National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Ocmulgee Mounds National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2464

ON THE COVER
Photograph of the Great Temple and Lesser Temple mounds at Ocmulgee Mounds National Historical Park. The mounds rise dramatically above the surrounding muted landscape. Passenger car for scale. Thick deposits of unconsolidated sediments were used as building material for the ancient mounds. Photograph by Georgia Hybels (Colorado State University) taken in spring 2012.

THIS PAGE
Photograph of the Norfolk Southern Railroad line that transects the main unit at Ocmulgee Mounds National Historical Park. Throughgoing trains are a regular occurrence in the park. Cretaceous bedrock (not pictured) is exposed in cuts along the railroad tracks. This bridge is just south of the village site. Photograph by Georgia Hybels (Colorado State University) taken in spring 2012.

Ocmulgee Mounds National Historical Park

Geologic Resources Inventory Report

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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 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.

Echoes of human history stretch back more than 12,000 years and contrast with a modern suburban park in central Georgia at Ocmulgee Mounds National Historical Park (herein called "the park"). The great earth mounds, built by early humans between 900 and 1200 common era (CE), stand as testament to the importance of the area and its abundance of natural resources that encouraged people to live and settle there. The park sits near the fall line, a major escarpment running along the length of the eastern US, which separates the hard, resistant bedrock of the Piedmont from the softer sediments of the Atlantic Coastal Plain. For more than 200 million years, the rocks beneath the park have been deeply weathered, producing a thick layer of overlying clay and regolith that became part of the area's soils. Earth surface processes continue to change the landscape, lowering the heights and reworking sediments along the stream channels. Today, the park has abundant wetlands and serves as the terminus of a disjointed greenspace corridor of undeveloped land trending northwestward from the Bond Swamp National Wildlife Refuge. The park's proximity to the city of Macon, Georgia creates challenges for resource managers including storm drain wastewater, transportation corridors (railroad and interstate), and encroaching suburban development.

This report is supported by a GRI-compiled digital geologic map data set (GRI map code ocmu) of the geology of Ocmulgee Mounds National Historical Park and vicinity. This dataset is herein referred to as the GRI GIS data. Geologic units, geologic contacts, spring locations, and mine points and areas are all part of the data. Geologic units will be referenced in this report using map unit symbols. For example, the Perry Sand is map unit **Tp**. A poster illustrates the GRI GIS data. The GRI GIS data and poster are available for download on the GRI publications website http://go.nps.gov/gripubs. The original maps used to compile the GRI GIS data were produced by the Environmental Protection Division, Georgia Department of Natural Resources, and US Geological Survey.

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 source maps used by the GRI team in compiling the GRI GIS data for the park and provides specific information about the use of these data. It also calls attention to the poster that illustrates these data.

Geologic Heritage of Ocmulgee Mounds National Historical Park—This chapter highlights the significant geologic features, landforms, landscapes, and stories of the park preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories such as why and how the mounds are located there.

Geologic Setting and History—This chapter describes the chronology of geologic events that formed the present landscape and includes a geologic time scale with park-significant events and units.

Geologic Features, Processes, and Issues—This chapter describes the geologic features and processes of significance for the park and places them in a context of geologic time. The features and processes are discussed in order of geologic time, oldest to youngest with a focus on their associated geologic map units. Potential management issues related to these geologic features and processes are also discussed in this chapter.

Guidance for Resource Management—This chapter provides resource managers with a variety of ways to find and receive management assistance with geologic resources and related issues.

Literature Cited—This chapter is a bibliography of references cited in this GRI report. Many of the cited references are available online, as indicated by an Internet address included as part of the reference citation. If park managers are interested in other investigations and/or a broader search of the scientific literature, the NPS Geologic Resources Division has collaborated with—and funded—the NPS Technical

Information Center (TIC) to maintain a subscription to GEOREF (the premier online geologic citation database). Multiple portals are available for NPS staff to access this database. Park staff may contact the GRI team or the NPS Geologic Resources Division for instructions to access GEOREF.

Introduction to the Geologic Resources Inventory

The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate, provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the national park system. The GRI is one of 12 inventories funded by the NPS Inventory and Monitoring Program.

GRI Products

Starting in 2012, the GRI team—which is a collaboration between staff at the National Park Service, Geologic Resources Division, and Colorado State University, Department of Geosciences—completed three tasks as part of the GRI for Ocmulgee Mounds National Historical Park: (1) conducted a scoping meeting and provided a scoping summary, (2) provided digital geologic map data in a geographic information system (GIS) and poster formats, and (3) provided a GRI report (this document). GRI products are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov . Enter "GRI" as the search text and select a park from the unit list. Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.

GRI Scoping Meeting

On 22 March 2012, the National Park Service held a scoping meeting at the park in Macon, Georgia. The scoping meeting brought together park staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report. A scoping summary (KellerLynn 2013) summarizes the findings of that meeting.

GRI GIS Data and Poster

Following the scoping meeting, the GRI team compiled the GRI GIS data for the park from four source maps. The data was compiled by the GRI in 2012 and updated in 2022. The GRI GIS data may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format. 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 7 January 2021, the GRI team hosted a follow-up conference call for park staff and interested geologic experts. The call provided an opportunity to get back in touch with park staff, introduce "new" (since the 2012 scoping meeting) staff to the GRI process, and update the list of geologic features, processes, and resource management issues for inclusion in the final GRI report.

This report is a culmination of the GRI process. It synthesizes discussions from the scoping meeting in 2012, the follow-up conference call in 2021, and additional geologic research. The selection of geologic features was guided by the previously completed GRI map data, and writing reflects the data and interpretation of the source map author. Geologic units will be referenced in this report using map unit symbols. For example, the Perry Sand is map unit **Tp**. Information from the park's foundation document (National Park Service 2014a) was also included as applicable to the park's geologic resources and resource management.

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 a fundamental tool for depicting the geology of an area. A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the park follows the source maps listed here and includes components described in this chapter.

Introduction to Geologic Maps

Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). The colors on a geologic map indicate the rocks or deposits. In addition to color, map unit symbols delineate rocks on geologic maps. Usually, a map unit symbol consists of an uppercase letter indicating age (e.g., **P** for Paleozoic, **K** for Cretaceous, **T** for Tertiary, **M** for Miocene, and **Q** for Quaternary) and lowercase letters indicating the rock formation's name or the type of deposit (e.g., **Qa** with **a** for alluvium). Other symbols on geologic maps depict the contacts between map units or structures such as faults or folds. 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 process, or depositional environment differentiate surficial geologic map units. The digital geologic map for the park includes both bedrock and surficial geologic data.

Source Maps

The GRI team does not conduct original geologic mapping. 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 and converts digital data to conform to the GRI GIS data model and digitizes paper maps.

To provide map coverage of the entire park area, four maps of different scales and geologic interpretations were used as source maps. This resulted in irregular geologic unit boundaries and some overlapping areas (fig. 1). The GRI GIS dataset is a compilation of data (ocmu map code) from the source material. The sources also provided information for this report. The source maps for the GRI GIS data are:

- Geology and ground-water resources of the Macon area, Georgia (LeGrand 1962)
- A geologic atlas of the central Georgia kaolin district (Hetrick and Friddell 1990)
- Geologic atlas of the Fort Valley area, Georgia (Hetrick 1990)
- USGS national hydrography dataset best resolution for hydrologic unit 4 (US Geological Survey 2018)

GRI Geodatabase Model and Data Sets

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

The GRI GIS data was compiled by the GRI in 2012 and updated in 2022. The data may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format. More information about the GRI GIS data can be found in the files accompanying the data on IRMA. The GIS readme file 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.

GRI Poster

A poster of the GRI GIS data ("GRI poster") draped over a shaded relief image of the park and surrounding area is the primary figure 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 park features have been added to the poster. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

Use Constraints

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the poster. Based on the source map scales (1:24,000, 1:100,000 and 1:181,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 12 m (40 ft), 51 m (167 ft), and 79 m (259 ft), respectively of their true locations.

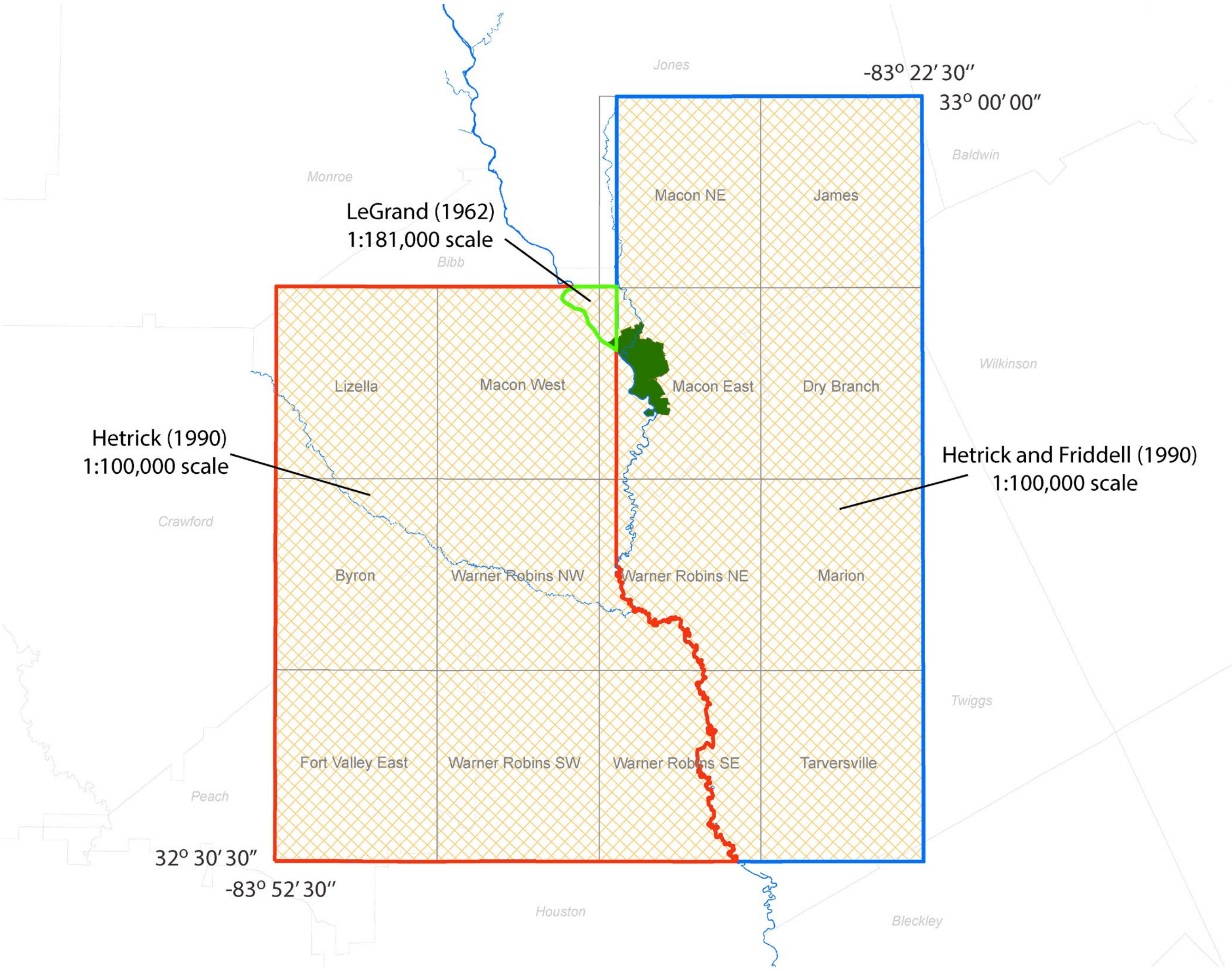

Figure 1. Index map of GRI GIS data sources.
Overlapping maps cover the entirety of the park lands. A small sliver of the western side, bright green outlined area is from *Geology and ground-water resources of the Macon area, Georgia* (LeGrand 1962). The rest of the western side, outlined in red is from *Geologic atlas of the Fort Valley area, Georgia* (Hetrick 1990). The eastern side, blue outlined area, is from *A geologic atlas of the central Georgia kaolin district* (Hetrick and Friddell 1990). Where Hetrick (1990) and Hetrick and Friddell (1990) overlap, Hetrick and Friddell (1990) was used in the GRI GIS data. River and water feature boundaries came from the US Geological Survey (2018). Map includes 7.5-minute quadrangles (names commonly refer to local landforms or geographic names). The solid green area is the park, which is entirely within the Macon East 7.5-minute quadrangle. Graphic by Jim Chappell (Colorado State University).

Table 1. GRI GIS data layers for Ocmulgee Mounds National Historical Park.

Data Layer	On Poster?
Geologic Point Features	No
Mine Point Features	No
Mine Area Feature Boundaries	No
Mine Area Features	No
Geologic Contacts	Yes
Geologic Units	Yes

Acknowledgements

The GRI team thanks the participants of the 2012 scoping meeting and 2021 follow-up conference call for their assistance in this inventory. The lists of participants (below) reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the Georgia Department of Natural Resources for its maps of the area. This report and accompanying GIS data could not have been completed without them.

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Geologic Heritage of Ocmulgee Mounds National Historical Park

For about 12,000 years, humans have used the natural resources of Ocmulgee Mounds National Historical Park, leaving behind a vast archeological record. The namesake mounds, including Earth Lodge, seven temple mounds, and a funeral mound, were built by Mississippian people from about 900 to 1200 CE. Paleoindians, Archaic, Woodland, Lamar, and historic Creek Indians also left traces of their presence in the area. This chapter highlights the significant geologic features, landforms, landscapes, and stories of the park preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories.

Park Background and Establishment

The name Ocmulgee is from the Hitchiti words "oki", meaning water, "och," meaning in or down in, and "mulgis," meaning boiling or bubbling (Burkholder et al. 2017). Established originally as Ocmulgee National Monument on June 14, 1934, Ocmulgee Mounds National Historical Park was redesignated on March 12, 2019. The name change emphasizes the importance of the prehistoric earth mounds at the site constructed for burial, ceremonial, and domiciliary purposes. Until 2022, the park covered about 284 ha (702 ac) of central Georgia in Bibb County, within the suburbs of Macon, Georgia. It consisted of one large unit along the Ocmulgee River (fig. 2), which is bisected by the Norfolk Southern Railroad, and a smaller unit to the southeast on the Ocmulgee River floodplain—the Lamar unit. In 2022, the park will finalize the acquisition of about 490 ha (1,200 ac) to include upstream areas of Walnut Creek, and a large tract of land that will encompass the Lamar unit and beyond (Greg Luna Golya, Ocmulgee Mounds National Historical Park, integrated resources manager, written communication, 26 January 2022). These lands will take some time to inventory and describe. This report will incorporate information about these new lands wherever possible. Park visitation since 2012 fluctuated around 120,000–150,000 annual recreational visitors (National Park Service 2021).

The landscape of the main unit of the park consists of riverine and wetland habitats, along with upland grassy fields and forests (DeVivo 2008). It contains the Mississippian earth mound complex, prehistoric trenches, green space, hiking trails, and a picnic area. About 4 km (2.5 mi) southeast of the main mounds area are the Lamar mounds on a low-lying floodplain area along the Ocmulgee River. The Lamar mounds, one of which includes a spiral ramp (the only prehistoric spiral ramp known to exist in the US), are the primary resource at the former Lamar unit (Obey 2002). Confederate Way is the road between Hwy 23 to the gate to the Lamar access road.

The park is entirely within the Ocmulgee River watershed, an area of 16,000 km^2 (6,180 mi^2). Its headwaters originate in the Atlanta metropolitan area where Tussahaw Creek, Yellow River (north segment)/South River (south segment), and the Alcovy River converge into impounded Lake Jackson (KellerLynn 2013). The Ocmulgee River begins at the outflow of this reservoir (Burkholder et al. 2010). Local topography is muted with elevations ranging in the park from 122 m (400 ft) atop Dunlop Mound to less than 85 m (280 ft); the highest reaches are anthropogenic—the mounds themselves (figs. 3 and 4). Landforms, topography, and underlying geology were all important components in the long human history of the park.

The park's foundation document (National Park Service 2014a) outlines the park's significance and explanations for the establishment of Ocmulgee Mounds National Historical Park:

- Ocmulgee Mounds National Historical Park preserves evidence of one of the longest periods of human habitation at any one site in the national park system. Occupation is indicated by prehistoric earthen mounds, including the only known spiral mound in the country; a restored ceremonial earth lodge with original clay floor; prehistoric trenches; an early colonial trading post; and Civil War earthworks.
- Ocmulgee Mounds National Historical Park has yielded artifacts from every major period of American Indian history in the Southeast, beginning with the Paleo-Indians and followed by a succession of cultural groups (10,000 BC to the present) who lived at the Ocmulgee Old Fields.
- The investigation and recovery of artifacts and information in the area known as the Ocmulgee Old Fields was instrumental in the development of the field of scientific archeology. Sites within the monument and surrounding area were part of one of the largest archeological investigations in North American history.

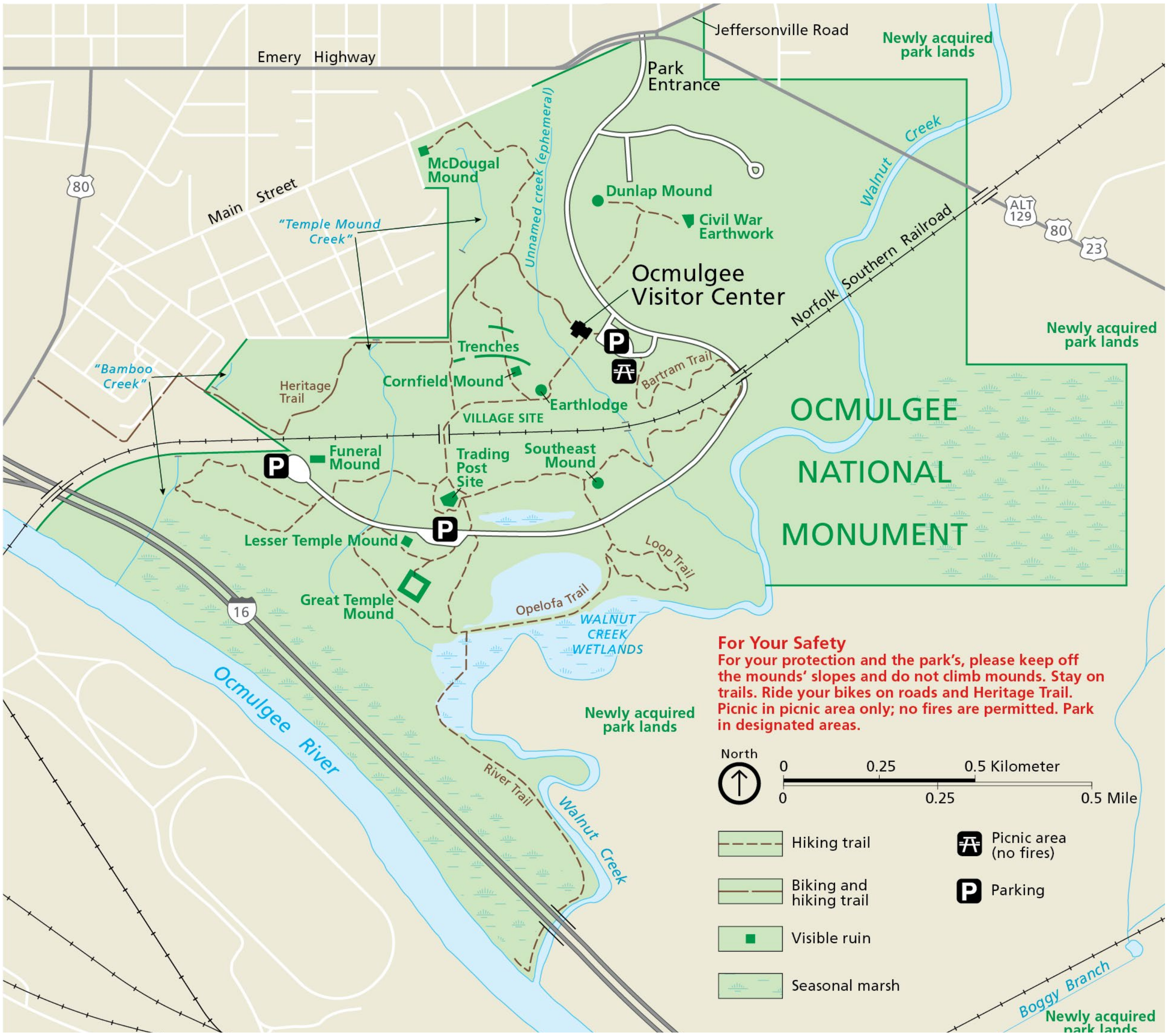

Figure 2. Map of Ocmulgee Mounds National Historical Park.
The park is in Macon, Georgia. Northwest of the park are the streets of the Macon suburbs. Southeast of the park is a noncontinuous floodplain green corridor. The park includes the earth mound complex, Civil War Earthworks, stretches of Walnut Creek, smaller creeks, and hiking trails such as the Opelofa, Loop, River, Heritage, and Bartram Trails. The Lamar mounds area, southeast of the main unit, is not included on this map. It is now enveloped by newly acquired park lands. In 2022, the boundary expanded to more than twice the size depicted here. See "Park Background and Establishment" for more details. National Park Service map with modifications by Trista L. Thornberry-Ehrlich (Colorado State University) from the Harpers Ferry Center available at: https://www.nps.gov/carto.

