National Park Service
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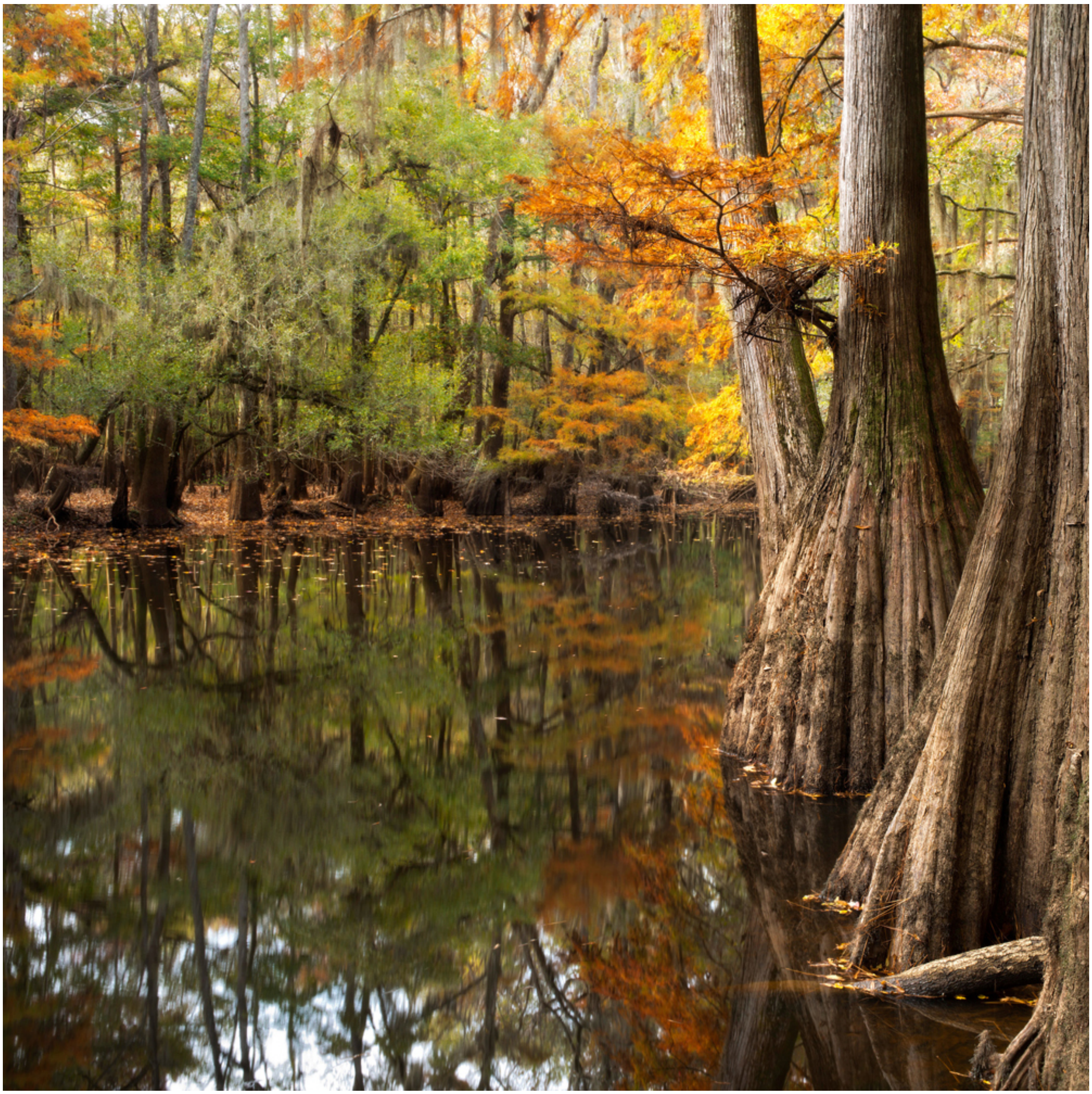
Natural Resource Stewardship and Science

Congaree National Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2014/857



ON THE COVER
Large cypress trees with spanish moss line the banks of Dawson's Lake on Cedar Creek at Congaree National Park. The old-growth forest at Congaree National Park is a wonderful laboratory for studying floodplain system science. The wide, asymmetrical, dynamic floodplain encompasses a variety of depositional environments and processes that are good analogs for understanding fossil systems and reference conditions for similar modern landscapes. The park also evokes a sense of place for primeval forests that have existed during earth's long history. National Park Service photograph by James and Jenny Tarpley (JT fine ART) courtesy David Shelley (Congaree National Park).

THIS PAGE
The confluence of the Congaree (left) and Wateree (right) rivers forms the southeast corner (forested background) of Congaree National Park. Together these rivers drain over 14,000 square miles at this point. At this point there are obvious differences in water quality between the turbid (and cool) water of the Congaree River and the relatively clear (and warm) water of the Wateree River; these differences are due to different rainfall patters in their respective watersheds. National Park Service photograph by Steven McNamara courtesy David Shelley (Congaree National Park).

Congaree National Park

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Fort Collins, Colorado

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

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Printed copies of this report are produced in a limited quantity and they are only available as long as the supply lasts. This report is available from the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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NPS 178/126781, October 2014

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Executive Summary

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. It is a companion document to previously completed GRI digital geologic map data.

Congaree National Park is located near the inland edge of the Upper Coastal Plain Province of central South Carolina. The area is a large floodplain formed by a fifth-order stream that drains more than 36,000 km^2 (14,000 mi^2). The majority of geologic units mapped in the park were formed during and since the end of the most recent ice age, but the geologic history of central South Carolina encompasses approximately 200 million years of climate change, sea-level fluctuations, tectonics, and, much more recently, anthropogenic impacts.

Beneath the Coastal Plain, fault-bounded, pull-apart (rift) basins that formed as the supercontinent Pangaea began to break apart approximately 200 million years ago are filled with sediments eroded from the Blue Ridge and Piedmont provinces, northwest of Congaree National Park. Subtle uplift and fluctuations in sea level occurred throughout the Paleogene and Neogene (66.0–2.6 million years ago). North of the park, the Orangeburg Scarp, which marks the boundary between the Upper and Middle Coastal Plain, records the maximum sea level rise during the Pliocene, 5.3–2.6 million years ago. Approximately 13 km (8 mi) north of the park, the scarp parallels the Congaree River, indicating that the river's current location is coincident with a Pliocene physiographic embayment.

During the Pleistocene ice ages, sea level fell and rivers began to dissect the uplands and carve terraces into the valleys of the Congaree and Wateree rivers. Since the arrival of Europeans in the 16th century, significant anthropogenic activities have impacted the Coastal Plain. Rivers have been altered and sediment has increased in rivers and streams due to activities related to logging, agriculture, urbanization, and population growth. Today, the park's fluvial landscapes and dynamic floodplain ecosystem demonstrate the intimate association among geology, hydrology, and vegetation.

The park also protects the largest intact tract of old-growth bottomland hardwood forest remaining in the southeastern United States. The forest is home to several state and national champion trees found within 22 distinct plant communities. Because of its biodiversity, Congaree National Park has been recognized as a Ramsar Wetland of International Importance, a National Natural Landmark, an International Biosphere Reserve, and a Globally Important Bird Area. Established as Congaree Swamp National Monument in 1976, the park was re-designated Congaree National Park in 2003.

Noteworthy geologic features at Congaree National Park include:

- Congaree River Floodplain Complex (CRFC). Quaternary alluvium of the Congaree River floodplain (geologic map unit Qacf) consists of sand, silt, clay, and peat and is collectively known as the CRFC. This complex includes several fluvial features, such as abandoned channels, secondary streams, meander belts, natural levee deposits, dune fields, oxbow lakes, alluvial fans, and rimswamps.
- Congaree River Valley Terrace Complex (CRVTC). The CRVTC is north of the CRFC and includes river terraces that have been carved in the Coastal Plain since the Pliocene. Three terraces are mapped in Congaree National Park (Qt2, Qt3, and Qt6). Qt6, the first major terrace that can be identified above the floodplain, is a broad feature that forms the northern floodplain bluffs and terrace beneath the Harry Hampton Visitor Center. The oldest terrace, which formed north of the park, is correlative with the Pliocene Dublin Formation (Td) and the formation of the Orangeburg Scarp.
- Congaree River channel and associated features. Because of historic upstream land use practices, the Congaree River contains high suspended sediment (clay) and is known as a "brown water" system. At a large scale, the Congaree River has been divided into five sections, or reaches. Reaches 4 and 5 form the southern border of Congaree National Park. Features associated with the channel's meandering pattern include cutbanks, point bars, natural levees, and meander scars from previous channels. Tectonic tilting of South Carolina has caused the Congaree River to migrate southward.
- Tributary channels. Tributary streams in Congaree National Park, such as Cedar Creek, Tom's Creek, and Dry Branch, are "black water" systems because, unlike the brown water systems, their water is clear but stained red-brown-black from the leaves in the floodplain soils. Tributary streams have a low pH and are associated with bioaccumulation of mercury. They contain many of the features associated with the Congaree River, but on a smaller scale. The channels carry sand recycled from the terrace complex and disaggregated woody debris.
- Rimswamps. Also known as seepage wetlands, rimswamps occur where groundwater is at or near the surface of the floodplain. Muck Swamp is a prominent rimswamp adjacent to the Qt6 terrace near the Visitor Center. Cores from this and other rimswamps have

provided insight into ancient environments, climate, and flood events in the Congaree River floodplain.

- Oxbow lakes. When a meander loop is cut off from the main channel, its bend becomes isolated in a U shape that resembles the shape of an oxbow. If this isolated bend becomes filled with water, it is known as an oxbow lake. Weston Lake, which was once part of the Congaree River, is the largest oxbow lake in Congaree National Park and the largest permanent body of standing water on the floodplain. It is also relatively deep, lacking the shallow clay and silt layer that characterizes most oxbow lakes.
- Alluvial fans. The subtle alluvial fans (named for their fan-like shape; Qaf2) associated with Cedar Creek, Tom's Creek, Dry Branch, and other tributary streams in Congaree National Park are collectively known as the "north rim alluvial fan complex." Many of these fans are expressed by only 0.6–1.2 m (2.0–4.0 ft) gentle elevation at the surface, but are more than 3.7 m (12 ft) thick in the subsurface. Composed of well-drained sandy soil, the alluvial fans in Congaree National Park support the national champion and other loblolly pine (*Pinus taeda*) trees.
- Paleontological resources. In the CRFC, Late Quaternary microfossils from Muck Swamp have helped define four distinct paleoecological zones. Fossils have also been recovered from units in the southern bluffs, beyond the boundaries of Congaree National Park.
- Biogeomorphology of old-growth forests. Congaree National Park's old-growth forest illustrates the abiotic–biotic interactions that help shape surface landforms. River channels influence the location of vegetation, and vegetation checks erosion, baffles flows across the floodplain, and influences sediment deposition. The park is a field laboratory in which to study the biogeomorphology of old-growth forests. Modern abiotic–biotic interactions may serve as an analog to past coal formation, as well as a baseline with which to measure responses related to changing climate conditions.

Although not within the boundaries of Congaree National Park, two additional units of interest are also found in the immediate vicinity:

- Southern bluffs. Adjacent to the park's southern boundary, steep bluffs rise from the southern bank of the Congaree River, exposing Upper Cretaceous and Tertiary Eocene sediments. Easily eroded, the strata form four distinct units in the bluffs (from oldest to youngest): (1) undifferentiated Upper Cretaceous clay, sand, and conglomerates (Kus); (2) the Upper Cretaceous Sawdust Landing Formation (Ksl); (3) the Upper Paleocene Lang Syne Formation (Tls); and (4) the Upper Middle Eocene Congaree Formation (Tc). Sedimentary features and fossils in these units indicate deposition in deltas and shallow marine paleoenvironments.
- Carolina bays. These shallow, elliptical depressions (Qcb) formed as a result of wind and fluctuating groundwater levels. Although not mapped in the park, they are common on the CRVTC and other Coastal Plain surfaces nearby.

Geologic processes and issues of particular significance for resource management at Congaree National Park include:

- Flooding. The landscape and ecology of the floodplain are fundamentally shaped by regular floods. Backflooding of floodplain channels occurs approximately ten times a year, and partial surface inundation occurs a little more than three times per year. Fluctuating water levels provide nutrients that sustain the plant and animal communities, as well as energy and sediment to shape the geomorphic features of the floodplain. Long-term monitoring of the flood regime is critical for understanding climate change and the biogeomorphology of the park.
- Groundwater hydrology. Groundwater flow is critically integrated with surface water flows, water quality, soil development, nutrient cycling, and organic matter preservation in the floodplain. Changes in groundwater recharge will impact the sustainability of the park's wetlands, oxbow lakes, and rimswamps.
- Legacy sediment from upstream land use changes. Since colonial times, upstream land use practices have caused significant top soil erosion, which has increased the sediment load in mainstem and tributary channels. Increased sedimentation has buried some archaeological sites in the park beneath up to 2 m (7 ft) of sediment.
- Moved earth. Fill from construction projects significantly impacts the flow of surface water. Changes in surface water flow have direct consequences for patterns of erosion and deposition across the floodplain.
- Hurricanes. Hurricanes, like flooding, have complex impacts on the park's ecosystem. They increase species richness by encouraging turnover and regrowth of the forest. Fallen trees provide habitats for a variety of plant and animal species.
- Climate change. Climate change impacts, such as changing seasonality of precipitation and increased drought, may directly affect geomorphic feedbacks by altering suspended sediment concentrations. Forests may become more vulnerable to threats of wildfires or pest outbreaks, which may result in an increased amount of large woody debris in rivers. Hurricanes may already be stronger as a result of global warming, and climate change may also increase their frequency in the future. Changes in long-term biogeomorphic feedbacks may result from changes in water quality, water availability, and phenology.
- Earthquakes. Earthquakes are surprisingly frequent in South Carolina; 640 earthquakes of magnitude 2 or greater (eight of which were magnitude 5 or greater) were recorded between 1776 and 2011. The 1886 Charleston earthquake, which had an estimated magnitude of 7.6, is the strongest historical earthquake recognized along the eastern seaboard. The underlying tectonic stress fields involved in these earthquakes are

complex, but many of these events seem to involve reactivation of old faults, such as the Augusta Fault beneath the Congaree River Valley. Ground shaking from a strong earthquake may “liquefy” subsurface, water-saturated sand (a process known as liquefaction). In general, however, Congaree National Park is in an area of low liquefaction potential.

