National Park Service
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Natural Resource Stewardship and Science

Kennesaw Mountain National Battlefield Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2021/2324

ON THE COVER
A sunset reflects off the surface of an outcrop on Kennesaw Mountain. The metamorphic rock of the mountain resists weathering and erosion, and remains a high point on the landscape after the surrounding material has been eroded way. National Park Service photograph by Tom Wilson.
THIS PAGE
This 1894 photograph shows the Kennesaw Mountain ridge as it appeared only 30 years after the battle. United States Geological Survey photograph by J. K. Hillers.

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Executive Summary

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. This report synthesizes discussions from a scoping meeting held in 2012 and a follow-up conference call held in 2020. Chapters of this report highlight the park's geologic setting and significance, describe its distinctive geologic features, outline the geologic history leading to the present-day landscape, summarize the geologic issues facing resource managers, and provide information about the associated GRI GIS map data. Information in this report may also be useful for interpretation.

The American Civil War battles of Kolb's Farm and Kennesaw Mountain in June 1864 were the last Confederate defense of Atlanta against Union Major General William T. Sherman. Prior to the Battle of Kennesaw Mountain, Sherman had advanced against Confederate General Joseph E. Johnston with a series of flanking maneuvers. However, intense storms that turned the backcountry to mud and swelled creeks and drainages, combined with the imposing landscape of Kennesaw Mountain, heavily defended by Confederate forces, forced Sherman to change tactics and attempt a frontal assault culminating in the Battle of Kennesaw Mountain. The battle is considered a Union defeat, with Sherman's forces failing to break through the line and suffering around 3,000 casualties to the Confederacy's 1,000. However, a flanking maneuver following the loss at Kennesaw Mountain did achieve the end goal: forcing the Confederate forces to abandon their defenses and allowing Sherman to lay siege to Atlanta. The city fell on 2 September 1864, and this significant Union victory is credited with securing President Abraham Lincoln's reelection.

The events leading up to and including the Battle of Kennesaw Mountain were directly and indirectly influenced by the geology and geomorphology of the area. From the defensible mountains, relicts of a once-towering Appalachian range, to the weathered product of those eroded mountains providing the material for earthworks construction, and the summer tropical depression that drenched the area with rain, geologic features and processes provided the framework for the landscape and set the stage for this pivotal moment in American history.

Continental collision and mountain building that began about 470 million years ago (in the Middle Ordovician) and continued through about 419 million years ago (the Silurian) thrust an assemblage of rocks that had been deposited on the sea floor through a combination of sedimentary deposition and igneous intrusion and eruption onto an assemblage of continental rocks deposited in a shallow basin. Magma intruded within and between both assemblages, and the intense heat and pressure associated with the collision and stacking produced metamorphism, partial melting, and mixing of some of the rocks together to create new rock types. One of the rocks produced was migmatite, a hard, erosion-resistant rock. As the towering Appalachians of more than 250 million years ago (the Paleozoic Era) eroded and diminished during the breakup of Pangea and the formation of North America over millions of years, the migmatite (labelled as **OZkm** on the park's GRI GIS data) has remained as isolated peaks, or monadnocks. Kennesaw Mountain is one of those monadnocks.

This report is supported by a GRI-compiled map of the geology of Kennesaw Mountain National Battlefield Park that covers the park and surrounding area. The GRI map was compiled from a 2003 map at 1:100,000 scale completed by Higgins and others. The spatial distributions and unit descriptions of the map units informed a discussion of geologic features, processes, and associated resource management issues in Kennesaw Mountain National Battlefield Park. See the Geologic Map Data chapter for more information about the map.

Geologic features, processes, and associated resource management issues identified during the GRI scoping meeting and follow-up conference call include the following:

- Erosion and Mass Wasting. Erosion, or the natural processes that loosen, dissolve, wear away, and simultaneously move materials from one place to another; and mass wasting, the gravity-driven transport of material, are processes that can threaten park resources, infrastructure, and visitor safety. At Kennesaw Mountain National Battlefield Park these processes occur along trails and waterways where they are accelerated and exacerbated by visitor use, and in areas where human activity has altered the natural structure of the land, such as at the Illinois Monument.

- Fluvial Features and Processes. Fluvial features are formed by flowing water, either constructing or eroding landforms. There are two named fluvial features in Kennesaw Mountain National Battlefield Park: Noses Creek and John Ward (sometimes just Ward) Creek. Additional fluvial features in the park include ephemeral streams, gullies, and drainage ditches. The flashy flow (flow that has higher than expected peak flows that quickly pass through the system) of the streams in the park, typical of those with urban–suburban drainages, and visitors crossing, or recreating near streams, contribute to erosion and mass wasting.
- Monadnocks. Monadnocks are conspicuous hills or mountains consisting of erosion-resistant rock that remains after the surrounding, less-resistant rock has worn away. The Kennesaw Mountain line, consisting of Kennesaw Mountain, Little Kennesaw Mountain, and Pigeon Hill, is a monadnock formed by migmatite (**OZkm**). The monadnock defines the landscape of the park.
- Earthworks. Earthworks are defensive structures consisting of a rampart and a borrow pit on one or both sides. The construction of earthworks was influenced by underlying geology, both in building material and placement. The earthworks at the park are susceptible to erosion, especially where visitors recreate. The connections between earthworks and geology offer opportunities for interpretation.
- Stone Quarry. A quarry and associated rock crusher were established on the east side of Kennesaw Mountain in 1939 by the Civilian Conservation Corps (CCC). The quarry includes an 18 m (60 ft) tall headwall excavated into the side of the mountain. The quarry, which produced aggregate, is no longer active.
- Building Stone. The stone used to construct the Illinois Monument and other cultural resources at Kennesaw Mountain National Battlefield Park was not sourced from the park bedrock. The Monument was funded by the state of Illinois and erected by the McNeel Marble Company of Marietta, Georgia, known for their construction of Confederate monuments across the South.
- Ultramafic Rock. Ultramafic rocks are those with high concentrations of magnesium and iron, and low amounts of silica, and are characteristic of the Earth's mantle. Ultramafic rocks at the park are a result of intense tectonic deformation and collision in the Paleozoic Era. They are now exposed at the surface and are mapped in the GRI GIS data for Kennesaw Mountain National Battlefield Park.
- Seismic Activity. The park has a history of felt earthquakes, although is not considered to be at high risk of strong earthquakes. Seismic activity is not considered a hazard to park resources or people.
- Cave and Karst Features and Processes. Caves typically form as part of a karst landscape where soluble rock is removed by flowing water. The bedrock in Kennesaw Mountain National Battlefield Park is non-soluble and does not host caves in the traditional sense. Erosion at the park, however, has created some alcoves and rock shelters; any historical significance of these features is not yet known.
- Eolian Features and Processes. Eolian features are those formed, deposited, eroded by, or related to the action of wind. Eolian processes may have affected some summits and ridgelines in the park. In these areas, topsoil can be observed to be missing or eroded, and some trees may have had their growth stunted by wind.

Introduction to the Geologic Resources Inventory

The GRI 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 National Park Service (NPS) Inventory and Monitoring Program. The NPS Geologic Resources Division partners with Colorado State University's Department of Geosciences to produce GRI products. The US Geological Survey developed the source maps used to produce the GRI products. NPS staff and faculty from universities in Georgia reviewed the report. This chapter describes GRI products and acknowledges contributors to this report.

GRI Products

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document (i.e., KellerLynn 2012), (2) provide digital geologic map data in a geographic information system (GIS) and poster format, and (3) provide 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.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues to be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI team conducts no new fieldwork in association with their products.

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 *Management Policies 2006*, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). See the Guidance for Resource Management chapter for links to these and other resource management documents and information.

Acknowledgments

The GRI team thanks the participants of the 2012 scoping meeting and 2020 conference call for their assistance in this inventory. Thanks very much to the US Geological Survey for their maps of the area; this report could not have been completed without them. Many thanks to Thomas Crawford (University of West Georgia, retired) for his thoughtful review of this report. Thanks to Anthony Winegar and Patrick Gamman (Kennesaw Mountain National Battlefield Park) for their review of this report. Thanks to Eric Bilderback (NPS Geologic Resources Division) for his review of the Erosion and Mass Wasting section of this report. Thanks to Trista Thornberry-Ehrlich (Colorado State University) for producing many of the graphics in this report. Thanks to Katie KellerLynn (Colorado State University) for developing standard report content and organization.

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Geologic Setting and Significance

This chapter describes the regional geologic setting of Kennesaw Mountain National Battlefield Park and summarizes connections among geologic resources, other park resources, and park stories.

Park Establishment

Kennesaw Mountain National Battlefield Park, herein called "the park," was established as a National Park Service unit by Franklin D. Roosevelt on 26 June 1935 with the stated purpose "to preserve, protect, and interpret, for the benefit and inspiration of the people, the historical and natural features of this major battle site in the American Civil War's 1864 Atlanta Campaign." Although the area did not come under NPS management until 70 years after the battle, much of the landscape still reflected the historical character, including nearly 14 km (9 mi) of original earthworks. This preservation is due to a group of American Civil War veterans from Illinois, led by Lasing J. Dawdy (Burkholder 2010), who purchased 24 ha (60 ac) of the battlefield area following the war and erected a monument upon it. This area formed the core of what would become the park (Figure 1).

The monument and land were gifted to the Federal Government in 1916 by the veterans and placed under the jurisdiction of the War Department (now incorporated into the Department of Defense) until its transfer to the Department of the Interior and establishment as a unit of the National Park Service (Burkholder 2010). Upon park establishment, additional land was acquired and improved by the Civilian Conservation Corps (CCC). These improvements include building and road enhancements, stabilization of earthworks, erosion control, and maintenance facilities.

In 2019, the park saw nearly 2,621,000 recreational visitors, and almost ten times that number of non-recreational visitors used the commuter roads that pass through the park (Ziesler 2020). Visitation was down slightly in 2020, due to COVID-19, but the park still welcomed 2,356,401 recreational visitors (Ziesler and Spalding 2021). This reflects the park's value as an outdoor recreation area in an otherwise densely urban setting.

