of dolines (sinkholes), pits, blind valleys, rise pools or springs, a paucity of surface drainage, and sinking or loosing streams. Additionally, karst is further defined by the subsurface, often the presence of caves, conduits, and rapid hydrologic transmissivity (measure of water flow) (fig. 21; Toomey 2009; Jack Wood, NPS Geologic Resources Division, geologist, written communication, 15 January 2022). Karst features require four geologic conditions to form: (1) soluble rocks (e.g., the carbonate or carbonate-cemented sandstone at the preserve), (2) mildly acidic water as a solvent (formed by rainwater becoming acidic as it percolates through detritus and soil layers and then circulates down through cracks in the bedrock). (3) hydrogeologic framework (hydraulic gradient); and (4) time.

Caves are naturally occurring underground voids that are sufficiently large for human entry and must have a permanent dark zone. Caves are a common feature in karst landscapes but also form under other conditions. Caves and bedrock crevices provide habitat for bats and other animals. Cave features are nonrenewable resources.

Sinkholes form when the overlying cover of soil, colluvium, or other insoluble rock is no longer supported as a result of the continuing dissolution of the underlying carbonate bedrock; this can be through the collapse or slumping of the "roof" into the conduit (White 1988; Jack Wood, NPS Geologic Resources Division, geologist, written communication, 15 January 2022). Areas with a resistant sandstone cap rock tend to form subjacent collapses that have an orthogonal (composed or right angles), joint-controlled distribution. Joints are the major geologic controlling factor, and the orientation and frequency of joints influence the morphology and distribution of dolines (Chenoweth 1997). Joints parallel to a bedding plane contact regularly cause a linear cluster of dolines. When two joints intersect, sinkholes are formed commonly with an associated short cave. The intersection of three or more joints repeatedly forms a deep, vertical shaft.

Another aspect to the karst setting at the preserve is paleokarst, which is defined as karst that has been buried by younger rocks and sediments. Paleokarst serves as a clear indicator of terrestrial environments of the past, and, to some extent, duration of emergence (i.e., exposure to the atmosphere) (Simms 2014). Although paleokarst is common, it is often difficult to recognize in successions of limestone layers. Identification of paleokarst may be complicated by two factors: (1) it is usually visible only in two, rather than three, dimensions, and (2) burial by younger rocks does not prevent modification or even destruction of the paleokarst by subsurface dissolution. Sharp rock composition contrasts, which commonly are associated with paleokarst surfaces, may focus water movement. Paleokarst, such as cave passages, may remain open as potential conduits for water flow long after burial of the karst surface, and sometimes are themselves mineralized by fluids flowing through (Simms 2014). Over time, as the surface bedrock erodes and the river continues to cut down, paleokarst will slowly be exposed in Little River Canyon (Patricia Seiser, NPS Geologic Resources Division, National Cave and Karst Program coordinator, written communication, 14 January 2022).

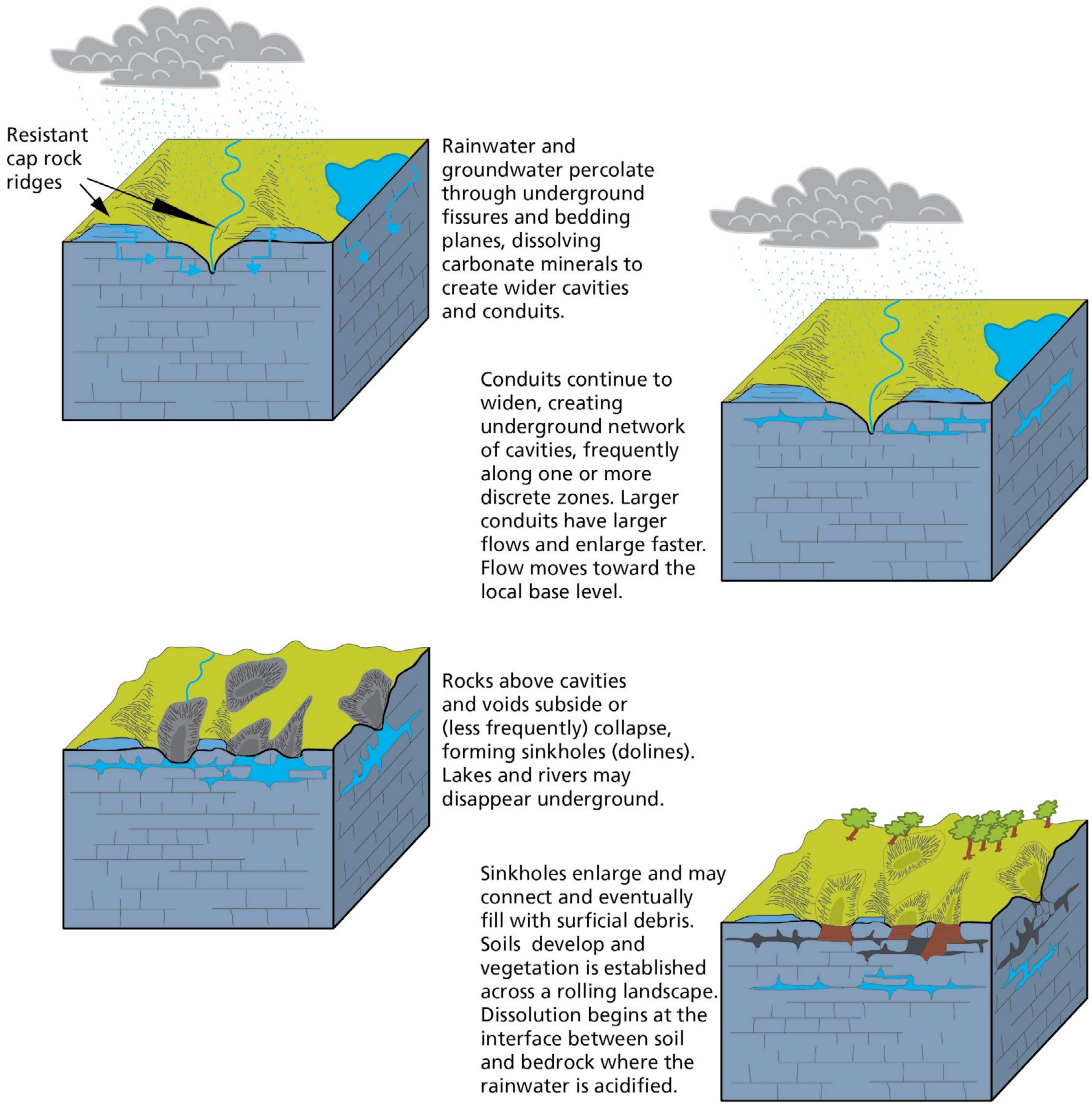


Figure 21. Three-dimensional illustration of karst landscape formation.
Karst is not well developed at the preserve, but its bedrock contains substantial carbonate rocks, and sinkholes are known in upland areas. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

The purpose of the Federal Cave Resource Protection Act 1988 (FCRPA) is to secure, protect, and preserve significant caves on federal lands for the perpetual use, enjoyment, and benefit of all people. It further established the policy that federal lands be managed in a manner which protects and maintains, to the extent practical, significant caves. The policy of the National Park Service, pursuant to its Organic Act of 1916 [16 U.S.C. 1, et seq.] and Management Policies (Chapter 4:20, December 1988), is that all caves are afforded protection and will be managed in compliance with approved resource management plans. Accordingly, all caves on National Park Service-administered lands are deemed to fall within the definition of "significant cave" (Patricia Seiser, NPS Geologic Resources Division, National Cave and Karst Program coordinator, written communication, 14 January 2022).

As of September 2017, cave and/or karst resources were documented in 159 NPS areas, including Little River Canyon National Preserve (Thornberry-Ehrlich 2009); this is the most up-to-date number known. According to the US Geological Survey national karst map, 0.73% of the preserve area is considered or has the potential to be karst (National Park Service 2016a). Sinkholes are present on the edges of the preserve but are not part of the GRI GIS data. The Geological Survey of Alabama's sinkhole database shows the closest mapped sinkhole to preserve boundaries at less than 2 km (1 mi) away from the northern most part of the preserve near DeSoto State Park. One sinkhole collapsed beneath a local church cemetery. Most of the rocks exposed within the preserve are sandstones, siltstones, and shales that are not prone to dissolution. Underlying limestone may be dissolving in situ below the insoluble units; this would affect the hydrogeologic system at the preserve (Thornberry-Ehrlich 2009). Park staff have noted karst-like springs in limited limestone outcrops in the preserve (GRI conference call participants, 5 May 2020). The need of cave documentation within the preserve was listed as a management need in National Park Service (2016a). The NPS Geologic Resources Division and National Cave and Karst Research Institute (NCKRI) can assist with cave and karst resource management (see "Guidance for Resource Management").

Sandstone Glades

Map unit: Pottsville Formation (**PNpv**)

Sandstone balds or glades, such as those at Lynn overlook, are rare habitats. They developed because of the underlying geology. Sandstone glades are areas underlain by resistant, weathered sandstone with little to no soil development along the Little River Canyon rim and elsewhere in some upstream areas (fig. 22). These are similar in nature to cedar glade habitats in areas underlain by limestone. The Alabama Cumberland sandstone glades are G-1 globally rare communities, defined as being critically imperiled or at very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors. Nearly bare rock, they harbor plants that only grow in harsh environments (e.g., very acidic, low pH soils, xeric conditions). To visitors, they resemble lichen rock gardens (Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020).