- The Ocmulgee Old Fields Project (1933–1941) employed one of the largest numbers of workers on an archeological investigation in the history of the Works Progress Administration (WPA) (more than 800, including an all-female African American crew). This site served as a field school for several well-known archeologists, including Arthur Kelly, James Ford, and Gordon Wiley, who had an impact on the field of archeology for generations.
- Ocmulgee Mounds National Historical Park possesses one of the largest collections of recovered artifacts (approximately 2.5 million) in the national park system. The collections also contain associated maps and other documentation of the archeological sites.

Figure 3. Photograph from the top of Great Temple Mound.
The anthropogenic mounds at Ocmulgee Mounds National Historical Park are the highest elevations in the park. Mississippian Period (900–1600 CE) mound builders excavated the thick, unconsolidated deposits available nearby to use as source material to fill large mounds, including the Lamar mounds. The view westward from the top of the Great Temple Mound takes in the skyline and largest buildings of Macon, Georgia. Photograph by Rebecca Port (NPS Geologic Resources Division) taken in March 2012.

Geologic Heritage

Geologic Heritage, or "geoheritage," encompasses the significant geologic features, landforms, and landscapes characteristic of our nation which are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values. The NPS also identifies geologic heritage aspects of museum collections, soils, and scientific data sets.

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, there is

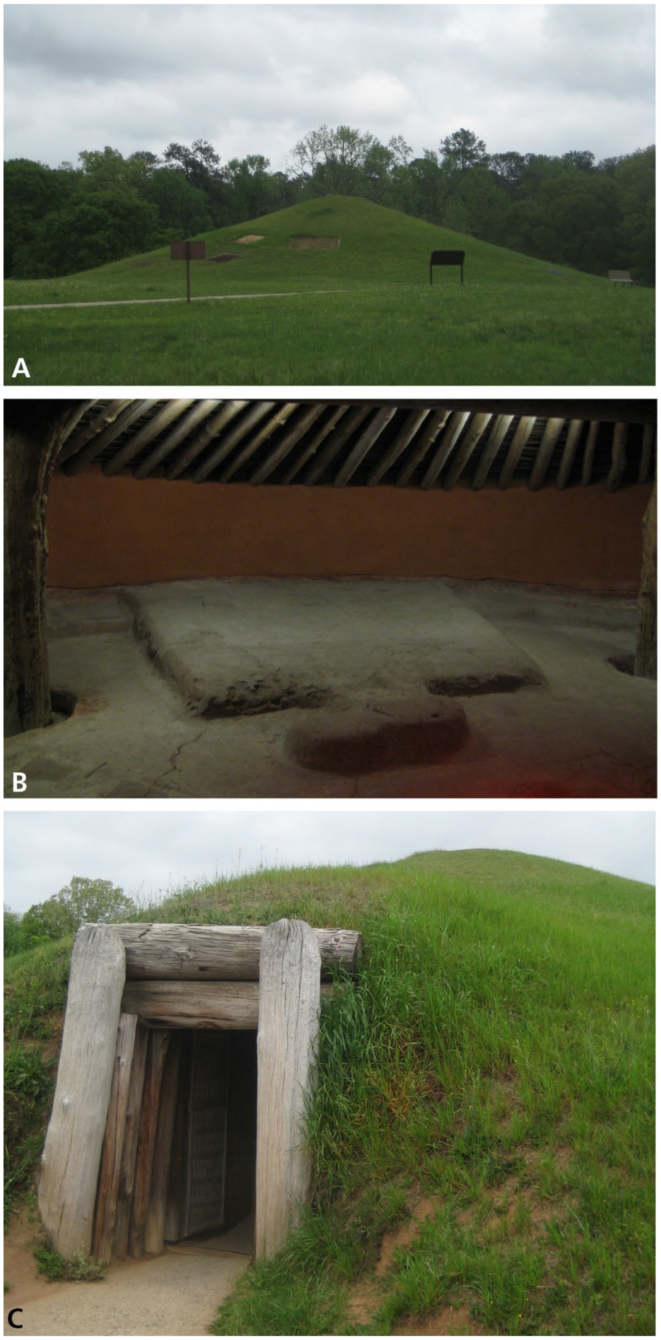

Figure 4. Photographs of Earth Lodge. The mounds rise high above the adjacent floodplains of Ocmulgee River and Walnut Creek. A) Earth Lodge was reconstructed and rises conically above its base. B) The floor of Earth Lodge is intact, dating back to the Mississippian Period (900–1600 CE) with a radiocarbon age of 1015±110 years CE or Early Mississippian Period. The perfectly round floor was built up with kaolin mined from a pond below Great Temple Mound. C) The timber-framed entrance to Earth Mound allows entry to see the original floor. Photographs by Georgia Hybels (Colorado State University) taken in March 2012.

no comprehensive national registry that includes all geoheritage sites in the United States.

Geology underpins the landscape at Ocmulgee Mounds National Historical Park. Its influences on the landscape and soil composition created a setting conducive to a long human history and, of course, forms the foundation of the current landscape and ecosystem.

Geology and the Long Human History of the Ocmulgee Floodplain

Compared to the geologic record, spanning millions of years, the human history of the park is quite short; however, for North America, the nearly continuous record of human presence for at least 12,000 years is significant as one of the longest periods of human habitation at any one site in the national park system and the southeastern United States. Many of the natural resources used by humans at Ocmulgee Mounds are geologic in nature, such as stone for tools and clay for building material and pottery. The following historical discussion was condensed from National Park Service (2019) and Wheeler (2007) and input from Greg Luna Golya (Ocmulgee Mounds National Historical Park, integrated resources manager, written communication, 26 January 2022).

The earliest evidence for human presence at Ocmulgee Mounds is distinctive “Clovis” spear points, from about 12,000 years ago, left on the Macon Plateau by people of the Paleoindian Culture (17,000–9,600 BCE). These long, fluted chipped stone projectiles (first recognized in Clovis, New Mexico) were characteristic tools at this time, and were made from chert, a sedimentary rock composed of silica (SiO_2), when and where it was available. It is thought that the people of the Paleoindian culture lived in small, mobile groups and used these points to hunt ice age mammals, such as giant bison and deer. It is likely that the abundance of natural resources was a significant factor in attracting people to the area. The nutrient-rich soils, formed by millions of years of weathering and erosion interacting with plants and climate, provided fertile land for growing and sustaining crops. Clay and earth for pottery and building materials was abundant as a result of weathering and deposition by local rivers. The rivers themselves were both vital water sources and tools for transportation and trade. The broad, fertile floodplains and adjacent uplands were ideal locations for habitation. In areas of undifferentiated sedimentary rocks (geologic map unit Ku) above the alluvium floodplain (Qa) are a complex of Paleoindian/Archaic and more recent archeological sites.

Similar to the earlier peoples, the people of the Archaic Period (9,600–1,000 BCE) lived in small, mobile bands.

Recovery of non-local chert at Ocmulgee Mounds provides evidence for trade from other areas that supported increasing populations and allowed for further trade with other local groups. In addition to weaponry, chert was used for knives, drills, choppers, flake knives and scrapers, gouges, hammer stones, and other tools. These people camped along major rivers in seasonal patterns; the local proximity to the river and elevated topography made the Ocmulgee area ideal for them to inhabit (Wheeler 2007).

Following the Archaic Period, the local geology, once again, is thought to have attracted the people of the Woodland Period (1,000 BCE–900 CE) to settle in the area. Though their geographic origins remain elusive, they likely chose to settle here due to the abundance of local clay and sand along river channels in the Ocmulgee area (Wheeler 2007; GRI conference call participants, 7 January 2021). They used these surficial geologic materials to make pottery tempered with sand and grit. Stone effigy mounds were built at this time in addition to earthen burial and platform mounds. The fertile floodplains also promoted the development of agriculture, supporting growth of sunflowers, gourds, corn, beans, and squash.

By 900 CE, the Woodland Period gave way to the Mississippian Period (900 CE–1600 CE) with newcomers arriving to the Ocmulgee area once again, this time to build villages. They brought with them a different type of pottery and a building tradition that led to the construction of the large ceremonial center with huge earthen temples, burials, domiciliary mounds, and earth lodges—the Earth Lodge floor dates to 1015 CE. Abundant unconsolidated surficial geologic units would have been needed to be readily available to construct such wonders. The perfectly round Earth Lodge floor, discovered in pristine condition in the 1930's excavations, had been built with kaolin (a soft white clay formed from deeply weathered rocks) mined from a pond below Great Temple Mound that is now part of the Walnut Creek wetlands (Wheeler 2007; K. KellerLynn, Colorado State University, geologist, field trip notes, 33 March 2012). This culture thrived at Ocmulgee until around 1250 CE.

About 100 years after the abandonment of these villages around 1250 CE, a new village was constructed at the Lamar site. This Lamar Culture became widespread in the southeastern US. Following the discovery of North America by Europeans, Spanish explorer Hernando De Soto was the first and nearly last European to interact with the mound-builder culture. In 1540, he and his crew carried European diseases to the Mississippian Period people and decimated the population.

European settlement began in earnest in 1690, when a British trading post (five-sided fortified stockade) was constructed on the Ocmulgee River (then called the Ochese Creek). A local native group, the Muscogee, who had moved nearby from the Chattahoochee River and established towns in the area were called by early European traders the Ochese Creek Nation. To the British, they were simply the "Creeks" and trading partners. The archeological record from this time records active trading of goods such as iron pots, steel knives, and cotton cloth. Ocmulgee Town, one of the Muscogee towns on Ochese Creek, was burned by the British in retaliation for fighting against the British during the Yamassee War in 1715 (Wheeler 2007; American Park Network 2013).

Once the United States of America was established following independence from Britain, Muscogee losses of ancestral territory from tribal migrations to other lands and landgrabs continued at an increased pace. In 1805, all land (except a 39-km2 [15-mi2] tract that included Ocmulgee Old Fields) east of the Ocmulgee River was ceded to the American government. Fort Hawkins was built where East Macon is today as a supply depot, post office, and trading post. A series of squabbles and land treaties culminated in 1826 with the incorporation of all Muscogee lands into the state of Georgia. As the city of Macon was established and expanded, the mounds were mentioned in a local newspaper in 1828 as a "romantic site" worth preserving. Sadly, nothing was done to preserve the mounds. In 1843, construction of a railroad running through Macon, destroyed portions of the Lesser Temple Mound, left a littering of artifacts, and exposed prehistoric burials. Intense nearby agriculture eroded topsoil and deposited vast silt sediments downriver near the Lamar mounds (Wheeler 2007).

During the Civil war, earthworks were constructed in the area. These earthworks represent the only skirmishes around Macon, Georgia (National Park Service 2014b). At that time, Samuel Dunlap owned the plantation on Ocmulgee Old Fields and his former home served as temporary headquarters for General George F. Stoneman of the Union Army, around which union soldiers hastily constructed fortifications and embrasures near the occupied house (Wheeler 2007).

Efforts to preserve the mounds first began in the 1920s by General Walter A. Harris, who ultimately involved the Smithsonian Institution (National Park Service 2014b). By this time, the landscape had already been altered by construction of the railroad and activity during the Civil War.

Of historical geologic interest, Charles Lyell (1797–1875)—one of the most renowned geologists of the 19th century—visited the greater Macon area in 1846. He wrote about his experiences in *Travels in North America: With Geological Observations on the United States, Canada, and Nova Scotia*, published in 1846. Lyell made many keen observations about the formation of the American landscape and described erosional processes across the Ocmulgee region (KellerLynn 2013; Wilson 1998; Al Mead, Georgia College, paleontologist, conference call, 7 January 2021).

Ocmulgee is also considered one of the birthplaces of modern archeology, acting as a training ground in the 1930s for an entire generation of American archeologists. Some of the type sites that define entire cultural periods are present in the park (e.g., Lamar, Swift Creek, Macon Plateau; National Park Service 2014b).

Geologic Ecosystem Connections

In addition to the historical connections briefly presented here, geologic features and processes play a fundamental role in shaping the local vegetation patterns, animal habitats, soils, and water resources. Weathering and erosion of local bedrock gives rise to soil formation, which is largely dense and heavy in texture, rich in clay and sandy loam, and highly erodible (Burkholder et al. 2017). 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 Ocmulgee Mounds National Historical Park were updated in 2004–2005 and are available at: https://irma.nps.gov/Datastore/Reference/Profile/1048946.

For being at an urban interface, the park contains a variety of ecosystems, which fosters significant biodiversity of fish, bird, mammal, and herpetofaunal communities. There is a total of 713 taxa reported within park boundaries, including 276 fauna and 437 vascular flora (Burkholder et al. 2017). Five vegetation communities are mapped within the park: disturbed (open) areas, upland hardwood, upland mixed hardwood-pine, floodplain forest (swamp), and open wetland (marsh; Burkholder et al. 2017). In general, the floodplain forest (swamp) and open wetland (marsh) communities are located on alluvium (map unit **Qa**), whereas the upland hardwood and upland mixed hardwood-pine are underlain by older sedimentary rocks (**Ku**). Floodplain or (bottomland) forests harboring hardwood species are among the most rapidly diminishing wetland ecosystems remaining in the US (Gosselink et al. 1990; Burkholder et al. 2017). This type of forest provides significant habitat for migratory birds, wildlife corridors for mammals, and spawning habitat for fish, as well as providing natural flood control by spreading or slowing flow and acting a sediment and pollutant sink (Gosselink et al. 1990; Burkholder et al. 2017).

Additional information about the park's ecosystems is available in the following references.

- Vegetation mapping with photointerpretation key https://irma.nps.gov/Datastore/Reference/Profile/2266896
- Geospatial data for vegetation mapping https://irma.nps.gov/Datastore/Reference/Profile/2271892
- Species lists https://irma.nps.gov/Datastore/Reference/Profile/2205731
- The NPS Southeast Coastal Inventory and Monitoring Network currently inventories and monitors natural resources such as climate, species, wadeable streams, vegetation communities, amphibians, and land birds (https://www.nps.gov/im/secn/index.htm).

Geologic Setting and History

This chapter describes the order of geologic events that formed the present landscape. A geologic time scale (table 2) shows the chronology of geologic events (bottom to top) that led to the park's present-day landscape.

Table 2. Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses; cell colors are standard US Geological Survey colors for different time periods. The Paleogene and Neogene Periods are also collectively referred to as the Tertiary, a widely used but no longer formally recognized term for the geologic period from 66.0 million–2.6 million years ago. Ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (ICS 2022). Only geologic units mapped within the park are included (see GRI poster).

Era	Period	MYA	Geologic Map Unit Symbols	Geologic Events
Cenozoic (CZ)	Quaternary (Q)	2.6–today	**Qa** deposited and reworked along modern streams	Human history; fluvial meandering, incision, and deposition Ice age climate changes; weathering and incision accelerated
Cenozoic (CZ)	Tertiary (T); Neogene (N)	23.0–2.6	**QToa** weathered and reworked; **QToa**, **Ta** deposited; **Tr** weathered	Ongoing erosion and weathering
Cenozoic (CZ)	Tertiary (T); Paleogene (PG)	66.0–23.0	**Tbt**, **Tp**, **Th**, **Tmc** deposited	Ongoing erosion and weathering
Mesozoic (MZ)	Cretaceous (K)	145.0–66.0	**Kg**, **Ku** deposited	Global mass extinction at end of Cretaceous (dinosaurs extinct)
Mesozoic (MZ)	Jurassic (J)	201.3–145.0	None mapped	Ongoing erosion and weathering
Mesozoic (MZ)	Triassic (TR)	251.9–201.3	None mapped	Global mass extinction at end of Triassic Breakup of Pangaea begins; Atlantic Ocean opened
Paleozoic (PZ)	Permian (P)	298.9–251.9	None mapped	Global mass extinction at end of Permian. Supercontinent Pangaea intact.
Paleozoic (PZ)	Carboniferous; Pennsylvanian (PN)	323.2–298.9	All units deformed and/ or metamorphosed	Alleghany (Appalachian) Orogeny
Paleozoic (PZ)	Carboniferous; Mississippian (M)	358.9–323.2	None mapped	Erosion and weathering of overlying sediments
Paleozoic (PZ)	Devonian (D)	419.2–358.9	None mapped	Global mass extinction at end of Devonian
Paleozoic (PZ)	Silurian (S)	443.8–419.2	All units deformed and/ or metamorphosed	Ongoing marine sedimentation Neoacadian Orogeny
Paleozoic (PZ)	Ordovician (O)	485.4–443.8	All units deformed and/ or metamorphosed	Global mass extinction at end of Ordovician; deeper marine settings Sea level fluctuations; marine and nearshore settings Taconic Orogeny; open marine settings
Paleozoic (PZ)	Cambrian (C)	538.8–485.4	**PZtl** deposited or emplaced	Extensive oceans covered most of proto-North America (Laurentia); sediments accumulated in ocean basin; erosion and weathering

Table 2, continued. Geologic time scale.

Era	Period	MYA	Geologic Map Unit Symbols	Geologic Events
Proterozoic Eon; Neoproterozoic (Z)	n/a	1,000–538.8	None mapped	Supercontinent Rodinia rifted apart; erosion and uplift
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

Ocmulgee Mounds National Historical Park contains rocks that span a 541-million-year history (see GRI poster). The oldest rocks are Paleozoic (542 million–251 million years ago) and are mapped just inside of the northeast corner of the main unit of the park and extend northward through much of north-central Georgia. The rest of the park consists of relatively unconsolidated layers from the Upper Cretaceous to Holocene (approximately the last 90 million years of geologic time). These sedimentary layers slope gently to the southeast and include sand, clay, and gravel, as well as Quaternary alluvium (sand, clay, lenses of gravel, and some organic material; geologic map unit **Qa**) deposited along major streams (LeGrand 1962; Hetrick and Friddell 1990; KellerLynn 2013).