Regional Geologic Setting

The park is in the Appalachian Piedmont physiographic province, one of several long, linear provinces that roughly parallel the east coast of the United States and make up the Appalachian Mountains (Figure 2). The Appalachian Piedmont is characterized by Paleozoic (500 million to 250 million years ago) and older igneous and metamorphic rocks formed (and deformed) during a series of mountain building events, or orogenies, that created the Appalachian Mountain range. During the Paleozoic Era, the Appalachian Mountains are thought to have rivaled the Himalayas of today: jagged peaks towering over the landscape, pushed up by ongoing continental collisions. The 250 million years since the last great orogeny in eastern North America has seen a lot of change in the topography. During that time of relative tectonic quiescence, the forces of weathering and erosion have reduced the Appalachians to the more gentle topography of today, a landscape upon which several key battles of the American Civil War took place.

Kennesaw Mountain was formed from a particularly tangled set of rocks, with an equally tangled history. In the 1970s, Leslie and Burbanck (1979) identified the rocks which make up Kennesaw Mountain as granite, an igneous rock formed when magma cools slowly deep within the earth. On the fundamental level of rock classification (sedimentary, igneous, metamorphic), this is incorrect. Although igneous rocks are present in the Appalachian Piedmont and in the GRI GIS data of the region, the rocks within the park are all metamorphic (KellerLynn 2012). The rocks that form the actual "mountains" of the park (Big and Little Kennesaw Mountains, and Pigeon Hill) are a particularly interesting type of metamorphic rock called migmatite. They are mapped as the "informal migmatite of Kennesaw Mountain (labelled as **OZkm** in the GRI GIS data)" because they have not been officially named. The migmatite formed when continental collision subjected several rock units (**OZmt** and **OZr**, among others) to conditions that approached their melting temperatures. The rocks partially melted but did not liquefy entirely. For an analogy, think of several different colored waxes with different melting temperatures being heated until soft and pressed from multiple angles. Those waxes with lower melting temperatures would flow and separate from the higher melting temperature wax, and pressure would form banded layers of the different waxes that bend and swirl. Tectonic forces created a deformed crystalline metamorphic rock that could be, and sometimes is, mistaken for granite, an igneous rock (Figure 3). The texture and mineralogy of **OZkm** make it highly resistant to weathering and erosion.

Figure 1. Map of the Kennesaw Mountain National Battlefield Park.
The park is located in the Atlanta metro area and is crossed by several heavily traveled commuter roads. The Kennesaw Mountain line, consisting of Big and Little Kennesaw Mountains and Pigeon Hill, is a weathering- and erosion-resistant remnant of tall Paleozoic mountain ranges. The line formed a natural defense of Atlanta against advancing Union troops. Attractions include hiking trails, historical monuments, earthworks, and interpretative information about the battle. National Park Service map.

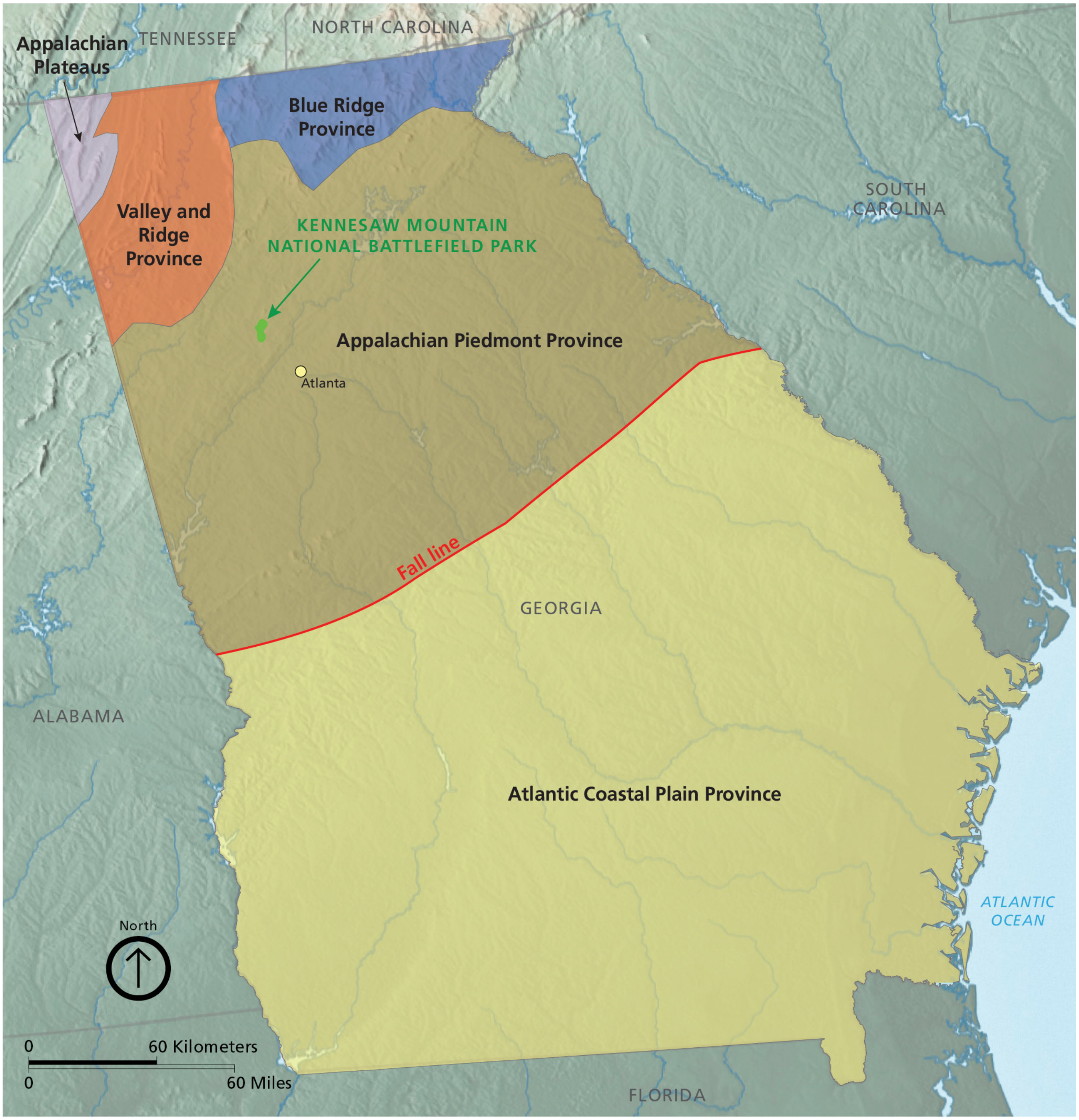

Figure 2. Map of the physiographic provinces of Georgia.
Most of Georgia is divided into the Appalachian Piedmont province (to the northwest) and the Atlantic Coastal Plain province (to the southeast). The two provinces are divided by the fall line, an escarpment that marks the boundary between the metamorphic and igneous rocks of the Appalachian Mountains, and the relatively flat outwash plain of the upper continental shelf. Kennesaw Mountain is in the Appalachian Piedmont province, which is characterized by rolling uplands punctuated by isolated hills and mountains including the Kennesaw Mountain line. Prior to reaching Atlanta, General Sherman had been advancing through the aptly named Valley and Ridge province to the northwest. The change in terrain forced a change in military strategy. Graphic by Rebecca Port (National Park Service).

Figure 3. Photograph of migmatite outcrop on Kennesaw Mountain summit.
The informal migmatite of Kennesaw Mountain (OZkm) was created when different types of rocks (metatrondjemite and metabasalt) were heated close to melting causing intermixing and cooling to the banded, swirling pattern which is displayed here. This type of rock is often characterized by alternating bands of color. In the lower photograph, dark bands of more mafic minerals are visible, separated by white-grey siliceous minerals. Green blotches on the rock are lichens. Photographs by Katie KellerLynn (Colorado State University).

Connections Between Geology and the Battle

The geology of Kennesaw Mountain influenced the battle on many levels, from providing the topography and physical conditions of the ground that forced Union General Sherman to attempt a frontal assault, to providing the boulders that defending Confederate soldiers rolled down Little Kennesaw Mountain onto advancing Union troops (NPS 2015). Although the soldiers fighting these battles likely took the landscape for granted, much as some scientists took the rock type for granite, the connections between the geology of the region and the human history become apparent when considered in detail.

Until they reached the Appalachian Piedmont, much of the Atlanta Campaign had been fought in the Valley and Ridge physiographic province (see Figure 2), characterized by clastic sedimentary rocks arranged in a series of the province's namesake features. Moving the campaign closer to Atlanta, and onto the Appalachian Piedmont physiographic province, the combatants found themselves fighting on a series of highly deformed and eroded igneous and metamorphic rocks. Different susceptibilities to weathering and erosion of these igneous and metamorphic rocks had created a rolling upland with isolated higher hills or mountains called monadnocks, including the "Kennesaw Mountain line." The Kennesaw Mountain line consists of Big Kennesaw Mountain, Little Kennesaw Mountain, and Pigeon Hill (see Figure 1, GRI map poster), striking high points on the generally low-relief topography that were important for defensive positions.

Another geologic factor which influenced the fighting is the suite of rocks flanking the Kennesaw Mountain line on both sides, the Ropes Creek Metabasalt (**OZr**, **OZrk**, **OZrt**, **OZrf**). These metabasalts weather to a thick, clay-rich soil. The Confederates may have benefitted most from this regolith. Hippensteel (2018) describes the ways in which this influenced the battle; it is an excellent material for constructing earthwork defenses. Exposure of the clay-rich soil to common summer tropical depression downpours resulted in muddy terrain which forced General Sherman to abandon his nimble, backcountry flanking maneuvers and attempt frontal assaults on the well-defended monadnocks.