- Erosion of the southern bluffs. As the Congaree River migrates southward, it naturally undercuts and erodes the southern bluffs. Erosion is influenced by a combination of hillslope processes, river erosion, and mass wasting.
- Industrial operations. Mining is not allowed in the park, but potential impacts of mining adjacent to the park include light and noise pollution and disruption of the viewshed by construction activities. Local mining activities are not a major concern for resource management, but a potential upstream gold mine and fly ash storage landfill may negatively impact water quality in the park. The landfill may also impact the surrounding viewshed.

This GRI report was written for resource managers to support science-informed decision making. It may also be useful for interpretation. The report was prepared using available geologic information, and the NPS Geologic Resources Division conducted no new fieldwork in association with its preparation. Sections of the report discuss distinctive geologic features and processes within Congaree National Park, highlight geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the GRI geologic map data. A poster (in pocket) illustrates these data. The Map Unit Properties Table (in pocket) summarizes report content for each geologic map unit.

Products and Acknowledgments

The NPS Geologic Resources Division partners with institutions such as Colorado State University, the US Geological Survey, state geological surveys, local museums, and universities to develop Geologic Resources Inventory products. This section describes those products and acknowledges contributors to this report.

GRI Products

The objective of the Geologic Resources Inventory is to provide 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. To realize this objective, the GRI team undertakes three tasks for each natural resource park: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report (this document). These products are designed and written for nongeoscientists.

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 that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to digital geologic map 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 compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (section 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The "Additional References" section and the Appendix provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at: http://www.nature.nps.gov/geology/inventory/. The current status and projected completion dates of products are at: http://www.nature.nps.gov/geology/GRI_DB/Scoping/Quick_Status.aspx.

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Geologic Setting and Significance

This section describes the regional geologic setting of Congaree National Park, and summarizes connections among geologic resources, other park resources, and park stories.

Park Setting

Congress established Congaree Swamp National Monument in 1976, and after boundary changes in 1988 and 2003, the monument was re-designated Congaree National Park in 2003 (fig. 1). The park, which covers approximately 11,000 ha (27,000 ac), protects the largest intact tract of old-growth bottomland hardwood forest [approximately 4,500 ha (11,000 ac)] remaining in the southeastern United States (fig. 2). The park also includes approximately 6,100 ha (15,000 ac) designated wilderness.

Congaree National Park preserves a distinctive Coastal Plain ecosystem. Landforms record the dynamic, geologically recent movements of the Congaree River and, at a much broader scale, fluctuations of past sea levels. Forested wetlands, oxbow lakes, creeks, and sloughs provide habitat for a wide variety of animals and plants.

Congaree National Park's swamp-cypress and broadleaf forest includes 22 distinct plant communities, as well several state and national champion trees (Shelley et al. 2012). To be designated a champion, a tree must be the largest of its species based on a standard measurement formula incorporating trunk circumference, tree height, and average crown spread. A tree must also be native to the continental United States. In addition to offering a myriad of recreational and research opportunities, Congaree National Park has been recognized as a Ramsar Wetland of International Importance, a National Natural Landmark, an International Biosphere Reserve, and a Globally Important Bird Area (Shelley et al. 2012).

The park's fluvial landscapes and dynamic floodplain ecosystem demonstrate the intimate associations among geology, hydrology, and vegetation. From geologic and geomorphic perspectives, Congaree National Park illustrates three significant factors that influence fluvial landscapes (Shelley et al. 2012). First, the geology and vegetation are interrelated. Detrital organic sediment, such as peat, muck, and coarse woody debris, provides critical nutrients for vegetation communities, as well as pollen for paleoecological studies and material for radiocarbon dating. Plants also impact soil formation, water budgets, and surface flow patterns. Second, although the river is the primary architect of the floodplain at a large scale, significant depositional

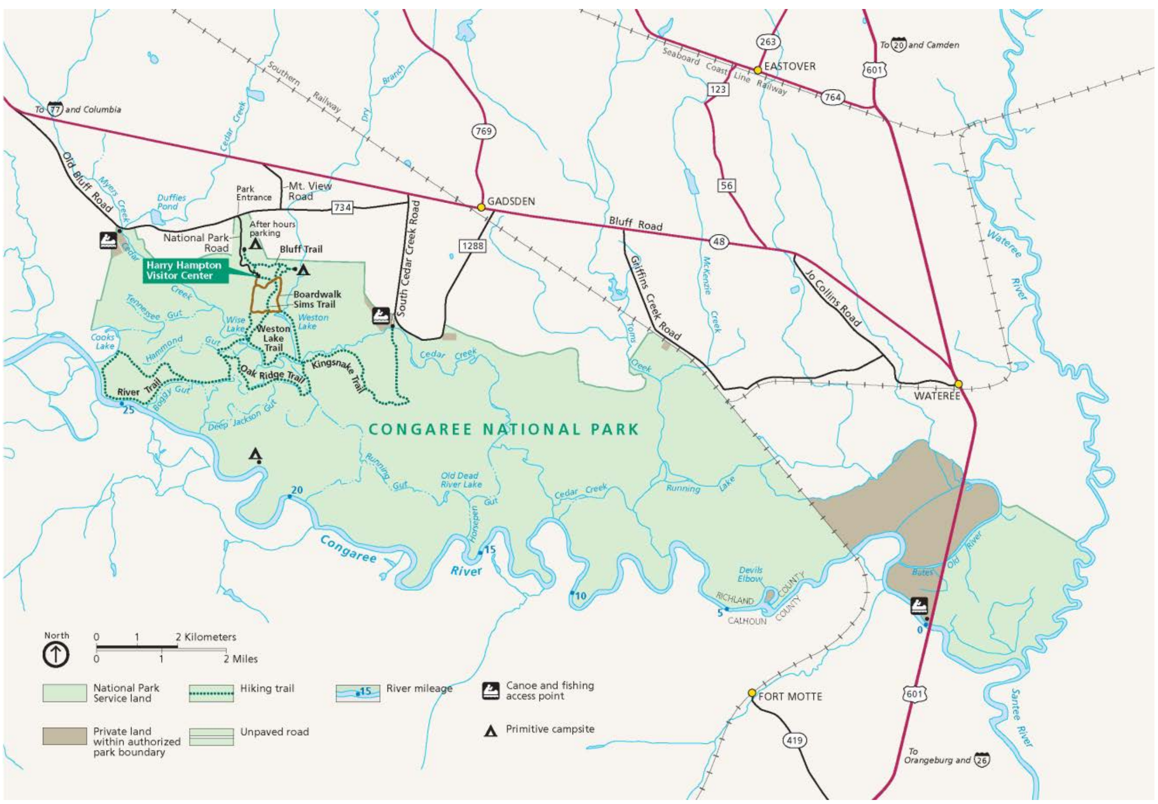

Figure 1. Map of Congaree National Park. Note the sinuous, meandering pattern of the Congaree River and the various tributary streams that flow across the floodplain. Weston Lake was once part of the Congaree River, but it is now an oxbow lake. National Park Service map, available at http://www.nps.gov/hfc/cfm/carto.cfm (accessed 16 January 2014).

Figure 2. Bald cypress (*Taxodium distichum*) tree. Such trees became the favorite of loggers in the late 19th and early 20th centuries. Bald cypress trees in Congaree National Park may be 700–1,000 years old. Person for scale. National Park Service photograph, available at http://www.nps.gov/media/photo/gallery.htm?id=391FD5A4-1DD8-B71C-070C6DB2D2075EAA (accessed 25 January 2014).

environments and processes operate independently from it. Tributary streams, groundwater rimswamps, and alluvial fans, for example, are associated with valley-perpendicular stream systems and groundwater flow near floodplain margins. Third, fluvial landscapes consist of a complex variety of geomorphic features that are subtle and difficult to distinguish. Many boundaries between features are also depositional and/or ecohydrologic gradients. The best way to identify these features is to use an array of data sources and focus on the boundaries of the surfaces, rather than the features themselves.

The Congaree River forms the southern border of Congaree National Park, and the Wateree River flows along the eastern border of the park above the confluence of the two rivers (fig. 1). The Congaree and Wateree rivers are part of a 36,000-km^2 (14,000-mi^2) watershed that extends across the Piedmont and into the Appalachian Mountains. They join to form the Santee River, which is dammed downstream to form Lake Marion. The three rivers are characterized by high-suspended sediment concentrations and are classified as "flashy" brown-water systems (Levy 1974; Laurie and Chamberlain 2003; Shelley et al. 2012). Winter and spring floods periodically inundate the forest in Congaree National Park.

Geologic Setting

Geologic processes of tectonic collision, erosion, deposition, transgression (sea-level rise), and regression (sea-level fall) have shaped the South Carolina landscape into five distinct physiographic provinces (fig. 3). A physiographic province is a large area containing similar rocks, landforms, soil, climate, and vegetation. Congaree National Park is within the Upper Coastal Plain, which is the most inland of the three typical coastal plain divisions in South Carolina (i.e., the Upper, Middle, and Lower Coastal Plains; Clendenin et al. 1999). Upper Coastal Plain geologic units mapped in the vicinity of the park include Upper Cretaceous to Holocene deposits (fig. 4). Tertiary and Mesozoic (fig. 5) deposits are mapped in the bluffs south of the Congaree River, just outside the park.

To the northwest, the Upper Coastal Plain is separated from the deeply weathered metamorphic and igneous rocks of the Piedmont by a northeast-trending zone referred to as the Fall Line. The Fall Line marks the last downstream exposure of bedrock in the river channels and the first appearance of rapids above the sea in any major river along the Atlantic seaboard (Shelley et al. 2012). When Europeans arrived, the Fall Line became the inland limit of early river travel and an obvious place to establish settlements. Augusta, Columbia, Richmond, Washington, Trenton, and Tuscaloosa are a few of the cities that developed along its length. Geologically, the location of the Fall Line in South Carolina may be broadly related to the Augusta Fault and the Eastern Piedmont Fault System, which is a reactivated Paleozoic fault zone (Hatcher et al. 1977; Shelley et al. 2012). The Sand Hills zone is also found discontinuously along the Fall Line. It is generally associated with Late Cenozoic aeolian sand sheets, although many local inhabitants mistakenly associate it with nearby ancient sandy marine deposits.

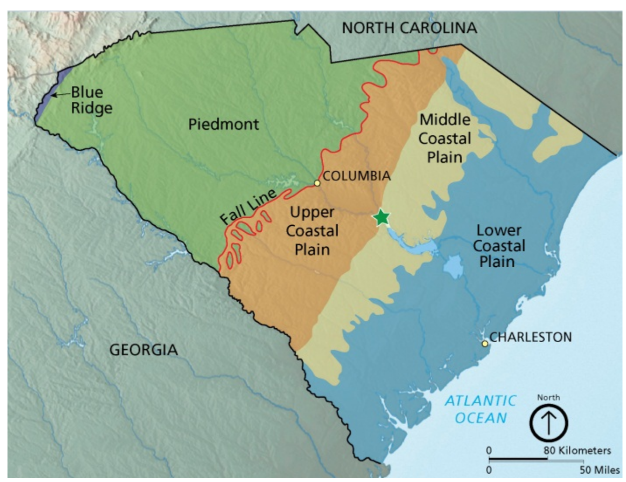

Figure 3. Physiographic provinces of South Carolina. The Blue Ridge, Piedmont, Upper, Middle, and Lower Coastal Plain provinces are present in South Carolina. The Fall Line is a topographic break that separates the Piedmont from the Coastal Plain. Congaree National Park (green star) lies within the Coastal Plain Province. Graphic by Trista Thornberry-Ehrlich (Colorado State University), created using data from the South Carolina Geological Survey (Columbia, South Carolina) available at http://www.dnr.sc.gov/GIS/descgeolrp.html (accessed 15 January 2014).

The Upper Coastal Plain is bounded to the southeast by the Orangeburg Scarp, which is a regional, northeast–southwest-trending ridge that overlooks the town of Orangeburg. The prominent escarpment, which developed in the Pliocene, ranges in elevation from 55 m (180 ft) to 66 m (215 ft) above current sea level (Murphy 1995; Shelley 2007a). Mapped adjacent to the Orangesburg Scarp, the shallow to marginal marine sand and clay of the Pliocene Duplin Formation (geologic map units Tdl and Tdu) form the dominant Middle Coastal Plain geologic unit in the vicinity of the park.

Sea level change over the past 90 million years has made the complex chronology of the depositional features in the Congaree River Valley difficult to decipher. A gradient of estuarine to fluvial terraces underlies the current Congaree River Valley Terrace Complex [CRVTC; David Shelley, National Park Service (NPS) Congaree National Park, Education Coordinator, written communication, 26 June 2014].

Brief Geologic History of Central South Carolina

During the Paleozoic, multiple mountain-building events, referred to as "orogenies," formed the Appalachian Mountain chain as tectonic plates collided (fig. 5). Tectonic collisions formed the Augusta Fault, which underlies the Congaree River Valley (Hatcher and Odom 1980; Dallmeyer et al. 1986; Hatcher 1987; Barker et al. 1998; Hibbard et al. 1998; Hibbard 2000; Shelley and Cohen 2010). In the Triassic, all of the large land masses on the globe sutured together to form the supercontinent Pangaea, which then began to split apart. South Carolina became part of the Atlantic coastline as the Atlantic Ocean opened.

Fluctuating sea levels produced upper and lower delta-plain and nearshore shallow marine depositional environments during the Upper Cretaceous, Paleocene, and Eocene (fig. 5). Multiple fluctuations of sea level and coastal uplift occurred throughout the Cenozoic (Gohn 1988; Nystrom et al. 1991; Clendenin et al. 1999; Willoughby et al. 1999). When relative sea level fell, rivers flowed across the exposed Coastal Plain, depositing conglomerates and coarse sand. A sea-level rise (transgression) in the Pliocene inundated previous Miocene fluvial systems and established nearshore marine environments only a few miles from the park. Approximately 13 km (8 mi) north of the park, the Orangeburg Scarp locally trends southwest, parallel to the river, indicating that the Congaree River Valley was a physiographic embayment during the Pliocene.