Georgia comprises five major physiographic provinces that each record an episode of Georgia's geologic history. A physiographic province is a geographic region in which climate (weathering) and geology have given rise to landforms distinct from those of surrounding regions. These provinces are, from roughly northwest to southeast: Appalachian Plateau, Ridge and Valley, Blue Ridge, Piedmont, and Atlantic Coastal Plain provinces (fig. 5). The park is situated along the inner margin of the Atlantic Coastal Plain province on the Macon Plateau against the boundary between the Piedmont and Atlantic Coastal Plain provinces (fig. 6). The boundary between the two provinces is known as a "fall line." It is a low, east-facing escarpment that parallels the Atlantic coastline from New Jersey to Alabama. An escarpment is a long, steep slope that faces one direction breaking the continuity of the land by separating two adjacent surfaces and is commonly produced by erosion or faulting. This erosional scarp formed along the juxtaposition of the hard igneous and metamorphic Paleozoic Era (542 million–251 million years ago) rocks of the Piedmont and the softer, gently dipping, Mesozoic Era (251 million–65.5 million years

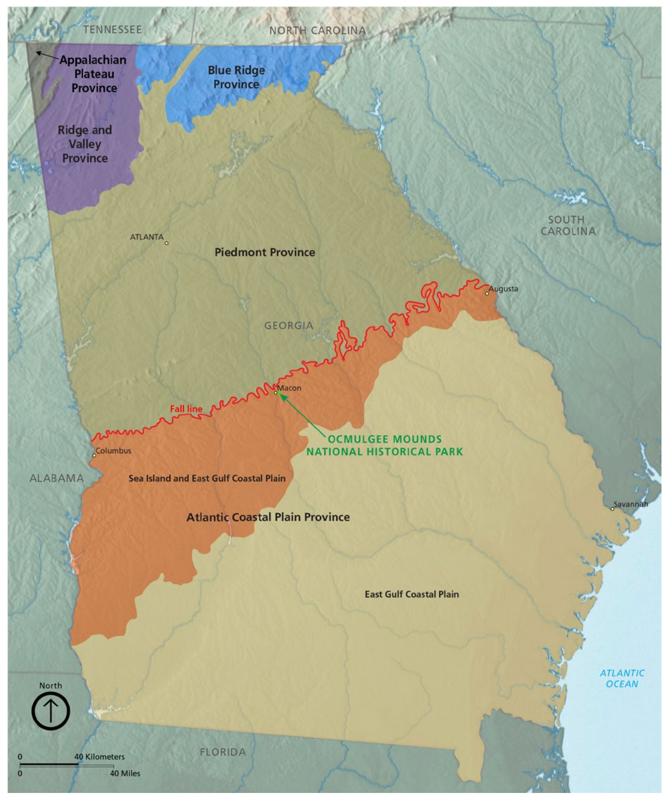

Figure 5. Map of physiographic provinces of Georgia.
Ocmulgee Mounds National Historical Park (bright green area adjacent to Macon) is located along the fall line between the Piedmont province to the northwest and the Upper Coastal province to the southeast. Bold red line denotes the fall line, bisecting the state. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using map data from the Georgia Geological Survey, available at https://epd.georgia.gov/outreach/publications/georgia-geologic-survey-maps. Basemap by Tom Patterson (National Park Service), available online: http://www.shadedrelief.com/physical/index.html (accessed 31 March 2020).

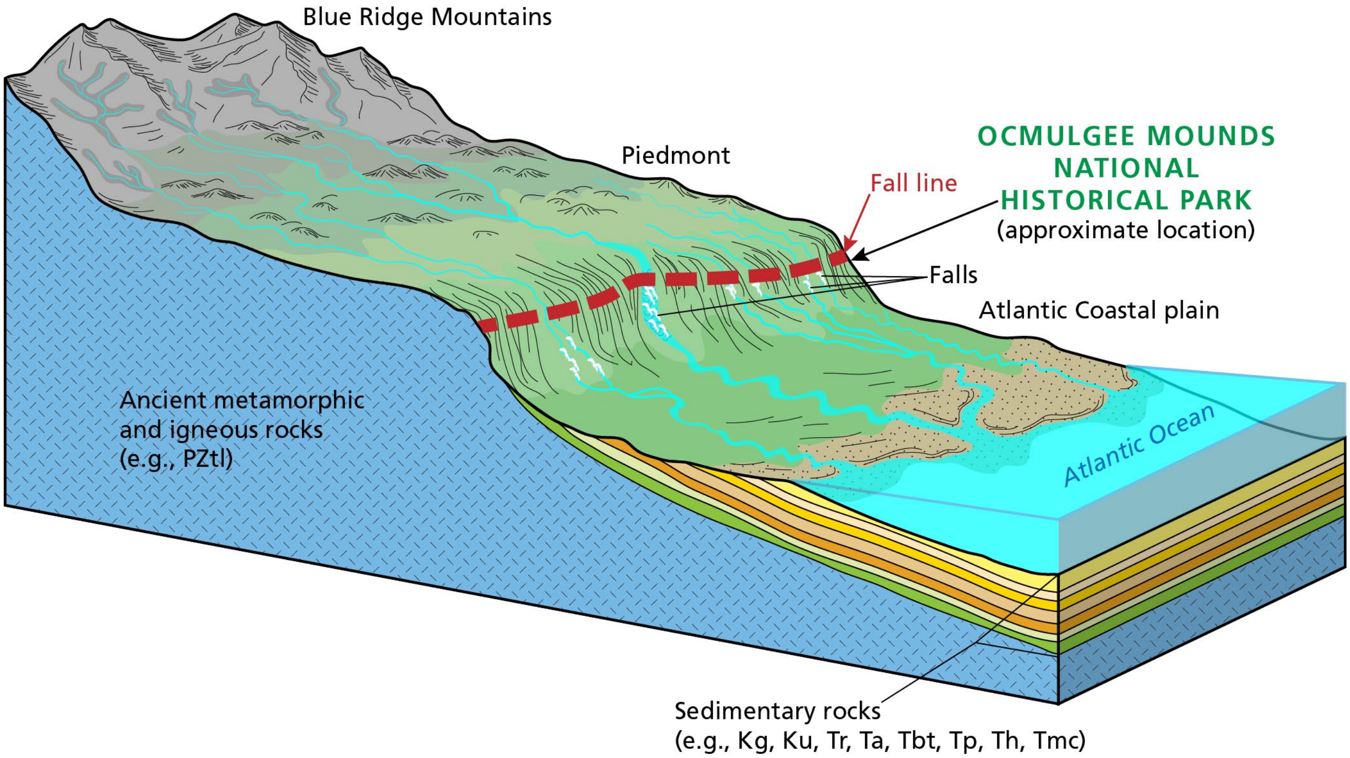

Figure 6. Block diagram and cross section of the geologic setting of the fall line.
The fall line occurs where the soft, sedimentary rocks of the Atlantic Coastal Plain lapped on the hard, crystalline bedrock of the Piedmont. Erosion and weathering has caused a scalloped zone along the length of the fall line, rather than a sharp, distinctive line. The sediments are progressively younger and deeper seaward. Ocmulgee Mounds National Historical Park has both rocks of the Piedmont (PZtl) and the Atlantic Coastal Plain (Ku) within boundaries because it is located within the fall line and localized weathering has exposed some of the Piedmont rocks below the sedimentary rocks. Graphic by Trista L. Thornberry-Ehrlich (Colorado State Univeristy) after Encyclopedia Britannica (2015).

ago) and Tertiary (65.5 million–2.6 million years ago) sedimentary rocks and unconsolidated sediments of the Atlantic Coastal Plain. The fall line is the site of many waterfalls that yielded flume- and waterwheel-powered industries in colonial times and thus became the location of major cities such as Columbia, South Carolina, Philadelphia, Pennsylvania, Baltimore, Maryland, Washington DC, and Richmond, Virginia (US Geological Survey 2004).

The Piedmont province extends 1,600 km (1,000 mi) from Alabama northeastward to southern New York. The Piedmont contains highly complex metamorphic and igneous rocks that have been weathered and eroded for millions of years to produce a rolling, hilly, muted landscape adjacent to the rugged Blue Ridge, Ridge and Valley, and Appalachian Plateau provinces to the northwest and the nearly flat Coastal Plain to the east.

At the dawn of the Paleozoic Era, some 541 million years ago (table 2 and fig. 7), the rocks that would eventually form the Piedmont province were accumulating in an ocean basin (the Iapetus Ocean) that formed during the rifting of a Precambrian supercontinent, Rodinia (fig. 8). As forces pushing and pulling Earth's tectonic plates changed, crustal extension that formed a passive margin eventually gave way to compression and a subduction zone formed along the margin around 450 million years ago as bits of land, volcanic arcs, and subcontinents began to collide with what would become North America (figs. 7and 8).

360 million years ago, the land underlying the park—part of the Avalon or Carolina terrane—collided with North America (geologic map unit **PZtl**; Hooper and Hatcher 1990; Hanley et al. 1997; Hatcher 2001; GRI GIS data). The Piedmont of Georgia is broadly divisible into terranes that accreted to the growing edge of Laurentia (ancient North America) during the Paleozoic Era. A terrane is a group of rocks with similar characteristics and geologic history that differ from those around it that commonly formed somewhere other than its present location. Terranes are associated with continent-scale plate tectonic forces that displace,

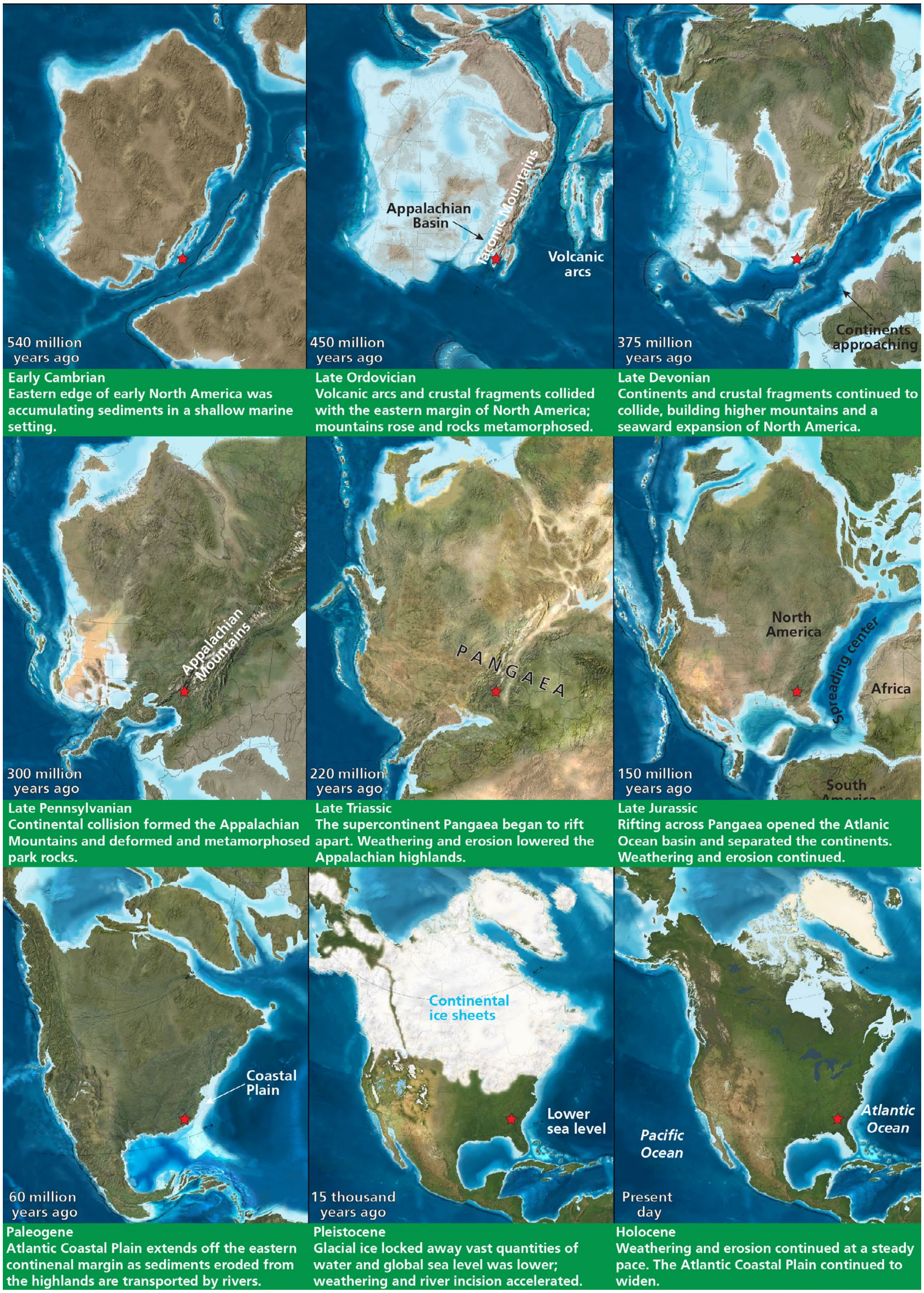

Figure 7. Paleogeographic maps of North America.
The red star indicates the approximate location of Ocmulgee Mounds National Historical Park. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic maps created by Ron Blakey, "North American Key Time Slices" © 2013 Colorado Plateau Geosystems Inc, used under license; see https://deeptimemaps.com.

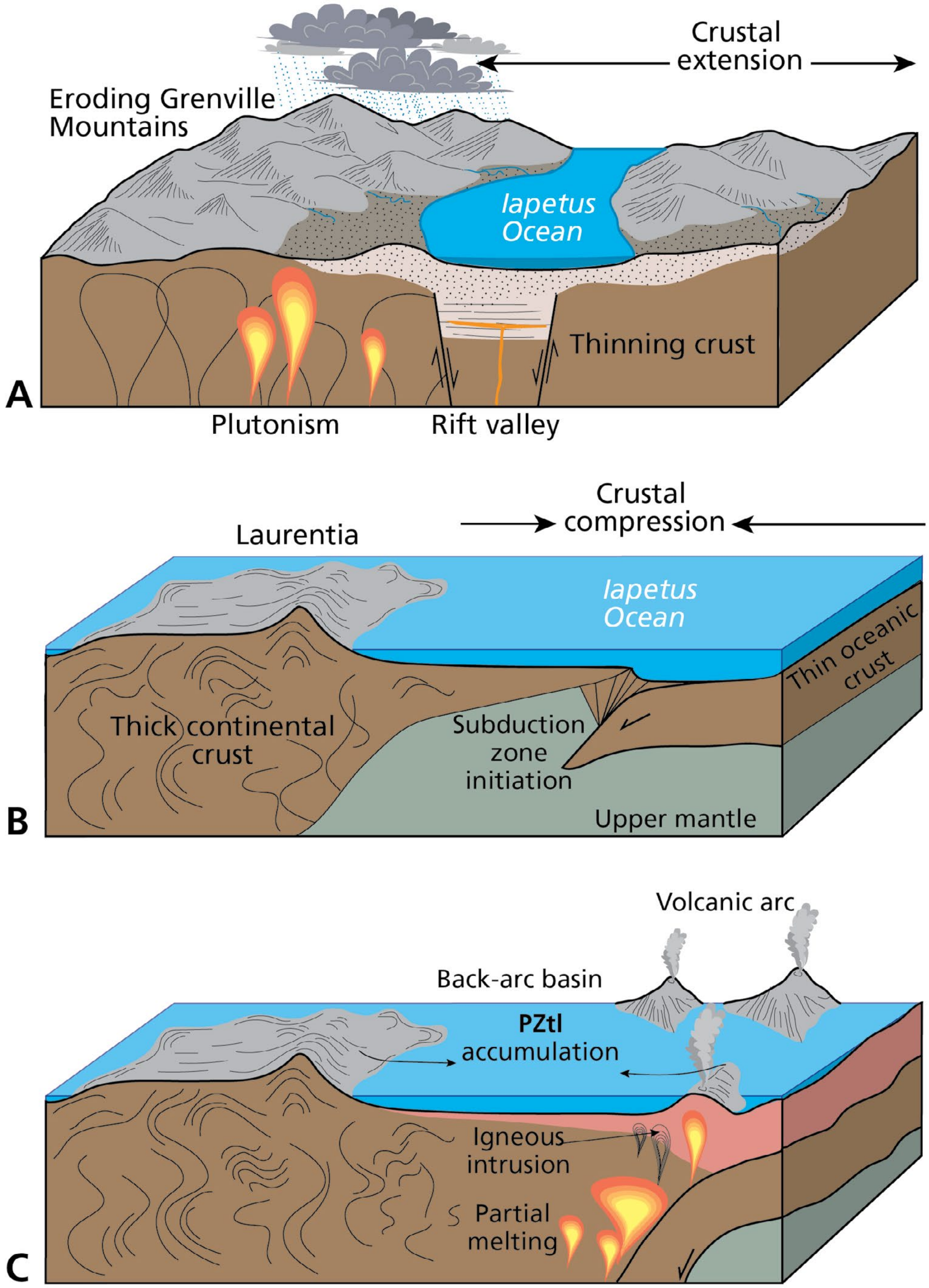

Figure 8. Illustration of the Neoproterozoic to Ordovician evolution of the park landscape and geologic foundation.
(A) In the Neoproterozoic, more than 541 million years ago, the supercontinent was rifting apart (crustal extension) and the Iapetus Ocean basin collected mixed sediments and igneous rocks. (B and C) During the Cambrian and Ordovician from 541 million to 444 million years ago, crustal extension and rifting changed to compression as a subduction zone developed in the Iapetus. The rocks of the Piedmont (map units PZtl) started to accumulate at this time and volcanic arcs moved toward the eastern edge of Laurentia (proto-North America). Graphics are not to scale. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps and correspond to the colors on the geologic time scale (see table 2). Map symbols are included for the geologic map units in the GRI GIS data. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Bobyarchick et al. (1988), Barineau et al. (2015), Hawkins (2013), and the GRI GIS data.

squeeze, or rip apart large bodies of rock across distances ranging from a few kilometers to thousands of kilometers. Examples of terranes may include fragments of continents, volcanic arcs, and oceanic basins. The Avalon and Carolina terranes are further subdivided into individual belts—piles of rock that slid westward along major thrust faults. The Inner Piedmont, Pine Mountain, Charlotte, Uchee, and Kiokee belts are bounded/separated by the Towaliga, Bartletts Ferry, Goat Rock, Middletown-Lowndesville, Modoc, Ocmulgee, and Dean Creek faults (Hanley 2018).

Mapped within Ocmulgee Mounds National Historical Park are rocks of the Kiokee belt (**PZtl**; see GRI poster) exposed at this fall-line location by erosion or removal of the overlying coastal plain sediments. The general northeast-southwest trends of local landforms (e.g., fall line, hills, and ridges) can in part trace their origins back to these roughly parallel regional features. Ocmulgee Mounds lends its name to the Ocmulgee fault, a 2-km (4-mi) wide zone of oblique rock movement, which is a fundamental boundary within the Piedmont of central Georgia separating Inner Piedmont rocks from exotic rocks of the Avalon or Carolina terrane. It trends northeast to southwest about 30 km (18 mi) northwest of the park (Hooper and Hatcher 1990).

As the rocks that make up eastern North America gradually pushed onto (accreted to) the eastern edge of the growing continent, which was located west of present-day Georgia (figs. 7 and 9), the continent grew eastward. From about 325 million to 260 million years ago, groups of rock in the accreted terranes—including the rocks in the Piedmont—were metamorphosed, deformed, intruded by granitic magmas, and thrust westward during a series of Paleozoic mountain-building events (orogenies) that culminated in the formation of a supercontinent, Pangaea, and ultimately created the Appalachian Mountains (figs. 7 and 9; Boland 2006). The Appalachian Mountains transversed the interior of the supercontinent and may have rivaled the modern Himalayas with elevations potentially exceeding 6,100 m (20,000 ft) (Harris et al. 1997; Southworth et al. 2009). Pangaea endured for about 80 million years before splitting apart into smaller continents.

During the Late Triassic Epoch, approximately 185 million years ago, the supercontinent Pangaea began rifting into landmasses that would eventually become the modern continents. Because collisional tectonic forces ceased during rifting, the Appalachian Mountains were no longer being pushed upward, and weathering and erosion became the dominant processes shaping the mountains (fig. 9). The Piedmont was beveled into undulating hills. Large rivers transported vast amounts of sediments down from the mountains and deposited them to build the Atlantic Coastal Plain seaward (figs. 7 and 10).

Beneath the sedimentary layers of the Coastal Plain are harder igneous and metamorphic rocks, such as those found in the Piedmont (geologic map unit **PZtl**; Frazier 2019). Commonly referred to as the "basement," these hard rocks are buried increasingly deeper toward the south and east, occurring at depths of 3,050 m (10,000 ft) or more beneath the modern Georgia coast.