Geologic History

This chapter highlights the chronology of geologic events that formed the present-day landscape of the park. The Geologic Features, Processes, and Resource Management Issues chapter describes the features and associated issues mentioned in this timeline. The presence of 1.1-billion-year-old detrital zircons (very old mineral grains included in younger rocks) indicates that the geologic history of the park begins at least that long ago. The majority of the rock units in the GRI GIS data can be divided into two assemblages: the "parautochthonous assemblage," meaning "of mixed origin" and referring to continental rocks derived from the supercontinent Rodinia; and the "allochthonous assemblage," meaning "having originated elsewhere" and referring to rocks that formed during deep sea deposition and were attached to the continent by tectonic processes. Table 1 puts these events into the context of geologic time.

- Earth forms about 4.6 billion years ago.
- Around 1 billion years ago (Precambrian Era) the Grenville orogeny takes place, associated with the formation of the supercontinent Rodinia.
- Between 600 million and 400 million years ago (from the Neoproterozoic to the Silurian), the Precambrian supercontinent Rodinia rifts apart, creating a series of block-faulted basins (Hatcher 1987). Sediments, including zircon grains, deposited in these shallow basins are derived from continental rocks formed during the Grenville orogeny. The rocks that form from these sediments, which have since been metamorphosed and deformed, make up the parautochthonous assemblage (Figure 4A). Table 2 presents a stratigraphically organized summary of the GRI GIS units within this assemblage.
- Between 485 million and 470 million years ago, during the Early Ordovician, an eastward-dipping subduction zone develops off the coast of the North American craton, creating a back arc basin depositional environment (Hatcher 1987). Fine-grained sediments are deposited on the seafloor, at the same time that melting associated with the subduction zone emplaces magma into the sediments as dikes and sills. Some of this melt erupts onto the seafloor where it interacts with the cool saltwater to form epidotized (hydrothermally altered) pillow basalts (Figure 4B). Table 3 presents a stratigraphically organized summary of the GRI GIS units within this allochthonous assemblage.
- Between 470 million and 440 million years ago, from the Middle Ordovician into the Silurian, the Taconic orogeny is closing the Iapetus Ocean (a precursor to the Atlantic Ocean). As terranes collide with and accrete on to the North American craton, the igneous and sedimentary rocks deposited on the sea floor are thrust onto the continent, and onto the parautochthonous assemblage. The intense upheaval of the landscape causes metamorphism and deformation of both assemblages, shearing and altering the metasedimentary units (Figure 4C).
- Ongoing mountain building throughout the Silurian (444 million to 419 million years ago) creates melts that intrude into and between units of both assemblages. Additionally, the intense heat and pressure causes partial melting and mixing of several different rock types, creating migmatite; separation of light-colored and dark-colored minerals produces gneisses. These rocks are now exposed at Kennesaw Mountain (Figure 4D). Table 4 describes the intrusive and mixed units of the GRI GIS data associated with this obduction (thrusting of oceanic plate onto continental plate) and orogenesis.
- Beginning in the Silurian and continuing until as recently as 273 million years ago, high temperatures and pressures caused by the mountain building processes moves rocks along and within the Brevard fault zone (Permian period; Hatcher 1987). These forces deform the rocks, creating stacks of folds, modifying existing folds, and creating crushed rocks called mylonite (Figure 4E).
- The time between the Mississippian and the Jurassic (335 million to 170 million years ago) sees the creation and breakup of the supercontinent Pangea. The most recent large-scale tectonic event to affect the Appalachians is the post-orogenic erosion of the mountain chain following Mesozoic (252 million to 66 million years ago) rifting of Pangea and the change in directed forces from compression to extension (Figure 4F).

- During the Cenozoic Era (66 million years ago to present) the eastern coast of North America becomes a passive continental margin and during this time of tectonic quiescence, the destructive forces of weathering and erosion reduce the once-towering mountains to the low-relief "rolling" topography of today. The rocks most resistant to weathering remain and now form ridges and isolated peaks, or monadnocks (Figure 4G). The informal migmatite of Kennesaw Mountain (**OZkm**) is the most weathering- and erosion-resistant of these rocks and remains as a towering monadnock (551 m [1,808 ft]) above the surrounding landscape and the city of Atlanta. During the Civil War, this high ground was a strategic site for the Confederate defense of Atlanta.

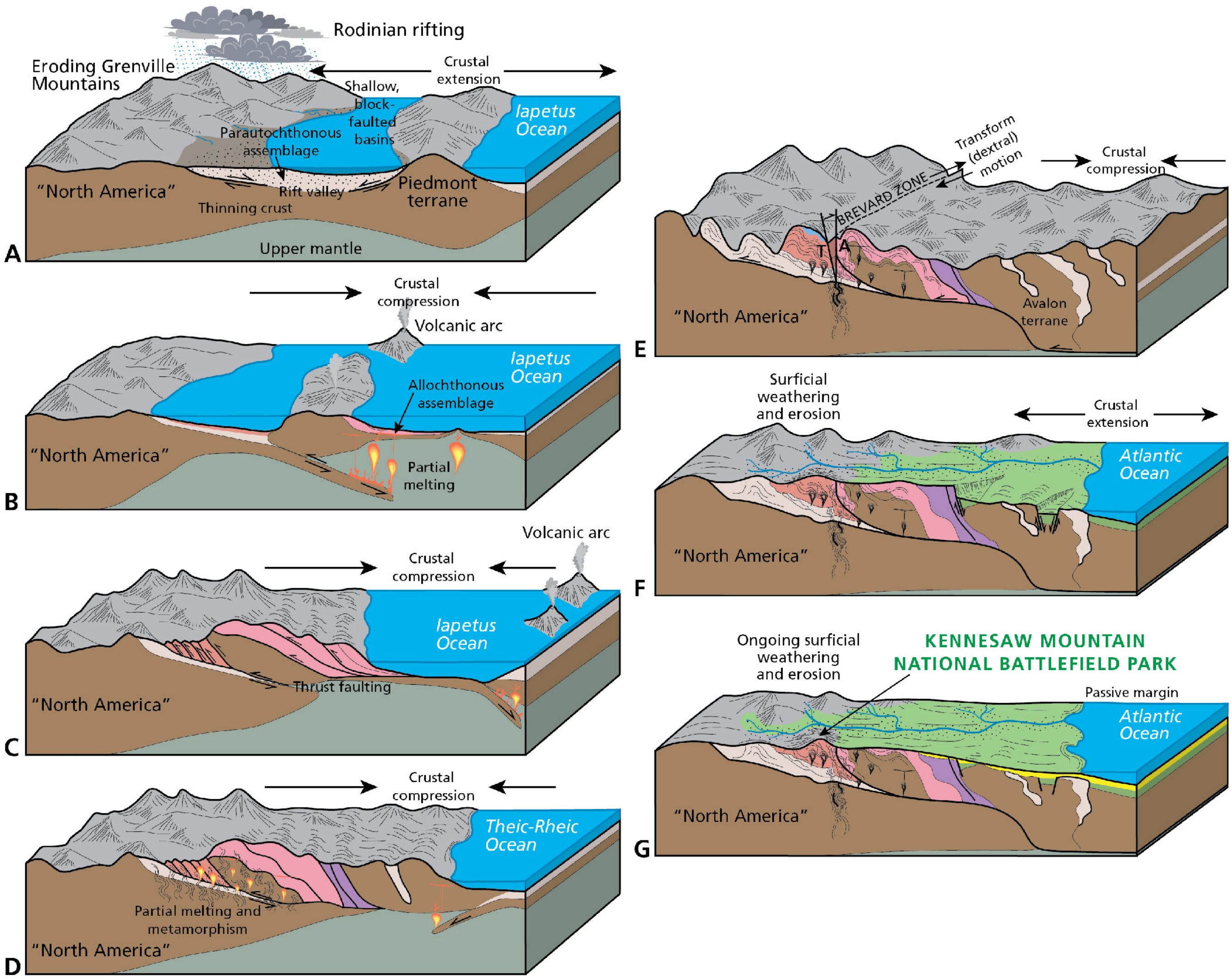

Figure 4. Block diagrams showing the tectonic evolution of the park in order of oldest (A) to youngest (G). The landscape of Kennesaw Mountain is the result of millions of years of geologic activity. The breakup of the supercontinent Rodinia and the formation of an eastward-dipping subduction zone led to the deposition of sediments and emplacement of igneous rocks that would become the allochthonous assemblage (A, B). Subsequent closure of the Iapetus Ocean associated with Appalachian mountain building thrust the allochthonous assemblage onto the continental rocks of the parautochthonous assemblage (C). This mountain building, which continued for millions of years, resulted in the partial melting and mixing, deformation, and metamorphism of both assemblages (D, E). With the Mesozoic breakup of supercontinent Pangea, the forces acting upon the landscape changed from compressional to extensional (F). The weathering and erosion of those rocks resulted in the terrain upon which the American Civil War played out G). Figure by Trista Thornberry-Ehrlich (Colorado State University) adapted from Hatcher (1987) and sketches by author.

Table 1. Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are included in parentheses after the geologic time unit. The rocks mapped in the park were formed over more than 500 million years, from the Neoproterozoic Era (Z) to the Ordovician Period (O). The Paleogene, Neogene, and Quaternary Periods are part of the Cenozoic Era. The Triassic, Jurassic, and Cretaceous Periods are part of the Mesozoic Era. The periods from Cambrian through Permian are part of the Paleozoic Era. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2020).