All surficial deposits located within the 2013 boundary of Congaree National Park are of non-marine to marginal marine origin. Deposits in the Middle and Lower Coastal Plain record cycles of sea-level rise and fall due to tectonic activity or climate (glaciation) controls in the Pliocene, Pleistocene, and Holocene prior to the current sea-level rise (Murphy 1995; Clendenin et al. 1999). These changes were related to inland changes in the river system that formed the area that is now the park.

Research efforts to tease out the architectural relationships and history of various floodplain features continue, but some of them clearly indicate deposition under significantly different climate regimes.

Congaree River valley terraces in the park (Qt1–Qt11b) developed in the Pleistocene and consist of multiple sequences of estuarine to fluvial sand and clay. The sand, silt, clay, and organic-rich Pleistocene–Holocene floodplain deposits (Qacf and Qawf) record a complex array of intra-floodplain terraces, meander belts, alluvial fans, dune fields, natural levees, abandoned channels, and swamps.

Since Europeans first began to settle on South Carolina's coastal plain in the 16th century, the landscape has undergone significant alteration. Activities related to logging, agriculture, and urban development have changed the geomorphic features of the region and accelerated sedimentation into lakes and streams.

Cultural History

Prehistoric peoples lived in the Congaree River Valley for thousands of years prior to the arrival of 16th-century explorer Hernando de Soto (NPS 2013a). At that time, Cofitachequi, a large paramount chiefdom centered at the Mulberry Mound Complex, was located a few miles up the Wateree River Valley. By 1700, the local population had been tremendously reduced by disease, and European immigrants began using the land for agriculture. The "Congarees" or "Congaree Swamp" became well known for its rich soil, as cited in 18th-century land records and preserved today in the name Richland County (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). When the Revolutionary War broke out in 1776, Francis Marion, also known as the Swamp Fox, attacked the British from the South Carolina swamps and forests (NPS 2013a). One of these battles, the Battle of Fort Motte, was fought just across the Congaree River from the park (Smith et al. 2007).

Constant flooding brought nutrients to the floodplain and allowed the area's trees, especially the bald cypress, to thrive (fig. 2). Loggers arrived in the late 19th and early 20th centuries. Although logging efforts were extremely successful at a national scale, they were thwarted locally by logistical problems. Local industry and logging operations ceased in 1915, leaving significant portions of the floodplain, except for tracts of land along waterways, largely untouched (NPS 2013a).

In 1969, rising timber prices prompted a new round of logging operations. Due to the efforts of conservationist and newspaper editor Harry Hampton, for whom the park's visitor center is named, in the 1950s and a significant grass-roots movement launched by the Sierra Club in the 1970s, Congress established Congaree Swamp National Monument in 1976 and re-designated the site as the nation's 57th national park in 2003.

Era	Period		Epoch	Rock/Sediment Unit (map symbol)	Description
Cenozoic	Quaternary		Holocene	Moved earth (Qme)	Anthropogenic construction material.
				Freshwater marsh and swamp deposits (Qfw)	Clay and peat deposited in stream valleys.
			Holocene and Pleistocene	Sandhills lakebed deposits (Qskl)	Sand in lakebeds or savannahs.
				Carolina bay deposits (Qcb)	Sand and peat deposits in lakebeds, and coarser sand in aeolian rims of bays.
				Aeolian sand (Qe, Qeeb, Qem)	Wind-blown sand associated with regional Carolina bays.
				Quaternary alluvium (Qacf, Qawf, Qatt)	Sand, silt, clay, and peat deposited in the floodplains of the Congaree and Wateree rivers and tributaries.
				Quaternary alluvium (Qasf, Qatv)	Sand, silt, clay, and peat deposited in the Santee River floodplain and tributary valleys.
				Quaternary alluvial fan deposits (Qaf, Qaf1, Qaf2)	Sand and silty clay deposited in alluvial fans. Qaf2 is present in the park.
			Pleistocene	Dune complexes (Qd)	Well-sorted sand in vegetated sand dunes.
				Packs Landing beds (Qpl)	Sand and pebbles with a subordinate clay matrix.
				Congaree River Valley Terrace Complex (Qt1–Qt11b)	Terraces of graded sequences of sand to clay originally deposited in estuarine and fluvial environments.
				Wateree River Valley Terrace Complex (Qtw1–Qtw2)	Similar to the Congaree River Valley Terrace Complex.
				Wicomico Toney Bay Member (Qwtb)	Sand in a silt to clay matrix.
				Fluvial terrace deposits of Halfway Swamp (Qhs)	Sand, sandy conglomerate, and minor sandy clay matrix.
				Terrace sediments of Low Falls Landing (Qlf)	Sand, conglomerate, and minor amounts of clay.
				Marietta unit (Qm)	Sand with minor amounts of heavy minerals and clay matrix.
	Tertiary	Neogene	Pliocene	Congaree River Valley Terrace Complex (Tt12–Tt13)	Pliocene terraces similar to Quaternary terrace complex of the Congaree River Valley (Qt1–Qt11b).
				Duplin Formation (Td, Tdu, Tdl)	Sand, granules, clay, and shell fragments. Locally calcareous. Marginal marine environment.
			Miocene	Altamaha Formation (Tal)	Sand, gravel, and cobbles deposited in a braided fluvial system.
		Paleogene	Oligocene	Units of this age interval are absent in the Congaree National Park area.	
			Eocene	Tobacco Road Sand (Ttr)	Sand with gravel at the base of the unit.
				Dry Branch Formation (Tdb)	Sand with coarse-grained sand, granules, and gravel at the lower contact.
				Orangeburg District bed (Todb)	Sand and clay with scattered pebbles.
				Santee Limestone (Ts)	Microfossiliferous mudstone, wackestone, and packstone (see Glossary).
				Warley Hill Formation (Twh)	Glauconitic sand with rare shark teeth.
				Congaree Formation (Tc)	Glauconitic sand and interstitial clay with pebbles and rip-up clasts near the base of the unit.
			Paleocene	Lang Syne Formation (Tls)	Variable lithology of clay to sand. Local shell fragments. Waxy, black clay top layer.
Mesozoic	Cretaceous		Upper	Sawdust Landing Formation (Ksl)	Interbedded sand and clay that grades up into cohesive, variably colored clay.
				Undifferentiated (Kus)	Clay, sandy clay, clayey sand, and sand deposits.

Figure 4. General stratigraphic column for Congaree National Park. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps; they also correspond to the colors on the Map Unit Properties Table. Colored rows indicate units mapped within the park. See the Map Unit Properties Table for more detail.

Eon	Era	Period	Epoch	MYA		Life Forms	North American Events
Phanerozoic	Cenozoic (CZ)	Quaternary (Q)	Holocene (H)	0.01	Age of Mammals	Extinction of large mammals and birds; Modern humans	Ice age glaciations; glacial outburst floods; Cascade volcanoes (W)
			Pleistocene (PE)	2.6			Linking of North and South America (Isthmus of Panama)
		Tertiary (T) – Neogene (N)	Pliocene (PL)	5.3		Spread of grassy ecosystems	Columbia River Basalt eruptions (NW)
			Miocene (MI)	23.0			Basin and Range extension (W)
		Tertiary (T) – Paleogene (PG)	Oligocene (OL)	33.9			
			Eocene (E)	56.0			Laramide Orogeny ends (W)
			Paleocene (EP)	**66.0**		Early primates; Mass extinction	
	Mesozoic (MZ)	Cretaceous (K)		145.0	Age of Reptiles	Placental mammals; Early flowering plants	Laramide Orogeny (W); Western Interior Seaway (W); Sevier Orogeny (W)
		Jurassic (J)		201.3		Dinosaurs diverse and abundant; Mass extinction	Nevadan Orogeny (W); Elko Orogeny (W)
		Triassic (TR)		**252.2**		First dinosaurs; first mammals; Flying reptiles; Mass extinction	Breakup of Pangaea begins; Sonoma Orogeny (W)
	Paleozoic (PZ)	Permian (P)		298.9	Age of Amphibians		Supercontinent Pangaea intact
		Pennsylvanian (PN)		323.2		Coal-forming swamps; Sharks abundant; First reptiles	Ouachita Orogeny (S); Alleghany (Appalachian) Orogeny (E); Ancestral Rocky Mountains (W)
		Mississippian (M)		358.9		Mass extinction	Antler Orogeny (W)
		Devonian (D)		419.2	Fishes	First amphibians; First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian (S)		443.4		First land plants; Mass extinction	
		Ordovician (O)		485.4	Marine Invertebrates	Primitive fish; Trilobite maximum; Rise of corals	Taconic Orogeny (E-NE)
		Cambrian (C)		**541.0**		Early shelled organisms	Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic		Precambrian (PC, X, Y, Z)		2500		Complex multicelled organisms; Simple multicelled organisms	Supercontinent rifted apart; Formation of early supercontinent; Grenville Orogeny (E); First iron deposits; Abundant carbonate rocks
Archean				4000		Early bacteria and algae (stromatolites)	Oldest known Earth rocks
Hadean				**4600**		Origin of life; Formation of the Earth	Formation of Earth's crust

Figure 5. Geologic time scale. The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. Geologic Resources Inventory map abbreviations for each time division are in parentheses. Compass directions in parentheses indicate the regional locations of events. Boundary ages are millions of years ago (MYA). National Park Service graphic created using dates from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale; accessed 23 April 2014).

Geologic Features and Processes

This section describes noteworthy geologic features and processes in Congaree National Park.

Geomorphic features associated with the Congaree River floodplain are the primary geologic features in Congaree National Park. Some of these features and processes are associated with the Congaree River, but others function independently of it. In the surrounding area, additional geologic and geomorphic features include the unique Carolina bays and bluffs that mark the margins of the modern Congaree River floodplain. The wider array of geomorphic features in and around the park may be grouped to include:

- Congaree River Valley Terrace Complex (CRVTC)
- Congaree River Floodplain Complex (CRFC)
- Congaree River channel
- Tributary channel features
- Rimswamps
- Oxbow lakes
- Alluvial fans
- Paleontological resources
- Biogeomorphology of old-growth forests
- Southern bluffs
- Carolina bays

Congaree River Valley Terrace Complex

Since the Pliocene, downcutting by the Congaree River carved a succession of river terraces in the Coastal Plain. Scarps, or bluffs, separate the terraces and river channels. The floodplain terraces, scarps, and straths (buried erosional surfaces with river deposits positioned atop much older Cretaceous deposits) north of the Congaree River floodplain are collectively referred to as the CRVTC (fig. 6). The broader CRVTC, including the floodplain (geologic map unit Qt0), is underlain by approximately 180 m (600 ft) to 240 m (800 ft) Upper Cretaceous sediment at the park's western and eastern ends, respectively. These underlying sediments represent a regional aquifer that is the source for drinking-water wells at the park.

A terrace is a relatively flat bench- or step-like surface that breaks the continuity of a slope (fig. 7). Terraces can be deposited in marine or fluvial environments. Fourteen distinct fluvial terraces have been recognized in the CRVTC, with the current floodplain designated "Terrace 0" and older terraces numbered upward in order of age (Shelley 2007a–f). The oldest (highest) terrace (Terrace 14) in the CRVTC is correlative with the Pliocene Dublin Formation (Td) and the formation of the Orangeburg Scarp.

Four terraces (Qt2, Qt3, Qt6, and Qt8) have been mapped in Congaree National Park, although terrace surfaces may be too small to map at the 1;24,000 scale of the source maps. Fragments of Qt2 in the park have been mapped north of the railroad tracks, south of US Highway 601. Qt3 consists of two terrace fragments approximately 2.4 km (1.5 mi) long (Shelley 2007a). Qt6 is a broad feature that forms the northern floodplain bluffs and underlies the Harry Hampton Visitor Center. It is also the first major terrace that can be consistently defined above the floodplain (Shelley 2007a). A sliver of Qt8 is present at the park entrance. At a site just outside the park boundary, Qt8 may contain a fossil groundwater rimswamp that formed much as Muck Swamp did (see Rimswamps section below). Large gravel is also locally abundant near the surface of Qt8, suggesting that the fluvial system at that time consisted of braided streams carrying coarse sediment (Shelley 2007a).

The fluvial terraces in the CRVTC average approximately 10 m (33 ft) thick. An ideal, complete terrace consists of two parts, similar to the Congaree River Floodplain Complex (Shelley 2007a; Shelley et al. 2012). The lower part consists generally of medium- to coarse-grained sand, which is overlain by red clay and sandy clay of variable thickness. The CRVTC is separated from the rest of the Upper Coastal Plain by the estuarine equivalent of the Orangeburg Scarp (fig. 6; Shelley et al. 2012).

Scarps separating terraces may also result from fluvial or marine processes. Scarps formed by river erosion are typically oriented parallel to the valley axis and perpendicular to the Atlantic shoreline. In contrast, marine scarps cut by a rising sea level are oriented parallel to the modern coastline. Scarps are also subject to subsequent modification by various processes. Scarps in the CRVTC may be subtle features and may be buried by alluvial fans, may have slumped, or may have retreated due to gravity or groundwater processes (Shelley et al. 2012).

Congaree River Floodplain Complex

The Quaternary alluvium of the Congaree River floodplain (Qacf) is the main unit mapped in Congaree National Park. Congaree River flooding deposits sand, silt, and clay on the floodplain. The decay of vegetation has locally resulted in the accumulation of muck and peat. Collectively, these riverine and organic deposits are referred to as the CRFC (fig. 6; Shelley and Cohen 2007).