The Coastal Plain is essentially a large, wedge-shaped mass of sediment, which is thickest along the modern coast and the Florida state line and thinnest along the "feather-edge" of the fall line (fig. 10). Because these layers dip towards the sea in most cases, the oldest layers exposed at the surface are closest to the fall line (e.g., in the vicinity of Ocmulgee Mounds National Historical Park; geologic map units **Ku** and **Kg**; see figs. 6, 11, and GRI poster), where the sedimentary rocks are at least 65 million years old (LeGrand 1962; Hetrick and Friddell 1990; Frazier 2019). These sediments mainly collected in shelf (marine), coastal, and estuarine settings. Alternating layers of nonmarine and marine sediments reflect long-term sea-level fluctuations with marine sediments accumulating during high sea levels and nonmarine sediments accumulating when sea level dropped (Richards 1956; Schwimmer 1986; Savrda and Nanson 2003; Frazier 2019).

During the Tertiary, subaerial conditions caused reworking of older units and development of weathered layers of those units, including the formation of kaolin layers from weathered feldspars and other aluminosilicate minerals (geologic map units **Tr**, **Ta**, **Tbt**, **Tp**, **Th**, and **Tmc**; Hetrick and Friddell 1990; Hetrick 1990). These processes of weathering and reworking are ongoing today.

The youngest geologic map units at the park include the unsorted clay, sand, and gravel deposited along the Ocmulgee River channel and floodplain (geologic map units **Qa** and **QToa**, see GRI poster; LeGrand 1962; Hetrick and Friddell 1990). They represent flooding during the Quaternary Period, over at least the last 2.6 million years (Cosner 1973). See “Fluvial Features and Processes” and “Lacustrine Features and Processes” for more details about the formation of these deposits and ongoing depositional processes in the park.

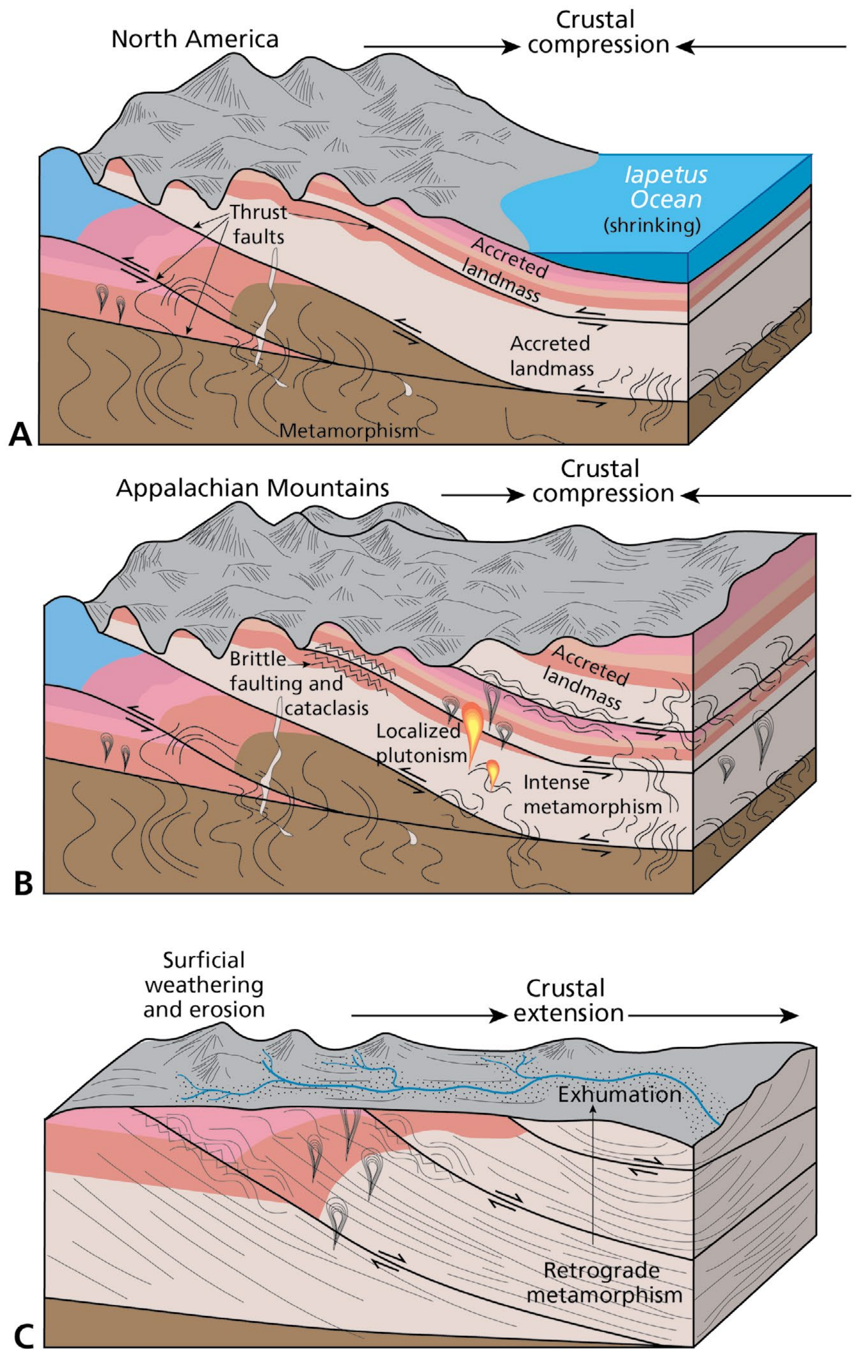

Figure 9. Illustration of the Ordovician to Triassic evolution of the park landscape and geologic foundation. (A) In the Ordovician and Silurian, from 485 million to 419 million years ago, periodic collisions of volcanic arcs and microcontinents built out the eastern margin of Laurentia. (B) By the Pennsylvanian, from 323 million to 298 million years ago, major continental collision pushed the Appalachians up to their highest point and all the accreted landmasses and thrust sheets were deformed and metamorphosed. Cataclasis refers to intense crushing and grinding of rocks along faults. (C) Since the Triassic, from 251 million to 201 million years ago, when the landmasses began to break apart, the landscape at the park has been subjected to continuous weathering and erosion and deposition. Sediments were transported eastward to become part of the Atlantic Coastal Plain. Graphics are not to scale. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps and correspond to the colors on the geologic time scale (see table 2). Map symbols are included for the geologic map units in the GRI GIS data. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Bobyarchick et al. (1988), Barineau et al. (2015), and GRI GIS data.

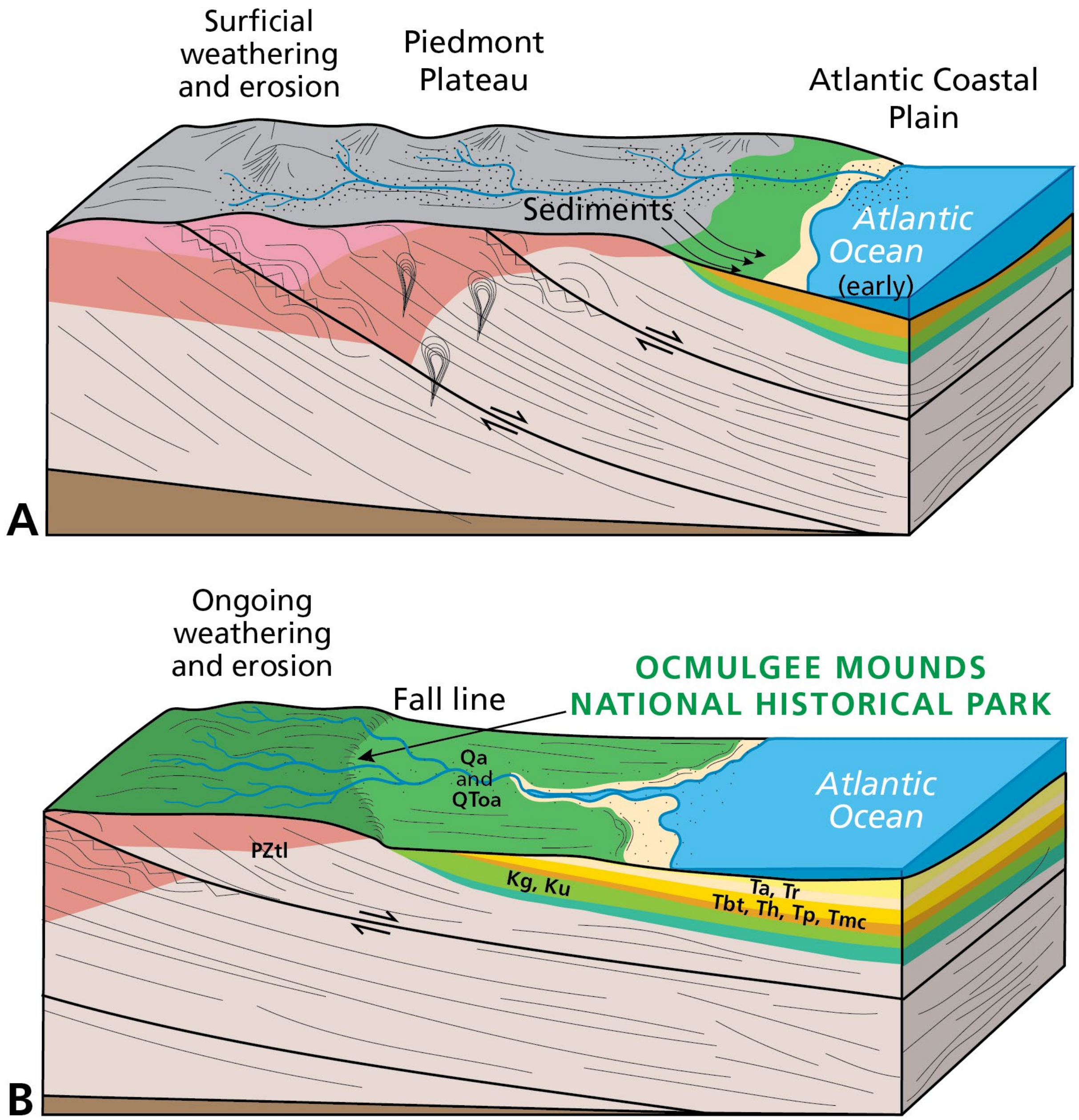

Figure 10. Illustration of the Mesozoic to present day evolution of the park landscape and geologic foundation.
(A) In the Mesozoic, from 252 million to 66 million years ago, thick piles of sediments were accumulating as part of the Atlantic Coastal Plain. Some of the oldest, Cretaceous sediments are exposed in the park. (B) Today, rivers continually rework, transport, and deposit alluvium along their channels. Graphics are not to scale. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps and correspond to the colors on the geologic time scale (see table 2). Map symbols are included for the geologic map units in the GRI GIS data. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Bobyarchick et al. (1988), Barineau et al. (2015), and GRI GIS data.

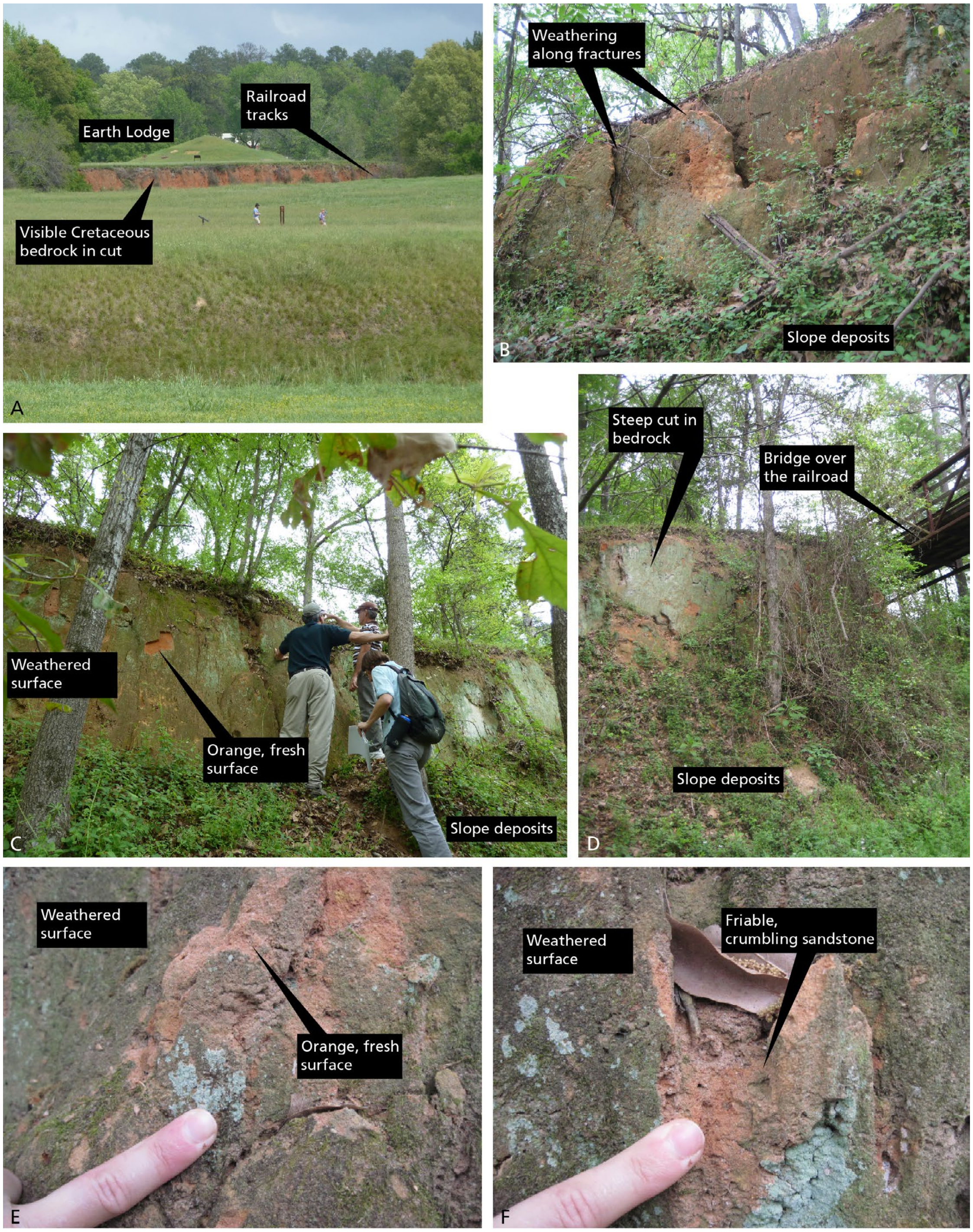

Figure 11. Photographs of Cretaceous bedrock exposed in the park.
A railroad cut through the center of the main unit at Ocmulgee Mounds National Historical Park exposes some of the deeply weathered bedrock. A) View looking north toward Earth Lodge shows the bright orange bedrock above the railroad tracks. B) Weathering has been ongoing for millions of years. Any preexisting fractures funnel water and surfaces weather preferentially. The area below the slope is littered with slope deposits shed from the steep cut. C) Fresh orange surfaces stand in contrast to the dull gray to brown of weathered exposures. D) The pedestrian bridge spans the steep cuts through the bedrock. E) and F) The textures of the rock up close is mottled and pebbly. The sandstone appears friable and weakly cemented. Photographs A and C by Rebecca Port (NPS Geologic Resources Division), photographs B and D by Georgia Hybels (Colorado State University), and photographs E and F by Katie KellerLynn (Colorado State University), all taken in March 2012.

Geologic Features, Processes, and Issues

The geologic features and processes highlighted in this chapter are significant to the park's landscape and history. Selection of these features and processes was based on input from scoping and conference-call participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. These features and processes are discussed more-or-less in order of geologic age (oldest to youngest) where feasible. Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. Table 3 summarizes these data as they pertain to individual geologic map units.

Table 3. Geologic features, processes, and resource management issues in Ocmulgee Mounds National Historical Park.

Map unit refers to the name of the unit appearing in the GRI GIS data and poster. Each map unit has a corresponding symbol indicating an abbreviated geologic age of the unit and its name (see "Geologic Map Data"). Cell colors reflect the unit colors in the GRI GIS data and poster. Detailed descriptions of each unit are in the ancillary map information document (see "geologic map data"). The park boundary reflecting lands acquired in 2022 were used to determine areal extents of mapped units. Water is mapped in less than 1% of the park area.

Map Unit (symbol)	Description and Spatial Distribution	Geologic Features, Processes, and Issues
Alluvium (**Qa**)	Alluvium is mapped in 82% of the area inside park boundaries. In the park, the alluvium consists of clay, silt, and fine- to coarse-grained sand. Some gravel stringers and organic material are present. Alluvium occurs as a belt along local rivers.	**Fluvial Features and Processes** **Qa** is being deposited, eroded, and reworked by modern rivers and streams. Alluvium (unconsolidated clay, silt, and sand) lines the modern stream channels. Low-lying areas of **Qa** may be prone to flooding. **Geologic Hazards: Seismic Activity** Seismic shaking in unconsolidated units like **Qa** would cause considerable instability.
Older alluvium (**QToa**)	**QToa** is not mapped within park boundaries. **QToa** is mostly clay, silt, and sand with some stringers of gravel. Cross beds in some areas are prominent and the high iron oxide content is results in orange coloring.	**Fluvial Features and Processes** **QToa** is associated with ancient river courses. **Geologic Hazards: Seismic Activity** Seismic shaking in unconsolidated units like **QToa** would cause considerable instability.
Residuum from Upper Eocene and younger sediments (**Tr**)	**Tr** is not mapped within park boundaries. It is pebbly with clay, silt, and sand with a high iron oxide content that tends to make it very orange in appearance.	**Wetland Features and Processes** Thick clay layers in **Tr** may act as aquitards underlying wetland areas.
Altamaha Formation (**Ta**)	**Ta** is not mapped within park boundaries. **Ta** is mostly gravel with clay and sand. Most of the unit is poorly sorted.	**Geologic Hazards: Seismic Activity** Seismic shaking in unconsolidated units like Ta would cause considerable instability.
Barnwell Group and Tivola Limestone (**Tbt**)	**Tbt** is not mapped within park boundaries. **Tbt** is limestone with some silt, clay, and sand. Bedding varies from laminar to indistinct. Some areas have chert.	Locally, this unit is eroded into steep gullies. **Paleontological Resources Inventory, Monitoring, and Protection** **Tbt** is fossiliferous with dinoflagellates, angiosperm pollen, foraminifera, shells, sharks, frogs, snakes, early whales, and terrestrial mammals documented from elsewhere.
Perry Sand (**Tp**)	**Tp** is not mapped within park boundaries. **Tp** is nearly pure sand with little clay. Some of the sand is calcareous. Some layers are stained.	**Coastal Plain Clay and Mining Activity** **Tp** contains some of the purest sand in terms of silica content in Georgia.
Huber Formation (**Th**)	**Th** is not mapped within park boundaries. **Th** is sand and clay with some cross beds and clay clasts and cut and fill structures.	**Coastal Plain Clay and Mining Activity** **Th** contains commercial grade "hard" kaolin beds. Pseudobauxite cobbles are in the upper levels of this unit.

Table 3, continued. Geologic features, processes, and associated resource management issues in Ocmulgee Mounds National Historical Park.