Upland Bogs and Other Wetlands

Map units: Bangor, Monteagle, and Tuscumbia Limestones, undifferentiated (**Mbmt**); Parkwood and Pennington Formations, undifferentiated (**PNMpwp**); Pottsville Formation (**PNpv**)

Wetlands such as marshes, swamps, seeps (fig. 23), pools, and bogs are transitional areas between land and water bodies, where water periodically floods the land or saturates the soil. Wetlands provide several significant functions, including (1) provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) retention of sediments, to name a few.

Figure 22. Photographs of sandstone glades along the rim of Little River Canyon.
Such glades are where weathered, resistant sandstone beds in the Pottsville Formation (PNpv) are exposed at the surface with little to no soil development. They are a globally rare habitat harboring lichens and rare plants that only grow in harsh environments (e.g., very acidic, low pH soils, xeric conditions). Examples of sandstone glade plants include Nuttall's rayless goldenrod (*Bigelowia nuttallii*), pineweed (*Hypericum gentianoides*), and eastern prickly pear (*Opuntia humifusa*). Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

Morgan et al. (2009) identified 127 wetlands covering 28.7 ha (71.1 ac) within the preserve. Wetlands in the preserve have shallow surface water or water within the root zone most of the year; some are wet only seasonally. Of the 127 identified wetlands, 107 are slope wetlands, 14 are depressions, and 8 are riverine wetlands (figs. 24 and 25). The riverine wetlands

Figure 23. Photograph of seeping water at a bedrock outcrop.
Percolating groundwater may flow along the tops of bedding planes within the sedimentary bedrock (e.g., the Pottsville Formation, PNpv). Where the plane intersects the ground surface, a seep forms. The outcrop shows well-defined bedding planes with individual beds about 3 to 5 cm (1 to 2 in) thick. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

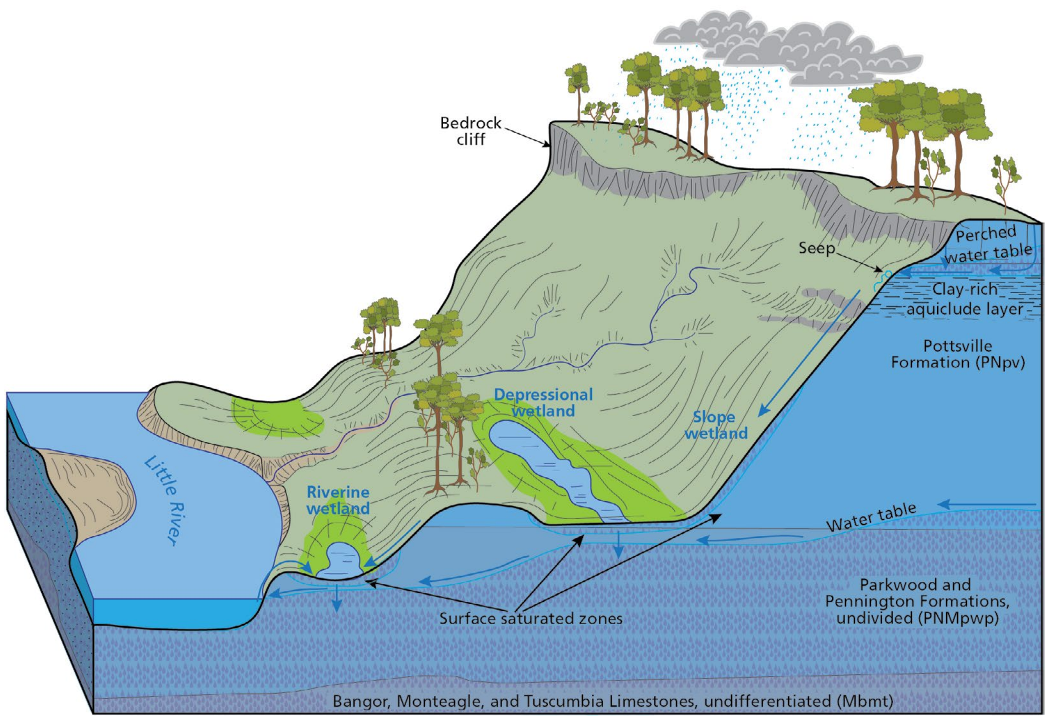


Figure 24. Cross-sectional view of wetland types across the Little River valley.
Three major types of wetlands occur in different settings throughout the preserve: riverine, depressional, and slope wetlands. Underlying geology controlling topography and groundwater chemistry, availability, and movement strongly influences the formation and longevity of wetlands in the preserve. Because of an aquiclude's composition or texture (e.g., fine-grained), water does not easily permeate these layers. Saturated zones are those in which nearly all pore space is filled with water. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from Bingham et al. (2016, figure 3).

Figure 25. Photographs of wetlands at Little River Canyon National Preserve.
Scientists identified three major types of wetlands at the preserve: slope, depression, and riverine. Slope wetlands (A and B) are the most prevalent, commonly forming where the slope intersects a local water table forming seeps. Such seeps may form atop a layer in the bedrock that acts as an aquiclude to percolating groundwater. Water flows along the top of this layer until it intersects the ground surface. Depression wetlands (C and D) may form in natural depressions in the bedrock or other scoured areas. Riverine wetlands (E and F) commonly form as vegetated fringes along the Little River and its tributaries. Graphic compiled by Trista L. Thornberry-Ehrlich (Colorado State University), using images from Morgan et al. (2009): (A) LIRI_082, (B) LIRI_114, (C) LIRI_014, (D) LIRI_127, (E) LIRI_122, and (F) LIRI_121.

were all bedrock lined as opposed to underlain by unconsolidated alluvium (Morgan et al. 2009).

The upland areas of Little River Canyon support unique upland bogs and wetlands–southern Appalachian low mountain seepage bogs. Habitat for several rare and/or endangered species such as the green pitcher plant (*Sarracenia oreophila*) and Kral's water plantain (*Sagittaria secundifolia*) is protected in these areas of the preserve (Thornberry-Ehrlich 2009; National Park Service 2016a). Little River Canyon National Preserve has half of the known green pitcher plant patches in the world (National Park Service 2016a).

Slope Movements and Erosion

Map units: Bangor, Monteagle, and Tuscumbia Limestones, undifferentiated (**Mbmt**); Parkwood and Pennington Formations, undifferentiated (**PNMpwp**); Pottsville Formation (**PNpv**)

Slope movements, also called "mass movements" or referred to generally as "landslides," have occurred and will continue to occur in the preserve. Slope movements are the downslope transfer of material (e.g., soil, regolith, and/or rock; fig. 26). Slope movements can occur rapidly (e.g., debris flows or rockfall, which occur in seconds) or over long periods of time (e.g., slope creep over the course of years). The magnitude of slope failures depends on slope, aspect, soil type, and geology, as well as climate-related factors. Within the preserve, much of the landscape is moderate to steep slopes including sheer cliffs and bedrock-lined ravines.

Blockfall in which the rocks tend to break off in a large column (National Park Service 2016a) is a natural process and a major contributing factor to the development of Little River Canyon (see fig. 26). The resistant sandstones and conglomerates (e.g., **PNpv**) that form the cap rock for many of the upland areas and waterfalls are prone to blockfalls when undercut by the erosion of softer, underlying units. Shaley and coal-rich layers within the Pottsville Formation (**PNpv**) create zones of weakness or slip surfaces where failures could occur. In resistant rock units, pervasive joint sets—commonly intersecting at nearly 90° angles (though not formally measured via joint analysis during mapping; Ed Osborne, Geological Survey of Alabama, geologist, GRI conference call, 5 May 2020)—form natural spalling surfaces. Tree-root wedging and frost weathering also cause bedrock instability at Little River Canyon (Thornberry-Ehrlich 2009) and preserve staff have noted several slides and falls since heavy seasonal precipitation in spring 2020 (Little River Canyon National Preserve staff, GRI conference call, 5 May 2020).