Geologic Time Unit	MYA	Geologic Events at Kennesaw Mountain National Battlefield Park
Quaternary Period (Q): Holocene (H)	0.0117–today	n/a
Quaternary Period (Q): Pleistocene Epoch (PE)	2.6–0.0117	n/a
Tertiary (T): Neogene Period (N)	23.0–2.6	n/a
Tertiary (T): Paleogene Period (PG)	59.2–23.0	n/a
Cretaceous Period (K)	145.0–66.0	From 66 million years ago and continuing today, ongoing weathering and erosion of the Appalachian Mountains reduces the landscape to the rolling hills with scattered ridges and isolated peaks.
Jurassic Period (J)	201.3–145.0	n/a
Triassic Period (TR)	251.9–201.3	About 200 million years ago, Pangaea begins breaking up. The North American and Eurasian continents, previously joined, rift apart; the rift between these two continents becomes the Atlantic Ocean. The change from compressional to extensional forces creates an erosional environment in eastern North America.
Permian Period (P)	298.9–251.9	Large-scale faulting along and within the Brevard Zone that had begun in the Silurian continues until about 273 million years ago, creating stacks of folds, modifying existing folds and creating mylonite.
Pennsylvanian Period (PN)	323.2–298.9	About 300 million years ago, major continents come together to form the supercontinent Pangaea.
Mississippian Period (M)	358.9–323.2	n/a
Devonian Period (D)	419.2–358.9	n/a
Silurian Period (S)	443.8–419.2	Mountain building continuing until about 419 million years ago creates melts that intrude into and between units of both assemblages. The intense heat and pressure cause partial melting and mixing of various rock types creating migmatite and gneiss, including the informal migmatite of Kennesaw Mountain.
Ordovician Period (O)	485.4–443.8	About 480 million years ago, an east-dipping subduction zone forms off the coast of the North American craton. Sedimentary and igneous rocks deposited and emplaced in the backarc basin form the allochthonous assemblage. Between 470 and 440 million years ago the Taconic orogeny closes the Iapetus ocean and thrusts the allochthonous assemblage onto the continental parautochthonous assemblage.

Table 1, continued. Geologic time scale.

Geologic Time Unit	MYA	Geologic Events at Kennesaw Mountain National Battlefield Park
Cambrian Period (C)	541.0–485.4	n/a
Proterozoic Eon: Neoproterozoic (Z)	1,000–541	Between 600 and 400 million years ago, Rodinia rifts apart and creates a series of block-faulted basins. Sediments deposited in these basins, since metamorphosed and deformed, make up the parautochthonous assemblage.
Proterozoic Eon: Mesoproterozoic (Y)	1,600–1,000	Grenville orogeny and formation of supercontinent Rodinia.
Proterozoic Eon: Paleoproterozoic (X)	2,500–1,600	n/a
Archean Eon	~4,000–2,500	n/a
Hadean Eon	4,600–4,000	Earth forms about 4.6 billion years ago.

Table 2. GRI GIS units of the parautochthonous assemblage, with descriptions.

The "parautochthonous assemblage" refers to the suite of rocks that existed as part of the supercontinent Rodinia and forms the basement rock in the GRI GIS data for the park.

Group or Formation	GRI GIS units (map unit symbol)	Description/Explanation
Sandy Springs Group	Aluminous schist unit (**Cas**) Chattahoochee Palisades quartzite (**Ccp**) Aluminous schist unit, muscovite quartzite (**Caq**)	The Sandy Springs group is interpreted by Crawford et al. (1999) to be cover sequence rocks that have been metamorphosed to kyanite-staurolite grade (amphibolite facies). **Cas** and **Ccp** commonly occur adjacently and may grade into each other. **Caq** may be fault slices of **Ccp**. Zircons from **Ccp** have been U/Pb dated to 1.1 billion years old (Crawford et al. 1999). This is inferred to mean that the quartzite, and the Sandy Springs group at large, were derived from Grenville basement material.
Bill Arp Formation (**OCb**)	Bill Arp Formation (**OCb**) Informal schist of Hulett facies (**OCbh**)	**OCbh** is inferred to be a part of **OCb**, as part of the Austell-Frolona anticlinorium, or a large anticline on which minor folds are superimposed (Higgins et al. 2003). **OCb** is a biotite metagraywacke, a metamorphosed poorly sorted sandstone unit created by turbidity flows. It contains blue-quartz and microcline crystals similar to those in, and likely derived from, the underlying Corbin basement.
Sweetwater Creek and Illinois Creek Formations	Do not appear in GRI GIS data	Metasedimentary and metaconglomerate units derived from the underlying Nantahala Formation and the Corbin basement
Nantahala Formation	Does not appear in GRI GIS data	Metaconglomerate units containing grains sourced from underlying Corbin basement.
Crawfish Creek Formation (**Ccf**)	Crawfish Creek Formation (**Ccf**, mapped in park) clean quartzite units (**Ccq**)	**Ccf** is a quartz schist, with mappable clean (primarily composed of quartz) quartzite units (**Ccq**). **Ccf** contains locally abundant garnets. **Ccf** is erosion resistant and holds up high, steep ridges. La Forge and Phelan (1913) assigned **Ccf** to be the base of the Nantahala Formation. Higgins et al. (1996) use stratigraphic evidence to include **Ccf** in the Chilhowee Group, a group of sedimentary rocks in the Blue Ridge province.
Corbin metagranite of the Allatoona Complex	Does not appear in GRI GIS data	Underlies much of the western Piedmont-Blue Ridge provinces in Georgia. Many of the overlying metasedimentary and metaconglomerates contain grains sourced from the Corbin metagranite.

Table 3. GRI GIS units of the allochthonous assemblage, with descriptions.

The "allochthonous assemblage" refers to rocks that formed in the deep sea and became attached to the continent through tectonic processes. "Primary" GRI GIS units are massive and/or widespread geologic units in the data. The "associated and derivative" GRI GIS units are those that are formed from weathering or combination of the primary units. For example, the Stonewall Gneiss is a primary unit and the Stonewall Gneiss weathered to slabs is a derivative of the broader Stonewall Gneiss.

Primary GRI GIS unit(s)	Associated and derivative GRI GIS units	Description/Explanation
Paulding volcanic-plutonic complex of the Paulding allochthon (**OZp**)	Pine Mountain Alteration Zone (**POpa**)	Spell and Norrell (1990) identify the Paulding as an arc complex, or the suite of rocks associated with the volcanic arc of a subduction zone. It appears only in the northwest corner of the GRI GIS data. **POpa** is described as "like Paulding complex, but less chaotic."
Stonewall Gneiss (**OZs**, mapped in park) Stonewall Gneiss, Powers Ferry member (**OZsp**)	Stonewall Gneiss, weathered to slabs (**OZsi**) Altered meta-ultramafic rock (**OZu**, mapped in park) Metapyroxenite (**OZmp**)	**OZs** is intensely deformed pegmatitic gneiss that commonly contains lenses and pods of **OZu** and **OZmp**, which occur as boulders on **OZs**.
Ropes Creek metabasalt (**OZr**, mapped in park) Ropes Creek metabasalt, kyanite quartzite (**OZrk**) Ropes Creek metabasalt, amphibolite (**OZrt**) Ropes Creek metabasalt, plagioclase-hornblende gneiss (**OZrf**) Magnetite quartzite (**OZmq**) Manganiferous schist and gondite (**OZmn**)	Crider Gneiss (**OZcr**, mapped in park) Unmapped metatrondjemite gneisses (**OZmt**) Metatrondjemite breccia (**JMb**) Informal migmatite of Kennesaw Mountain (**OZkm**, mapped in park) Spheroidally weathering amphibolite (**OZrs**, mapped in park) Chlorite schist (**POag**) Altered meta-ultramafic rocks (**OZu**) Gossan (**Qg**, mapped in park)	**OZmt** is identical in most outcrops to Villa Rica gneiss, a metatrondjemite body mapped in western Georgia (Spell and Norrell 1990), which, along with **OZcr**, intrudes **OZr**. **OZmt** is a result of mixing of felsic and mafic bodies during obduction, and mixes with **OZr** to create **OZkm**. **POag** is derived from shearing and alteration of amphibolite along faults and is therefore likely related to **OZr** and other units. The generic unit **OZu** is included here as well as with **OZs**. **OZmq** occurs within **OZr** and **OZmn** as medium-grained, thin (0.3 m to 6 m [1 ft to 20 ft]) layers and is a result of seafloor hydrothermal alteration. **Qg** is a dark brown saprolitized, or chemically weathered, product of **OZr**, **OZm**, and **OZu**. It commonly occurs near **OZmq**.
Informal mixed unit (**OZm**) Informal mixed unit, garnet-rich schist (**OZmgs**)	Button schist (**POb**) Button schist and sheared amphibolite (**POms**) Amphibolite (**OZa**)	**OZm** is interpreted to be a mixture of the Sandy Springs group and the allochthonous assemblage. **POb** and **POms** are derived by shearing of **OZm**.

Table 4. GRI GIS units associated with obduction of the allochthonous onto the parautochthonous assemblage.

Units formed during obduction (thrusting of oceanic plate onto continental plate) that intrude into both assemblages; or were created by partial melting and mixing or metamorphism of one or both assemblages.

GRI GIS unit	GRI GIS units intruded into	Notes
Ben Hill Granite (**PNMb**)	N/A	**PNMb** has been very tentatively dated to the Carboniferous Period, and is believed to have intruded during strike-slip faulting. **PNMb** possibly grades into the Long Island Creek gneiss (**PYl**) along the Brevard Zone.
Austell Gneiss (**Sa**)	Bill Arp formation (**OCb**)	Rare earth element (REE) content of **Sa** indicates formation by partial melting of crustal basement rocks, possibly Corbin metagranite. **Sa** intrudes into the faults that are believed to have placed the allochthonous assemblage upon the parautochthonous assemblage. **Sa** intrudes **OCb** in lit-par-lit fashion, or in thin sheets between the layers of **OCb**. Whole rock and zircon dating of **Sa** to the early Silurian Period, combined with its structural relation to other units, has provided much of the relative ages for the regional geology (Higgins et al. 1997).
Crider Gneiss (**OZcr**)	Ropes Creek metabasalt (**OZr**)	**OZcr** commonly found as boulders where the unit is deeply weathered.
Unmapped metatrondhjemite gneisses (**OZmt**)	Ropes Creek metabasalt (**OZr**	**OZmt** created by melting a mixture of oceanic (allochthonous) and continental (parautochthonous) material. The protolith, or original rock before metamorphism, of **OZmt** is likely the same, or highly related to, the protolith of **OZcr**. Intrusion of proto-**OZmt** and/or proto-**OZcr** into **OZr**, and subsequent melting and deformation, produced the informal migmatite of Kennesaw Mountain (**OZkm**).