Map Unit (symbol)	Description and Spatial Distribution	Geologic Features, Processes, and Issues
Marshalville and Clayton Formations (**Tmc**)	**Tmc** is not mapped within park boundaries. **Tmc** is thin beds of white, kaolinitic, micaceous sand with some kaolin layers and massive clay layers.	**Coastal Plain Clay and Mining Activity** Kaolinitic clay layers are present in **Tmc**. **Paleontological Resources Inventory, Monitoring, and Protection** Tmc is fossiliferous with oyster beds.
Gaillard Formation (**Kg**)	**Kg** is not mapped within park boundaries. **Kg** is pebbly sand and clay with some mica rich layers. Some layers are cross bedded.	**Coastal Plain Clay and Mining Activity** **Kg** contains commercial grade "soft" kaolin beds.
Undifferentiated sediementary rocks (**Ku**)	16% of the mapped area inside park boundaries is **Ku**. It occurs in the northwestern corner of the main unit. **Ku** is mostly sands, clays, and gravels.	**Paleontological Resources Inventory, Monitoring, and Protection** **Ku** is fossiliferous with leaves, logs, nannofossils, foraminifera, sponges, bryozoans, cephalopods, gastropods, bivalves, worm tubes, scaphopods, ostracodes, sharks, bony fish, turtles, mosasaurs, crocodilians, pterosaurs, and duckbilled dinosaurs documented elsewhere.
Undifferentiated crystalline rocks (**PZtl**)	Slightly more than 1% of the mapped area inside park boundaries is **PZtl**. It occurs in the very northeastern corner of the park. **PZtl** is lumped gneisses, schists, granites, and phyllites so it includes igneous and metamorphic rocks of Paleozoic and older ages.	None documented

Paleontological Resources

Geologic map units: undifferentiated sedimentary rocks (**Ku**), alluvium (**Qa**)

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 October 2021, 283 parks had documented paleontological resources in at least one of these contexts.

Tweet et al. (2009) completed a baseline paleontological inventory based on literature sources (not field-based) for the Southeast Coast Network, including Ocmulgee Mounds National Historical Park (then Ocmulgee National Monument). Museum collections from the park include 2.5 million archeological specimens; however, only a handful of paleontological specimens have been recovered. The exact number is unclear due to limited information, but in 2009 the Southeast Archeological Center held five specimens categorized as fossil from the monument and two other catalog numbers of interest (Justin Tweet, National Park Service, paleontologist, written communication, 9 October 2021). Fossil specimens include bivalves and petrified wood. The potential for the discovery of more fossils is high because the rock units and unconsolidated deposits within the park have yielded fossils at other locations outside of the park. Future field surveys within the park are likely to produce fossils (Tweet et al. 2009).

All the units present at the surface or in the shallow subsurface of the park are potentially fossiliferous, as well as the formations that may be present in the undifferentiated Cretaceous–lower Cenozoic rocks eroded by the park drainage system (Tweet et al. 2009; KellerLynn 2013). These include the undifferentiated sedimentary rocks of Cretaceous age (**Ku**), and Quaternary rocks and sediments (alluvium, **Qa**; Tweet et al. 2009). Nearby formations that could be present in the undifferentiated deposits include the Gaillard Formation of the Upper Cretaceous, and the late Eocene Barnwell Formation and Tivola Limestone (Lawton et al. 1976). Additionally, drainage from the Ocmulgee River–Walnut Creek system through the park could introduce eroded material from upstream undifferentiated Cretaceous and early Cenozoic sedimentary rocks (Tweet et al. 2009). As discussed in "Abandoned Mineral Lands and Disturbed Lands," the park is in the process of expansion. If the park acquires new land, it is possible that fossiliferous units such as the Ocala Limestone—which contains remains of organisms typical of shallow marine reefs—may be present in the new tracts (Al Mead, Georgia College, paleontologist, conference call, 7 January 2021).

The park is rich in archeological resources, some of which are also or may also be paleontological resources. Shell beads, shell ornaments, bone pins, shell-temper sherds, a puma jaw, a conch cup, and building wood are among the known potential fossil resources of the park in a cultural resource context (Tweet et al. 2009). Fossils are possible among the approximately 2.5 million artifacts from the park, some of which have not yet been cataloged and present unique insights into the human dimensions of paleontological resources (Jill Halchin, Southeast Archeological Center, archeologist, conference call, 7 January 2021; Santucci et al. 2021). Kenworthy and Santucci (2006) summarized and described selected examples of National Park Service fossils found in cultural resource contexts. Santucci et al. (2021) provided an overview of paleontological resources preserved in prehistoric and historic structures both intentional and unintentional (e.g., petrified wood, fossil invertebrates and vertebrates, fossil footprints and other trace fossils).

Paleontological Resource Inventory, Monitoring, and Protection

All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (see Appendix B). A field-based paleontological resource survey has not been completed for the park but could provide detailed, site-specific descriptions and resource management recommendations. Field work could be accomplished by establishing a cooperative agreement with one or more of the local natural history museums with paleontological expertise, such as the William P. Wall Museum of Natural History at Georgia College & State University, Milledgeville, Georgia, and Georgia Museum of Natural History at University of Georgia, Athens, Georgia. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions or potentially use the Scientists-in-Parks (SIP) program (see "Guidance for Resource Management"). A variety of publications and resources provide park-specific or servicewide information and paleontological resource management guidance. For example, in the *Geological Monitoring* chapter about paleontological resources, Santucci et al. (2009) described five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use.

Fluvial Features and Processes

Geologic map unit: alluvium (**Qa**), Barnwell Formation (part of geologic map unit **Tbt**), Blufftown Formation (possibly equivalent to part of **Kg**)

Fluvial features are those which are formed by flowing water. Fluvial processes both construct (deposit alluvium; geologic map unit **Qal**) and erode landforms (e.g., the local streams and river channels). Ocmulgee River and Walnut Creek, as well as three unnamed streams (sometimes referred to informally as "Bamboo Creek", "Temple Mound Creek", and unnamed creek) and an ephemeral spring at one of the mounds, are the primary fluvial systems at the Ocmulgee Mounds area of the park (see GRI poster). The Ocmulgee River forms the southwestern boundary of the park, of which the National Park Service has jurisdiction to the middle of the channel (DeVivo 2008). The Lamar mounds sit atop Ocmulgee River floodplain (KellerLynn 2013). Fluvial features within the newly acquired lands (ca. 2022) include Boggy Branch, Swift Creek, and associated wetlands. Because the boundary so recently changed, these features have not been inventoried or studied for inclusion in this report.

Examples of the park's fluvial features include meandering channels, point bars, oxbow lakes and backwater sloughs, sand and gravel bars, riffles, floodplains, riparian zones, natural levees, and steep banks (fig. 12; Burkholder et al. 2017; Cooper et al. 2019). Channels are the linear courses the water flows through. Three general fluvial channel types exist: straight, meandering, and braided. These types are then subdivided into many more categories depending on variables such as flow velocities and/or sediment load. Meandering river channels are the most common course of perennially flowing water below the fall line on the Atlantic Coastal Plain (fig. 13). In a meandering river system, as water flows around curves (meanders), flow velocity (and thus erosive potential) is greatest on the outside of the meander. These higher velocity flows can erode sediments from the streambank on the outside of the meander (known as the cutbank), while lesser velocity flows deposit sediments on the inside of the meander forming a point bar (e.g., stretches of "Temple Mound Creek" near the parking lot). As the process continues, the outside streambank retreats farther (via erosion), while the inside point bar migrates laterally (via deposition), thus creating migrating meanders. Meandering reaches its extreme when the narrow neck of land between two separate meanders is breached (see fig. 12). Oxbow lakes and backwater

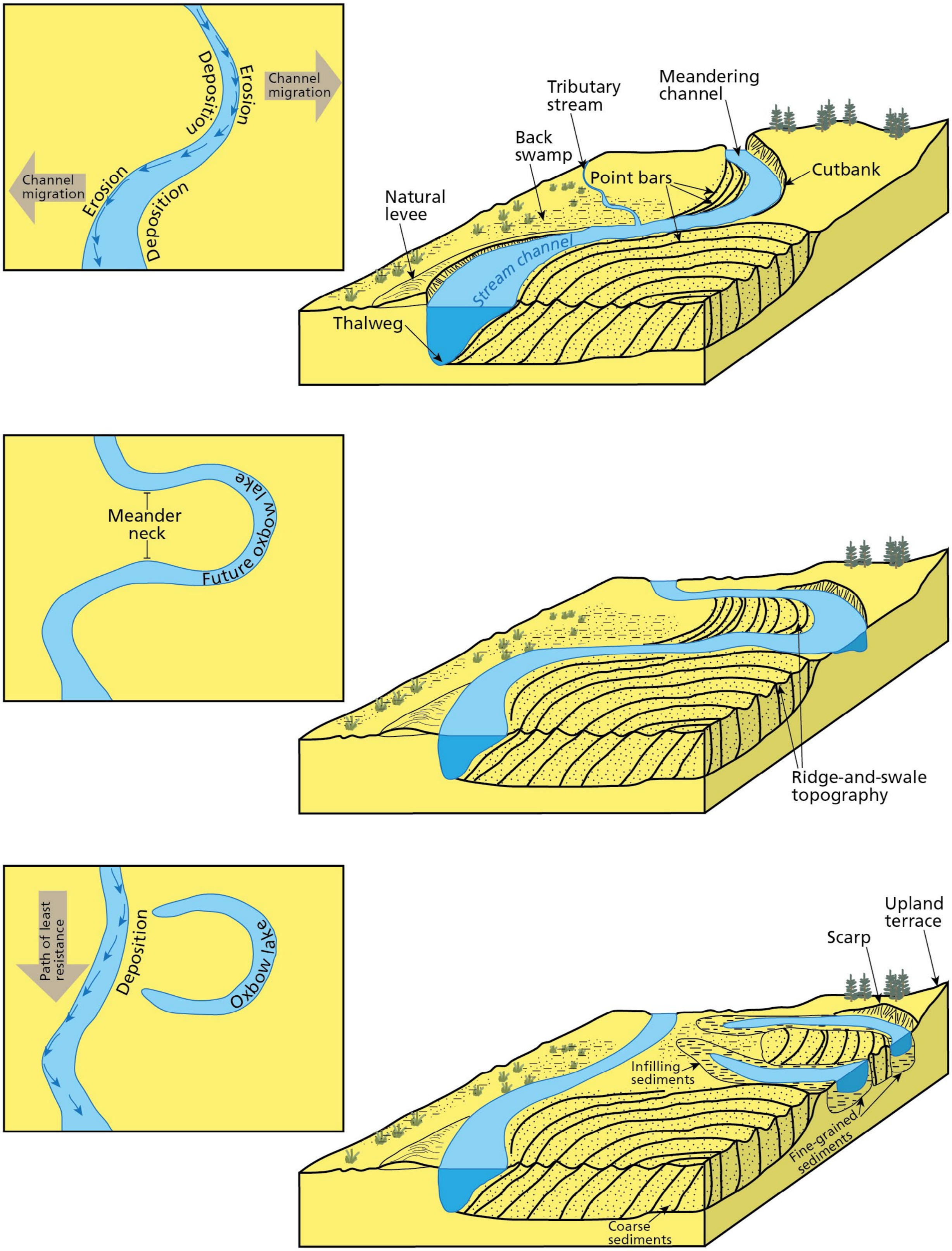

Figure 12. Schematic graphic of generalized fluvial features and oxbow lake formation.
The streams at Ocmulgee Mounds National Historical Park range from broad rivers to short, narrow streams. Fluvial features in the park include channels, cutbanks, levees (both natural and artificial), gravel bars, oxbow lakes, back swamps, point bars, and thick deposits of alluvium (geologic map units Qa and QToa). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

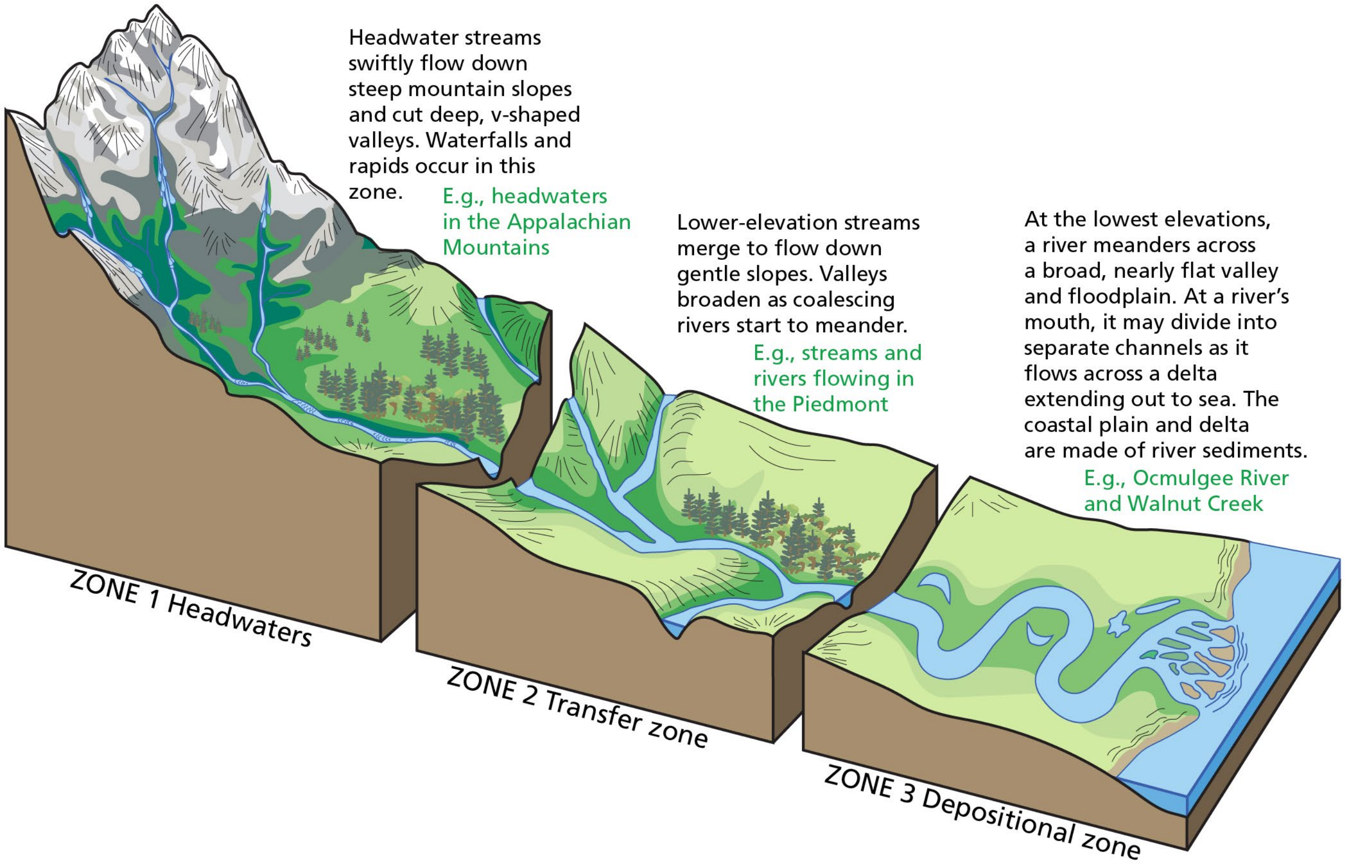

Figure 13. Schematic graphic of a 3-zone fluvial system.
The streams and rivers at Ocmulgee Mounds National Historical Park are in the transition between the transfer zone (zone 2) and depositional zone (zone 3). The park is located near the fall line where rivers change from broadening valleys to meandering channels. Local examples are given in green text. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Miller (1990).

sloughs form where meanders are cut off; they preserve a former river course and provide snapshots of the previous channel substrate.

Sand and gravel bars are areas of relatively coarse sediment deposited along the stream channel. Stretches of Walnut Creek have high concentrations of bar surfaces (McDonald and Starkey 2019). Where water flows brokenly over shallow areas, riffles form. Floodplains are areas of land adjacent to a river or stream which stretch from the banks of the channel to the base of the enclosing valley walls, and which experiences flooding during periods of high flow. Riparian zones are related to floodplains as they form the interface between the channel and adjacent land. Riparian zones are characterized by water-tolerant (hydrophilic) plants. Floodplains and riparian zones are well-developed on stretches of Walnut Creek east of the main mounds area (McDonald and Starkey 2019). Developing floodplains occur on stretches of "Temple Mound Creek" (McDonald and Starkey 2019).

During floods, the stream can deposit sand and silt along its banks and repeated localized flood deposition may form natural levees (see fig. 12). Natural levees occur southeast of the Ocmulgee Mounds along Walnut Creek (Cooper et al. 2019). Natural levees can form only where a stream course is stable enough to continuously deposit overbank sediments in the same area (Stephen Cooper, NPS Southeast Coast Inventory and Monitoring Network, physical scientist, written communication, 19 October 2021). These deposits represent the relatively coarse-grained component of a river's suspended sediment load and form a high area on the floodplain immediately adjacent to the stream channel. This is not to be confused with man-made levees (see "Flooding, Erosion, and Rapid Sedimentation" and "Anthropogenic Changes to the Fluvial System" sections).

In areas where a river or stream channel has cut deeply into the adjacent land, scoured channels and steep banks may form. Steep banks, about 3 m (9 ft) high, occur upstream of the mounds on "Temple Mound Creek;" "Bamboo Creek" has banks over 2 m (6 ft) high (McDonald and Starkey 2019). The steep banks that are forming along the park's streams are susceptible to slumping (failure) as they mainly consist of unconsolidated sediments that were deposited following the clearcutting of forest and further bad agricultural practices of the mid-to-late 1800's. Now, bank slumping seems to be a stage in the stream's natural morphologic progression as it seeks a return to an equilibrium level (fig. 14; Trimble 1969; James 2018; Cooper et al. 2019; Bateman McDonald, 2020).

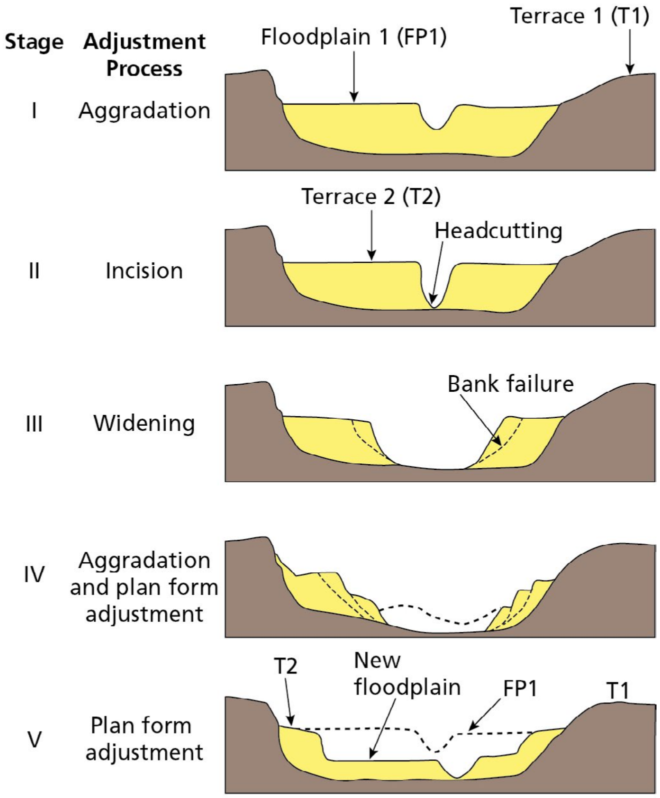

Figure 14. Generalized cross section of a channel evolution model.
Each stream will be in its distinct stage of evolution. In general, local streams are in the third stage of channel development with abundant bank failures and undercutting as the stream cuts through the abundant sediment. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) modified from Schumm et al. (1984) and Cooper et al. (2019).

The stretch of the Ocmulgee River that flows in the main unit of the park is relatively straight, bounded by the Macon Levee on the western bank and Interstate 16 on the eastern bank. Walnut Creek meanders across the eastern part of the main unit then along the southeastern boundary, where it empties into the Ocmulgee River (see fig. 2; KellerLynn 2013). Walnut Creek drains a large part of east Macon (Burkholder et al. 2017) and flows through several sloughs and abandoned channels under even moderate flood levels. The Lamar mounds area is situated on the Ocmulgee River floodplain to the south of the former main unit; in historical times this segment of the river freely meandered across this floodplain creating a number of oxbow lakes (see "Lacustrine Features and Processes").