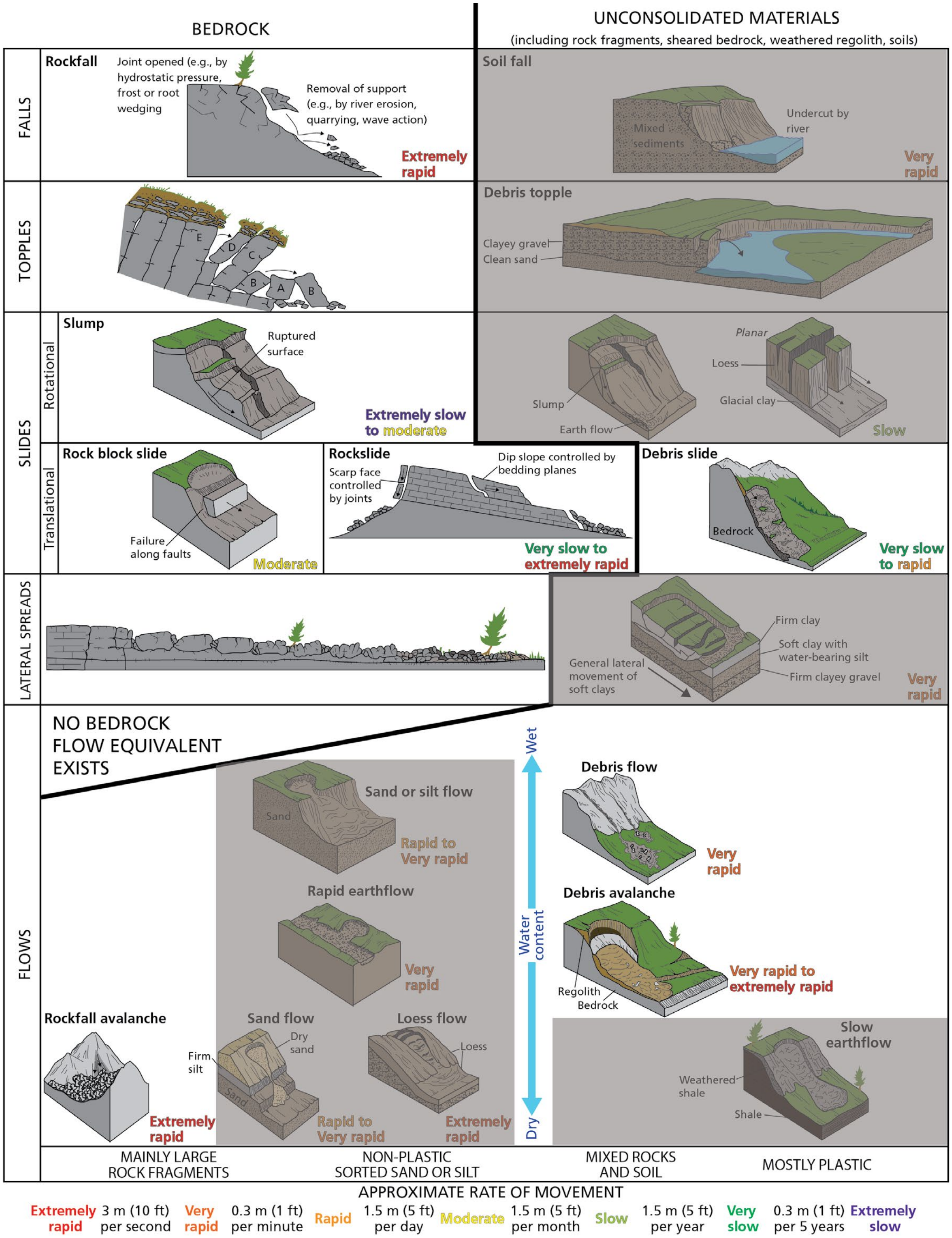


Figure 26. Illustrations of slope movements.
Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at the preserve. Most slope movements within the preserve originate from bedrock rather than unconsolidated deposits. Falls and topples are the most common slope movement at the preserve. The abundant vegetation in the preserve stabilizes some slopes, but slope movements could be exacerbated by factors such as natural or anthropogenic removal of vegetation and climate change. Numbers represent a continuum along a scale. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

Geologic Resource Management Issues

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

Flooding and Stream Stabilization

Flooding is common along the Little River and its tributaries at all times of the year. Discharge in the Little River and its tributaries can range from nearly dry to a raging torrent after rainfall events (National Park Service 2016a). Flood events may raise stream levels as much as 5–6 m (15–20 ft) (Rinehart et al. 2011). Waterfalls appear throughout the preserve following heavy rains (Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). Spring 2020 was particularly wet as a single rainfall event in April caused the Little River's flow to increase from 0.1 cubic meters per second (cms) (5 cubic feet per second [cfs]) to 12 cms (408 cfs) in less than 24 hours (Little River Canyon National Preserve staff, GRI conference call, 5 May 2020).

Floods are the primary geomorphological agents 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 river deposits natural levees of sand and silt along its banks; this only happens in limited ways within the high-energy canyon itself. These deposits represent the relatively coarse-grained component of a river's suspended sediment load and form a high area on an alluvial region's land surface. Plants preferring high drainage soils tend to grow here, whereas beyond the levees, where the finer grained deposits settle, drainage is decreased, and the plants change accordingly.

Flooding in Little River Canyon is a natural process generally driven by intense rainfall. Narrow channels are overwhelmed when heavy rains funnel through the drainages, resulting in flash floods. While extreme floods are often generated by tropical storms and hurricanes, occurring in the summer months, floods may occur at any time during the year. This annual hydrologic cycle of high flows is necessary for channel and floodplain maintenance as well as supporting other ecosystem services. However, extreme floods may present a substantial threat to visitor services, park infrastructure, and cultural resources (Mike Martin, NPS Water Resources Division, hydrologist, written communication, 15 October 2021).

Two stream gages provide records of annual peak flows on the Little River. US Geological Survey gage number 02399200 is located near Blue Pond, Alabama, drains an area of 515 km^2 (199 mi^2), and has a period of record of 64 years (1948–2019). US Geological Survey gage 02399000 is near Jamestown, Alabama, drains 324 km^2 (125 mi^2), and has a period of record of 34 years (1929–1967). US Geological Survey Stream Stats calculations for the gage near Jamestown report a 1% annual exceedance probability (AEP) flood magnitude (commonly referred to as the 100-year flood) of 840 cms (29,600 cfs). The highest recorded flow at that gage is 710 cms (25,000 cfs), occurring on 3 March 1966. The 1% AEP flood magnitude at the gage near Blue Pond is 1,250 cms (44,100 cfs). The highest recorded flow at that gage was 1,500 cms (53,800 cfs), occurring on 24 July 1985, close to the calculated 0.2% AEP flood magnitude (commonly referred to as the 500-year flood) of 1,660 cms (58,600 cfs). Incidentally, the peak flow that occurred on 4 March 1966 (the day after the flood of record on the upstream gage) was 910 cms (32,000 cfs; Mike Martin, NPS Water Resources Division, hydrologist, written communication, 15 October 2021).

Detailed data on the location of the 100-year floodplain at Little River Canyon are not readily available and an accurate location of this floodplain boundary has not been delineated. However, the Alabama Office of Water Resources hosts online flood maps from around the state, which may be of use to resource managers at the preserve. The floodplain elevations for the 1% AEP flood on these maps are reported through Little River Canyon with links corresponding to flood insurance rate maps (FIRMs) for the area (see "Guidance for Resource Management").

Because of the narrowness of Little River Canyon, much of the streambank areas are prone to inundation. Any structure or cultural resource within the flood zone in the preserve would be affected by flooding. Three primitive campsites within the preserve often flood (one at Sandy Dune). Based on existing information, all the channels and canyon bottoms within Little River Canyon should be considered within the 1% AEP (100-year) floodplain. Additionally, these drainages should be considered high-hazard flood zones and provisions should be made to protect human life to the greatest extent practicable (Mike Martin, NPS Water Resources

Division, hydrologist, written communication, 15 October 2021).

Another, and possibly more substantial flood hazard, is associated with the numerous water impoundment structures present in the watershed (fig. 27). The failure of 1920s-era dams—including Cash, Temple, Owens Lake, Rotch and Cassidy, Sharp Branch, Camp Corner, A. A. Miller, and Lahusage—on tributaries of the Little River outside of the preserve could result in hazardous flood conditions with little to no warning. These dams were constructed to create reservoirs for residents in neighboring upland housing developments or to provide hydropower for local communities and industry. Most of these dams are poorly maintained, concrete and steel structures. As of 2009, no parties were responsible for ownership and/or maintenance of the dams; Alabama has no regulatory body to inspect these structures (Thornberry-Ehrlich 2009; Little River Canyon National Preserve staff, GRI conference call, 5 May 2020; Mike Martin, NPS Water Resources Division, hydrologist, written communication, 15 October 2021).

No flood-warning system exists in the preserve. If flash flooding occurs or if any of the dams were to fail, an unexpected flood could inundate reaches of Little River Canyon or its tributaries, cause major scouring of the entire canyon, and present a substantial risk to anyone present (Little River Canyon National Preserve staff, GRI conference call, 5 May 2020). Steep Little River Canyon with its near vertical walls become a safety hazard with several drownings and more than 15 canyon rescues each year. The risk associated with flash flooding has been exhibited in the recent past. In 1985, a dam retaining a 4 ha (10 ac) farm pond failed following heavy rain. The resultant flood in Johnnies Creek resulted in casualties, boats capsizing, and rescues from the roof of the building at Canyon Mouth (United Press International 1985; Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). The flood damaged anchors (blocks about the size of a small car) for a cable bridge and the bridge itself; remaining cables were removed in 2000 (Mary Shew, Little River Canyon National Preserve, resources management specialist, “Johnnies Creek Cable Removal 12/2000” [notice] and written communication, 19 July 2020). Dams at Alpine Lake and Lake Lahusage have partially failed in the past (exact dates are unknown), resulting in large slabs of sandstone being snatched from the riverbed at Little River Falls and moved downstream that instantly created large pools (Thornberry-Ehrlich 2009; Mary Shew, Little River Canyon National Preserve, resources management specialist, written communication, 18 November 2021). Another dam-related feature that poses a safety hazard for kayakers is a wooden cofferdam that is rock-filled and contains iron spikes on the main branch near Eberhart Point. In the past, this structure was used to float logs or supply controlled rushes of water for recreational purposes (Thornberry-Ehrlich 2009).