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

The NPS Geologic Resources Division (GRD; see http://go.nps.gov/grd) can provide technical and policy support for geologic resource management issues or direct park managers to other resources, such as for climate change, monitoring, interpretation, and resource education relating to the park's geologic resources. GRD programs and staff focus on three areas of emphasis: (1) geologic heritage, which would address monadnocks, the Brevard fault zone, ultramafic rocks, and earthworks; (2) active processes and hazards, which would address fluvial features and processes, mass wasting, cave features and processes, eolian features and processes, and seismic hazards; and (3) energy and minerals management, which would address stone quarries and building stone.

Resource managers may find *Geological Monitoring* (Young and Norby 2009) useful for addressing geologic resource management issues. The manual, which is available online at http://go.nps.gov/geomonitoring, provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter of *Geological Monitoring* covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Where applicable, those chapters are highlighted in the following discussion. Notably, the Southeast Coast Network is currently monitoring wadeable streams, a vital sign related to the geologic resources in the park (see https://www.nps.gov/im/secn/wadeable-streams.htm).

Since scoping in 2012, the National Park Service completed a foundation document for the park (NPS 2013a) and a state of the park report (NPS 2013b). Because these documents are a primary source of information for resource management within the park, they were used in preparation of this report to draw connections between geologic features and "core components" such as "fundamental resources and values" and "other important resources and values."

In 2020, a follow-up conference call with park staff, a University of Western Georgia geologist, and GRI team members (see the Introduction to the Geologic Resources Inventory chapter) verified the present-day pertinence of the issues identified in 2012. In addition, the call helped to update the list of geologic resource management issues and guide research of this report.

The following updated list of geologic features and processes and resource management issues is based on the 2012 scoping summary, 2013 foundation document and state of the park report, 2020 conference call discussion, and report reviewers' comments. The issues are ordered based on management priority.

- Erosion and Mass Wasting
- Fluvial Features and Processes
- Monadnocks
- Earthworks
- Stone Quarry
- Building Stone
- Ultramafic Rocks
- Seismic Activity
- Cave and Karst Features and Processes
- Eolian Features and Processes

Erosion and Mass Wasting

Erosion and mass wasting is the highest priority geologic resource management issue at the park, especially when taken in tandem with fluvial features and processes (see the Fluvial Features and Processes section of this chapter). The State of the Park report (NPS 2013b) rated terrestrial soil erodibility as "warrants moderate concern," and the Foundation Document (NPS 2013a) cites weathering or erosion as threats to both fundamental resources or values (FRVs) and other important resources or values (ORVs).

As is often the case, the threat to resources from erosion at the park is both instigated and aggravated by human use and infrastructure to accommodate that use. The

Kennesaw Mountain Road is an asphalt-paved road that leads from the visitor center to the summit of Kennesaw Mountain, cutting across the line of Confederate earthworks in several locations (KellerLynn 2012). The road is cut into the slope of the mountain and, while the slope is not very high, there is no catchment for earth materials that move downslope, which creates the potential for rockfall and/or debris ending up on the pavement. The impermeable asphalt surface serves as a spillway of storm runoff, creating a catalyst for erosion. Other roads also cross the park (see Figure 1) and (though not as steep as the Kennesaw Mountain Road) have the same effect, concentrating culvert flow and catalyzing runoff-related erosion.

The Illinois Monument may be the location of greatest erosion-related concern in the park. Construction of the Monument included grading the hilltop, and this change in topography influences modern-day erosion. Compounding the issue, the metamorphic Stonewall Gneiss (**OZs**) that underlies the hill weathers to a silt that produces soil with a "severe" erosion hazard rating (Figure 5). Because the Monument is a popular destination for park visitors, all these issues are exacerbated by high volumes of foot traffic. Erosion mitigation projects at the Illinois Monument mentioned in the 2012 scoping summary (KellerLynn 2012) include construction of water bars (Figure 6) to divert water away from the monument, and fences to discourage visitors from climbing on earthworks that line the trail to the monument.

Visitor use of trails, both official and "social," is an area of concern elsewhere in the park as well. Social trails are formed when visitors cut through parklands from nearby subdivisions and can become unnatural drainages. With more than 2 million recreationists (Ziesler and Spalding 2021) using 29 km (18 mi) of trails, some wear and tear is to be expected. However, weather events compound and accelerate trail erosion processes in several ways. The average annual rainfall of the area is 127 cm (50 in; Wright et al. 2011). During storms that muddy the trails, visitors often are tempted to "go around," trampling vegetation, widening the trails, and increasing erosion risk. Conversely, during periods of drought the trails become trampled to fine-grained dust which is easily removed by wind or future rains. While the weather is outside of resource managers' control, climate change predictions suggest "wetter wets and dryer dries" which can only increase these problems. Thus, resource managers will have to deal with these issues under future climate regimes.

Fluvial Features and Processes

Fluvial features and processes are related to flowing water, such as rivers and streams. Fluvial features in the park include perennial and ephemeral streams, gullies, and drainage ditches (Figure 7). Rivers and streams of the Appalachian Piedmont are typically characterized by meandering channels with vegetated banks (Leigh 2008; McDonald and Starkey 2019). These river systems have been affected by multiple generations of anthropogenic disturbance related to deforestation, agriculture, and a general lack of soil conservation resulting in increased sediment loads in streams (Trimble 1969). A better understanding and implementation of soil conservation practices in the early 20th century has led to streams in the southeastern United States returning to near-historic levels as they re-equilibrate to a system with much less free sediment. For a timeline of human activities affecting streams monitored by the Southeast Coastal Network (SECN), see *Monitoring Wadeable Stream Habitat Conditions in Southeast Coast Network Parks Protocol Narrative* (McDonald et al. 2018).

Noses Creek and John Ward Creek

Two third order (headwater) perennial streams, Noses Creek and John Ward (sometimes referred to as just Ward) Creek, run through the park and are part of the Chattahoochee River watershed (Burkholder 2010; McDonald et al. 2018). These two creeks originate outside of the park and drain mostly urban and suburban areas before flowing through the park. Consistent with streams that drain developed areas, Noses and John Ward Creeks likely exhibit flashy flow, or flow that has higher than expected peak flows that quickly pass through the system (McDonald et al. 2018). Flashy flows occur when precipitation falls onto paved or other less-than-permeable surfaces, runs off quickly or all at once, and does not infiltrate into the soil surfaces. Both streams are recovering from a legacy of poor land-use practices in their watersheds, and as they begin to reestablish a meandering panform, the amount of lateral migration will be an important driver of the amount of sediment produced. Bateman McDonald (2020) identified the importance of episodic and progressive bank slumping in the development of these stream systems. Surfaces interpreted in 2017 (McDonald and Starkey 2019) to be stable floodplain surfaces have been reinterpreted, based on changes in height and size, to be unstable and representative of the processes by which the stream will continue to widen (Bateman McDonald 2020).