Flooding, Erosion, and Rapid Sedimentation

Flooding is a natural process and is the primary driver of change in the fluvial system. Floods also play a role in controlling the pattern of riparian vegetation adjacent to channels and on floodplains. However, flooding becomes a resource management issue when significant cultural or natural resources are threatened. Additionally, the streams in the park are heavily influenced by the high percentage of developed adjacent land that borders the park and unnatural conditions such as sediment buildup stemming from previous land use (McDonald and Starkey 2019; Cooper et al. 2019). Flooding was recognized by National Park Service (2014a) as a threat to the park, and the Lamar period village and mounds in particular, because it causes erosion and rapid sedimentation. During flood conditions, streams such as Walnut Creek overflow their channels and flow across their floodplains and through various secondary channel and flood chutes, sometimes inundating infrastructure or other natural resources, including into powerline right-of-way and wetlands to the west (Cooper et al. 2019).

The impacts of past and present land use continue to reverberate on the fluvial system of the park. On the Ocmulgee River floodplain, rapid sedimentation or deposition of more than 3 m (10 ft) of alluvial sediments occurred along the river in the main unit between the 18th and mid-20th centuries (Cosner 1973; KellerLynn 2013). At this time, deforestation, increased row crop agriculture, and a lack of soil conservation measures caused widespread erosion of topsoil from the sloped Piedmont region (Trimble 1969; Cooper et al. 2019). Some sedimentation along a floodplain is part of the natural fluvial processes, but poor land-use practices lead to the rapid deposition of these sediments at Ocmulgee. Excess sediment buried shoal and riffle habitats; hard-bottomed, clear-flowing streams described by early surveyors were transformed into conduits of turbid water and sand (Cooper et al. 2019). These artificially thick deposits are then scoured, reworked, and redeposited during flood events. Each stream is equilibrating to its current flow and sediment regime through a series of evolutionary stages: aggradation, incision, widening, aggradation, and plan form adjustment (see fig. 14; Schumm et al. 1984; James 2018; Cooper et al. 2019). In aggradation, the stream is receiving more sediment that it can transport. When sediment supply is decreased and/or overall flow increases, this transitions to incision and narrowing as the channel cuts down through the sediment. Finally, channel widening and meandering is followed by some aggradation, stabilization and reworking (plan form adjustment) of in-channel sediments (geologic map unit **Qa**) (Schumm et al. 1984). The exact stage of each stream in the park is dependent on the location of the stream within its network and historical land use patterns and conditions. In general, local streams are at the third stage of channel development with widening and unstable banks (Ruhlman and Nutter 1999; Cooper et al. 2019).

Extreme precipitation events, often associated with tropical depressions, cause high stream discharge and flooding which drives change in the fluvial system. For example, in 1994, Tropical Storm Alberto dropped 58 cm (23 in) of rainfall in Atlanta and about 33 cm (13 in) in Macon. The Ocmulgee River crested at an estimated 11 m (35 ft) (The Telegraph 2019). Local rivers deposited 1.7 m (5.5 ft) of silt on their floodplains. Storm water runoff is likely driving sedimentation patterns (KellerLynn 2013; GRI conference call participants, 7 January 2021). Before Tropical Storm Alberto, visitors could walk under the bridge that crosses the boggy stream channel. In 2012, the area was nearly filled with sediment (fig. 15). However, the situation has changed rapidly since then. The stream is now a perennial fluvial feature and is incising the previously Alberto-deposited sediment, re-establishing its channel (Stephen Cooper, NPS Southeast Coast Inventory and Monitoring Network, physical scientist, conference call, 7 January 2021).

Natural erosion and sedimentation become exacerbated by runoff from upstream urban areas where impervious surfaces such as parking lots prevent natural absorption of the precipitation, which in turn decreases overall baseflow because of impaired groundwater recharge. Increases in overland or sheet flow cause streams to flash flood more frequently (Rose and Peters 2001; KellerLynn 2013; Cooper et al. 2019; Jack Wood, National Park Service, physical scientist, written communication, 7 October 2021). “Bamboo Creek” originates as the outflow of a storm water collection culvert, receives runoff from the park’s parking lot and road, and is prone to flash floods (Burkholder et al. 2017). On “Bamboo Creek”, debris from high flows becomes stranded more than 2 m (7 ft) off the ground in trees (GRI conference call participants, 7 January 2021). “Temple Mound Creek” originates from a paved urban culvert. It was maintained as a ditch or channel by the park until about 2007. At this point, it was allowed to flow more or less naturally, resulting in an increase in wetlands. The stream is doing different things at different reaches due to the placement of obstructions like culverts (Stephen Cooper, NPS Southeast Coast Inventory and Monitoring Network, physical scientist, written communication, 26 October 2021). In some areas, it can carry significant sediment loads which may then bury bottomland habitats. In other areas, it has cut a 6-m (20-ft) deep channel. The unnamed creek originates at a culvert on the edge of East Macon and is derived from the city’s storm water collection system; it is heavily silted in places and deeply eroded in others (Burkholder et al. 2017). Within park boundaries, siltation, or blocking/filling of sediments within culverts (fig. 16) at the main unit is a concern for maintenance of the park road. “Temple Mound Creek”, flowing between Funeral Mound and the trading post, is prone to rapid sedimentation (fig. 17). Sediments that are being eroded from upstream (where the stream originates from the culvert and has carved the deep “canyon”) are being deposited as stream flow is constricted and slows down before entering another culvert under the main park road before the wetland (Stephen Cooper, NPS Southeast Coast Inventory and Monitoring Network, physical scientist, written communication, 7 October 2021).

Walnut Creek and the three smaller streams in the park are characterized by severe streambank alteration and sedimentation. Streambanks were listed as in poor condition by Burkholder et al. (2017), Walnut Creek’s in-stream habitat was classified as poor to fair by Cooper at al. (2019), and the park’s foundation document and state of the parks report (National Park Service 2014a and 2014b, respectively) recognize erosion as a threat to the Macon Plateau earth mounds and spiral ramp at the Lamar mounds area. When streambank erosion undermines tree roots and causes tree falls, it becomes a threat to the archeological sites at the park (National Park Service 2014a). When then root ball is upended along with the surrounding sediments and soils, it exacerbates additional erosion potential and loss of cultural materials (Jack Wood, National Park Service, physical scientist, written communication, 7 October 2021). The park’s foundation document calls for a functional hydrology restoration study to assess and mitigate the risks of flooding and erosion and sedimentation—designated a high priority data need. A need also exists to understand whether sedimentation rates are strongly exacerbated by human activities (GRI conference call participants, 7 January 2021). Additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at the park (Cooper et al. 2019).

Figure 15. Photographs of wetlands and streams at Ocmulgee Mounds National Historical Park. A) View looking at Walnut Creek from the Great Temple Mound. A great wetland complex occurs on both sides of Opelofa Trail running between two formerly mined areas. B) Walnut Creek has shifted its course numerous times in human history, typically in response to flooding. Pilings in the lower left-hand corner indicate some infrastructure that was undermined by streambank erosion. C) Uprooting trees may cause a short pulse of sediment into the adjacent waterway. This tree was growing on the southeastern slopes of Great Temple Mound. D) A small stream flows through the Opelofa wetlands. E) Wetlands occur in most low-lying areas of the park, including along an unnamed stream. The flowing water is laden with sediment. F) Sediment choked stream channel. Flow is dispersed across a broad area of wetland. Photographs A and C by Rebecca Port (NPS Geologic Resources Division), photographs B and D by Georgia Hybels (Colorado State University), and photographs E and F by Katie KellerLynn (Colorado State University); all taken in March 2012.

Figure 16. Photographs of streams and culverts at Ocmulgee Mounds National Historical Park.
A) View looking upstream at Temple Mound Creek. Stream channel has trash, and bare high steep banks because it is extremely entrenched and scoured with deeply undercut trees and slumping along its banks. B) Unnamed streams originating from storm drains and sewers from Macon flow through the park. The water is polluted and commonly leaves trash and contaminated sediments on the landscape C) Sediments clog the stream channel leading to two culverts beneath the railroad which are nearly buried with sediments. Photograph A is site number Oc006 from McDonald and Starkey (2019). Photograph B by Katie KellerLynn (Colorado State University) and photograph C by Georgia Hybels (Colorado State University), both taken in March 2012.

Figure 17. Photographs of "Temple Mound Creek" and "Bamboo Creek".
Top image of Temple Mound Creek: this creek is a small sand-bedded channel with a high frequency of large slumps and sedimentation. Abundant trash and debris are noted along its length. Bottom image of Bamboo Creek: Bamboo grows along the edges of this small sand and gravel bedded stream with high banks and slumping. This stretch was not chosen for monitoring because of safety concerns given the steep high walls and undercut trees, as well as the adjacent upstream development rendering the stream prone to flash flows. Photographs presented in Appendix A of McDonald and Starkey (2019).

Anthropogenic Changes to the Fluvial System

Human activities have profoundly impacted the fluvial system at the park. Impervious surfaces within the watershed have increased runoff, human activities in the area have contributed to decreased water quality, and development has altered the natural flow patterns in the area. Higher flow velocities occur in urbanized watersheds with high impervious areas, thus increasing streambank erosion rates (Burkholder et al. 2017). The park receives storm drainage from the city of Macon. Pollution associated with this drainage is a concern for park managers (see fig. 16). Within the park, streams flow through canals, culverts, under bridges, and under the railroad. When water diversion systems (e.g., culverts) are inadequate to accommodate high flows, water backs up behind them (McDonald and Starkey 2019).

Stretches of streams that flow through the park are characterized by high streambank erosion and thick sediment deposits along with trash accumulation (see fig. 16; McDonald and Starkey 2019). The Ocmulgee River and Walnut Creek are described as impaired waters for biota and/or recreational use because of fecal coliforms (Burkholder et al. 2017); however, neither Walnut Creek nor Ocmulgee River are currently listed in the Environmental Protection Agency's (EPA) 303(d) ratings, which would authorize the EPA under section 303(d) of the Clean Water Act to assist in developing total maximum daily loads for the streams as a starting point or planning tool for restoring water quality. Instead, both are just noted as being impaired (EPA 2020).

Constructed in 1950, the Macon levee (maintained by the US Army Corps of Engineers), was constructed for flood control. The levee is located on the west bank of the Ocmulgee River immediately downstream of the City of Macon and effectively channelized the Ocmulgee River, separating the river from its floodplain. The levee consists of a 446-m (1,462-ft) long concrete flood wall and 8,007-m (26,270-ft) long earth dike extending downstream from high ground at the Otis Redding Bridge in Macon (US Army Corps of Engineers 2020). Floodwalls and dikes cut rivers off from their floodplains (GRI conference call participants, 7 January 2021). Sandy ground behind the levee is so porous that water bubbles up out of the ground. Unfinished levees (ca. 1930s) border the north, east, and southeast sides of the park near the Lamar mounds. Around 1960, road materials (sand and gravel) for construction of Interstate 16 were quarried in the vicinity of the Lamar mounds. Since that mining activity, the Lamar mounds area consistently has more standing water (KellerLynn 2013). The standing water comes from the interstate and associated berm, which disrupted natural sheet flow in the area. Before construction, water would have flowed freely across the land surface absorbing into the subsurface along the way in a dispersed flow. Now, the berm blocks sheet flow, funneling water into four culverts to cross the berm (KellerLynn 2013). The ecological impacts of these modifications at the Lamar mounds, particularly to wetlands and natural flood frequency, are poorly understood (DeVivo 2008).

Wadeable Stream Habitat Management

Burkholder et al. (2017) identified the need for stream sediment quality and wetland ecosystem (see "Lacustrine and Wetland Features and Processes" section) information as a resource management concern at the park. The physical character within and near a stream habitat has a strong influence on ecologic integrity. Therefore, studying and monitoring stream habitat provides an understanding of not just the physical suitability for aquatic species, but also identifies stressors that could degrade park resources and negatively affect visitor experiences. Vital signs such as wadeable stream habitat were identified as necessary for monitoring (McDonald et al. 2018). Recent publications, including a site suitability survey, long-term monitoring suitability of perennial and ephemeral streams, and recorded changes since 2017 are now available for park management: McDonald and Starkey (2019), Cooper et al. (2019), and Bateman McDonald (2020), respectively.

A stretch of Walnut Creek (fig. 18) was selected for stream habitat condition long-term monitoring because it (1) is representative of the processes influencing the streams in the park; (2) can address current and anticipated management concerns; and (3) offers the most utility for future complementary studies. The suitability of the stretch was based on whether the stream could be safely accessed; was part of a single channel or wadeable stream; and was not greatly influenced by upstream impoundments or catchments (McDonald and Starkey 2019). Cooper et al. (2019) described the stream's condition in 2017 as having floodplains, natural levees, runs and pools, lack of riffle habitat, and homogenous channel slope. The depositional environment was subject to regular flooding, wherein floodwaters inundate an adjacent secondary flow zone, and slow post-flood draining. The in-stream habitat was classified as poor to fair. The following data were collected during long-term monitoring:

- Basin characteristics—drainage density, magnitude and duration of floods, rainfall-runoff potential, potential sediment yield, and available energy to move sediment.
- Reach-scale measurements—vegetative bank cover, presence of eroding banks, bed and bank material, channel widths, water depth, and bank height/angles.
- Detailed transect cross sections—transect surveys, streambed elevation, bank profiles.

Figure 18. Photograph of a stretch of Walnut Creek.
Walnut Creek is a medium-sized, sand-bedded stream. At the time of this photograph in May 2017, the channel width was estimated to be approximately 6.5 meters (21.3 feet). If it were flowing at bank-full conditions, the width would be around 10 meters (32.8 feet). Water depth along this stretch ranged from 0.2–0.5 meters (0.7–1.6 feet). Floodplains are well developed throughout the segment. The banks were fairly vegetated (approximately 50–90%) with grasses, shrubs, and trees. Large woody debris was present and serving multiple functions such as habitat creation and bank protection. Several smaller (ephemeral) creeks were observed entering the stream throughout the segment. This reach was chosen for long-term monitoring. Photograph presented in Appendix A of McDonald and Starkey (2019).

Bateman McDonald (2020) presented substantial changes of in-stream habitats over just two years of monitoring, from 2017 to 2019. Former mixtures of runs and pools were now mostly almost all run habitats. The deepest part of the channel, or thalweg, decreased in depth and the bed sediment was also finer. Floodplain aggradation, bank slumping, and streambed restructuring had also occurred. These data suggest that substantial sedimentation has occurred within the monitored reach of Walnut Creek, possibly as a result of bank slumping. The overall classification of the habitat was downgraded from "poor to fair" to "poor" because of a reduction of in-stream habitat diversity and finer bedload. However, further work is needed to determine how flow, water quality, and stream physical characteristics affect habitat health at the park and whether these processes are in fact natural or anthropogenically influenced. The next field surveys are tentatively scheduled for spring or summer 2022.

Demand for Freshwater

Upriver from the park, the urban areas of Atlanta and Macon are placing increasing demands for supplies of freshwater. Pressure to impound headwater streams and create reservoirs has the potential to reduce the amount of water that flows through the park (DeVivo 2006; Burkholder et al. 2010), which will inevitably change the fluvial system there, potentially causing loss of wetland areas. Park managers are concerned about this process (KellerLynn 2013; GRI conference call participants, 7 January 2021).

Most of the water used in the park and surrounding areas comes from surface waters such as Ocmulgee River and freshwater aquifers in the region (Burkholder et al. 2010, 2017). The regional geology controls the groundwater aquifer types present. There are three aquifers present in the region: the surficial aquifer, the Southeastern Coastal Plain Aquifer System (SECP), and the Piedmont Aquifer. The surficial (unconfined) aquifer is composed of relatively permeable sand and gravel with some clay. It is the youngest aquifer, with units from Pliocene to Holocene age (younger than about 5 million years). It is recharged by rainwater. The SECP is the major aquifer for the region and is located below the surficial aquifer and locally consists of three layers: the Barnwell Formation (part of geologic map unit **Tbt**), Blufftown Formation (possibly equivalent to part of **Kg**), and older, pre-Cretaceous rocks (undifferentiated crystalline rocks, saprolite, red beds, basalt, diabase, Jurassic sedimentary rocks, and Paleozoic sedimentary rocks). The oldest aquifer is the Piedmont Aquifer, located just north of the park, in which water is stored in fractures within the crystalline rocks of the Piedmont (Renken 1996; Burkholder et al. 2017).

A primary issue regarding the demand for freshwater is that surface water quality/quantity was listed as in poor condition by Burkholder et al. (2017) in an assessment of water resources at the park. Trash and debris regularly wash through the park after a storm; significant pollution occurs on every flow path (Eric Starkey, aquatic ecologist, Southeast Coastal Network, conference call, 7 January 2021). In addition, local groundwater levels have lowered by more than 6 m (20 ft) since about 2007 (Burkholder et al. 2017) making this a less and less reliable freshwater source.

The need for monitoring of water resources has been indicated by park staff (National Park Service 2014a). This includes regular monitoring of surface and groundwater quality, contaminant levels, stream sediment load, and an inventory of off-site contaminant sources (e.g., septic tanks, developments). There is also a need for monitoring of undesirable high-water conditions in the park, the effects of which are described in the "Flooding, Erosion, and Rapid Sedimentation" section of this report. According to Burkholder et al. (2017), the park does not have a water resources management plan.

Climate Change Impacts

The central Georgia climate is warm and humid, temperate with a mean annual temperature of 15.6°C (60°F) and mean precipitation of 129.5 cm (51 in) (Burkholder et al. 2017). Predicted climate change trends will impact the ecosystem at the park. The Intergovernmental Panel on Climate Change (IPCC) has projected that temperature in the southeastern US will increase 2.2 to 5.0°C (4 to 9°F) by 2080 (Karl et al. 2009; Burkholder et al. 2017). Since 1970, average annual temperatures in the southeast, including the Macon area, have increased by 1.1°C (2°F) (Karl et al. 2009, Fisichelli 2013, Kunkel et al. 2013; Burkholder et al. 2017). Climate change models suggest that there will be heavier downpours interspersed with increased droughts between storm events—conditions apt to increase the risk of flooding in the park. According to Monahan and Fisichelli (2014), ongoing and future changes in climate will affect all aspects of park management including natural resource protection, park operations, and visitor experience. Understanding the triggers and outcomes of these changes is crucial to protecting the natural and cultural resources at the park.

Water and Climate Specific Resources

- Wadeable stream habitat monitoring protocol narrative by McDonald et al. (2018)
- Site suitability assessment for monitoring by McDonald and Starkey (2019)
- Baseline conditions for wadeable stream habitat monitoring by Cooper et al. (2019)
- Wadeable stream habitat monitoring change by Bateman McDonald (2020)
- Fluvial monitoring and geomorphology by Lord et al. (2009)
- Hydrographic and impairments statistics https://irma.nps.gov/Datastore/Reference/Profile/2242201
- Key watershed boundaries https://irma.nps.gov/Datastore/Reference/Profile/1048120
- Water quality inventory https://irma.nps.gov/Datastore/Reference/Profile/2173987
- Water resources assessment and watershed conditions https://irma.nps.gov/Datastore/Reference/Profile/2167855
- Streamflow conditions https://irma.nps.gov/Datastore/Reference/Profile/2195937
- Information regarding the park's water resources is available from the NPS Water Resources Division (http://go.nps.gov/waterresources)
- Climate change trends https://irma.nps.gov/Datastore/Reference/Profile/2195834
- Weather and climate inventory https://irma.nps.gov/Datastore/Reference/Profile/649203
- Recent climate change exposure https://irma.nps.gov/Datastore/Reference/Profile/2213491

Lacustrine Features and Processes

Geologic map units: water and alluvium (**Qa**)

Lacustrine (lake) features and processes are intermittent and/or ephemeral at Ocmulgee Mounds National Historical Park; they only exist as temporary bodies of water (KellerLynn 2013; Mark Ford, NPS Southeast Region, wetland ecologist, conference call, 7 January 2021). In 2012, three ponds, informally named Junkyard Pond, Turtle Pond, and an unnamed pond/"clay hole" near Great Temple Mound (see "Coastal Plain Clay and Mining Activity"), were within the park (KellerLynn 2013). Also, the road to the Lamar mounds dead-ends at Black Lake, which is now part of the park resulting from the 2022 land acquisition. The new lands include several small water bodies, which are not labeled on topographic maps and have yet to be inventoried. In historic times, a series of oxbow lakes formed as the Ocmulgee River naturally meandered (see "Fluvial Features and Processes"). The anthropogenic manipulation of the Ocmulgee River effectively channelized the river, ceasing meandering, and as a result, the oxbow lakes slowly filled with sediment and ceased to exist in this area. Although these lakes no longer exist, an 1827 map shows their locations (Burkholder et al. 2010; KellerLynn 2013).