Figure 27. Photographs of dams within the Little River watershed.
Dams are present throughout the Little River watershed in the preserve area. Most dams have been abandoned with no one claiming responsibility for their upkeep and/or removal. If a local dam were to fail, this could potentially send a dangerous and damaging flood roaring down through Little River Canyon. Top image has a dam located downstream of the confluence of the West and East Forks Little River at Lookout Mountain camp. The bottom image is of a dam just upstream of DeSoto Falls, outside the preserve boundary. NPS photographs by Joe Meiman (NPS Cumberland Piedmont Network) taken in 2007 (top) and 2006 (bottom).

The preserve's natural resource condition assessment (Rinehart et al. 2011) noted flood risk, risk and impacts of failure of degraded dams, and an updated inventory of dams as information gaps regarding the preserve's hydrology. In addition, Rinehart et al. (2011) noted groundwater resources as an information gap. The NPS Water Resources Division may be able to assist with groundwater-related needs and issues (see "Guidance for Resource Management").

The Little River and its canyon are listed among the fundamental resources at the preserve by National Park Service (2016b). Natural river meandering erodes streambanks, threatening the stability of natural and cultural resources along the Little River and its tributaries. Trees regularly wash into the river after their roots are exposed through streambank erosion. This process adds large wood to the fluvial ecosystem, which is generally viewed as very positive, but collections of channel and floodplain wood threaten infrastructure such as at a bridge or road crossing (Mike Martin, NPS Water Resources Division, hydrologist, written communication 22 October 2021). Human impacts at high-use areas such as watercraft access points, swimming areas, beaches, and trails can exacerbate streambank retreat and result in unnatural widening of the channel, which in turn, affects geomorphic and riparian processes (Little River Canyon National Preserve staff, GRI conference call, 5 May 2020). Within the preserve, safety hazards exist along riverside trails that have been undercut by streamflow.

Bank stabilization structures, mainly gabions, have been put in place to try to stem the streambank loss in certain reaches of the rivers such as Canyon Mouth (currently closed following Easter 2020 flood; Thornberry-Ehrlich 2009; Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). Gabions have been installed in backwater areas to absorb energy and flow from seasonal floods in places such as at the picnic area at Canyon Mouth. Although used widely in the past, gabion structures generally provide inadequate bank protection with little long-term resiliency (Mike Martin, NPS Water Resources Division, hydrologist, written communication, 16 November 2021). At Blue Hole, old concrete picnic tables were repurposed to provide steps to the river (Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). Unfortunately, artificial stabilization or armoring in one area tends to increase erosion in adjacent areas. Stabilization efforts at some of these areas are only short-term solutions. The preserve's budget does not allow for large-scale stabilization solutions (Thornberry-Ehrlich 2009; GRI conference call participants, 5 May 2020).

Documentation of erosive processes within the preserve is a management need. Recreational activities likely exacerbate erosion: the steep trails accessing the river and river fords are degraded from heavy use, and social trails (fig. 28) are widespread (National Park Service 2016a, 2016b).

Figure 28. Photographs of trails eroding at Little River Canyon.
Steep slopes, off-trail foot traffic, and runoff are causing erosion on some preserve trails. Preserve staff have attempted to stem this problem with water bars (diagonal channel cut across the trail that diverts surface water that would otherwise flow down the whole length of the trail) and borders, but heavily used trails are often circumnavigated or widened by visitor use. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

Sediment Loading and Water Quality

Because most of the streams in the preserve exist on scoured bedrock channels, relatively small amounts of fine-grained sediment are part of the bedload. Sediment flushing into the watershed during high flows is part of the natural system, but when the sediment is generated anthropogenically, it could be detrimental to the aquatic ecosystem by removing substrate or potentially introducing unfiltered contaminants to the system. A study of sediment transport into the local drainages remains a resource management data need (National Park Service 2016a). The Little River is experiencing more spikes in water flow; this trend is likely to continue as climate change models predict increased number and severity of storms (National Park Service 2016b).

In the preserve's natural resource condition assessment (Rinehart et al. 2011), state of the parks report (National Park Service 2016a), and foundation document (National Park Service 2016b), the following geologic-related planning and data needs were presented for the Little River ecosystem:

- Investigate locations of high land cover change and mining areas, to identify and isolate sources of contaminants concerning water quality.
- Monitor flood events for their potential impacts to landscape and species of management concern. See Lord et al. (2009) for fluvial monitoring guidance.

"Guidance for Resource Management" provides additional information and online resources for addressing water resource issues in the preserve.

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 preserve's resources, including geologic resources. Climate change models predict more frequent and stronger storms coupled with prolonged droughts to impact northern Alabama. Flooding resulting from these storms may become more frequent and cause increases in sediment load in the preserve's streams and rivers. Climate models project an increase in average temperatures of about 2.5°C (4.5°F) by the 2080s (Karl et al. 2009).

Park managers are directed to the NPS Climate Change Response Program 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 (see "Guidance for Resource Management"). The resist-accept-direct decision framework for managing resources during ecological change assists managers in making informed, purposeful choices about how to respond to the trajectory of change, and moreover, provides a straightforward approach to support resource managers in collaborating at larger scales across jurisdictions (Schuurman et al. 2020).

Geologic Hazards

Primary resource management issues in the preserve are geologic hazards from slope movements and earthquakes. A geologic hazard, or geohazard, is a naturally occurring, dynamic geologic 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 Holmes et al. 2013).

Slope Movements

Rockfalls could pose a safety hazard to visitors within the canyon and undercutting infrastructure such as the boardwalk at Little River Falls or the Wolf Creek overlook (Little River Canyon National Preserve staff, GRI conference call, 5 May 2020). The preserve's 10 overlooks (fig. 29 and GRI poster; Rinehart 2008) may also be at risk from blockfall (figs. 30 and 31).

Slope processes may be contributing to road destabilization and trail erosion in the preserve. Canyon Rim Drive abuts the edge of the canyon in many areas without guardrails. This poses a safety hazard to visitors using the roadway (Thornberry-Ehrlich 2009). Lack of guardrails may encourage increased use at non-designated sites, exacerbating erosion locally. The shear canyon walls attract abundant climbing interest and climbers have installed thousands of rock bolts for climbing and rappelling in the preserve. These and other visitor activities concentrate erosion along social trails and other off trail use sites. Attempts to curb these adverse effects with signs and warnings have had limited success (Thornberry-Ehrlich 2009). Erosion is also accelerated in areas where people cut down trees for recreation purposes such as establishing campsites. Removal of stabilizing vegetation causes increased erosion, channelization, and gullying on preserve slopes in addition to increasing sediment load within the Little River system (Thornberry-Ehrlich 2009).

Occasionally, vehicles and assorted debris have been pushed off the canyon rim as garbage, resulting in degradation of preserve resources. Where possible, preserve staff are removing these foreign objects.

Figure 29. Photographs of Little River Falls observation deck.
Most of the preserve's overlooks are located on the rim of the canyon. These locations may be compromised by slope processes in such an active setting. Top image shows the deck when it was first constructed at the edge of the precipice atop the Parkwood and Pennington Formations, undifferentiated (PNMpwp). Bottom image shows vegetation growing along the ledge. Plants obscure surface cracks and roots may act to wedges rocks apart. Fresh surfaces on the bottom image suggest some small blocks have fallen. Blocks of rock litter the slope below. NPS photographs provided by Mary Shew (Little River Canyon National Preserve) taken in unknown year (top) and 2020 (bottom).

The NPS Geologic Resources Division employs three rockfall management strategies: (1) an Unstable Slope Management Program (USMP) for transportation corridor risk reduction, (2) quantitative risk estimation for specific rockfall hazards, and (3) monitoring of potential rockfall areas. Park managers can contact the 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."

Radon

Radon is a heavier-than-air, colorless, odorless, radioactive gas and a natural decay product from uranium and thorium (also naturally occurring). Long term exposure to elevated levels of radon creates an increased risk for lung cancer. Radon naturally accumulates in caves, basements, and other subterranean cavities. Limited air circulation in these spaces concentrates radon gas to levels appreciably higher than outside. Radon is measured in picocuries per liter of air (pCi/L), a measurement of radioactivity. In the United States, the average indoor radon level is about 1.3 pCi/L. The average outdoor level is about 0.4 pCi/L. The US Surgeon General and Environmental Protection Agency (EPA) recommend fixing spaces with radon levels at or above 4 pCi/L. In spaces where people spend a significant amount of time, such as homes or offices, EPA also recommends fixing at radon levels between 2 pCi/L and 4 pCi/L (Alabama Public Health 2021). Because radon is naturally occurring, remediation of the threat requires monitoring and ventilation.

At the preserve, layers in the Devonian shales (**Dc**) are radioactive and may naturally emit radon (Geological Survey of Alabama 2020). These layers are buried in the bedrock beneath the preserve, but the gas could permeate the overlying layers. Testing is the best way to determine a radon issue. Alabama has three "radon zones"; the preserve is part of zone 2, which has moderate potential for elevated levels of radon (Alabama Public Health 2021).