On a large scale, CRFC deposits can be characterized as a two-part fining-upward sequence (Shelley et al. 2012). The lower part is a sand sheet representing the amalgamation of multiple channels that migrated

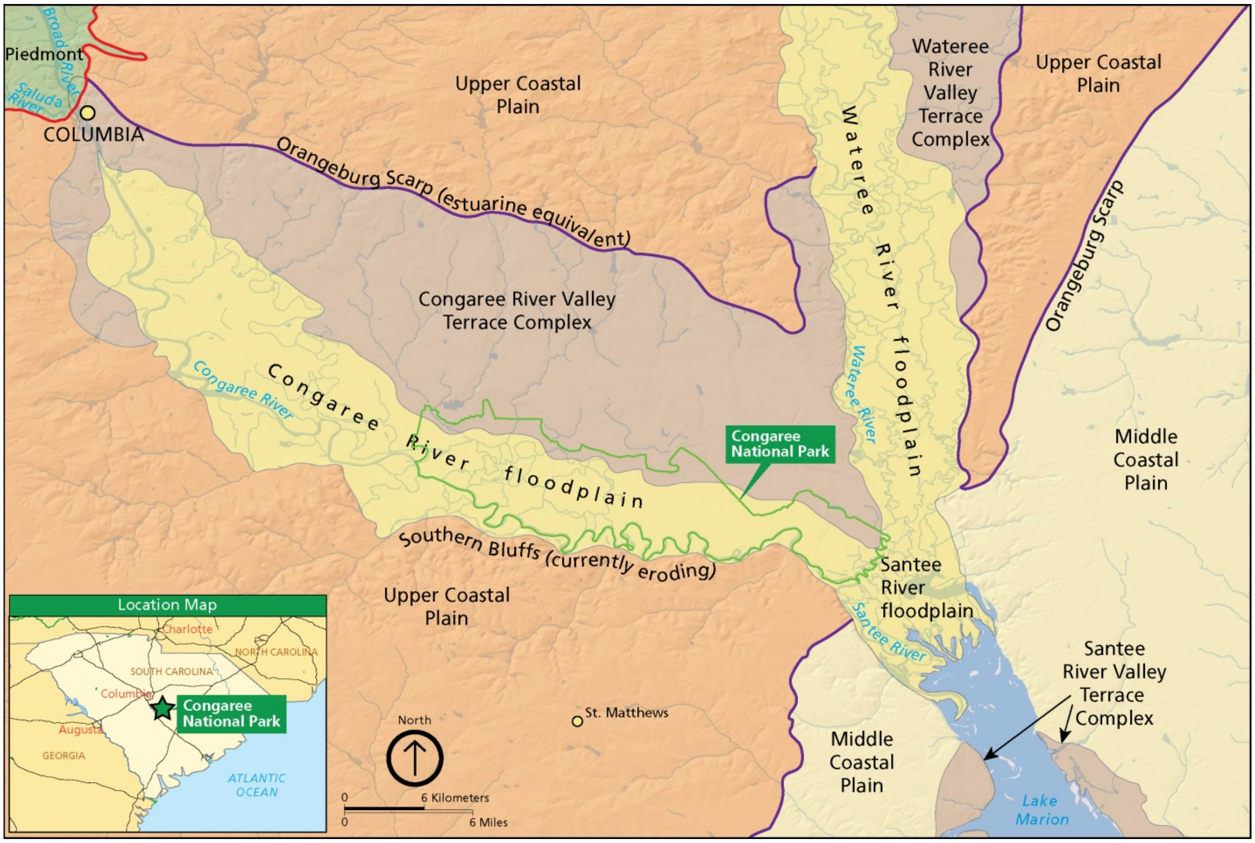

Figure 6. Regional geologic and geomorphic areas of central South Carolina. Congaree National Park (green boundary) lies primarily within the Congaree River floodplain. Graphic by Trista Thornberry-Ehrlich (Colorado State University) with information from Shelley (2007a).

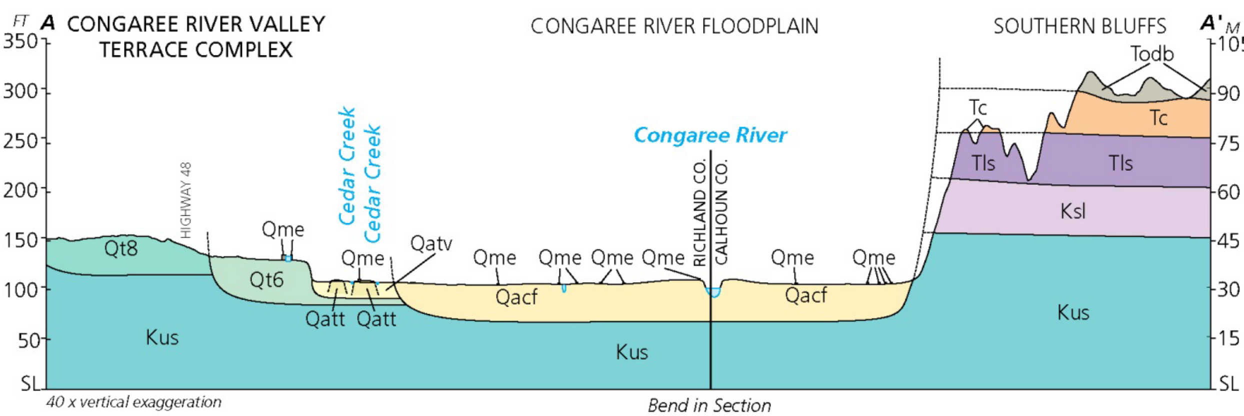

Figure 7. North–south (A–A′) geologic cross section through the northern part of Congaree National Park. The cross section includes the Congaree River Valley Terrace Complex, Congaree River Floodplain Complex, and southern bluffs. Map unit symbols correspond to GRI GIS data. SL = sea level; CO. = County. Cross section modified from Shelley (2007d) by Jason Kenworthy (NPS Geologic Resources Division).

laterally across the floodplain, leaving behind sand-rich channel deposits. Individual channel boundaries are nearly impossible to detect, but this sand sheet is an important, shallow aquifer. The upper part also represents an amalgamation of meandering channels, but it is highly variable in thickness and may contain a series of fining-upward sequences of sand, silt, clay, and organic debris.

Much of the CRFC surface is generically termed a “backswamp.” The generalized “textbook” model of a fine-grained floodplain backswamp involves the accumulation over time of thin layers of silt and clay that settle out of slowly moving floodwaters. In reality, plant roots and animals destroy any layers present, and soil processes overprint the slow deposition with horizons formed by fluctuating groundwater tables.

Although sometimes mapped as a single unit in Congaree National Park, the floodplain actually incorporates several water and geomorphic features, including abandoned channels, oxbow lakes, secondary streams,

Table 1. Types of channel and water body in the Congaree River floodplain.

Water Type	Name	Description
Flowing	Artificial cuts	Historical cuts along Cedar and Tom's creeks made to transport timber.
	Batture channels	Underfit channels that lie within abandoned river channels.
	Chutes	Secondary channels associated with point bars and meander neck cutoffs.
	Crevasse channels	Linear, ephemeral, approximately 3-m- (10-ft-) deep channels that cut through levee deposits and connect the mainstem river with backswamps. Flow may be bidirectional as floods rise and ebb.
	Floods	Slow-moving floodwaters that may temporarily fill the entire floodplain.
	Guts	Ephemeral channels that are the first and last sites of moving flow during flood events.
	Mainstem rivers	Includes the Congaree and Wateree rivers.
	Swale channels	Small, ephemeral, swale-parallel channels in ridge-swale complexes.
	Tributary creeks	Well-defined, sinuous, perennial channels connected to adjacent uplands.
Standing	Borrow pits	Several small historical basins excavated for road fill and earthworks.
	Oxbows	Typically associated with abandoned channels near the mainstem river, but some are associated with creeks and groundwater on the floodplain, detached from any abandoned channel.
	Puddles	Any small, shallow pool of water.
	Rimswamp pools	Several small, spring-fed pools found in groundwater rimswamps.
	Sloughs	Low, swampy areas of abandoned channels. Dominated by cypress-tupelo forest communities.
	Temporary impoundments	Any puddles or flow diversions incidentally developed upstream from roads, causeways, historic earthworks, or other anthropogenic structures.

Data from Shelley et al. (2012).

meander belts, natural levee deposits, dune fields, alluvial fans, and backswamps (table 1; Willoughby 2003a, 2003b; Shelley 2007c–e; Meitzen et al. 2009; Shelley et al. 2012). Some of these features that occur in Congaree National Park are described in further detail below.

Congaree River Channel

The Congaree River, which forms the southern border of the park (fig. 1), has meandered across the landscape to form sinuous loops and curves (fig. 8; Sexton 1999; Shelley 2007a). In general, rivers meander laterally across floodplains consisting of unconsolidated sediment, meaning that their main current migrates from bank to bank. Erosion occurs at a "cutbank," which forms the outside of a meander curve, where the higher-velocity part of the channel (known as the "thalweg") intersects the bank. Opposite the cutbank, the channel's energy decreases around the inside of the bend and sediment is deposited in a "point bar" (fig. 8). As the channel migrates laterally, sand and gravel deposited on a point bar are overlain by finer silt and clay in a fining-upward sequence. Meander "scars" on the floodplain represent previous channel patterns. See the "Oxbow Lakes" section below for more information on these features.

Subtle, almost-imperceptible tectonic tilting of the bedrock underlying the South Carolina region to the south has resulted in asymmetry of the Congaree River Valley. Because of this tilting and the flow of water along the shortest, straightest downhill path, the overall direction of Congaree River migration is to the south (Schumm et al. 2000; Shelley 2007a). This southward migration involves the river's erosion of steep bluffs of Upper Cretaceous and Eocene semi-consolidated sediments (Todb, Tc, Tls, Ksl, and Kus). The terrace complex that exists north of the park is not present south of the park because the Congaree River has eroded in that direction, rather than formed terraces. The southward migration of the Congaree River and subsequent bluff incision have occurred from the Middle Pliocene (approximately 3.5 million years ago) to recent times (Shelley and Cohen 2006).

Although gradual changes occur daily, episodic movements during large floods punctuate river movement on a time scale of decades to centuries. Thus, the river may migrate to the south at an average, long-term rate of 1–3 m (3–10 ft) per year, but it may remain in the same place or even move northward at any given location in a given year (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). A location may also change suddenly during a large flood.

As the Congaree River flows along the southern border of the park, the character of the channel changes. From the northern border of the park to river mile 5 (fig. 1), the channel is highly sinuous and flows over a relatively steep slope. Sinuosity increases south of the northeast–southwest-trending Bates Mill Creek Fault (or fault zone), which enters the park north of the Horsepen Gut tributary (Shelley et al. 2012). Although this fault affects the river, it is buried deeply and no evidence of dramatic, historical surface rupture has been

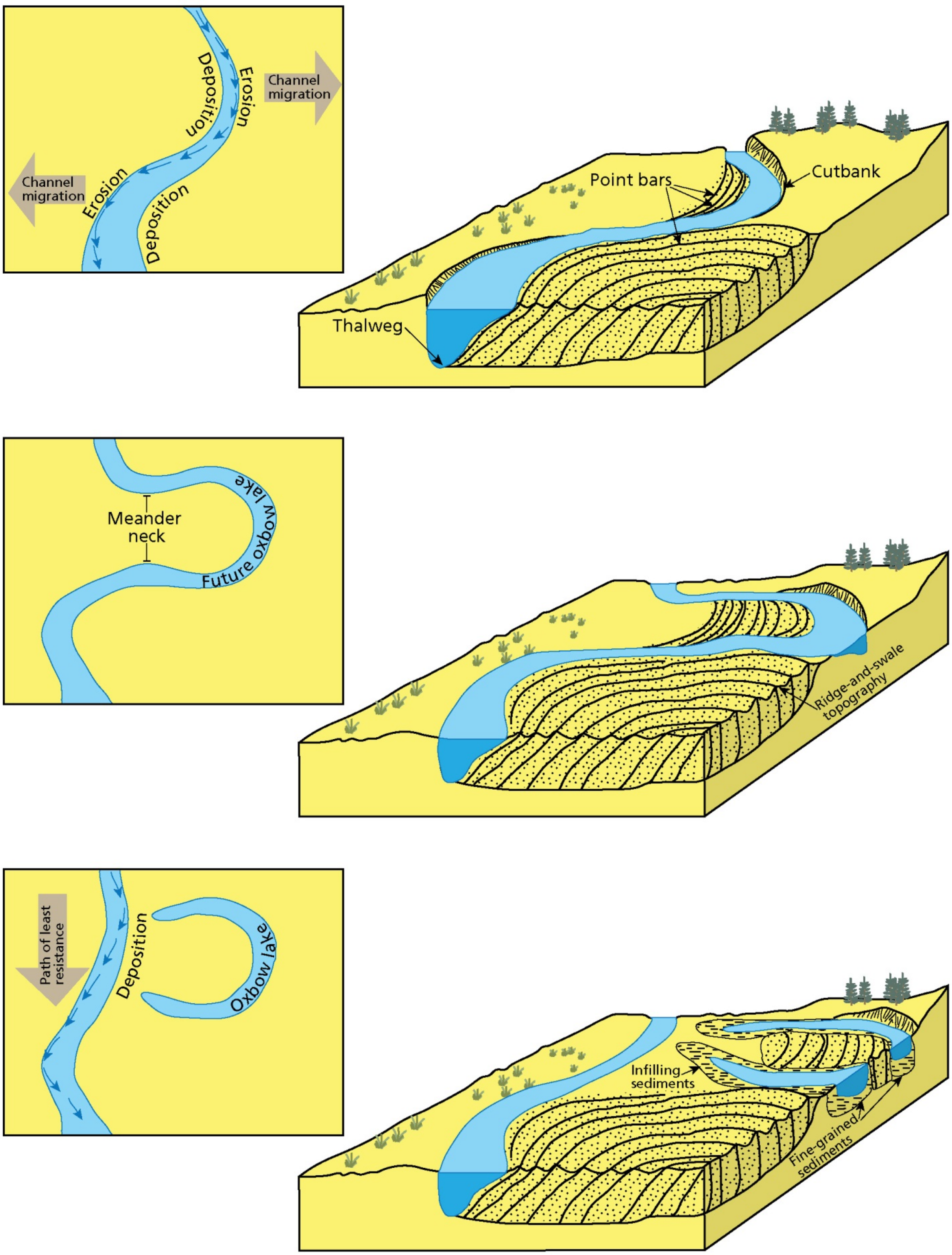

Figure 8. Schematic illustrating various features associated with a meandering stream. Point bars are areas of deposition. Lateral erosion takes place at cutbanks. The thalweg is the path of highest current velocity and is represented by arrows within the stream. When a meander neck is cut off, an oxbow lake forms. Weston Lake is an oxbow lake in Congaree National Park. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

documented. Past movement along this fault, however, may have influenced the valley slope and subsequent sinuosity of the channel.