The ephemeral nature of standing surface water appears to be a long-term, recurring feature of the park landscape (KellerLynn 2013). For example, the meandering Walnut Creek influences the existence of Turtle Pond near the overpass. Within the last 25 years, this pond disappeared and reappeared. This is likely due to stream re-routing during Tropical Storm Alberto in 1994. Floods forced the water to erode channels away from the pond, but it has since meandered back. As of 2012, the stream has started to run again (Katie KellerLynn, Colorado State University, geologist, field trip notes, 22 March 2012).

The lacustrine features in the park are likely all regulated as wetlands. Per these regulations, ponds and lakes up to a depth of 3 m (6 ft) are considered wetlands, and wetlands do not have to show standing water to be considered wetlands (Mark Ford, NPS Southeast Region, wetland ecologist, conference call, 7 January 2021).

Wetland Features and Processes

Geologic map units: water and alluvium (**Qa**)

Wetlands are transitional areas between land and water bodies where water periodically floods the land or saturates the soil, and includes marshes, swamps, seeps, pools, and bogs. Wetlands provide several significant functions, including (1) provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) sediment retention and erosion control. Wetlands are commonly depositional environments, creating a valuable record available as sample cores.

Land cover within the park boundary is predominantly riverine emergent wetland. In 2021, about 40 % of the park area, or approximately 121 ha (300 ac) of emergent wetlands, were mapped as surface hydrographic features at Ocmulgee Mounds National Historical Park (see fig. 15; DeVivo et al. 2008; Burkholder et al. 2017; McDonald and Starkey 2019). Wetlands feature prominently in the newly acquired park lands (ca. 2022) and this number will increase when these lands are accurately surveyed. Along with Bond Swamp National Wildlife Refuge, the park is part of a fragmented greenway corridor for wetland species (Burkholder et al. 2017). The wetlands include one of the largest peat bogs in the southeast (DeVivo et al. 2008; Burkholder et al. 2017).

Wetland areas along Walnut Creek are another example of ephemeral characteristics; submerged areas within the wetlands shift over relatively short time periods. Construction of the boardwalk provided a time marker of a recent change. In 2006, the boardwalk was constructed over standing water. In 2012, a drought year for Georgia, there was only dry land beneath the boardwalk and Walnut Creek meandered around this area (fig. 19; KellerLynn 2013). Mark Ford (NPS Southeast Region, wetland ecologist, conference call, 7 January 2021) notes that the area is again currently inundated with water supplied by Walnut Creek.

The wetlands at Ocmulgee Mounds National Historical Park may contain a valuable fossil pollen (palynological) record that would be of value to archeologists in reconstructing prehistoric and historic plant successions and paleoclimates. These data would be available through taking cores in the wetlands, correlating those cores with other studied cores from archeological sites, and C^{14} dating to determine sediment ages. Such a study would need to take into account how long the wetland has been persistent and possible large gaps in the data because of dry periods where deposition did not occur (Stephen Cooper, NPS Southeast Coast Inventory and Monitoring Network, physical scientist, written communication, 7 October 2021).

Coastal Plain Clay and Mining Activity

Geologic map units: alluvium (**Qa**) and undifferentiated sedimentary rocks (**Ku**)

Kaolin is a soft, white clay. The kaolin-bearing sediments of the inner Coastal Plain constitute the world's leading source of high-quality kaolin (Long et al. 1986). Kaolin was historically used for pottery and trade goods within coastal populations. More recently, kaolin is used in the manufacturing of paper and for liners of salt-production evaporation ponds (KellerLynn 2013). Deep weathering of Piedmont bedrock, particularly that of granitic composition containing feldspar and other aluminum silicate minerals, is the principal source of kaolin on the Atlantic Coastal Plain (Hurst et al. 1979). Kaolinitic clays, weathered from the Piedmont bedrock and deposited primarily during the Upper Cretaceous Period (100 million–65.5 million years ago) and middle Eocene Epoch (approximately 50 million years ago), are present at or near the surface in a widespread region that extends more than 500 km (300 mi) from Eufaula, Alabama, to Lexington County, west-central South Carolina (Patterson and Murray 1975). Kaolin deposits extend into Bibb County, Georgia and are mined east of the Ocmulgee River along the Twiggs County line (LeGrand 1962).

Figure 19. Photograph of a boardwalk over an intermittent wetland on the River Trail. The boardwalk was constructed in 2006 when the area was permanently underwater. Hydrologic changes since then have caused the water to drain and land emerge. Vegetation has been taking hold over the once submerged areas. Photograph by Georgia Hybels (Colorado State University), taken in March 2012.

The clay within the park is not the pure white kaolin that is valued for industry because it does not absorb water and expand when wet. Rather the clay is red, which provided a striking medium for mound construction (see fig. 4). The source for the red coloring is probably local weathering of iron-rich metamorphic rocks of the Piedmont physiographic province. An Eocene layer of red, sandy clay stratigraphically overlies the Upper Cretaceous soft, white kaolin.

As in the past, clay is mined today using the "open pit" method (Buie 1980), in which an environmental disturbance is created to the land through an excavated depression or pit. This removes the overburden (locally more than 30 m [100 ft] thick) to reach the underlying clay and commonly creates tailings (Buie et al. 1979). Water must be constantly pumped from most mines to allow access to the clay (Buie et al. 1979). The water-filled borrow pit (pond below Great Temple Mound), is evidence of clay extraction to build that mound. Another pond or "clay hole" along the Opelofa Trail was mined in the late 1800s by the Stratton Brick Company (renamed Cherokee Brick and Tile Company in 1949) (Historic Macon Foundation, date unknown). This clay was used for brick fabrication for both local buildings and for export elsewhere. The trail, which appears artificially raised, perhaps to construct a tram rail to transport material, is actually a remnant of an un-mined area (fig. 20; KellerLynn 2013; Carla Beasley, Ocmulgee Mounds National Historical Park, superintendent, written communication 17 October 2021).

Figure 20. Photograph of the Opelofa Trail.
What appears to be a raised trail bed is actually the remnant piece of land between two mined areas. The adjacent low-lying areas were mined for kaolin clay and unconsolidated sediment. Now, wetlands cover the low areas. Photograph by Georgia Hybels (Colorado State University), taken in March 2012.

Abandoned Mineral Lands and Disturbed Lands

According to the NPS Abandoned Mineral Lands (AML) database (accessed 30 April 2020) and Burghardt et al. (2014), Ocmulgee Mounds National Historical Park contains no inventoried AML features; however, known mined areas occur throughout the park and surrounding land. AML features present a variety of resource management issues related to visitor and staff safety; air, water, and soil quality; and animal habitats. Resource management of AML features requires an accurate inventory and reporting. All AML features should be recorded in the AML database (the NPS Geologic Resources Division may be able to provide assistance). An accurate inventory can identify human safety hazards and facilitate reclamation and restoration of features. When appropriate for resource management and visitor safety, features can also present opportunities for interpretation as cultural resources. The NPS AML Program website, https://www.nps.gov/subjects/abandonedminerallands/index.htm, provides further information.

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by human activities such as development; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Restoration activities return a site, watershed, or landscape to a previous condition, commonly some desirable historic baseline. At Ocmulgee Mounds National Historical Park, many of the disturbed lands are considered to be part of the park's cultural resources and fundamental to the purpose of the park (e.g., clay hole pond, excavations for brick material on the back side of the Temple Mound, and prehistoric ditches; Burkholder et al. 2017; GRI conference call participants, 7 January 2021).

Modern kaolin mining is not a primary concern for park resource managers; however, two heavily disturbed, unreclaimed areas of soil/regolith mining southeast of the park are remnants of 1960s Interstate-16 construction and brick-material quarrying (KellerLynn 2013; Jill Halchin, Southeast Archeological Center, archeologist, conference call, 7 January 2021). These disturbed areas, which are clearly visible on aerial photographs (fig. 21) with dirt tracks, are part of a parcel of land that is part of the 2022 park boundary expansion (KellerLynn 2013; Carla Beasley, superintendent, Ocmulgee Mounds National Historical Park, written communication 17 October 2021).

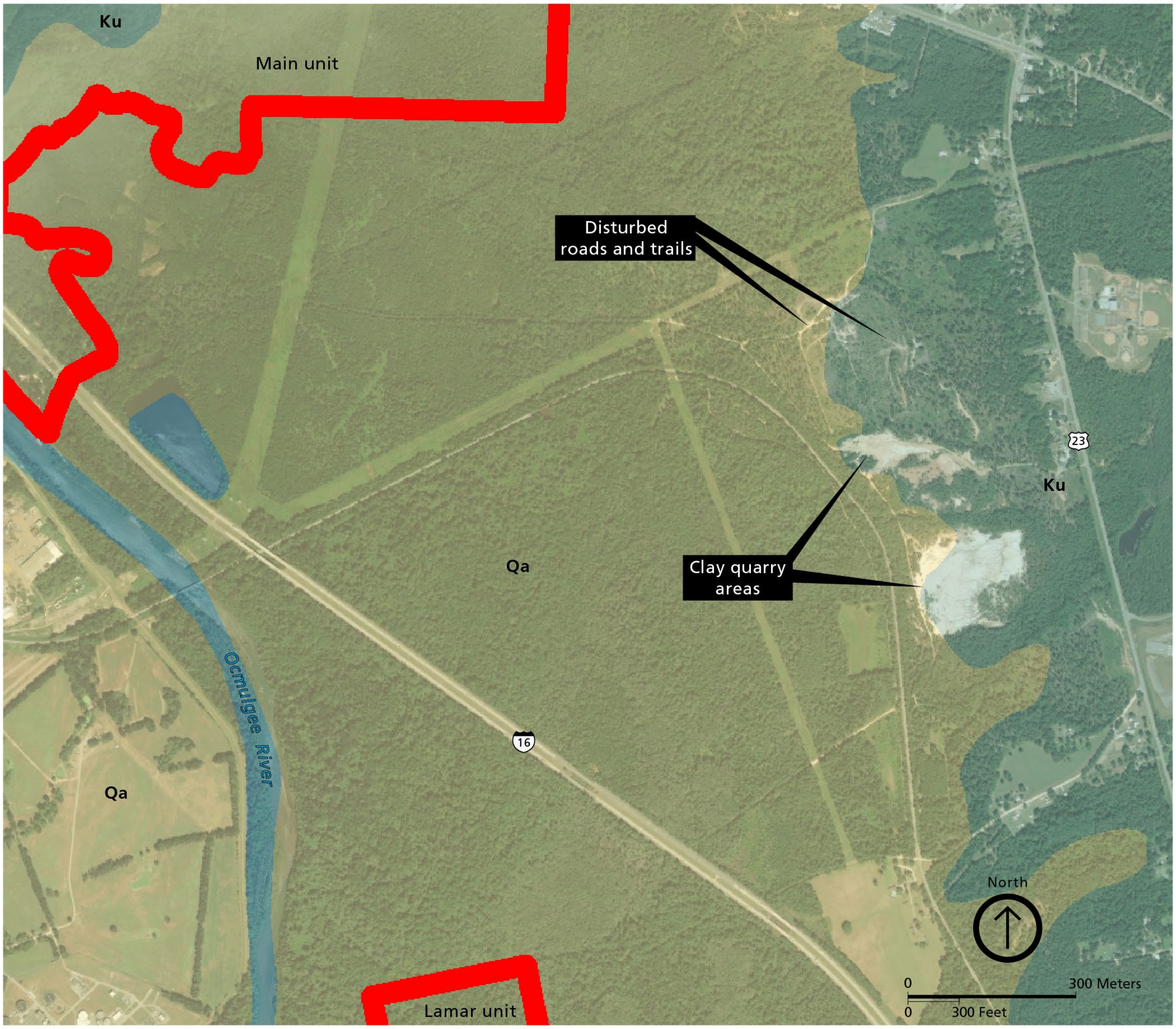

Figure 21. Aerial image of disturbed areas near the park boundary.
The disturbed areas identified in the image are part of the 2022 park boundary expansion. Park management considerations include restoration and providing safe access to the new parcels. Geologic map units alluvium (Qa) and undifferentiated sedimentary rocks (Ku) are mapped under the disturbed areas. The park boundary is represented by the thick red line. The main unit of the park is north of the disturbed areas and the Lamar unit is to the south. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap.

Railroad cuts from the 1870s removed a portion of the Funeral Mound, which is now a shadow of its former self. In addition to the railroad cut, plundering during early recreational outings sought to make souvenirs of the artifacts of Mississippian Indian leaders interred there (Katie KellerLynn, Colorado State University, geologist, field trip notes, 22 March 2012). The railroad also impacted the Lesser Mound, of which an entire side was removed.

Burkholder et al. (2017) identified encroaching urbanization (about two-thirds of the main unit borders urban and suburban development) and its associated water and air pollutants and other stresses as the primary threats to the natural resources within the park. Because of the park's small size, land-use practices of surrounding areas can strongly impact the ecosystem and visitor experience within the park. Agriculture adjacent to park boundaries tends to result in cleared lands, impounded drainages (farm ponds), and accumulation of animal waste. Housing and other suburban developments typically involve an increase in impervious surfaces such as buildings, parking lots, streets, and sidewalks. Impervious surfaces cause runoff to flow quickly and unnaturally into the drainage system rather than infiltrating the soil and slowly becoming part of the groundwater system. This runoff introduces pollution and waste into the park's streams. Increased impervious surfaces cause increased stormwater runoff, local erosion, sedimentation, stream channelization, and degradation of stream habitat and biodiversity. Resulting impacts include illicit dumping of trash and other refuse, erosion/washout of hiking trails that receive heavy use, and pollution.

The park initiated a boundary study and environmental assessment (published in 2014) that recommended the incorporation of up to 850 ha (2,100 ac) of surrounding land into the park, including areas between the two park units, Bond Swamp National Wildlife Refuge, and lands east and north of the main unit (Burkholder et al. 2017). At the time of publication in 2021, the park boundary was expanded, but the park was still in the process of acquiring some of the land. This is being finalized in 2022. The parcel in question is located primarily to the southeast of the current park boundary with a few sections on the northern and western edges as well (see figs. 1 and 2 and the GRI poster; Carla Beasley, Ocmulgee Mounds National Historical Park, superintendent, written communication 17 October 2021). The primary park resource management concern with the new parcels relates to accessibility, private bridge (over Black Lake) maintenance, and potential for flooding.

Geologic Hazards

A geologic hazard ("geohazard") is a natural or human-caused geologic condition or process that may impact park resources, infrastructure, or visitor safety. Geohazards include earthquakes, volcanic activity, landslides, tsunamis, and even meteorite impacts. The risk of a geohazard is defined as the probability of a hazard to occur 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). Not all geohazards require mitigation, only those with high risk. The preferred approach to any geohazard is to work proactively to identify and address the situation before any injury or property loss occurs, or at least plan for future hazard risk mitigation. National Park Service policy intends to let natural processes proceed unimpeded in parks unless infrastructure, visitors, other resources (e.g., cultural or archeological) are threatened. The NPS Resource Management and Risk Mitigation website (https://www.nps.gov/subjects/geohazards/managing-risk-and-mitigating-hazards.htm) has more information.

Seismic Activity

Geologic map unit: all

The primary geohazard at Ocmulgee Mounds National Historical Park is seismic activity. Seismic activity, or earthquakes, is ground vibrations—shaking—that occurs when blocks of Earth's crust suddenly move along a fault (crack), releasing accumulated energy (Braile 2009). Earthquake intensity ranges from being 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; another way to measure earthquake intensity is via the Mercalli scale which is based on the degree of damage caused by the shaking (fig. 22). Earthquakes can directly damage park infrastructure or trigger other hazards such as slope movements that may impact park resources, infrastructure, or visitor safety.

Although earthquakes are rarely felt within the park (KellerLynn 2013) and the park is not located along any major fault lines, small earthquakes are common in the area, and the park's foundation document outlined a need for further study of seismicity in the park due in large part to the vibrations caused by the railroad traffic (National Park Service 2014a; Carla Beasley, superintendent, Ocmulgee Mounds National Historical Park, written communication, 17 October 2021). Based on the National Seismic Hazard Model (Petersen et al. 2019), the park is in an area of moderate seismic hazard (fig. 23). According to the US

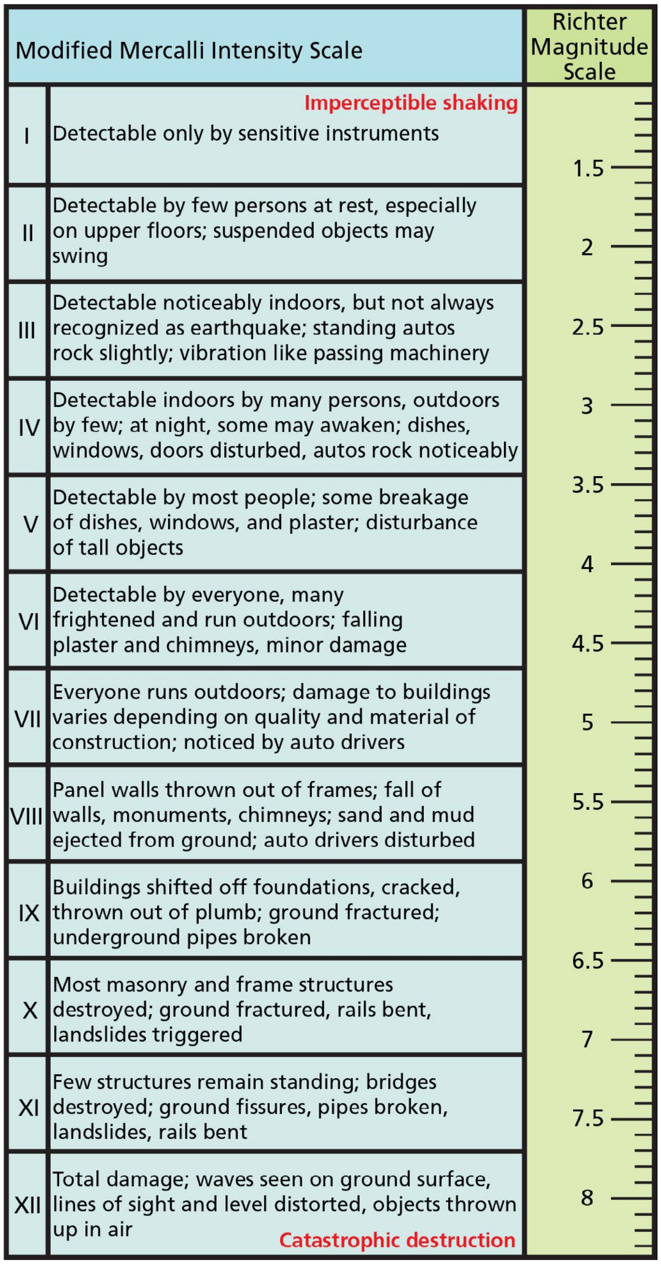

Figure 22. Scales of earthquake magnitudes. Seismologists report earthquake strength of intensity by two primary scales: Richter or Mercalli. Richter measures the seismic waves or energy released during the earthquake whereas the Mercalli scale focuses on the actual damage or effects caused by the shaking. Earthquakes with Richter magnitudes between 2 and 3 or Mercalli II and IV are the most likely to occur at the park. These earthquakes would cause rattling similar to a train or piece of heavy equipment rumbling by, but no substantial damage to infrastructure. Potential always exists for larger magnitude events with more shaking and possible damage. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Geological Survey's latest earthquakes viewer (https://www.usgs.gov/natural-hazards/earthquake-hazards/science/information-region-georgia?qt-science_center_objects=0#qt-science_center_objects), since 1983, about 18 earthquakes have occurred within a 60 km (40 mi) radius around Macon (fig. 24). These range in Richter magnitude from 2.0 and 3.5, which are rarely felt and do not damage infrastructure. Earthquakes with magnitudes between Richter magnitude 2 and 3, known as "microseismicity", are not uncommon at the park. They are caused by crustal adjustments along very old faults that formed when the Atlantic Ocean rifted apart hundreds of millions of years ago (Robby Morrow, South Carolina Geological Survey, field geologist, conference call, 18 December 2019; GRI conference call participants, 7 January 2021).