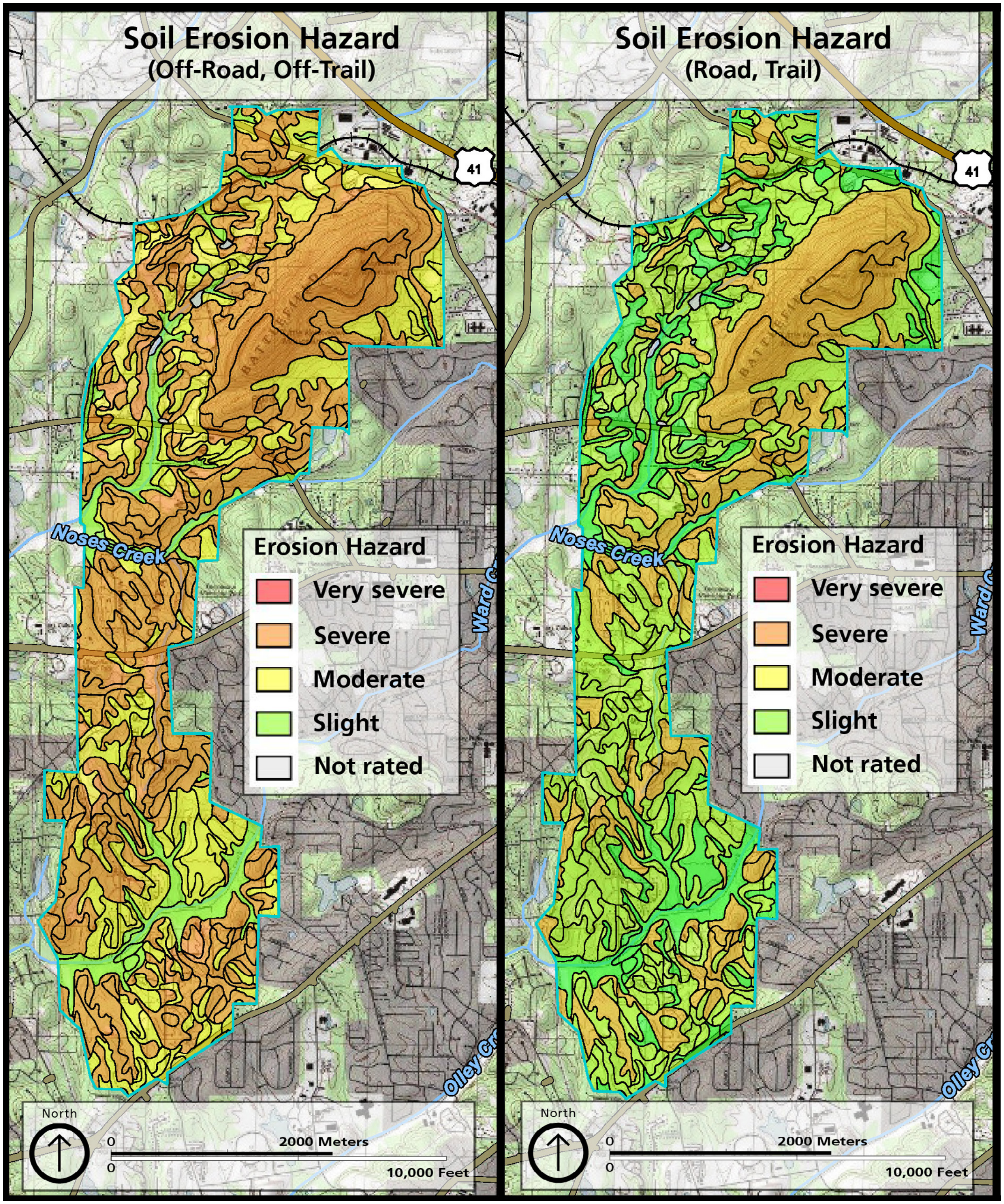

Figure 5. Soil erosion hazard map at Kennesaw Mountain.
The map on the left shows the erosion hazard in off-road and off-trail areas after disturbances that expose the soil surface. The map on the right shows erosion hazard on unsurfaced roads and trails. A rating of "slight" indicates that little or no erosion is likely; a rating of "moderate" means that some erosion is likely and occasional maintenance may be required; a rating of "severe" indicates that significant erosion is expected and frequent maintenance and/or erosion control measures may be required. Ratings are based on soil erosion factor K, slope, and content of rock fragments. The increased erosion hazard in "off trail/off road" areas emphasizes the impact of visitors going off trail. Both maps are limited to the outer NPS boundary. Graphic compiled by author with data from NRCS Web Soil Survey (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx; accessed 26 April 2021).

Figure 6. Photographs of Illinois Monument and water bars for erosion control.
Construction of the Illinois Monument (top photograph) involved changing the natural topography of the hill, which created an erosion problem that is exacerbated by visitor use and storms. In an effort to curtail this, fences and water bars were installed to direct visitors and drainage away from vulnerable areas (bottom photograph). The monument was restored in 2014 as part of the commemoration of the 150th anniversary of the battle. Photographs by Katie KellerLynn (Colorado State University).

Figure 7. Photograph of gully near John Ward Creek in the Cheatham Hill area.
A gully is a water-worn ravine formed by intense run-off. Due to the developed nature of the surrounding area, run-off near John Ward Creek in the Cheatham Hill area occurs in highly variable and intense flows creating a powerful agent of erosion. Photographs by Katie KellerLynn (Colorado State University).

Noses Creek is characterized by a steep watershed, covered by forested areas and development. The stream is highly entrenched and exhibits alternating sand and gravel bars, which, along with the presence of a floodplain, indicate that the stream is beginning to establish a more "natural" meandering system (McDonald and Starkey 2019). Noses Creek is interpreted to have a flashier flow regime than John Ward Creek based on geomorphic and land cover characteristics; however, stream gauges would be needed to determine this with certainty.

John Ward Creek's watershed has low relief and is primarily developed. The stream itself is also highly entrenched (McDonald and Starkey 2019). The park's chief ranger, Anthony Winegar, identified John Ward

Creek as having more intense streambank erosion than Noses Creek during the 2020 conference call.

At both creeks, riparian erodibility and stream sedimentation are ranked as "warrants significant concern" by the state of the park report (NPS 2013b). As discussed in the Erosion and Mass Wasting section of this chapter, these problems are commonly exacerbated by visitor use. In the case of the streams in the park, it is visitors accessing the streams, particularly those horseback riding, that threaten bank stability and create areas where bank erosion is a potential management concern (Bateman McDonald 2020). For more information on fluvial features and processes, see the "Monitoring River Systems and Fluvial Landforms" chapter in *Geological Monitoring* (Lord et al. 2009).

Springs

Springs are places where the water table intersects with the land surface. There are no specific springs in the park mentioned in either the scoping summary (KellerLynn 2012) or in McDonald and Starkey's (2019) wadeable stream habitat monitoring report, although McDonald and Starkey do characterize the landscape of Kennesaw Mountain as consisting of "less than ten percent mountain seeps and small bog wetlands." Additionally, the existence of "Powder Springs Road" to the south of the park suggests the existence of springs was notable to the history of the area.

Monadnocks

Monadnocks create the defining features of the park, the Kennesaw Mountain line. Named for the Abenaki Tribe of the Algonquin Nation's word for "lonely mountain," monadnocks are just that: isolated heights that rise distinctly above the surrounding terrain (NPS 2013a). Monadnocks are created when a type of rock that is more resistant to erosion is left standing after the more erodible material surrounding it is removed.

In the case of Kennesaw Mountain (Big and Little), the more resistant rock is the informal migmatite of Kennesaw Mountain (**OZkm**), which has a tight foliation and no discontinuities making it more resistant to erosion than the surrounding schist, gneiss, and metabasalts (KellerLynn 2012).

The complex geologic history of the region, including multiple metamorphic events and igneous intrusions, means that erosion-resistant rock types are not unusual. From the summit of Kennesaw Mountain other monadnocks not managed by the Park Service are visible, including Sweet, Blackjack, and Stone Mountains. These elevated positions were of strategic significance during the Civil War, granting extended lines of sight and defensible positions to the Confederates.

Earthworks

Earthworks are defensive constructions that were used primarily, but not exclusively, by Confederate forces at Kennesaw Mountain (Figure 8). Most of these take the form of linear parapets between 1 and 4 m high (4 and 12 ft) and 2 and 5 m wide (7 and 16 ft) with borrow ditches on one or both sides. Although some earthworks were destroyed as a result of farming and road construction post-Civil War, 18 km (11 mi) still exist within the park and another 16 km (10 mi) outside of the park. The earthworks provide details of the battle's development as a series of advancing entrenchments, flanking maneuvers, and assaults on entrenched positions. The Confederate earthworks are a nearly complete sinuous line occupying the high grounds of Big and Little Kennesaw Mountain, Pigeon Hill, and Cheatham Hill; the Union earthworks form a series of overlapping lines in the western side of the park.

The geology of Kennesaw Mountain interplays with the earthworks in several important ways. In fact, scoping participants observed that some of the earthworks are the geology, with soldiers using linear outcrops of bedrock as "pre-fabricated" earthworks (KellerLynn 2012). Beyond that, other earthworks are "crowned by stone," or fortified and topped with pieces of rock. The rocks of the Ropes Creek metabasalts suite (**OZr**, **OZrk**, **OZrt**, **OZrf**) weather to a thick, clay-rich soil which lends itself to earthwork construction (Hippensteel 2018).

Earthwork placement was influenced by the geologic landscape as well. Preexisting drainage ditches and streams (see the Fluvial Features and Processes section of this chapter), especially when combined with the summer rains, formed strong defensive positions that could be enhanced by constructing earthworks behind them.

Stone Quarry

A quarry and associated rock crusher were established on the east side of Kennesaw Mountain in 1939 by the Civilian Conservation Corps (CCC). The CCC was created as part of the Federal Unemployment Relief Act with the goal of mobilizing unemployed labor forces with tasks including reforestation and road and trail construction; the National Park System was a major beneficiary of much of this work. The quarry includes an 18 m (60 ft) tall headwall (Figure 9) excavated into the side of the mountain, which gives an idea of how much material was extracted (KellerLynn 2012). Most of the material excavated was used as aggregate, although some larger pieces were used in construction of culverts (NPS 2011).

Figure 8. Confederate earthworks at Cheatham Hill.
The earthworks at the park are vegetated and can be tempting areas for visitors to climb upon, causing erosion. However, the earthworks preserve important information about the evolution of the battle. Earthwork placement was influenced by existing drainage ditches; ongoing weathering and erosion along these drainages continues to threaten earthworks. Signs and fences have been installed to direct visitors away from these areas. Photograph by Georgia Hybels (Colorado State University).

Building Stone

Some of the most prominent rocks in the park are the stone used to construct monuments, including the Illinois Monument on Cheatham Hill (see Figure 6) and other cultural resources, but they are not a part of the geologic history of Kennesaw Mountain. The local bedrock was not the source material for these constructions, and identifying information about the building stone is not readily available. The scoping summary (KellerLynn 2012) suggests that the park superintendent at the time, Nancy Walther, had expressed interested in pursuing a Scientists in Parks (SIP, see the Guidance for Resource Management chapter and https://www.nps.gov/subjects/science/scientists-in-parks.htm) intern to identify information about the building stone. This program places young scientists, typically undergraduate students, in parks to work on scientific projects and would be an interesting geologic exercise that could promote the understanding of both cultural and geologic resources. As of 2019, no SIP projects had been completed at the park (Paige Lambert, youth program assistant, personal communication, November 2019).

The Illinois Monument is the largest commemorative marker in the park. It is constructed of marble, by the McNeel Marble Works Company, but no further information about the geologic origins of the monument stone is known. The McNeel Company, based in Marietta, GA, operated several granite and marble quarries in the foothills of the Blue Ridge Mountains. Below the Illinois Monument is the Union Tunnel Marker, a marble arch marking the location where Union soldiers attempted to literally undermine the Confederate trenches (Figure 10). The tunnel marker is flanked by a dry-stacked stone wall that may be constructed from local gneiss, but this is not verified (KellerLynn 2012).

Figure 9. Photograph of headwall of Civilian Conservation Corps quarry.
The 18 m (60 ft) tall headwall gives an idea of how much material was excavated from the quarry by the CCC in 1939. The extracted material (OZkm) was not suitable for building material and was primarily used as aggregate. Photograph by Katie KellerLynn (Colorado State University).

Figure 10. Photograph of marble marker and tunnel marker at Illinois Monument.
The stone used to construct monuments at the park was not sourced from the local bedrock. The exact provenance of the marble is unknown and could represent an opportunity for future study and interpretation at the park. The dry-stacked stone atop the tunnel marker may be local gneiss, although this is unconfirmed. Photographs by Katie KellerLynn (top, Colorado State University) and Georgia Hybels (bottom, Colorado State University).