Sinuosity decreases south of river mile 5, and the channel becomes confined between bottomland terraces and the southern bluffs. The conspicuous bend near Bates Old River (fig. 1) may be the result of previous movement along the Magruder Fault, another buried, northeast–southwest-trending fault zone (Shelley et al. 2012).

Tributary Channel Features

Tributary streams in Congaree National Park, such as Cedar Creek, Tom's Creek, and Dry Branch, contain many of the features associated with the Congaree River, but on a smaller scale (fig. 1). Like the Congaree River, these tributaries have sinuous channels, but their widths, meander amplitudes, and meander wavelengths are smaller than those of the main channel. Cedar Creek is the largest and best developed tributary in Congaree National Park, and portions of the creek have been recognized as Outstanding National Resource Waters because of their water quality and the condition of the surrounding ecosystem (Shelley et al. 2012).

Fluvial processes in the tributaries are similar to those found in the main river, but—during normal flow conditions in the Congaree River—flow conditions in these tributaries are strongly influenced by local features and processes, such as near-surface groundwater flow, rimswamps, sediment input, and vegetation (Shelley et al. 2012). During flood events, however, the lower portions of tributary channels may receive water, sediment, and coarse woody debris from the Congaree River.

Tributary channel beds primarily contain coarse, recycled Pliocene–Pleistocene sand transported from the terrace complex. During flooding, significant amounts of sediment may also be deposited in the channels at the mouths of the tributaries from the Congaree River.

A study of the channels draining the old-growth floodplain forests at Congaree National Park also showed that the tributaries in the park had fewer large natural logs than do some other forested streams in tropical or rocky-mountain settings (Wohl et al. 2011). The logs are considered to be "large woody debris" (LWD), which is defined as any piece of wood more than 10 cm (3.9 in) wide and 1.0 m (3.3 ft) long. Because the floodplain is wide, floodwater spreads out and slows down, so that current velocity weakens approximately 100 m (300 ft) from the stream, prohibiting the transport of LWD into the tributaries. Many logs also become locked up between standing trees. As floods recede, LWD is moved out of the tributaries and into the main river relatively quickly. During all of this episodic flood activity, the wet, subtropical conditions promote relatively rapid decay of LWD.

Tributary creeks, such as Cedar Creek, are characterized as "black water" systems because of their clear, tea-colored water (fig. 9). The creeks contain significantly less suspended sediment than the Congaree River

Figure 9. Tributary creeks. Tributary creeks in Congaree National Park, like this one, are "black water" systems. National Park Service photograph courtesty David Shelley (Congaree National Park).

(Shelley et al. 2012). Black water systems have a low pH and are associated with the bioaccumulation of mercury. Water quality and additional hydrologic data are available from the NPS Water Resources Division website, http://www.nature.nps.gov/water/horizon.cfm (accessed 25 October 2013).

Rimswamps

Rimswamps, also known as seepage wetlands, (included in Qacf and Qawf) occur where groundwater is at or near the surface because it is seeping out from under adjacent bluffs. In Congaree National Park, Muck Swamp is a rimswamp situated in the modern floodplain adjacent to the northern bluffs near the Harry Hampton Visitor Center and just below the Qt6 terrace. Muck Swamp contains the only true muck and peat deposits in the park (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). The groundwater table in Qt6 is approximately 3 m (10 ft) above the floodplain, and the arcuate shape of the bluffs causes the convergence of groundwater flow in this area (Shelley et al. 2012). Small, spring-fed pools are also found in Muck Swamp and other groundwater rimswamps, but these have not been well studied.

Stratigraphic features from Muck Swamp cores have been used to develop a five-zone model for the organic-rich sediment in rimswamps, which is known as Dorovan Muck (Shelley et al. 2012). These zones are described in table 2 and the "Paleontological Resources" section below. Dorovan Muck is found not only in Muck Swamp, but also in three other groundwater rimswamps along the northern Congaree River floodplain boundary. The CRVTC may also contain ancient groundwater rimswamps north of the park, which may provide information regarding past climates, fire history, and flood regimes (Shelley and Cohen 2006; Shelley et al. 2012).

The organic deposits in rimswamps are important to Congaree National Park for several reasons. They underlie the park's most diverse plant assemblage, which includes the endangered Carolina bogmint (*Macbridea*

Table 2. Five-zone model for groundwater rimswamps.

Zone	Lithology	Characteristics	Interpretation
5	Thin, inorganic layer.	Found in the top 0.2 m (0.7 ft). Sharp increase in frequency of gum and decrease in frequencies of oak, alder, and fern.	Represents a significant change from long-term depositional trends and processes. Uncertain origin.
4	Highly-degraded, wet, organic-rich peat.	Found between 0.8 m and 0.2 m (2.6 ft and 0.7 ft). Highly bioturbated peat includes abundant charcoal. Pollen resembles modern vegetation (oak, pine, alder, sweetgum, maple, tulip poplar) and documents a sudden increase in the frequencies of gum, fern, holly, and elderberry.	Slightly domed, forested wetland controlled primarily by fluctuations in groundwater flow from the bluffs. Pollen grains may indicate late prehistoric agricultural activity.
3	Peat with occasional, irregular clay-rich layers.	Found between 1.8 m and 0.8 m (5.9 ft and 2.6 ft). Contains more charcoal, fungal remains, woody tissues, and degraded tissue fragments than does Zone 2. Pollen assemblage includes pines, sweetgum, alder, maple, gum, cypress, and magnolia.	Gum, cypress, and magnolia indicate warm-temperate climate. Mid-Holocene age date of 3,160 years before present implies a significant hiatus between zones 3 and 2.
2	Peat and muck.	Found between 2.5 m and 1.8 m (8.2 ft and 5.9 ft). Degraded organic matrix with fecal pellets and charcoal. Pollen assemblage includes oak, chestnut, juniper, hickory, walnut, and elm. Decreased frequency of pine, alder, and cold climate forms, such as spruce. Emergent aquatics (arrowheads, swamp button, pickerelweed, knotweeds, sedges).	Aquatic vegetation suggests a shallow, open marsh environment. Soil zone that developed during post–Late Pleistocene infilling of the channel.
1	White to gray clay; orange to brown peat. Sandy grit.	Found below 2.5 m (8.2 ft). Layers of freshwater diatom fragments. Algal filaments and zygospores. Pollen assemblage includes spruce, pine, alder, wax myrtle, holly, sedges, peat moss, primrose, and ferns. No charcoal.	Age: 21,000 years before present. Deposition in an oxbow lake setting in a colder-than-present climate.

Note: Zone 1 is oldest. Summarized from Shelley et al. (2012).

caroliniana; Weeks 2009). Because they take years to recover from soil disturbance, organic deposits are very sensitive to feral hog rooting (Zengel 2008). Organic deposits filter groundwater flowing into the floodplain, while local soil bacteria have been known to degrade chlorofluorocarbons (Lovley and Woodward 1992). Radiocarbon and light-stable isotope data from organic deposits provide information about long-term ecological trends (Shelley et al. 2012).

Oxbow Lakes

When a meander loop is cut off from the main channel, the isolated U-shaped curve is called an "oxbow," named for the part of the yoke that fits over the neck of an ox (fig. 8). An oxbow filled with water is known as an oxbow lake. Weston Lake, which was once a bend in the Congaree River, is the largest oxbow lake in Congaree National Park and the largest lake on the floodplain (figs. 1 and 10; Shelley et al. 2012).

Oxbow lakes typically fill with sediment and become semi-perennial wetlands called sloughs (pronounced "slews"), which host distinct cypress-tupelo forest communities. The abandoned channel fill consists of basal sand from the active river, overlain by a dense clay plug that forms as finer-grained sediment settles out of the waning current and then a layer of peat and organic-rich clay. During the final slough phase, a hydric soil zone forms above the clay plug and organic deposits. A fifth layer may develop as tributary channels erode and

Figure 10. Weston Lake. This oxbow lake in Congaree National Park formed when a meander loop of the Congaree River was cut off from the main channel. National Park Service photograph, available at http://www.nps.gov/cong/photosmultimedia/index.htm (accessed 6 August 2013).

backfill within the slough. These inset channels are called "batture" (French for "to strike upon or against") channels (Shelley et al. 2012). Many abandoned channels also preserve remnants of point bars and natural levees that formed when the oxbow was an active channel. Champion-sized trees grow on some of these natural levees; for example, a 250-year-old loblolly pine (*Pinus taeda*) grows on the levee surrounding Weston Lake.

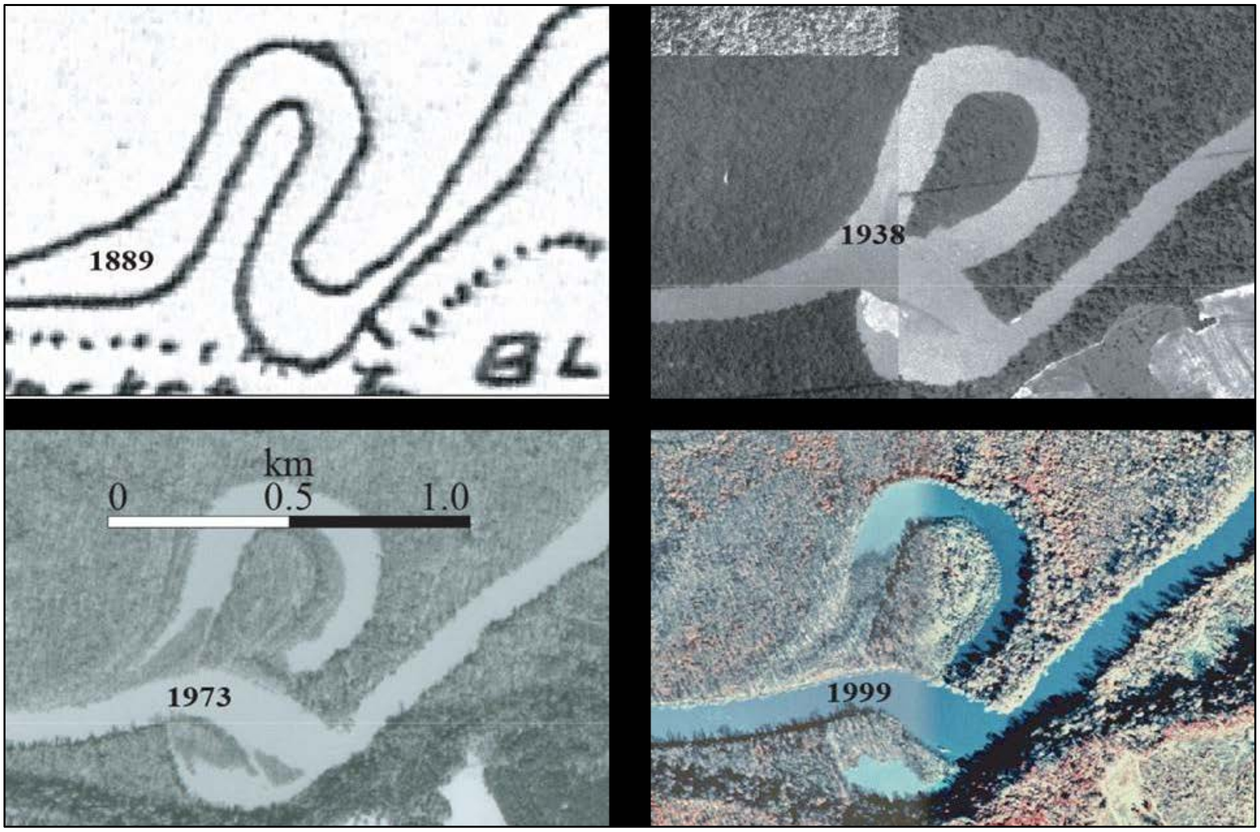

Figure 11. Evolution of the Devils Elbow oxbow. The four images illustrate the cutting off and eventual closing of the Devils Elbow meander from 1889 to 1999. Images courtesy of David Shelley (Congaree National Park).

Devils Elbow is another good example of an oxbow lake (figs. 1 and 11). The meander was cut off and a clay plug formed between 1889 and 1939 (Meitzen and Shelley 2005). However, local residents periodically removed the clay plug using dynamite and/or fertilizer explosives to keep the back part of the oxbow open for fishing (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). Observations of the process of oxbow formation on the Wateree River in the park indicate that oxbows do not form from single, dramatic events, but rather over a decade or more.

The bottom of Weston Lake lacks the shallow clay and silt layer typical of oxbow lakes. Rather, Weston Lake remains at least 6.5 m (21 ft) deep, with a lake bed consisting of gravel. Groundwater may be preventing the deposition of fine-grained sediment, thereby slowing the infilling of the lake (Shelley et al. 2012).

Alluvial Fans

An alluvial fan is a relatively flat to gently sloping, fan-shaped mass of unconsolidated sediment deposited by a stream as it crosses a topographic break. The subtle alluvial fans associated with Cedar Creek, Tom's Creek, Dry Branch, and other tributary streams in Congaree National Park are collectively known as the "north rim alluvial fan complex" (Shelley and Cohen 2007). Underlain by quartz sand and gravel eroded from terraces to the north, the fans are up to 3.6 m (12 ft) thick but rise only 0.6–1.2 m (2–4 ft) above the floodplain (Shelley et al. 2012). The distal portions of the fans have been buried by the accumulation of fine-grained sediments in the floodplain.

Alluvial fan deposits (Qaf2) were mapped adjacent to Tom's Creek, but most alluvial fans are too small to map at the 1:24,000 scale of the geographic information system (GIS) source map. These deposits consist of light-yellow to orange sand with abundant clay sediments. The sandy soils of the alluvial fans in Congaree National Park play an important ecological role. The well-drained soils support loblolly pine trees, including the national champion.

Paleontological Resources

Congaree National Park is one of at least 248 NPS units containing fossils as of September 2014. All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation, as outlined by the 2009 Paleontological Resources Preservation Act. Department of Interior regulations associated with the act are still being developed as of September 2014.