However, there are occasionally larger earthquakes in the region that can be felt and cause damage to infrastructure. As proven by the 2011 Virginia earthquake, major damage from an earthquake can occur in an area that was previously considered to be relatively inactive. Shaking from that earthquake was felt throughout the eastern seaboard, particularly along the fall line and damaged buildings such as the Washington Monument in Washington, DC (Horton et al. 2015). The great Charleston, South Carolina, earthquake of 1886 (~7.3-magnitude) was felt in central Georgia, where severe shaking was reported. On August 31, 1886, at 9:25 p.m., preceded by a low rumbling noise, seismic shock waves reached Savannah, and people had difficulty remaining standing. The shaking cracked walls, toppled chimneys, and broke windows (US Geological Survey 2012). Historical buildings in Macon that predate this earthquake show engineering efforts to shore up walls following damage incurred during the earthquake (e.g., decorative rosettes that cover the ends of cast iron or steel rods installed to enhance structural integrity).

Scoping participants noted that the railroad bed (compacted clay) is remarkably stable and unlikely to incur damage from seismic activity. However, seismic shaking related to the passing of trains is a concern for the preservation of archeological resources such as the Earth Lodge, which now has some cracks. No seismic study of the relationship between train traffic and archeological resources has been conducted at the national monument, however. This could be incorporated into the future seismographic study that was identified as a data need in the park's foundation document (National Park Service 2014a; GRI conference call participants, 7 January 2021).

Unconsolidated units such as alluvium (geologic map unit **Qa**) may become unstable during earthquakes.

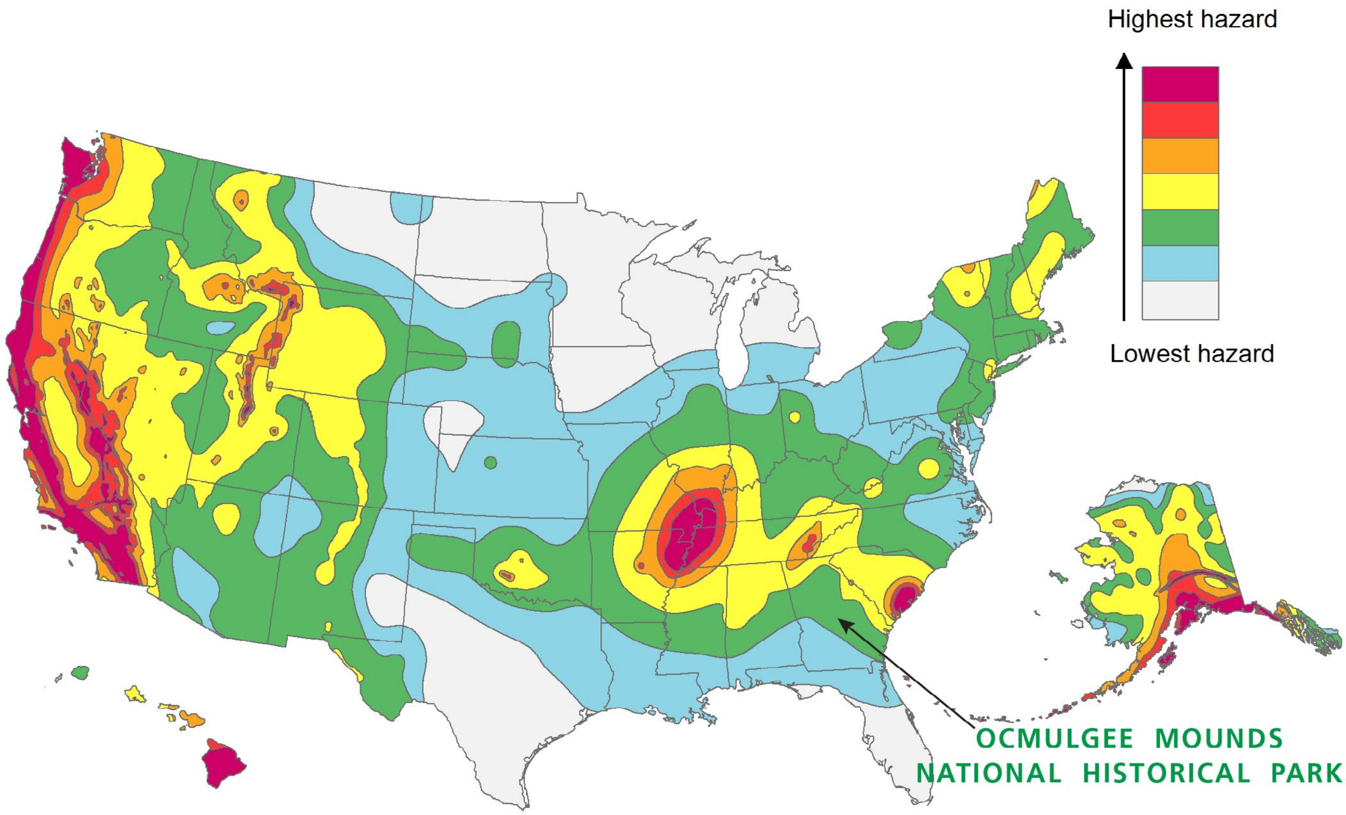

Figure 23. National seismic hazard map.
The map shows the degree of earthquake hazard across the United States based on the 2018 Update of the National Seismic Hazard Model. The map is based on US Geological Survey models which calculate peak ground accelerations having a 2 percent probability of being exceeded in 50 years for a firm rock site based on seismicity and fault-slip rates. The models 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. Georgia is near the East Tennessee Seismic Zone and has low to moderate probability of seismicity in the green-colored band. Public domain graphic by of the US Geological Survey.

This concern is relevant because these geologic map units are common at the park; alluvium underlies 100% of the Lamar mounds area, and over half of the mapped area inside the new park boundary (see GRI poster). The mounds themselves are composed of unconsolidated sediments. Some areas noted within the park that contain fill are reclaimed mining areas. This also has a high susceptibility to liquefaction and/or increased shaking potential during an earthquake (Jack Wood, National Park Service, physical scientist, written communication, 14 October 2021). For those areas with any infrastructure this would be a hazard concern too. More information about earthquake scenarios can be found at: https://earthquake.usgs.gov/scenarios/.

In the *Geological Monitoring* chapter about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

Resources Related to Geologic Hazards

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

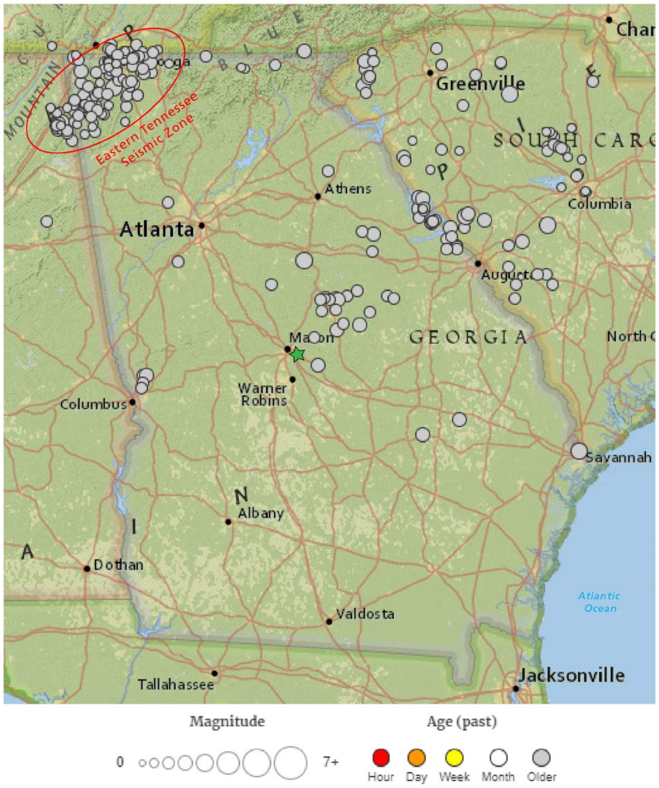

Figure 24. Map of Georgia with earthquake epicenters since 1900.
Seismicity occurs along a fault plane where energy is released as the fault slips and the two blocks on either side of the fault slide past each other. Since 1983, about 18 earthquakes have occurred near Macon and Ocmulgee Mounds National Historical Park (green star on map). Graphic is courtesy of the US Geological Survey (https://www.usgs.gov/natural-hazards/earthquake-hazards/information-region). Eastern Tennessee Seismic Zone is noted for reference, 270 km (170 mi) away from the park, in the northwestern corner of Georgia.

Geomorphological Connections with Archeology

Geologic map units: alluvium (**Qa**), undifferentiated sedimentary rocks (**Ku**)

GRI conference call participants noted a high need for a surficial geologic map for the park. The GRI GIS data is limited to just four geologic units mapped in the park with very little differentiation as to landform or formational/depositional process. Geomorphology is often one of the strongest predictors for locations of prehistoric sites (Jill Halchin, Southeast Archeological Center, archeologist, conference call, 7 January 2021). The Ocmulgee site, situated on an upland terrace and floodplain (fig. 25) would have been attractive to humans for its variety of natural resources and advantages (see "Geologic Heritage"). When used in concert with geomorphological and topographic data, archeologists can apply surficial data to predictive models to determine where prehistoric sites might be discovered. A surficial geologic map would also be useful for ecologists monitoring wadeable stream habitats and determining landscape evolution over time (see "Fluvial Features and Processes" section) (Eric Starkey, NPS Southeast Coast Inventory and Monitoring Network, aquatic ecologist, conference call, 7 January 2021). Cosner (1973) provided descriptions of eight sedimentary units of Holocene age within the Ocmulgee floodplain, which may provide a starting point for modern surficial mapping.

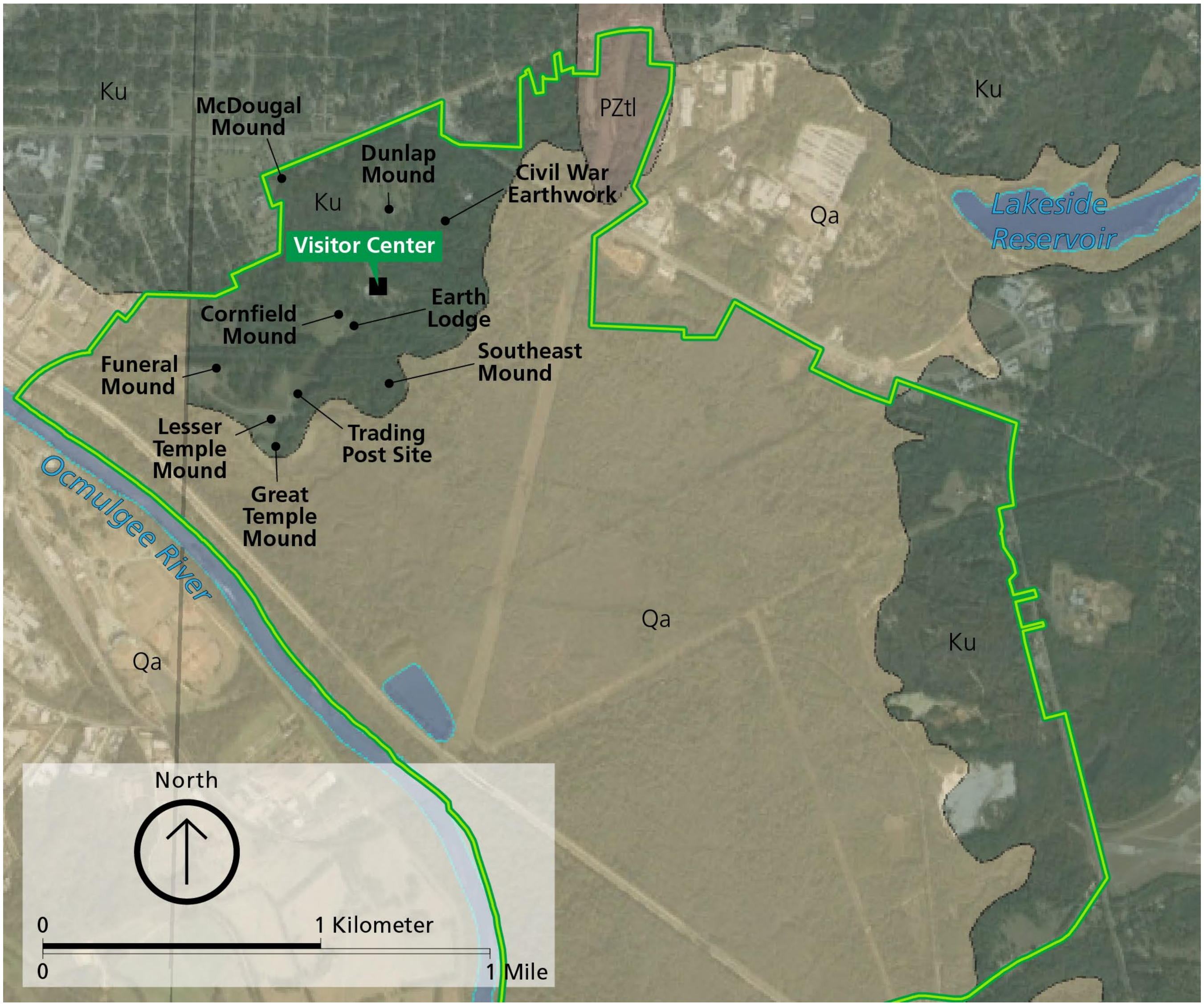

Figure 25. Maps showing the Ocmulgee Mounds site on a geologic map.
Most of the mounds are located on deposits of undifferentiated sedimentary rocks (geologic map unit Ku). Surficial geologic mapping is recommended to understand the intricacies of the site and determine the landforms contemporaneous with the mound builders. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap.

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).

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/.
- Submit a proposal to receive geologic expertise through the Scientists in Parks (SIP; formerly Geoscientists-in-the-Parks; see https://www.nps.gov/subjects/science/scientists-in-parks.htm). This program places scientists (typically undergraduate students) in parks to complete science-related projects that may 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.

Park Documents

The park's foundation document (National Park Service 2014a), State of the Parks report (National Park Service 2014b), and Natural Resource Condition Assessment (Burkholder et al. 2017) are primary sources of information for resource management within the park. National Park Service (2014a) listed the following fundamental resources and values as resource management priorities: reconstructed Earth Lodge, Macon Plateau earth mounds, Lamar Period village and mounds, other archeological sites related to the Ocmulgee Old Fields, sense of place and sacred ancestral homeland for American Indians, Creek Indian village and historic British trading post, archeological research collection, Ocmulgee River and floodplain, and existing and eligible national register properties (e.g., visitor center, Dunlap House, Civil War earthworks).

Cultural landscape restoration, administration, and management are addressed in several publications including Wheeler (2007), Dietrich-Smith et al. (2017), Marsh (1986), Marsh and National Park Service (1986), Fairbanks and Setzler (1956), and Oppermann and National Park Service (2008). Cosner (1973) described the stratigraphy of the Ocmulgee floodplain with attention to archeological resources. A cultural landscape restoration report for the park is currently in progress (GRI conference call participants, 7 January 2021).

NPS Resource Management Guidance and Documents

- NPS Management Policies 2006 (Chapter 4: Natural Resource Management): https://www.nps.gov/subjects/policy/upload/MP_2006.pdf
- 1998 National Parks Omnibus Management Act: https://www.congress.gov/bill/105th-congress/senate-bill/1693
- NPS-75: Natural resource inventory and monitoring guideline: https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Natural resource management reference manual #77: https://irma.nps.gov/DataStore/Reference/Profile/572379

Geologic Resource Laws, Regulations, and Policies

The following table (table 4), 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 4. 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 4, 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 4, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq.** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. **Part 610** governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. **Part 611** governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to -prevent unnatural erosion, removal, and contamination; -conduct soil surveys; -minimize unavoidable excavation; and -develop/follow written prescriptions (instructions).
Geothermal	**Geothermal Steam Act of 1970, 30 USC. § 1001 et seq.** as amended in 1988, states -No geothermal leasing is allowed in parks. -"Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead). -NPS is required to monitor those features. -Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects. **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.		**Section 4.8.2.3** requires NPS to -Preserve/maintain integrity of all thermal resources in parks. -Work closely with outside agencies. -Monitor significant thermal features.

Table 4, 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 4, 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 4, continued. 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**.
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.
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, as put forth by Beavers et al. (in review). **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 4, 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 4, 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.

Table 4, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coastal Features and Processes	**NPS Organic Act, 54 USC § 100751 et. seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). **Coastal Zone Management Act, 16 USC § 1451 et. seq.** requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone. **Clean Water Act, 33 USC § 1342/ Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit. **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs. **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.	**36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands. **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.	**Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/ park facilities/historic properties. **Section 4.8.1.1** requires NPS to: -Allow natural processes to continue without interference, -Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions, -Study impacts of cultural resource protection proposals on natural resources, -Use the most effective and natural-looking erosion control methods available, and -Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.

Additional References, Resources, and Websites

Georgia Geology

- Buie et al. (1979) discussed the geology and mineral resources of the area.
- The Environmental Protection Division of Georgia hosts the Georgia Geological Survey (no longer active) publications at https://epd.georgia.gov/outreach/publications.
- The New Georgia Encyclopedia website has detailed descriptions of the geologic provinces across the state and the geologic history at https://www.georgiaencyclopedia.org/topics/geology.
- Huddlestun and Hetrick (1985) discussed in detail the Upper Eocene stratigraphy of central and eastern Georgia.
- Huddlestun and Hetrick (1979) detailed the composition of the Barnwell Group (geologic map units **Tb** and **Tob**).
- Kogel et al. (2000) and Huddlestun and Hetrick (1991) discussed the geology of the commercial kaolin mining district of central and eastern Georgia as well as the associated regional stratigraphy of the Fort Valley Plateau.
- Duncan and Kath (2009) described the fall line geology of east Georgia.

- Howard and DePratter (1980) and Howard and Frey (1980) described Holocene geology and archeology-geology of the Georgia coast.

Climate Change Resources

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

Earthquakes

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

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- NPS Geoheritage Sites - Examples on Public Lands, Natural Landmarks, Heritage Areas, and The National Register of Historic Places: https://www.nps.gov/subjects/geology/geoheritage-sites-listing-element.htm
- UNESCO Global Geoparks: https://en.unesco.org/global-geoparks
- U.S. Geoheritage & Geoparks Advisory Group: https://www.americasgeoheritage.com/

Geologic Maps

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

Geological Surveys and Societies

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

Landslides and Slope Movements

- Unstable Slope Management Program for transportation corridor risk reduction: https://usmp.info/client/credits.php
- Geological Monitoring chapter about slope movements (Wieczorek and Snyder 2009): http://go.nps.gov/geomonitoring
- The Landslide Handbook—A Guide to Understanding Landslides (Highland and Bobrowsky 2008): http://pubs.usgs.gov/circ/1325/

NPS Geology

- America's Geologic Legacy: http://go.nps.gov/geology
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscience Concepts website: https://www.nps.gov/subjects/geology/geology-concepts.htm

NPS Reference Tools

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

Relevancy, Diversity, and Inclusion

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

US Geological Survey Reference Tools

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

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

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Bateman McDonald, J. M. 2020. Wadeable stream habitat monitoring at Ocmulgee Mounds National Historical Park: 2019 Change Report. Natural Resource Report NPS/SECN/NRR—2020/2200. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2280071.

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Buie, B. F., J. H. Hetrick, S. H. Patterson, and C. L. Neeley. 1979. Geology and mineral resources of the Macon-Gordon kaolin district, Georgia (scale 1:62,500). Open-file report OF-79-526. US Geological Survey, Washington, D.C.

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