Active Faults and Earthquakes

Earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensity ranges from imperceptible by humans to complete destruction of developed areas and alteration of the landscape. The "Richter magnitude" is a measure of the energy released by an earthquake. Earthquakes can directly damage infrastructure or trigger other hazards such as slope movements that may impact resources, infrastructure, or visitor safety. According to the Geological Survey of Alabama, Little River Canyon is within an area of moderately low seismic risk (Thornberry-Ehrlich 2009). Figure 32 shows the likelihood of a moderate earthquake (i.e., Richter magnitude 5) over the next 100 years for the preserve.

Figure 30. Photographs of potential rockfall hazards along Little River Canyon.
(A) Large blocks of Pottsville Formation (PNpv) commonly spall off the near vertical cliffs that form the upper reaches of the canyon walls. (B) Colluvium (a slope deposit) mantles the base of the cliffs and canyon slopes where material has fallen down from areas such as those in photographs (A) and (C). (C) Overhanging ledges of sandstone of Pottsville Formation (PNpv) pose a blockfall hazard at the preserve, particularly in areas where the underlying Parkwood and Pennington Formations, undifferentiated (PNMpwp), are exposed and have eroded back under the ledge. PNMpwp exposures begin just downstream of Little River Falls. Photographs by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

Figure 31. Photograph of car-sized blocks within Little River Canyon.
Naturally occurring joints and fractures in the rocks provide planes of weakness that may fail as a consequence of weathering. The blocks tumble downslope and to river channel below. Photograph courtesy of Jacksonville State University (photographer unknown) taken in spring 2010.

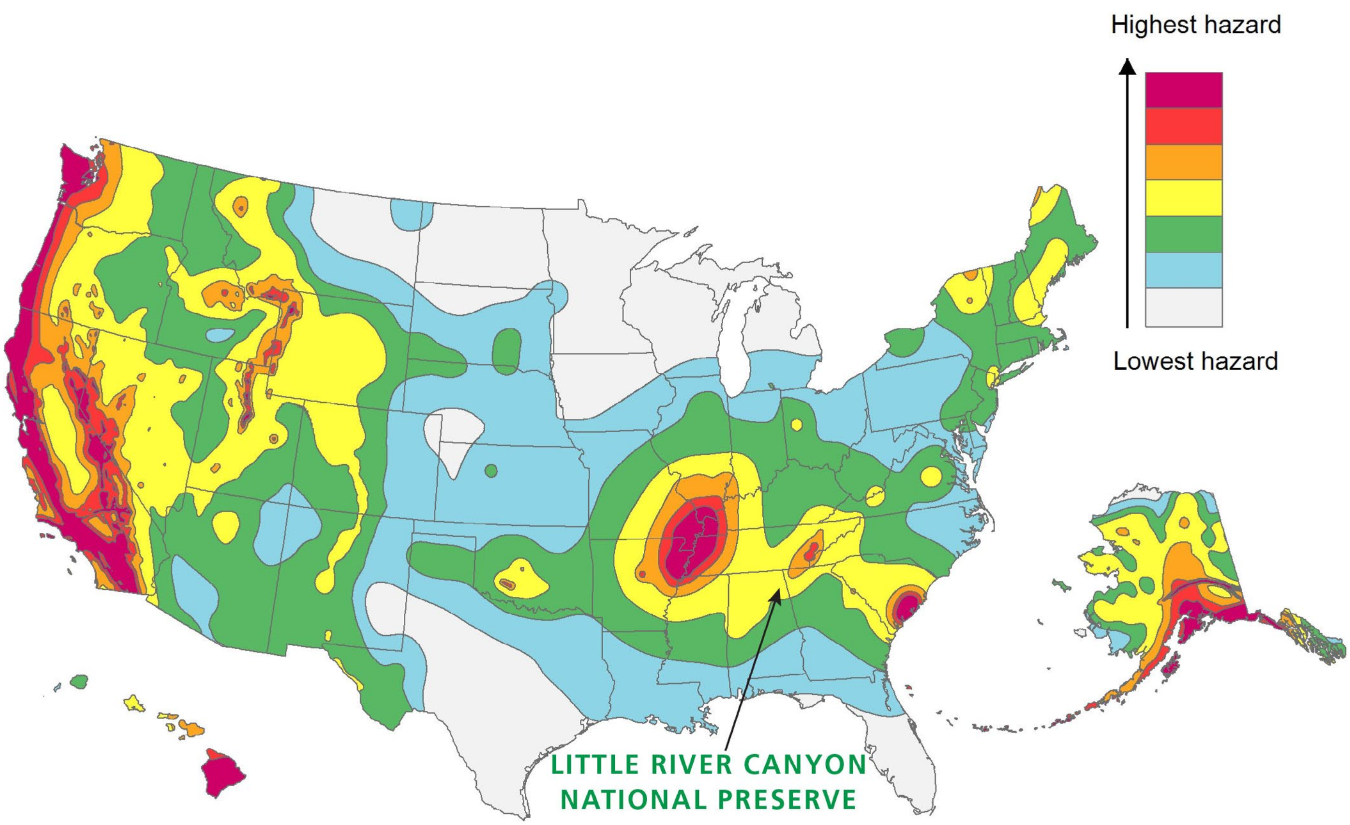


Figure 32. National seismic hazard map.
The map shows the potential for earthquake hazard across the United States based on the National Seismic Hazard Model (2018 update), which calculates peak ground accelerations having a 2% probability of being exceeded in 50 years for a firm rock site based on seismicity and fault-slip rates. The model also considered the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown because site geology (particularly unconsolidated sediment) may amplify ground motions. Alabama is near the east Tennessee seismic zone and has low (blue) to moderate (yellow) probability of seismicity. US Geological Survey graphic available at https://www.usgs.gov/programs/earthquake-hazards/science/national-seismic-hazard-maps (accessed 11 August 2022).

The preserve Is located near a known active seismic zone—the eastern Tennessee seismic zone (also known as the southern Appalachian seismic zone; see figs. 32 and 33). It is one of the most active seismic zones in eastern North America; more than 44 detectable (felt by humans) earthquakes have occurred since 1982 (Chapman et al. 2002). Intra-plate seismic zones such as the eastern Tennessee seismic zone are far from plate boundaries, which are the typical locations of earthquakes. The focal depths of most earthquakes in the seismic zone range from 5 to 22 km (3 to 14 mi) beneath large Paleozoic detachment surfaces (faults). Fault movement in the eastern Tennessee seismic zone is primarily lateral (strike-slip), with right-lateral motion on north–south-trending faults and left-lateral motion on east–west-trending faults (Chapman et al. 2002). Epicenters near the preserve include those located around Hartsville, Tennessee, and Fort Payne, Alabama, which experienced a magnitude 4.6 earthquake in 2003 that damaged local homes (fig. 34; Thornberry-Ehrlich 2009; Ed Osborne, Geological Survey of Alabama, geologist, GRI conference call, 5 May 2020). Renewed movement on several faults in the area is possible.

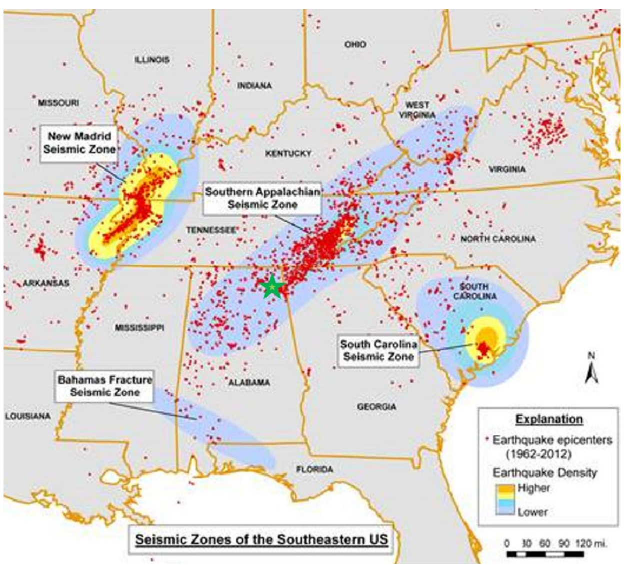
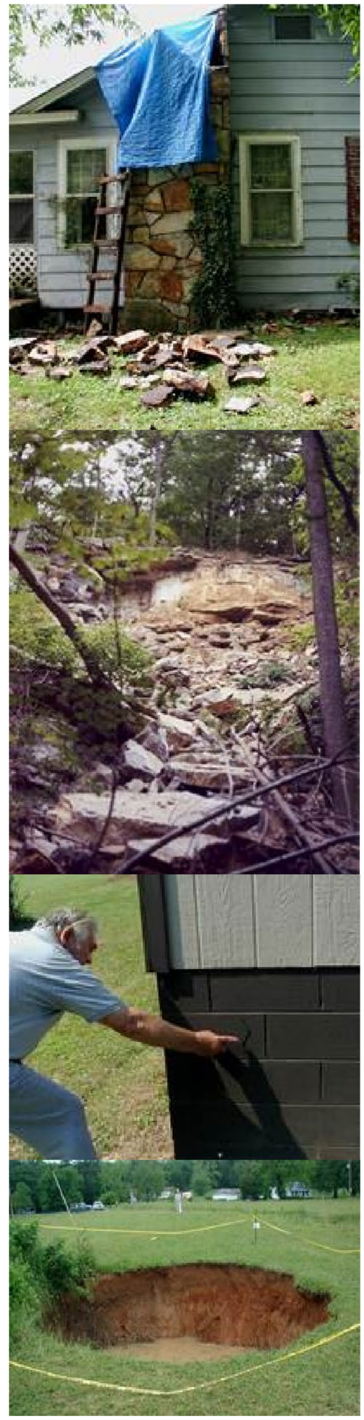


Figure 33. Map showing zones of frequent earthquake activity affecting Alabama.
The New Madrid, Southern Appalachian, South Carolina, and Bahamas Fracture seismic zones are delineated by earthquake epicenter density. Most earthquakes felt at the preserve (green star in northeastern Alabama) are associated with the southern Appalachian seismic zone—an extension of the eastern Tennessee seismic zone that runs along the Appalachian Mountains between West Virginia and Alabama. Geological Survey of Alabama graphic available at https://gsa.state.al.us/gsa/geologic/hazards/earthquakes/alquakes (accessed 8 August 2022).