Most fossils in Congaree National Park are quite young and small. In the CRFC, a peat deposit in Muck Swamp yielded Late Quaternary microfossils, including pollen, spores, plant fragments, diatoms, and freshwater sponge spicules, which have been used to help define four distinct paleoecological zones (Cohen et al. 2005a, 2005b; Tweet et al. 2009). The oldest zone, Zone 1, is approximately 29,000 years old and contains pollen from spruce, evening primrose, and short-spined members of the aster family (Shelley et al. 2004; Tweet et al. 2009). Algal remains, freshwater diatoms, water lily debris, and sponge spicules indicate ponded conditions. Peat and pollen suggest colder and drier conditions than today, with deposition occurring in river, floodplain, and oxbow lake environments. Organic-poor sediments, which represent a pause in deposition, cap this zone (Cohen et al. 2004, 2005b; Shelley et al. 2004).

Zones 2 and 3 compose a middle stratigraphic interval that contains charcoal, fungal spores, and fecal pellets (Shelley et al. 2004). Both zones represent a non-ponded wetland ecosystem. Zone 2 is characterized predominantly by increased frequencies of oak, chestnut, juniper, hickory, walnut, and elm pollen and the disappearance of spruce. Emergent aquatic plants, such as arrowhead, pipewort, and pickerel weeds, suggest a relatively shallow open marsh in which standing water supported floating plants. In Zone 3, pollen from pine, sweetgum, alder, maple, tupelo, cypress, and magnolia indicates a warm, temperate swamp environment. Intermittent wet and dry periods occurred under relatively unshaded conditions (Cohen et al. 2005b; Tweet et al. 2009).

Inorganic sediments dominate Zone 4, the uppermost interval, which comprises approximately the top 0.3 m (1 ft) of the deposit. Compared with the lower zones, the frequencies of tupelo, holly, heath, and ferns are increased in Zone 4 (Cohen et al. 2005b). The vegetation is similar to today's warm temperate Coastal Plain swamps. Groundwater flow from the bluffs is thought to control the forested wetland of Zone 4. Environmental changes are likely related to local land use practices, which simultaneously restricted groundwater flow and increased the erosion of Cedar Creek to the south. Because of the increased erosion, Cedar Creek now effectively collects the groundwater before it can back up in the swamp (Shelley et al. 2004; Tweet et al. 2009).

Paleontological resources may occur in units exposed beyond the boundaries of Congaree National Park (Tweet et al. 2009). Bluff exposures of the Sawdust Landing (Ksl), Lang Syne (Tls), and Congaree (Tc) formations have yielded a variety of microfossils and shell fragments. Within the Lang Syne Formation, silicified shell hash containing abundant bivalves and turritellid gastropods is known as the Buyck's (pronounced "bikes") Bluff Chert. Palynomorphs recovered from the Sawdust Landing Formation, which had been considered to be Paleocene in age, identified the unit as Late Cretaceous (Frederiksen et al. 2000; Christopher and Prowell 2002). Fossils of foraminifera, corals, bryozoans, gastropods, bivalves, scaphopods, chitons, barnacles, ostracodes, echinoids, sharks, reptiles, whales, and terrestrial mammals have been discovered in the Duplin Formation (Td, Tdu, and Tdl). Small exposures of the Duplin Formation, which are not mapped on the enclosed GIS map, are present in Congaree National Park, but fossils have yet to be recovered from these deposits (Tweet et al. 2009).

Biogeomorphology of Old-Growth Forests

Research is beginning to show how plants and animals help shape the geomorphic landscape (Reed 2000; Corenblit et al. 2008). An understanding of abiotic–biotic interactions, for example, is critical for the restoration of coastal wetland and creek systems (Reed 2000). Rivers influence the arrangement of landforms and vegetation communities. Plants on floodplains may be arranged along a gradient of available moisture and oxygen, for example (Hughes 1997). Simultaneously, biotic factors influence the geomorphology of floodplains. Vegetation along creek banks checks erosion and influences sediment deposition. Vegetated islands may develop in the floodplain and redirect streamflow (Hughes 1997; Corenblit et al. 2008).

In Congaree National Park, the roots of bald cypress and other old-growth trees baffle flows across the floodplain and along the banks of tributaries, influencing the accumulation of organic material and the deposition of sediment (fig. 12). Congaree National Park is an excellent field laboratory in which to study these abiotic–biotic interactions of old-growth forests, their influence on surface landforms, and biogeomorphic feedbacks related to storm events and changing climate conditions.

Figure 12. Biogeomorphology in Congaree National Park. Vegetation slows water flow in tributary creeks and on the floodplain, influencing the accumulation of organic matter and deposition of sediment. National Park Service photograph by David Shelley (Congaree National Park).

The park's biogeomorphology may also serve as an analog to past coal formation. Anastomosing channels in peat deposits, for example, differ markedly from alluvial channel morphologies (Corenbilt et al. 2008). Biological feedbacks in peat basins illustrate how living organisms can shape the physical landscape.

Southern Bluffs

Eocene to Cretaceous strata form four distinct units in the bluffs that border the southern bank of the Congaree River (fig. 13; Shelley et al. 2012). The bluffs are not in Congaree National Park, but are important for an understanding of the regional geology. Regional geometries suggest that they are underlain by a basal unconformity; basal bedrock elevations drop from approximately180 m (600 ft) under the western portion

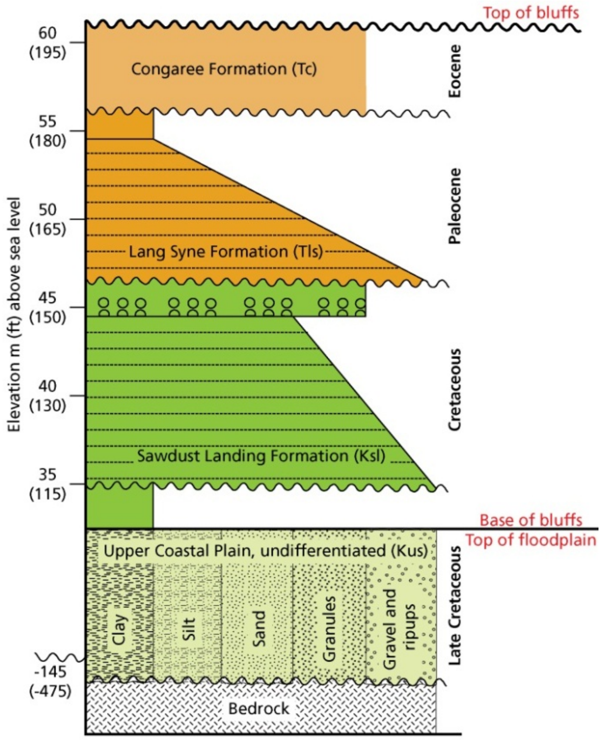

Figure 13. Stratigraphic profile of the southern bluffs. Note that grain size increases from left to right (clay to gravel). The fining-upward sequences form well-defined benches in the cliff. Wavy lines indicate unconformities, or periods of erosion. asl = above sea level. Original graphic from Shelley et al. (2012, fig. 6), modified by Trista Thornberry-Ehrlich (Colorado State University).

to around 800 feet under the eastern portion of the park. The lowermost Cretaceous unit visible at the base of the bluffs consists of undifferentiated Upper Cretaceous clay, sand, and conglomerates (Kus). Ripple marks, cross beds, parallel laminations, and channels suggest that the sediments were deposited in marginal to shallow-marine environments. This lowermost unit, which is directly related to the aquifer screened for the park's drinking water wells, is difficult to break into distinct units due to complications from channel geometries and extensive weathering (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Interbedded clay, sand, and conglomerate of the Upper Cretaceous Sawdust Landing Formation (Ksl) unconformably overlie this basal unit. The Sawdust Landing Formation consists of a fining-upward sequence capped by a distinct, cohesive, steel-blue to cream-colored clay that contains abundant granules. It has been interpreted as an upper delta plain deposit (Muthig and Colquhoun 1988; Nystrom et al. 1991; Christopher et al. 1999; Shelley et al. 2012).

The Sawdust Landing Formation and overlying Upper Paleocene Lang Syne Formation (Tls) form prominent benches in the bluffs. Beds of thinly bedded clay and sand, massive claystone, and iron oxide–cemented sandstone in the Lang Syne Formation contain local deposits of shell casts, silicified shell fragments of gastropods and bivalves (referred to as "Buyck's Bluff Chert"), and trace fossils, such as burrows. The "Tavern Creek bed," a black, waxy, plastic, cohesive clay, caps the unit. The Lang Syne Formation has been interpreted as a lower delta plain deposit (Padgett 1980; Nystrom et al. 1991; Shelley et al. 2012).

The loose to moderately cohesive, medium-grained quartz sand of the middle Eocene Congaree Formation (Tc) unconformably overlies the Lang Syne Formation and underlies the top of the bluffs. Glauconite, a clay mineral that forms in marine environments, and fossils of the molluscan bivalve *Anodontia augustana* suggest a shallow marine depositional environment (Shelley et al. 2012).

Carolina Bays

Although not mapped within Congaree National Park, thousands of Carolina bays (Qcb) dot the coastline from Delaware to Florida (Grant et al. 1998; Davias 2012). The Geologic Resource Inventory (GRI) GIS map database contains 1,300 polygons representing Carolina bay deposits, although the actual number of such bays is approximately 300 (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). The bays are relatively shallow (no more than several meters deep), elliptical ponds and wetlands with long axes generally oriented northwest–southeast. They vary in size and may be several kilometers long. A low sand rim usually borders a Carolina bay. The sand, which may form a parabolic dune, is most pronounced in the east-southeast quadrant of the bay (Johnson 1942; Carver and Brook 1989; Markewich and Markewich 1994; Murphy 1995; Grant et al. 1998).

For hundreds of years, fanciful theories ranging from meteorite impacts to fish-spawning beds have been proposed to explain the origin of Carolina bays. More recent research, however, has shown that their distribution across the coastal plain is not random and that they are identical to cold-climate features currently found in Alaska and Argentina. Accordingly, they are interpreted as periglacial features (features that formed during the cold climate of the ice ages) that resulted from katabatic winds blowing over terrace surfaces as water levels fluctuated during successive glacial–interglacial cycles (Kaczorowski 1977; Grant et al. 1998; Shelley et al. 2012).

Studies of the sand rims that border the Carolina bays have indicated that the surfaces of the sand sheet and bays have been reworked and modified multiple times since their initial formation (Ivester et al. 2002, 2003). For example, sand rims around Big Bay, a Carolina bay located approximately 10 km (6 mi) west of the confluence of the Congaree and Wateree rivers, shows evidence of surface reworking between 30,000 and 33,000 years ago (Ivester et al. 2003). Evidence from a bay in Georgia suggests that the sand rim was active approximately 12,630 years ago, well after the maximum advance of the last continental ice sheet approximately 25,000–20,000 years ago (Ivester et al. 2003).

Geologic Resource Management Issues

This section describes geologic features, processes, or human activities that may require management for visitor safety, protection of infrastructure, and preservation of natural and cultural resources in Congaree National Park. The NPS Geologic Resources Division provides technical and policy assistance for these issues.

Potential geologic resource management issues at Congaree National Park include:

- Flooding
- Groundwater hydrology
- Legacy sediment from upstream land use changes
- Moved earth
- Hurricanes
- Climate change
- Earthquakes
- Erosion of the southern bluffs
- Industrial operations.

Resource managers may find *Geological Monitoring* (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing some geologic resource management issues. The manual 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 and suggested methods of monitoring.

Flooding

Flooding of swamps and other low-lying areas may occur in two ways, which significantly influence the dynamics of material transport through the floodplain. Rivers may fill and overtop their banks so that floodwaters spill across the floodplain, transporting sediment and nutrients to the floodplain and recharging its aquifer system. Alternatively, groundwater levels may rise faster than river water, resulting in the mobilization and transportation of floodplain material to the river. A study of surface water and groundwater elevations in the park (Conrads et al. 2008) showed that water rose faster in the Congaree River and its tributaries than did groundwater in the floodplain. In the case of Cedar Creek, groundwater elevations lagged behind the rise of surface water by more than 2 days (Conrads et al. 2008).

Flood stage of the Congaree River at Congaree National Park is 4.6 m (15 ft) (National Parks Conservation Association 2013; National Weather Service 2013). Backflooding of floodplain channels near the mainstem river occurs approximately 10 times a year. Based on the frequency of a 2.4-m (8.0-ft) stage on Cedar Creek over 19 years of record (US Geological Survey 2014), at least partial surface inundation occurs a little more than three times per year. Floodwaters from the Congaree and Wateree rivers inundate the park's elevated boardwalks, which are more than 2 m (6 ft) above the ground, about once every 10 years (fig. 14; David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Figure 14. Flood events may inundate the boardwalks in Congaree National Park. The upper photograph shows floodwaters onlapping the first bench of the lower boardwalk in January 2007. National Park Service photograph, available at http://www.nps.gov/media/photo/gallery.htm?id=380315C9-1DD8-B71C-0761F7ECD1327C6D (accessed 6 November 2013). The boardwalk to Weston Lake was inundated during the May 2013 flood. National Park Service photograph courtesy of David Shelley, available at http://www.nps.gov/cong/parknews/2013-flood.htm (accessed 6 November 2013).

In addition to providing the energy and sediment to shape the geomorphic features of the floodplain, floods in Congaree National Park enrich, hydrate, and sustain plant and animal communities, and they improve the water supply by filtering and distributing sediments and nutrients across the floodplain (NPS 2013b). The bottomland forest in the Congaree floodplain slows the velocity of floodwaters, distributing a flood's energy and volume across the landscape. Wetlands store water that eventually percolates into the ground, recharging groundwater supplies.

Major floods occur less regularly. Recent examples of major floods include those occurring in 2013, the winter of 2009–2010, 2007, 2004, and 2003. Abundant rainfall in the spring of 2013 caused the most significant flooding in the park since 2004, with the Congaree River peaking at 5.526 m (18.13 ft) on May 9 (fig. 14; NPS 2013b; U.S. Geological Survey 2013). Increases in hurricane frequency and intensity due to global climate change may increase the risk of flooding and potential impacts to the park.