Ultramafic Rocks

During the scoping site visit on 20 March 2012, Tom Crawford (professor of geology, University of West Georgia) identified ultramafic rocks in two areas in the vicinity of Cheatham Hill (KellerLynn 2012). The GRI GIS data also include an outcrop of “altered meta-ultramafic rock” (**OZu**) in the same area.

Mafic and ultramafic rocks are rocks containing minerals with high concentrations of the elements magnesium and iron. The word “mafic” comes from magnesium and ferric (from the Latin for iron); its counterpart is “felsic,” meaning rocks that contain high amounts of feldspar and silica. Mafic rocks are of geologic interest because they originate in the upper mantle, just below the Earth’s crust which is made up of felsic rocks. Only in areas that have experienced significant tectonic upheaval are mafic or ultramafic rocks exposed at the surface. The exhumation of deep-earth rocks often involves low-grade metamorphism, or alteration, producing new minerals. The altered meta-ultramafic rock (**OZu**) cropping out at Cheatham Hill contains a high percentage of a soft, greenish metamorphic mineral called chlorite. The schistose texture, or parallel alignment of mineral grains, and the relative “softness” of chlorite make these ultramafic rocks easy to carve. There is evidence here of Native Americans, pioneers, and Union soldiers all carving these rocks. The Native Americans carved bowls; the pioneers chopped, sawed, and carved hearthstones; and the Union soldiers carved inscriptions (names and dates) into the stone (Figure 11).

Figure 11. Photographs of carvings in ultramafic rock.
Ultramafic rocks in the park contain high concentrations of the metamorphic mineral chlorite. The texture and composition of chlorite results in a relatively soft rock that has been carved for various reasons in the historic past. Native Americans carved bowls (bottom left, pen for scale); pioneers carved hearthstones (top left); and Civil War soldiers left inscriptions (right). Photographs by Katie KellerLynn (top and bottom left, Colorado State University) and Georgia Hybels (right, Colorado State University).

Ophiolite Suite

Mafic and ultramafic rocks of particular interest in the Kennesaw Mountain GRI GIS data include a suite of rocks (see Table 5) that appear to make up an ophiolite, albeit one that has been deformed and metamorphosed almost beyond recognition (Spell and Norrell 1990). An ophiolite is a segment of oceanic crust formed where magma and lava are intruding and erupting onto the sea floor while deep-sea sediment is being deposited in the same area. Ophiolites are common enough on the sea floor in some areas, but to see one exposed on land is a special treat for geologists and may offer an opportunity for interpretation at the park.

Table 5. GRI GIS units that may represent an ophiolite suite.

This table compares GRI GIS source map descriptions of map units from Higgins et al. (2003) with the components of an ophiolite suite in the Ropes Creek assemblage as described by Spell and Norrell (1990).

Ophiolite sequence components	GRI GIS units	Notes
Fossil sea floor, deep sea sediments, chert	Magnetite quartzite (**OZmq**) Manganiferous schist and gondite (**OZmn**) Ropes Creek metabasalt, kyanite quartzite (**OZrk**) Garnet-rich schist (**OZmgs**)	These units are interlayered within sequences of metabasalts containing pillow structures. Enrichment of iron and manganese is a result of hydrothermal fluids (i.e., from deep-sea vents) and likely formed during eruptive hiatus. The kyanite quartzite component likely represents metasedimentary aspects of deep seafloor.
Pillow basalts and sheet flows (extrusive complex)	Ropes Creek metabasalt (**OZr**)	**OZr** is "locally pillowed…generally epidotic" (Higgins et al. 2003). Pillow structures form when lava erupts into cold water and cools quickly. Interaction with seawater causes epidotization.
Sheeted dike complex	Unmapped metatrondjhemite gneiss (**OZmt**) Informal migmatite of Kennesaw Mountain (**OZkm**)	Trondjhemite is an intrusive rock often found in ophiolite suites as sheeted dikes. **OZkm** is "identical to **OZmt** but with abundant xenoliths of **OZr**," (Higgins et al. 2003) which further supports its being intrusive. Xenoliths are crystals from another rock that get included in a melt.
Relict magma chamber (gabbros)	Stonewall Gneiss (**OZs**)	**OZs** Includes "generally rare but locally fairly common layers, lenses, and pods of hornblende-plagioclase amphibolites" (Higgins et al. 2003). This description aligns with Spell and Norrell's (1990, p. 815) "small discontinuous bodies of amphibolites… present at isolated exposures… They consist of plagioclase-hornblende amphibolites…. We interpret these rocks as metamorphosed gabbros."
Cumulate mafic-ultramafic sequence (peridotite, dunnite, lherzolite, harzburgite)	Stonewall Gneiss (**OZs**) Metapyroxenite (**OZmp**) Altered meta-ultramafic rock (**OZu**) Ropes Creek metabasalt, plagioclase-hornblende gneiss (**OZrf**)	These units generally match the description of "most common ultramafic rock" from Spell and Norrell (1990, p. 815), who go on to say that "the geochemistry of these rocks suggests that the protolith may have been cumulate mafic or ultramafic rocks." Higgins et al. (2003) describes **OZu** as "now mostly soapstones and serpentinites, but originally probably pyroxenites, dunnites, and peridotites."

A complete and intact ophiolite suite consists of, from the bottom up: (1) ultramafic rocks of the upper mantle, including dunnite, lherzolite, and harzburgite; (2) a cumulate mafic-ultramafic sequence, meaning rocks that formed as crystals separating from a melt; (3) gabbro, or mafic igneous rock that makes up most of the oceanic crust; (4) sheeted dikes, which are parallel pillars of igneous rock that represent the path of magma rising to the surface; (5) pillow basalts, which form when molten rock flows onto the sea floor and cools quickly, forming a crust around a pillow-shaped blob of magma; and (6) sedimentary rocks formed by the deposition of fine grained oceanic sediment. These sedimentary rocks are often enriched with iron and magnesium as a result of hydrothermal fluids escaping through deep sea vents which, when metamorphosed by tectonic processes that bring these rocks onto the continental crust, produce a distinctive suite of rocks including kyanite- and magnetite-bearing quartzites (Figure 12). It is important to note that the original rocks of the potential ophiolite suite within the GRI GIS data for the park have been significantly metamorphosed during their emplacement on the continent. Geologists study the minerals and relict structures to determine the likely protolith (parent rock) of these rocks (see Table 5).

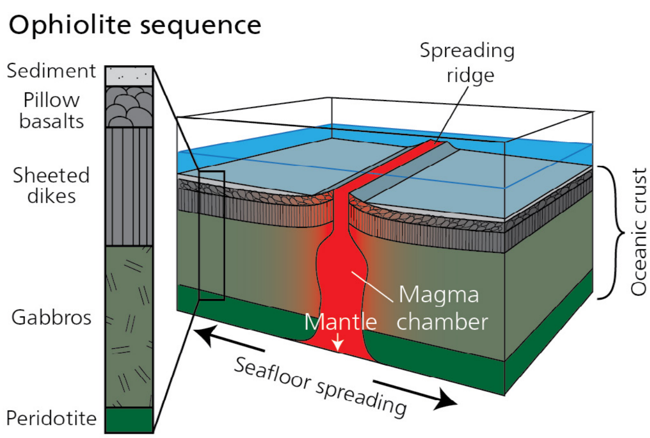

Figure 12. Diagram of an ophiolite sequence. Ophiolites form by a combination of igneous processes and sedimentation at and below the ocean floor. In rare situations, the ocean crust is obducted onto land, preserving the sequence of rocks created and presenting geologists with an opportunity to study undersea processes. Remnants of an ophiolite sequence may be among the rocks mapped in the GRI GIS data (e.g., OZr, OZmt, OZkm, OZs, etc.). Diagram by Amanda Lanik (National Park Service).

Seismic Activity

The park has a history of tectonic activity, although earthquakes are not considered a cause of structural damage or a significant risk at the park (Figure 13). A magnitude 2.3 quake occurred around the time of the scoping visit (24 April 2012), and the largest recorded quake with a magnitude of 4.5 occurred on March 5, 1914. The Brevard fault zone is the primary tectonic feature of the park and is largely inactive. For more information, see the “Monitoring Seismic Activity” chapter in *Geological Monitoring* (Braile 2009).

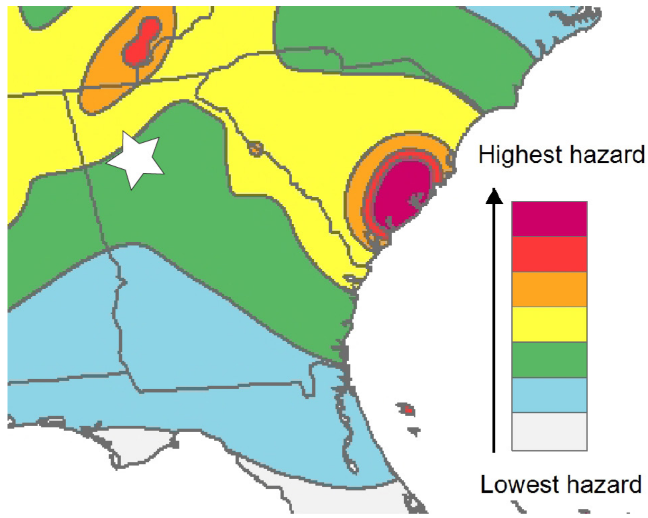

Figure 13. Seismic hazard map of the southeastern United States.
This map shows the relative seismic hazard for Georgia and the surrounding area, with the location of the park marked by a star. While earthquakes have been felt at the park, they are not considered a hazard to buildings or people. The areas of high hazard on the map are the East Tennessee Seismic Zone (to the north) and the Middleton Place-Summerville Seismic Zone (to the east). Map is a portion of the 2018 long term national seismic hazard map from USGS (https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map; accessed 7 July 2021).

Cave and Karst Features and Processes

Caves are naturally occurring underground voids. Commonly, caves exist as part of a karst landscape, or a landscape where dissolution of the bedrock by flowing water has created features such as sinkholes, springs, and caves. These landscapes require a soluble bedrock, such as limestone or gypsum, which is not present at Kennesaw Mountain National Battlefield Park. Marble, which is metamorphosed limestone and is soluble, exists within the Brevard Zone but not within the park. Therefore, there are no karst features associated with the park. See Weary and Doctor (2014) for more information about caves and karst in the United States.