A. Building damage included broken windows and toppled chimneys

B. Minor slumps and landslides occurred on steep slopes or in areas of unstable overhangs

C. Foundations and masonry cracked and/or shifted

D. Sinkholes opened and muddied the groundwater supply for local towns causing pump failures

Figure 34. Photographs of damage caused by the Fort Payne earthquake of 2003.
A magnitude 4.9 earthquake caused widespread damage with an epicenter 16 km (10 mi) northeast of the town of Fort Payne, Alabama. Photographs are not from within the preserve. Graphic compiled by Trista L. Thornberry-Ehrlich (Colorado State University) using Geological Survey of Alabama photographs available at https://gsa.state.al.us/gsa/geologic/hazards/earthquakes/alquakes (accessed 8 August 2022).

Though not likely, potential hazards associated with strong seismic shaking could include damage to preserve infrastructure including buildings, roads, trails, and bridges. Seismic shaking could also trigger massive slope movement along the walls of Little River Canyon (Thornberry-Ehrlich 2009). Moderate seismic shaking has the potential to trigger slope movements (e.g., slumps, landslides, and blockfalls). Susceptible areas could include those with unconsolidated deposits exposed on steep and/or undercut slopes, or those with large blocks of jointed rocks perched precipitously on the edge of steep slopes or cliffs (Thornberry-Ehrlich 2009).

Geologic Hazards Management

"Guidance for Resource Management" provides additional background information, suggested vital signs, and resources for assessing and documenting slope movements. 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 using techniques like photomonitoring, which involves taking a series of repeat images, using algorithms and models to detect landform change. The Scientist-in-the-Parks (SIP) program is an option to support such a project. The NPS Geologic Resources Division can provides technical assistance with photographic techniques, such as photogrammetry, which aid structural analysis of rockfall areas (see "Guidance for Resource Management").

A cooperative effort between the National Park Service, Federal Highways, University of Montana, and others is working to create a central database of unstable slopes with ranking systems. This database supports an unstable slope management tool to allow prioritization of mitigation to reduce slope hazard risks where unstable slopes and visitors are likely to coincide. It is designed for use along corridors and is ideal where slopes intersect trails, roads, climbing routes, or river recreation access areas. The slopes at the preserve would be ideal candidates for inclusion in the effort. The NPS Geologic Resources Division can assist with geologic hazards management (see "Guidance for Resource Management").

The preserve's natural resource condition assessment (Rinehart et al. 2011) noted cliff characteristics, including locations of concern, species inventories, impacts from visitors on cliff faces and biota, as well as records of geohazards, landslides, and earthquakes as information gaps for resource management. The need of geologic hazard documentation within the preserve was listed as a management need in the preserve's state of the park report (National Park Service 2016a).

Disturbed Lands

Disturbed lands are those where the natural conditions and processes have been directly impacted by development, including facilities, military bases, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. An example in the preserve is remote areas used as dumpsites in the past. Some disturbed lands may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities.

Regional urban development, poor land-use planning, logging, and improper land management practices upslope of Little River Canyon exacerbate erosion, which causes sediment loads to increase and sediment-laden water to flow into the preserve (fig. 35; Thornberry-Ehrlich 2009; GRI conference call participants, 5 May 2020). Pollution and low pH (acidic) waters in tributaries of the Little River are not chemically buffered by the sandstone substrate, as opposed to a limestone substrate. These water quality problems are particularly prevalent in the Yellow Creek basin with adjacent, old, reclaimed strip mines (Thornberry-Ehrlich 2009; Rhinehart 2011).

The preserve's natural resource condition assessment (Rinehart et al 2011) listed the following threats, stressors, and disturbances to natural resources: mining (see "Abandoned Mineral Lands"), ATV use, silviculture (logging), and degradation of dams.

ATV users were traveling off the pathways established by the preserve's off-road vehicle management plan; critical habitats were damaged or destroyed causing a closure to ATV use in 2010 (Rinehart et al. 2011; Mary Shew, Little River Canyon National Preserve, resources management specialist, written communication, 18 November 2021). The preserve is still closed to ATV use, but people are still using large trucks with big tires to get around unauthorized areas. A compromised culvert caused road closures in 2020, but people ignore the signs and proceed anyway (Steve Black, Little River Canyon National Preserve, superintendent, GRI conference call, 5 May 2020).

Logging and logging access removes stabilizing trees. Logging continues throughout the area, but not within the preserve boundaries (Thornberry-Ehrlich 2009). Land owned by the Alabama Power Company has been logged many times in the past. Local logging causes scars, drag lines, ruts, ditches, compacted soils,

Figure 35. Photograph of sediment-laden water from Bear Creek as it joins the flow of the Little River. The larger stream to the left is the Little River and the incoming tributary on the right is Bear Creek. Ground-disturbing activities cause sediment pulses into the system, seen here as cloudy brown water. Flow directions for both streams are toward the top of the page. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) taken in spring 2009.

and often replanting of cut areas with loblolly pines (Thornberry-Ehrlich 2009).

Knowledge about dams on the Little River and its tributaries is limited, largely because Alabama was very late to implement state dam safety regulations (Rinehart et al. 2011). At least 13 dams are located within the Little River watershed (fig. 36). Information on the structural status of these dams is unknown and more dams may exist (Rinehart et al. 2011).

Abandoned Mineral Lands

Abandoned mineral lands (AML) are lands, waters, and surrounding watersheds that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation, including oil and gas features and operations, for which the NPS takes action under various authorities to mitigate, reclaim, or restore in order to reduce hazards and impacts to resources. AML features may include adits, prospects, shafts, structures, open pits, tunnels, waste rock piles, mills, wells, and landform modifications such as service roads, drainage diversions, and drill pads.

AML features pose a variety of resource management issues such as visitor and staff safety and environmental quality of air, water, and soil. AML features can also provide habitat for bats and other animals, some of which may be protected under the Endangered Species Act or state species listings. Resource management of AML features requires an accurate inventory and reporting. All AML features should be recorded in the Servicewide AML Database; the NPS Geologic

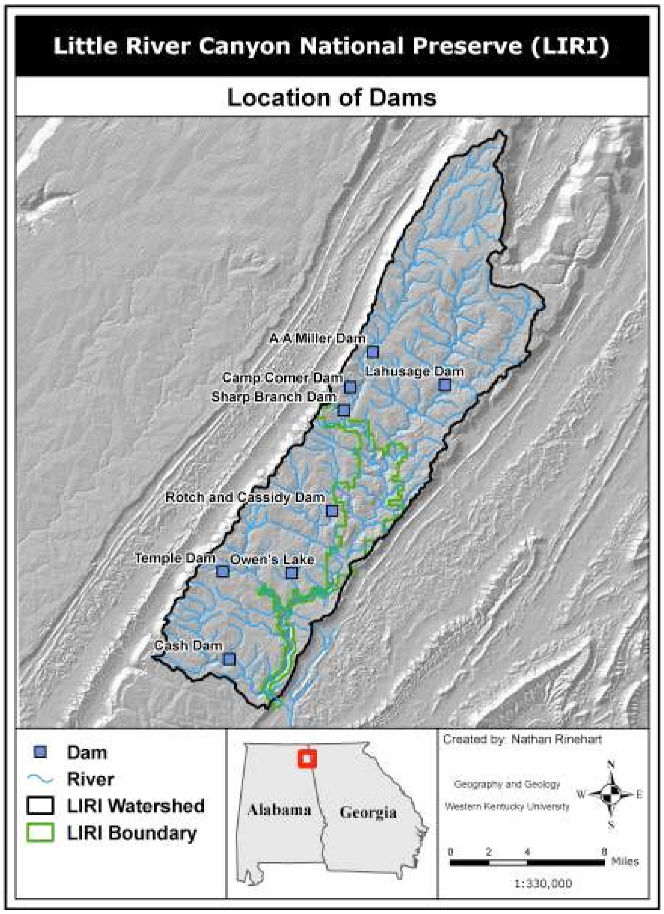


Figure 36. Map showing location of dams within the Little River watershed.
These may not be the only dams that exist, and their structural status is largely unknown but considered low hazard. Dam degradation and/or failure can cause floods and pulses of sediment that pollute the downstream aquatic environment. Graphic from Rinehart et al. (2011, figure 24).