Long-term monitoring of the flood regime is critical for understanding climate change and the biogeomorphology of the park. In the chapter on fluvial geomorphology in *Geological Monitoring* (Young and Norby 2009), Lord et al. (2009) described methods of inventorying and monitoring geomorphology-related vital signs for rivers, including: (1) watershed landscape (vegetation, land use, surficial geology, slopes, and hydrology); (2) hydrology (frequency, magnitude, and duration of stream flows); (3) sediment transport (rates, modes, sources, and types of sediment); (4) channel cross section; (5) channel planform; and (6) channel longitudinal profile. In partnership with the US Geological Survey, resource managers at Congaree National Park are implementing these methods through the Old-Growth Bottomland Forest Research and Education Center. Resource managers recommend support for at least two US Geological Survey gauges through park funding and partnerships (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Groundwater Hydrology

Groundwater and surface water dynamics are closely interrelated in swamps, such as those in Congaree National Park. The Congaree National Park floodplain is a local flow system with shallow and short flow paths from recharge to discharge areas. The floodplain aquifer is hydraulically connected to the Congaree River and its tributaries. When water levels in the river fall, groundwater flows from the floodplain to the river; when river levels are high, surface water flows into the aquifer (fig. 15).

Groundwater, surface water, water quality, soil development, nutrient cycling, and organic matter preservation are critical components of the hydrological system at Congaree National Park. Interaction among bank storage, overbank flooding, and groundwater elevations is constantly in a dynamic state of adjustment. Any change in groundwater recharge will impact the sustainability of the park's wetlands, oxbow lakes, and rimswamps. Precipitation, evaporation, and evapotranspiration have lesser effects on groundwater levels in the floodplain than do the stages of the Congaree River and its tributaries (Conrads et al. 2008).

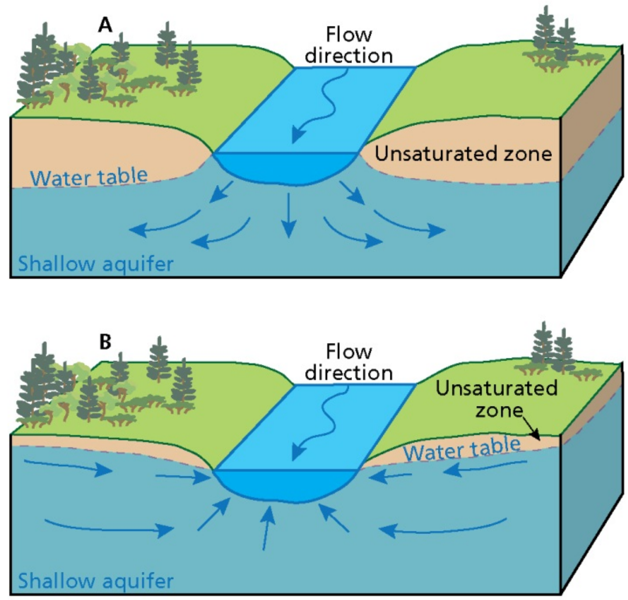

Figure 15. Schematics of gaining and losing streams. The water level in a losing stream (A) is higher than that in the adjacent aquifer, whereas the water level in a gaining stream (B) is lower than that in the aquifer. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Conrads et al. (2008, fig. 8).

Concern over the upstream Saluda Dam and the effects of reservoir flow release on downstream ecosystems and groundwater levels prompted a study to better understand the surface- and groundwater dynamics in the park (Conrads et al. 2008). Analysis of peak flow data showed that the decrease in large floods after the dam was completed in 1930 was the result of climate variability, rather than dam operations. Daily stream gauge data indicated that the dam had lowered river levels from December to May and raised them from June to November. Groundwater data showed similar results. Since the construction of the Saluda Dam, high groundwater elevations in the Congaree National Park floodplain have lowered and low groundwater elevations have increased. Rather than affecting the frequency and magnitude of floodplain inundation, the dam may have a considerable effect on subsurface water levels in the floodplain. The shift in seasonal groundwater levels (lower from December to May; higher from June to November) may affect the root zone and other aspects of vegetative structure in the swamp (Conrads et al. 2008).

Legacy Sediment from Upstream Land Use Changes

When English emigrants first began farming in South Carolina in the 17th century, top soil began to be eroded and transported downstream. Cotton farming practices in the 19th century accelerated the rate of soil erosion (Jackson et al. 2005). Net soil loss may be 1.5 m (5 ft) across the entire watershed, and the sediment may take 500 years to wash through the system. Increased sedimentation has buried some archaeological sites in the park with up to 2 m (7 ft) sediment (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Moved Earth

Heterogeneous material from construction projects significantly modifies the flow of surface water. These projects range from construction of the Highway 601 causeway to the Norfolk Southern Railroad to local hunt club roads. Changes to surface water flow directly alter the patterns of erosion and deposition across the floodplain (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Hurricanes

Hurricanes are potential threats to Congaree National Park. Hurricane-force winds may rip up trees, disturb sediment, and make the discovery and delineation of subtle floodplain features difficult. Hurricanes may also cause flooding in the park. In September 1989, Hurricane Hugo destroyed several of the park's national champion trees, including the Shumard oak tree (NPS 2013c). According to University of Georgia professor Rebecca Sharitz, the storm damaged 60% of the largest trees, primarily hardwoods (Hinshaw 2009).

Hurricane Hugo also promoted future forest diversity. By snapping tree tops, the hurricane allowed sunlight to penetrate the canopy, promoting new growth (Hinshaw 2009; NPS 2013a). Fallen trees provided habitat and shelter for many organisms, and a variety of plant and animal species, including fungi, insects, reptiles, birds, and bats, made homes in standing dead trees (NPS 2013a). Hurricanes are only one of several disturbance regimes associated with forest dynamics, however. For example, altered hydrology, impacts on water quality by point source and non–point source pollution, storm dynamics, and invasive species are constantly integrated into the complex ecosystem and all pose a threat to the overall resilience and integrity of the forest system (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Climate Change

Twentieth-century climate records indicate changing seasonality of precipitation in the watershed, and many climate models forecast increased drought in South Carolina [South Carolina Department of Natural Resources (SCDNR) 2013b; Intergovernmental Panel on Climate Change (IPCC) 2014; Melillo et al. 2014]. The number of hot days with temperatures ≥ 38°C (100°F) is predicted to increase, and these increased temperatures will be associated with increases in the frequency, intensity, and duration of extreme heat events, which will affect the forests in the southeastern United States (IPCC 2014; Melillo et al. 2014). Although data indicate that the amount of precipitation falling in the heaviest 1% of events in the Southeast increased by 27% between 1958 and 2012, drought is expected to increase by an estimated 9% (IPCC 2014; Melillo et al. 2014). Increasing drought will also affect groundwater recharge, which may impact the park's oxbow lakes, wetlands, and rimswamps. These changes will alter suspended sediment concentrations in the Congaree River and its tributaries, and may lead directly to immediate and long-term biogeomorphic feedbacks related to changes in water quality, water availability, and phenology (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). For example, forests may become more vulnerable to threats of wildfires or pest outbreaks, which may result in an increase in LWD in rivers.

As climate continues to change, the destructive potential of Atlantic hurricanes is expected to increase (IPCC 2014; Melillo et al. 2014), and increased wind speeds and rainfall intensity may impact Congaree National Park in ways similar to Hurricane Hugo. Although increases in hurricane frequency are difficult to attribute to climate change, recent studies have confirmed that hurricane intensity is linked to climate change (Saunders and Lea 2008). Increased hurricane intensity may increase patterns of erosion and deposition, as well as LWD budgets and biogeomorphic feedbacks. Although wind speed and rainfall may increase, data show no increase in the number of hurricanes making landfall in the state. Tropical cyclone activity along the South Carolina coast has not increased since 1891 (SCDNR 2013b). While an increase in hurricane frequency and intensity may result in increased erosion and debris in rivers and streams, increased frequency of drought may decrease the suspended sediment load in the tributaries that flow into the Congaree River.

Water supply and quality issues may also increase with climate change (IPCC 2014; Melillo et al. 2014). According to the SCDNR, groundwater models and monitoring are needed on the Coastal Plain to predict how groundwater withdrawal will affect aquifers (SCDNR 2013b). These data may then be used to evaluate the effects of changes in precipitation and groundwater recharge rates on the water supply.

Climate change is predicted to impact the biodiversity of many ecosystems and may already be significantly impacting the biogeomorphology of Congaree National Park. For example, vines are growing larger and more rapidly, and are more abundant (Allen et al. 2007; Schnitzer and Bongers 2011). Breeding seasons for amphibians have shifted by up to 76 days (Todd et al. 2010). Tree leaf-out timing has changed due to warmer winter temperatures, and the range of golden silk orb-weaver spiders is changing due to changing climate conditions (Zhang et al. 2007; Bakkegard and Davenport 2012). Events such as droughts, floods, wildfires and pest outbreaks, as well as altered timing of critical biological events, will disrupt ecosystems and reduce their buffering effects on extreme events (IPCC 2014; Melillo et al. 2014). Refer to the "Additional References" section for more climate change resources.

Earthquakes

Earthquakes are relatively common in South Carolina (Clendenin et al. 1999). Between 1776 and 2011, 640 earthquakes of magnitude 2 or greater were recorded in

South Carolina [SCDNR and South Carolina Emergency Management Division (SCEMD) 2012). Eight of these earthquakes registered a magnitude 5 or greater, and two of those were within 19 km (12 mi) of the park. The estimated magnitude 7.6 Charleston earthquake of 1886 is the strongest earthquake known along the Eastern Seaboard (US Geological Survey Earthquake Hazard Program 2012; SCDNR 2013a). Ground shaking was felt from Cuba to New York and from Bermuda to the Mississippi River, an area of more than 6.5 million km^2 (2.5 million mi^2). Mercalli intensity scale maps of this earthquake indicate a northeast–southwest-trending zone of intense activity registering VIII on the Mercalli scale. This zone extends into the lower Congaree River Valley (Visvanathan 1980). In 1913, an estimated 5.5 magnitude earthquake occurred near the town of Union, demonstrating that large, potentially destructive earthquakes may occur in the Piedmont region as well as the coastal zone. In 2008, a 3.6 magnitude earthquake occurred in Dorchester County (SCDNR 2013a).

Ground shaking from a strong earthquake may “liquefy” subsurface water-saturated sand (a process known as liquefaction). Liquefaction leads to land subsidence and potentially significant damage to buildings and infrastructure, especially in the coastal zone. Liquefaction features in South Carolina, such as sand blows, vents, landslides, and differential compaction, indicate that at least five large earthquakes have occurred in South Carolina in the past 5,000 years (Amick and Gelinas 1991). According to the SCDNR and SCEMD, the Congaree River floodplain and tributary channels in Congaree National Park lie within the region of liquefaction (fig. 16; Nystrom et al. 1996; SCDNR and SCEMD 2012).

Earthquakes are triggered when movement occurs along a fracture or fault surface. Near the Earth’s surface, rocks may be pressed together (reverse fault), pulled apart (normal fault), or slide past one another (strike-slip fault; fig. 17). Each of these movements generates stress, and when that stress is released, the ground shakes. The Augusta Fault, a major east–west-trending fault that extends across several states, passes approximately 5–10 km (3–6 mi) north of Congaree National Park. This fault is an old suture zone between North America and an island arc terrane (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). Branches of the fault, such as the Savany Hunt Creek Fault, are inferred to cut through the northern part of the park (fig. 18; Maybin 1998; Shelley 2007b). The northeast–southwest-trending Bates Mill Creek and Magruder faults may also be associated with the Augusta Fault (Shelley and Cohen 2010; Shelley et al. 2012).

Earthquakes commonly occur at tectonic plate boundaries, but South Carolina earthquakes are located within the North American Plate, far removed from the current Mid-Atlantic Rift spreading zone. Modern stress fields are not well understood, and uplift and subsidence rates vary among Coastal Plain regions (Cronin 1981). As a result, the causes of South Carolina earthquakes, including the 1886 Charleston earthquake, continue to be investigated (Talwani 1985; Clendenin et al. 1999). Potential movement on the faults, including those beneath the park, remains difficult to predict due to a lack of subsurface data on the faults and associated triggering mechanisms. However, movements along these faults are preserved in geomorphic features in the Congaree River floodplain architecture (Shelley and Cohen 2010; David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Erosion of the Southern Bluffs

Tectonic tilting of the Upper Coastal Plain has resulted in the lateral, southward migration of the Congaree River. This migration has carved and backfilled an extensive terrace complex as well as the modern floodplain. The southern boundary of the valley is marked by steep southern bluffs (Shelley and Cohen 2006; Shelley 2007a). The bluffs have been eroding since the Late Pleistocene at an estimated average rate of about 2.46 m (8.07 ft)/1,000 years (Shelley et al. 2012). Lateral bluff erosion is more episodic than continuous, however, and is influenced by a combination of hillslope processes, river erosion (including tributary stream incision), and slope movements (mass wasting; Shelley et al. 2012). Landslides occur on the opposite side of the river from the park, where the bluffs are comprised of undercut benches of semi-consolidated claystone, iron oxide–cemented sandstone, or iron oxide–cemented conglomerate (Shelley et al. 2012). On the South Carolina geologic hazards map, the Southern Bluffs region is identified as having landslide potential (fig. 16; SCDNR and SCEMD 2012).

Industrial Operations

Mining is not allowed in the park, and local mining activity is not a major issue for resource managers (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). However, upstream gold mining operations and the construction of a fly ash landfill may negatively impact water quality and the viewshed in Congaree National Park.

The proposed Romarco Minerals gold mine would be the largest in the eastern United States and affect approximately 450 ha (1,100 ac) of wetlands near Kershaw, South Carolina, about 84 km (52 mi) northeast of Congaree National Park (Fretwell 2014). The potential impact to the park would be surface water contamination from cyanide and other toxins leaking from tailing ponds. The parks biogeomorphology may also be affected (see Biogeomorphology section; David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 17 September 2014) The Army Corps of Engineers is currently reviewing the environmental impact statement for this proposed development and is expected to make a decision regarding the mine in 2014 (Fretwell 2014).