Erosional processes at the park have produced some alcoves and rock shelters, which fit under the broad discussion of cave and karst features. These locations were not visited on the scoping trip, and any cultural or geologic significance is unknown (KellerLynn 2012). An inventory and assessment of park alcoves and rock shelters could be a suitable SIP project (see the Guidance for Resource Management chapter and https://www.nps.gov/subjects/science/scientists-in-parks.htm). For more information about caves and karst, see the "Geological monitoring of caves and associated landscapes" chapter in *Geological Monitoring* (Toomey 2009).

Eolian Features and Processes

Eolian features and processes are related to wind activity and commonly refer to the formation and transportation of dunes. Wind can also be a powerful agent of erosion, often acting in concert with water and frost. Eolian features and processes are not prominent and there have been no studies of them at the park. However, anecdotal evidence from the 2012 scoping trip suggests that eolian processes may have affected some summits and ridgelines in the park. In these areas, topsoil can appear to be missing or eroded, and some trees may have had their growth stunted by wind. Eolian features and processes are not considered to be a significant resource management issue at the park. For more information, see the "Monitoring Aeolian Features and Processes" chapter in *Geological Monitoring* (Lancaster 2009).

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. The GRI GIS data produced for the park follow the source maps listed here and include components described in this chapter. A poster displays geologic map data draped over imagery of the battlefield park and surrounding area. Complete GIS data are available at the GRI publications website (http://go.nps.gov/gripubs).

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. 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 rock types or deposits present in an area, as well as the ages of these rocks and deposits. For example, on the geologic map for the park (Higgins et al. 2003), pinks and browns represent the oldest (Cambrian?) rocks whereas greens represent the younger (Mississippian? to Jurassic?) deposits. In addition to color, rocks and deposits are delineated as map units, and each map unit is labeled by a symbol. Usually, the map unit symbol consists of an uppercase letter indicating the age (e.g., **O** for Ordovician or **Z** for Proterozoic) and lowercase letters indicating the rock formation's name or the type of deposit (e.g., **mq** for the magnetite quartzite in **OZmq**; see tables 1, 2, and 3). Because many of the units on the geologic map for the park are of uncertain age, two letters are given to represent the span of age the unit is believed to belong to. Other symbols on geologic maps depict the contacts between map units, and structures such as faults or folds. Anthropogenic features such as mines or quarries, as well as infrastructure such as roads and railroads, may also be indicated on geologic maps. The American Geosciences Institute website (http://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses.

Geologic maps are typically one of two types: bedrock or surficial. Bedrock map units are differentiated based on age and/or rock type and commonly have formation names. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Higgins et al. (2003) is the source map for the bedrock GRI GIS data for the park (kemo_geology.mxd). Surficial geologic maps typically display deposits that are unconsolidated and formed during the past 2.6 million years (Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. The GRI product for the park does not include a surficial map component.

Source Maps

The GRI team does not conduct original geologic mapping. The team compiles existing data by digitizing paper maps or converting digital data to conform to the GRI GIS data model. GRI GIS data include essential elements of source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are included in the GRI ancillary map information document (kemo_geology.pdf), which is included with the GRI GIS data.

The GRI team used the following source map to produce the GRI GIS data for the park and surrounding area. The data cover the Atlanta quadrangle (Figure 14):

- Geologic Map of the Atlanta 30' x 60' Quadrangle, Georgia (scale 1:100,000; Higgins et al. 2003).

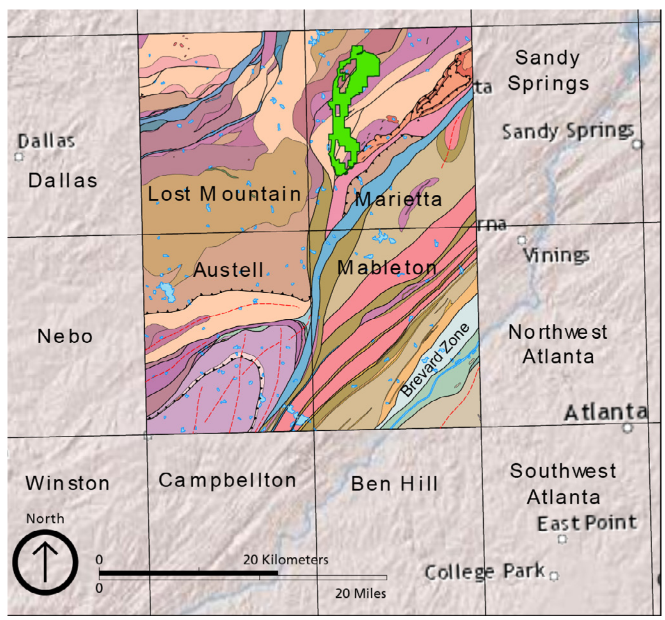

Figure 14. Index map of GRI GIS data.
This map shows the 7.5-minute quadrangles covered by the GRI GIS data. The NPS boundary of Kennesaw Mountain National Battlefield Park (in green) exists only in the Marietta quadrangle, but data are given for the Lost Mountain, Austell, and Mableton quadrangles as well. These data contribute to our understanding of the geology of the region, especially the Brevard Zone in the Mableton quadrangle. Graphic compiled by author.

GRI GIS Data

The GRI team standardizes map deliverables using a data model. The GRI GIS data for the park were compiled using data model version 2.1, which is available online (http://go.nps.gov/gridatamodel). The data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (http://go.nps.gov/gri) provides more information about the program's map products.

GRI GIS data are available on the GRI publications website and through the NPS Integrated Resource Management Applications portal (IRMA; https://irma.nps.gov/). Enter "GRI" as the search text and select a park from the unit list.

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

- A text document (kemo_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information
- Data in ESRI (10.0) geodatabase GIS format (kemo_geology.gdb)
- Layer files with feature symbology Table 6)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- An ancillary map information document (kemo_geology.pdf) that contains information captured from the source map such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures
- ESRI map documents (kemo_geology.mxd) that display the GRI GIS data
- A version of the data viewable in 2.2 KML/KMZ format for use with Google Earth
- A version of the data viewable via auto-generated ArcGIS online map service ("web service")

Table 6. GRI GIS data layers for Kennesaw Mountain National Battlefield Park.

Data Layer	On Poster?	Google Earth Layer?
Geologic Cross Section Lines	No	No
Geologic Attitude Observation Localities	No	No
Map Symbology	Yes	No
Folds	Yes	Yes
Faults	Yes	Yes
Geologic Contacts	Yes	Yes
Geologic Units	Yes	Yes

GRI Map Poster

A poster of the GRI GIS data draped over a shaded relief image of the park is referenced in this report. The poster is available on the GRI publications website http://go.nps.gov/gripubs and through the NPS IRMA portal https://irma.nps.gov/. Enter "GRI" as the search text and select a park from the unit list. Not all the GIS feature classes are included on the poster (see Table 6). 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. Park managers may contact the GRI team for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Park managers should neither permit nor deny ground-disturbing activities based upon the information provided here. Park managers may contact the GRI team with questions.

Minor inaccuracies may exist with respect to the locations of geologic features in the GRI GIS data and on the poster. Based on the source map scale (1:100,000) as well as US National Map Accuracy Standards, the geologic features represented in the GRI GIS data and on the posters are expected to be horizontally within 50 m (166 ft) of their true locations.

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 geoscience-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.

Kennesaw Mountain National Battlefield Park Documents

The park's Foundation Document (National Park Service 2013a) and State of the Park report (National Park Service 2013b) are primary sources of information for resource management within the park.

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: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- 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 7), 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 7. 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** (in development) will contain 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 7, 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 7, 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 7, 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 7, 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 7, 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 7, 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 7, continued. Geologic resource laws, regulations, and policies.

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

Table 7, 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.

Additional References, Resources, and Websites

Georgia Geology

- Georgia Geological Survey: https://epd.georgia.gov/outreach/publications/georgia-geologic-survey-bulletins
- Scott Ranger's Nature Notes: http://www.scottranger.com/geology-of-kennesaw-mountain.html

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- NPS Sea Level Rise Map Viewer: https://maps.nps.gov/slr/
- NPS Climate Change, Sea Level Change website: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- US Global Change Research Program: http://www.globalchange.gov/home

Earthquakes

- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/

Geologic Maps

- The American Geosciences Institute provides information about geologic maps and their uses: http://www.americangeosciences.org/environment/publications/mapping

Geological Surveys and Societies

- Georgia Geological Survey: https://epd.georgia.gov/outreach/publications/georgia-geologic-survey-bulletins
- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

Geology of National Park Service Areas

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

Landslide Information

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

NPS Reference Tools

NPS Technical Information Center (TIC; Denver, Colorado; repository for technical documents): https://www.nps.gov/orgs/1804/dsctic.htm

The GRI team collaborates with TIC to maintain an NPS subscription to GEOREF, 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.

GRI staff uploads scoping summaries, maps, and reports to the NPS IRMA portal (https://irma.nps.gov/DataStore/) and the GRI Publications Webpage (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm).

US Geological Survey Reference Tools

National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search

Geographic Names Information System (GNIS; official listing of place names and geographic features): https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names/domestic-names

GeoPDFs (download PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")

USGS Publications Warehouse (many publications available online): http://pubs.er.usgs.gov

Tapestry of Time and Terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

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

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Higgins, M. W., J. G. Arth, J. L. Wooden, T. J. Crawford, T. W. Stern, and R. F. Crawford. 1997. Age and origin of the Austell Gneiss, western Georgia Piedmont-Blue Ridge and its bearing on the ages of orogenic events in the Southern Appalachians *in* Sinha, A. K., J. B. Whalen, and J. P. Hogan, editors. The nature of magmatism in the Appalachian orogen. Geological Society of America memoir 191, p. 181–192. Boulder, CO.

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