Resources Division can provide assistance. An accurate inventory identifies human safety hazards and contamination issues, and facilitates closure, reclamation, and restoration of AML features. When appropriate for resource management and visitor safety, AML features can also present opportunities for interpretation as cultural resources (Burghardt et al. 2014).

According to the NPS AML database and Burghardt et al. (2014), the preserve contains no AML sites or features. The GRI GIS data include at least 11 mine features (e.g., gravel pits, sand pits, and quarries) beyond preserve boundaries. A stone quarry, used by the Civilian Conservation Corps (CCC) to build some local structures in the preserve, exists within the boundaries of DeSoto State Park. No stone quarries are known within preserve boundaries (Thornberry-Ehrlich 2009). A small amount of iron ore is present in the rocks of the canyon walls within the preserve.

Some mining is considered historical or cultural (e.g., coal mining in rock shelters for fuel used in moonshine distilling; GRI conference call participants, 5 May 2020) and therefore not targets for reclamation. In the 1800s, the presence of this iron ore and regional coal seams ignited iron-furnace operations. Nearby Fort Payne, Alabama, was originally an “iron town.” No historic coal mines are known to have existed within the preserve (Thornberry-Ehrlich 2009). The preserve’s natural resource condition assessment (Rinehart et al. 2011) listed 12 abandoned surface mines and two abandoned surface/underground mines adjacent to the preserve.

Active coal mining persists (including abandoned operations) in the northeastern part of the Little River watershed. Personal use (“groundhog”) pits or small-scale shafts, as well as shallow scrapes, into coal seams are common throughout the area. Neighboring DeSoto State Park contains closed coal prospect pits that now appear as shallow depressions (Thornberry-Ehrlich 2009).

Paleontological Resource Inventory, Monitoring, and Protection

The preserve has geologic units known to be locally fossiliferous. Potential exists for fossils in unconsolidated deposits. All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act. Fossils such as marine invertebrates, plant fragments, bark impressions, ferns, coal, crinoids, *Calamites*, and an iron-rich fossiliferous layer in limestone (geologic map unit **Mbmt**) are prominently exposed in several high-visitation areas of the preserve. In some places the crinoids are so numerous, the rock resembles a coarse conglomerate (Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). These exposures are at risk of theft and/or vandalism (Hunt-Foster et al. 2009). Preserve staff have not noted fossils being chipped away but do recognize that fossils are also prominent in cobbles that are easy to pick up and transport (see figs. 13 and 37; Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). The need for fossil documentation within the preserve was listed as a management need in the state of the park report (National Park Service 2016a).

The NPS paleontological resource summary for the Cumberland Piedmont Network (Hunt-Foster et al.

Figure 37. Photographs of fossils in dislodged boulders and cobbles.
Some of the most striking fossils in the preserve are visible in large boulders or cobbles along preserve trails. Park managers have not noticed any active collecting or vandalism at these sites but may want to continue to monitor. A) plant debris within a sandstone boulder. B and C) brush debris in outcrops. D) boulders and cobbles littering the slope and a trail below a shale canyon wall. In addition to their paleontological interest, accumulations of slope deposits on some preserve trails are a record of the risk of slope movements creating hazards for visitors in some areas. NPS photographs provided by Mary Shew (Little River Canyon National Preserve) taken in unknown year (top left), 2006 (top right), 2004 (bottom left), and 2007 (bottom right).

2009) was compiled through extensive literature reviews and interviews with preserve staff and professional geologists and paleontologists, but no field-based investigations. An on-the-ground paleontological survey would be an ideal Scientists in Parks (SIP) project (see "Guidance for Resource Management"). Resource-management recommendations from Hunt-Foster et al. (2009) for the preserve included:

- Encourage park staff to observe exposed gullies, other erosional bedrock, and streams for fossil material while conducting their usual duties.
- Photodocument and potentially monitor any occurrences of paleontological resources that may be observed in situ.
- Consider long-term monitoring of paleontological sites.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.
- Work with GRD to create a paleontological resources management plan and conduct a formal inventory of fossil resources within the preserve.

"Guidance for Resource Management" provides additional guidance, suggested vital signs, and online resources for assessing and documenting the preserve's paleontological resources.

Wetland Management

Wetlands are typically only mentioned in GRI reports where particular geologic connections exist to their development or resource management. The wetlands at the preserve form where slopes and depressions in bedrock and along riverbanks allow water to pool as well as in areas where seeps emerge along bedding planes within the bedrock. The NPS Water Resources Division is the primary contact for technical and policy assistance regarding wetlands. A wetland inventory for the preserve (Morgan et al. 2009) includes intensive surveys, hydrological data, water levels, and vegetation indices of biotic integrity.

Bedrock Vandalism

Unfortunately, the prominence of bedrock exposures and their eye-catching or unusual appearances (e.g., "mushroom rock") have caused them to be the target of spray paint vandalism (Mary Shew, Little River Canyon National Preserve, resources management specialist, GRI conference call, 5 May 2020). This type of vandalism is difficult to track, remediate, and monitor, particularly in areas where it occurs away from trails and roads. Increased outreach and signage may help better educate the visitors about this problem.

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
- GIS data model: http://go.nps.gov/gridatamodel

Three Basic Ways to Receive Geologic Resource Management Assistance

- Contact the NPS Geologic Resources Division (http://go.nps.gov/geology). GRD staff members provide technical and policy support 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; law, policy, and guidance; resource management planning; and data and information management. Park managers can formally request assistance via https://irma.nps.gov/Star/ (available on the Department of the Interior [DOI] network only).
- Submit a proposal to receive geologic expertise through the Scientists in Parks (SIP; see https://www.nps.gov/subjects/science/scientists-in-parks.htm). This program places scientists (typically undergraduate students) in parks to complete geoscience-related projects that can address resource management issues. The Geological Society of America and Environmental Stewards are partners of the SIP program. The Geologic Resources Division can provide guidance and assistance with submitting a proposal. Proposals may be for assistance with research, interpretation and public education, inventory, and/or monitoring.
- 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.

Assistance with Water-Related Issues

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

Little River Canyon National Preserve Documents and Needs

The preserve's foundation document (National Park Service 2016b), natural resource condition assessment (Rinehart et al. 2011), and state of the park report (National Park Service 2016a) are primary sources of information for resource management within the preserve. Cultural landscape restoration and management are also addressed in several publications such as Cornelison (1991), Marshal and Gregg (1997), and National Park Service (2005). An ethnographic overview and assessment as well as a cultural landscape inventory and resource stewardship strategy remain management needs at the preserve (National Park Service 2016a).

Many of the preserve's fundamental resources and values, as highlighted in the foundation document (National Park Service 2016b), pertain to or are influenced by geology: Little River, the canyon, canyon recreation, native plants and wildlife communities, backcountry experience and landscape, and cultural resources. Identifying fundamental resources and values helps to focus resource planning and management on the most imperative issues affecting aspects of the preserve. The NPS Cumberland Piedmont Network currently inventories and monitors natural resources such as forest vegetation communities, invasive species early detection, ozone/foliar injury, and water quality at the preserve (https://www.nps.gov/im/cupn/liri.htm).

To better protect and preserve fundamental resources and values, the following are planning and/or data needs:

- Planning for adaptation to climate change
- Drafting management plans for trails, climbing, backcountry areas, visitor use, watershed, and canyon (National Park Service 2016a).
- Documentation of geologic hazards, fossils, caves, and erosive processes (National Park Service 2016a).
- Mapping of Fort Payne Chert natural occurrences as they are significant to archeological sites because they were used to make stone implements and arrowheads (National Park Service 2016a).
- Detailed mapping of karst features at the preserve (National Park Service 2016a).
- Preparation of a point-of-view geologic guide to educate kayakers and other river recreationists, making the river the focal point. Such a guide would detail geologic outcrops, views, and other features visible from the river.
- Include geologic features in a visual resource inventory quantifying scenic views. The program is described at https://www.nps.gov/subjects/scenicviews/inventory-process.htm (public website) and https://doimspp.sharepoint.com/sites/nps-nrss-ardiv/SitePages/Visual-Resources.aspx#visual-resources-inventory (available on the DOI network only).
- Determine the impact of fine-grained sediment transport into the Little River during flood events (National Park Service 2016a).
- LiDAR for the preserve will be useful to identify road traces, trails, and cultural sites as well as compare imagery of erosion, deposition, and other landform changes over time (National Park Service 2016b).
- GIS mapping of the Trail of Tears (National Park Service 2016b).

NPS 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

Table 5, 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 5. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
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 5, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
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.
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.

Table 5, continued. 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.
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 5, 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 5, 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.

Table 5, 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 5, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
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.
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.

Table 5, 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.

Table 5, 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 5, 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).

Additional References, Resources, and Websites

Abandoned Mineral Lands

- NPS AML: http://go.nps.gov/aml

Alabama Geology

- Causey (1965) described the geology and groundwater resources of Cherokee County, Alabama.
- Geological Survey of Alabama website (https://gsa.state.al.us/) has a wealth of geologic information for the preserve area as part of their geologic investigations and groundwater assessment programs. Other information available from the survey includes: geologic mapping, natural hazards, paleontology, water information, well records, coastal resources, coal research, and oil and gas research.
- Szabo et al. (1988) provided a statewide geologic map and report.
- Thomas and Bayona (2005) discussed the Appalachian thrust belt in Alabama.

Cave and Karst Resource Management

- "Geological Monitoring of Caves and Associated Landscapes" (Toomey 2009) in *Geological Monitoring* (Young and Norby 2009) described methods for inventorying and monitoring cave-related vital signs, including the following: (1) cave meteorology, such as microclimate and air composition; (2) airborne sedimentation, including dust and lint; (3) direct visitor impacts, such as breakage of cave formations, trail use in caves, graffiti, and artificial cave lighting; (4) permanent or seasonal ice; (5) cave drip and pool water, including drip locations, rate, volume, and water chemistry, pool microbiology, and temperature; (6) cave microbiology; (7) stability issues associated with breakdown, rockfall, and partings; (8) mineral growth of speleothems, such as stalagmites and stalactites; (9) surface expressions and processes that link the surface and the cave environment, including springs, sinkholes, and cracks; (10) regional groundwater levels and quantity; and (11) fluvial processes, including underground streams and rivers.

- Karst aquifers: https://www.usgs.gov/mission-areas/water-resources/science/karst-aquifers. *Note*: Includes a map showing karst areas of the continental United States having sinkholes.
- Karst Information Portal (open-access digital library): https://digital.lib.usf.edu/karst
- Karst map of the United States: https://pubs.usgs.gov/of/2014/1156/
- National Cave and Karst Research Institute (NCKRI): http://www.nckri.org/
- NCKRI, Report of Investigation 4: *Evaluation of Cave and Karst Programs and Issues at US National Parks* (Land et al. 2013). https://www.nckri.org/publications/reports-of-investigation/
- NPS caves and karst: https://www.nps.gov/subjects/caves/index.htm
- NPS information about white-nose syndrome—a fatal disease caused by the fungus *Pseudogymnoascus destructans* that affects cave-dwelling bats: https://www.nps.gov/subjects/bats/white-nose-syndrome.htm
- Many other resources are available for cave management, including NPS policies and directives (table 5), inventory and monitoring reports, and the work at other parks to create cave management plans and management documents. The NPS Cave and Karst Program coordinator, who is located at NCKRI in Carlsbad, New Mexico, provides technical assistance.

Climate Change Resources

- Fisichelli et al. (2014) discussed ecosystem stewardship in the face of predicted climate change: https://irma.nps.gov/DataStore/Reference/Profile/2210682
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- Monahan and Fisichelli (2014) discussed climate change exposure for National Park Service units, including the preserve: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0101302
- NPS Climate Change Response Program: 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: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- US Global Change Research Program: http://www.globalchange.gov/home

Disturbed Lands Restoration

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

Earthquakes

- Geological Survey of Alabama, earthquake information and data: https://gsa.state.al.us/gsa/geologic/geospatial
- International Code Council (ICC) International Building Code (IBC): https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/ibc/
- "Seismic Monitoring" (Braile 2009) in *Geological Monitoring* (Young and Norby 2009) 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.
- US Geological Survey (USGS), Earthquake Hazards Program: https://earthquake.usgs.gov/
- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/

Energy Development and Mining

- Geological Survey of Alabama, geospatial data for coal, oil, and gas resources: https://gsa.state.al.us/gsa/geologic/geospatial
- NPS Energy and Mineral Development: https://www.nps.gov/subjects/energyminerals/index.htm
- NPS Geologic Resources Division completed an oil, gas, and minerals management handbook in 2017 that provides guidance for implementing existing NPS policy. Contact the NPS Geologic Resources Division (https://www.nps.gov/orgs/1088/contactus.htm) to request a copy.

Flooding

- Alabama Department of Economic and Community Affairs (ADECA), Office of Water Resources, online flood maps: https://alabamaflood.com/map/
- Federal Emergency Management Agency (FEMA) flood maps: https://www.fema.gov/flood-maps

Geologic Heritage

- *America's Geologic Heritage: An Invitation to Leadership* (National Park Service and American Geosciences Institute 2015). This publication introduced key principles and concepts of America's geologic heritage; these concepts are the focus of ongoing collaboration and cooperation on geologic conservation in the United States.

- NPS America's geologic heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- United Nations Educational, Scientific and Cultural Organization (UNESCO) global geoparks: https://en.unesco.org/global-geoparks
- US 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

Geological Surveys and Societies

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

Geology of National Park Service Areas

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

NPS Reference Tools

- NPS eLibrary: http://www.npshistory.com/
- NPS Technical Information Center (TIC) (repository for technical documents): https://www.nps.gov/orgs/1804/dsctic.htm
- The GRI team collaborates with TIC to maintain an NPS subscription to GeoRef (https://pubs.geoscienceworld.org/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.

Photogrammetry

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

Paleontological Resources

- Geological Survey of Alabama, paleontology collection: https://gsa.state.al.us/gsa/geologic/paleo/db.
- GRI GIS data: https://irma.nps.gov/DataStore/Reference/Profile/2194545. Data such as paleontological observation points are considered sensitive data and are only available on NPS computers.
- "Monitoring in situ Paleontological Resources" (Santucci et al. 2009) in *Geological Monitoring* (Young and /Norby 2009) detailed paleontological resource monitoring strategies, including five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use.
- NPS Fossils and Paleontology: https://www.nps.gov/subjects/fossils/index.htm
- A preliminary inventory of NPS paleontological resources found in cultural resource contexts: Kenworthy and Santucci (2006)

Radon in Alabama

- Alabama Public Health, radon information: https://www.alabamapublichealth.gov/radon/radon-in-alabama.html
- Environmental Protection Agency (EPA), radon information: http://www.epa.gov/radon/
- Geological Survey of Alabama, radon information: https://www.gsa.state.al.us/gsa/geologic/hazards/radon

Slope Movements

- The Geological Survey of Alabama's Geologic Investigations Program has information regarding geologic mapping, hazards (e.g., landslides, earthquakes, and radon), and accompanying geospatial data (fig. 38): https://www.gsa.state.al.us/gsa/geologic/geospatial
- The Landslide Handbook—A Guide to Understanding Landslides (Highland and Bobrowsky 2008): http://pubs.usgs.gov/circ/1325/
- Landslide hazards and climate change: Coe (2016)
- "Monitoring Slope Movements" (Wieczorek and Snyder 2009) in Geological Monitoring (Young and Norby 2009) described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks.
- Natural hazards science strategy: Holmes et al. (2013)
- NPS Geologic Resources Division Geohazards: http://go.nps.gov/geohazards
- NPS Geologic Resources Division Slope Movement Monitoring: http://go.nps.gov/geomonitoring
- US Geological Survey, landslide hazards: http://landslides.usgs.gov/

Soils

- Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. The most up-to-date soils information is available via WSS. Derivative maps can be created from the WSS including maps relevant for facilities siting or improvements. Please contact the GRI program for assistance in obtaining and using soils data.
- 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 an SRI has been completed. Download and extract all files.

US Geological Survey Reference Tools

- Geographic Names Information System (GNIS; official listing of US place names and geographic features): http://gnis.usgs.gov/
- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- US Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- USGS 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; Vigil et al. 2000): http://pubs.usgs.gov/imap/i2720/

Water Resources

- Meiman (2009) presented a water quality report with recommendations for future monitoring.
- NPS Water Resources Division, hydrographic and impairment statistics database for the preserve (Tucker and Ling 2021): https://irma.nps.gov/DataStore/Reference/Profile/2288559
- NPS Water Resources Division, information regarding the preserve's water resources: http://go.nps.gov/waterresources
- Rinehart (2008) provided an assessment of the condition of the Little River watershed and landscape resources for the preserve, as well as threats, stressors, and disturbances.

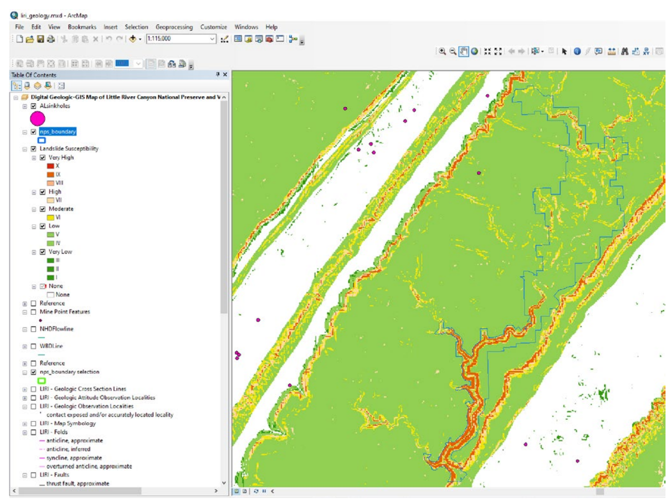


Figure 38. Screenshot of geospatial data. The Geological Survey of Alabama's geospatial data include slope hazards (i.e., landslide susceptibility) and sinkholes layers. The preserve boundary is the blue line. Mapped sinkhole locations are the purple spots. Much of the canyon corridor is very high (red) to high (orange) landslide susceptibility. Geospatial data are available for download from The Geological Survey of Alabama's online Geologic Investigations Program at https://www.gsa.state.al.us/gsa/geologic/geospatial (accessed 22 August 2022). The data were then added to the GRI GIS data.

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