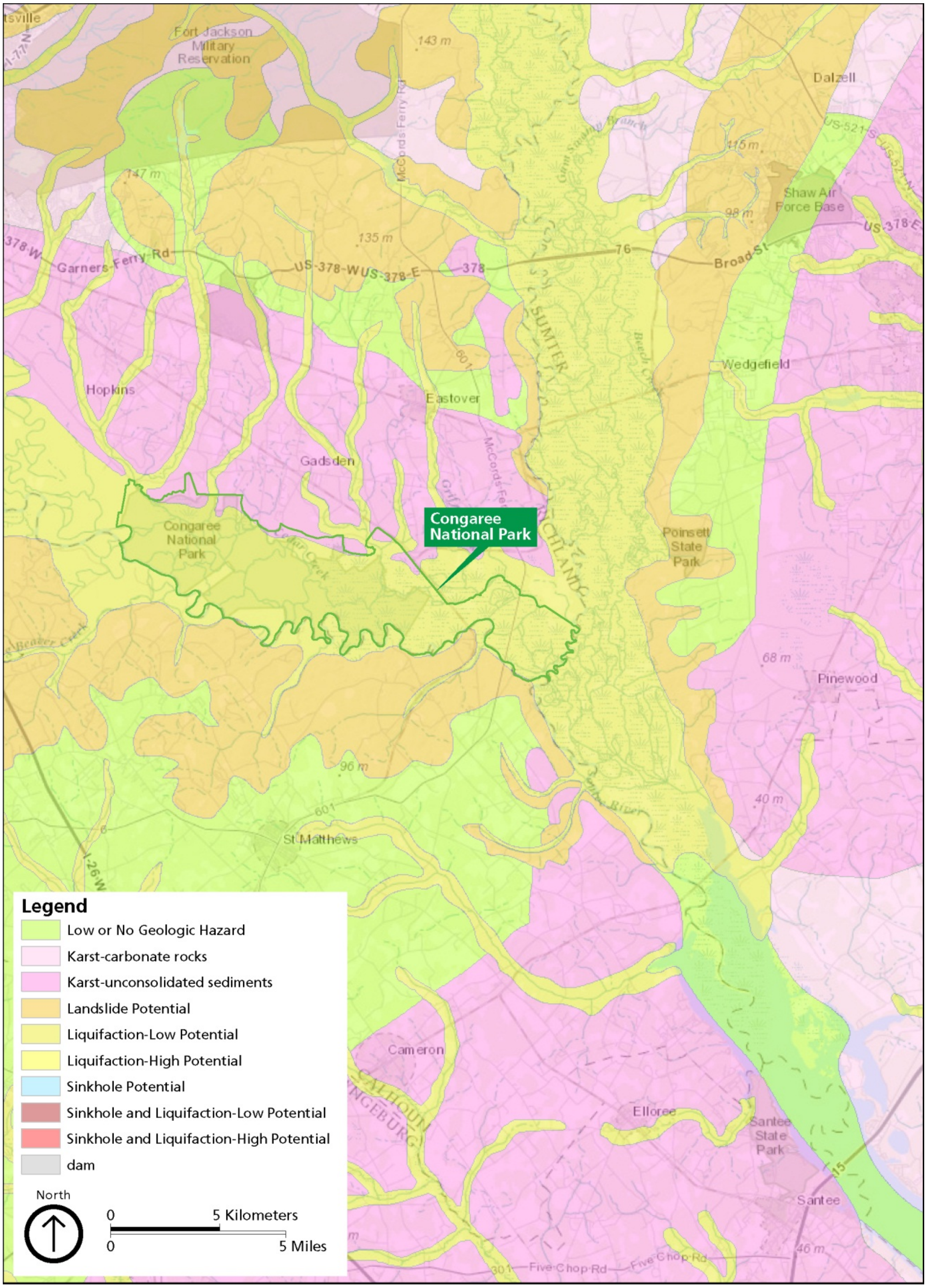

Figure 16. Map of geologic hazards in the Coastal Plain of South Carolina. Congaree National Park (boundary in green) lies in a region of liquefaction potential (yellow shading) and the southern bluffs have a potential for landslides (orange shading). Graphic by Jason Kenworthy (NPS Geologic Resources Division), using hazard data from South Carolina Department of Natural Resources and South Carolina Emergency Management Division (2012), available at http://www.dnr.sc.gov/geology/Pubs/GGMS/GGMS5.pdf (accessed 29 January 2014). Topographic map is Esri World Topo Map baselayer (accessed 3 September 2014) with information from: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community.

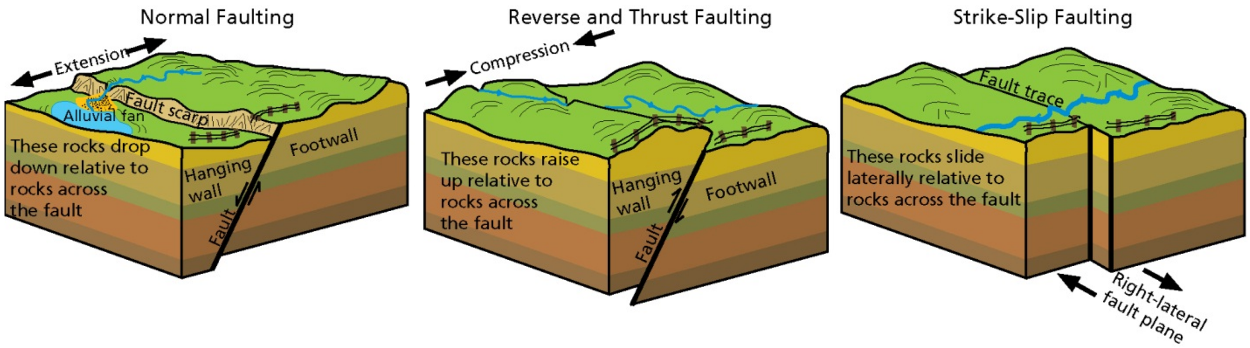

Figure 17. Schematic illustrations of fault types. Movement occurs along a fault plane. Footwalls are below the fault plane and hanging walls are above it. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging wall up relative to the footwall. A thrust fault is similar to a reverse fault, but has a dip angle of less than 45°. In a strike-slip fault, the relative direction of movement of the opposing plate is lateral. When movement across the fault is to the right, it is a right-lateral (dextral) fault, as illustrated above. When movement is to the left, it is a left-lateral (sinistral) fault. A strike-slip fault between two plate boundaries is called a transform fault. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

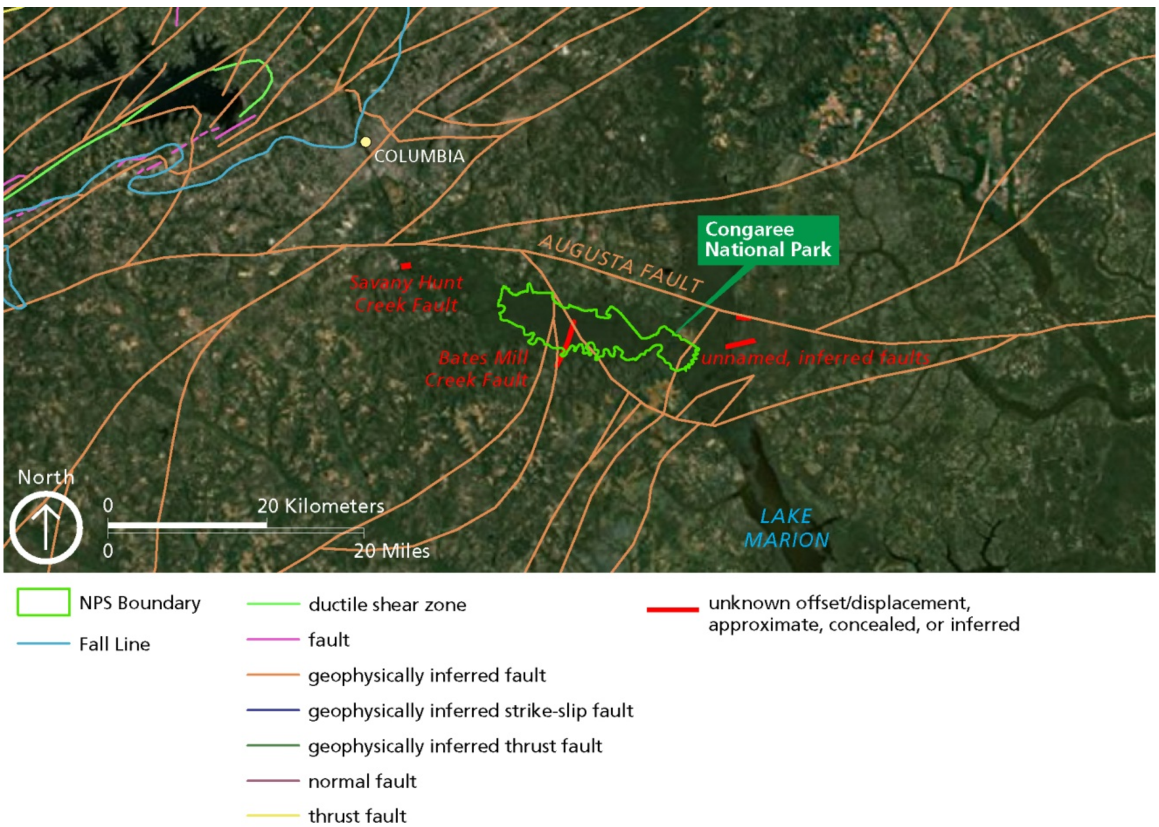

Figure 18. Fault locations, inferred from geophysical data, in the vicinity of Congaree National Park. Graphic compiled by Jason Kenworthy (NPS Geologic Resources Division) using fault information from Maybin and Clendenin (1998), available at http://www.dnr.sc.gov/geology/Pubs/GGMS/GGMS4.pdf (accessed 3 September 2014) and GRI GIS data (red lines; see "Geologic Map Data" section). Aerial imagery is Esri World Imagery basemap (accessed 3 September 2014) with imagery from Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Of greater concern to resource managers at Congaree National Park is the fly-ash storage landfill at the South Carolina Electric and Gas Wateree Station in Eastover, South Carolina, just north of the park (Catawba Riverkeeper Foundation 2010). As reported by Catawba Riverkeeper Foundation (2010), groundwater monitoring around the site recorded levels of arsenic that were 18 times the federal maximum contaminant level of 10 parts per billion. Arsenic contamination has migrated past the Wateree Station boundaries and has accumulated in Wateree River surface waters and fish. Arsenic and other contaminants leaking from the landfill have a significant potential to degrade the park's water quality and the biogeomorphology of the forest ecosystem (David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014). In addition, the landfill is expected to be 46 m (150 ft) tall, which will affect the surrounding viewshed.

Geologic History

This section describes the chronology of geologic events that formed the present landscape of Congaree National Park.

Pleistocene and Holocene deposits form the landscape of Congaree National Park. The oldest rocks in the area are Cretaceous rocks exposed in the southern bluffs, just south of the park. Prior to the Cretaceous, the bedrock of present-day South Carolina was compressed onto the eastern margin of ancestral North America before the opening of the Atlantic Ocean. Table 3 summarizes seven basic phases that shaped the geologic history of central South Carolina (Shelley 2007a; Shelley et al. 2012).

Phase I: Paleozoic Assemblage of Pangaea

The North American continent is an aggregate of older continental land masses. Throughout the Paleozoic (541–252 million years ago), continents collided and fused together to form Laurentia, the proto–North American continent (fig. 19). Along the eastern margin of Laurentia, several orogenies (mountain-building episodes) combined to close the Iapetus (pre-Atlantic) Ocean and form the supercontinent Pangaea (fig. 20; Suppe 1985; Sinha et al. 1989; Bradley 1997; Hoffman 1997). The assembly of Pangaea created a massive Himalayan-like mountain chain along what would become the east coast of North America. It also created zones of weakness that would be exploited later during rifting in the Mesozoic. These zones controlled the deformation of the Piedmont basement below the Coastal Plain of present-day South Carolina (Clendenin et al. 1999).

The northeast–southwest-trending Augusta Fault Zone, which underlies Congaree National Park and the Upper Coastal Plain, was formed during the Paleozoic Era (Hatcher and Odom 1980; Dallmeyer et al. 1986; Barker et al. 1998; Hibbard 2000; Shelley and Cohen 2010; Shelley et al. 2012). The Augusta Fault is a thrust fault that was reactivated as a normal fault during Mesozoic rifting. Movement along the Augusta Fault continued throughout the Mesozoic and into the Late Cenozoic (Nystrom 2006).

Phase II: Early Mesozoic Rifting of Pangaea

By the Early Triassic, all large land masses on the globe had sutured together to form the supercontinent Pangaea (fig. 21). When Pangaea began to split apart approximately 200 million years ago, the region of present-day South Carolina became part of the Atlantic coastline as the Atlantic Ocean opened. By the Cretaceous, the passive continental margin of eastern North America lay far to the east of the rifting North American plate boundary in the Atlantic. As the crust pulled apart and the Gulf of Mexico and Atlantic Ocean opened, the Augusta Fault, a zone of weakness, was

Table 3. Geologic history of central South Carolina.

Phase	Age (oldest to youngest)	Summary of Geologic History
I	Paleozoic	Several terranes accreted to the eastern margin of the North American continent. The Augusta Fault, which underlies the Congaree River Valley, formed.
II	Early Mesozoic	Rifting of the eastern margin of North America occurred as the Atlantic Ocean opens. Basalt flows and red beds accumulated in rift basins.
III	Late Cretaceous–Middle Eocene	Upper Coastal Plain strata were deposited. Generation of fault zones, arches, and basins would complicate the understanding of the region's deformation.
IV	Late Eocene–Miocene	Uplift of the region led to weathering and erosion, as well as scattered fluvial deposits.
V	Pliocene–Pleistocene	The Orangeburg Scarp and Middle Coastal Plain terraces formed. Formation of the Congaree River Valley Terrace Complex. The Carolina bays began to form. Subtle uplift continued. Global cycles of glaciation began and influenced relative sea-level change.
VI	Late Pleistocne–Holocene	Formation of the modern Congaree River Floodplain. The Surry Scarp and Lower Coastal Plain terraces formed. River systems dissected the uplands as the Holocene landscape evolved.
VII	16th Century–Present	Modification of the modern Congaree River Floodplain. Europeans arrived and began land-use practices that led to accelerated erosion rates and impact to the region's hydrology and surface features. Clearcutting, wildlife management, feral hog introduction, and upstream hydrologic alterations continue to impact the region today.

Multiple sources documenting these phases are presented in Shelley et al. (2012, table 1). Additional information from David Shelley (NPS Congaree National Park, Education Coordinator, written communication, 17 September 2014).

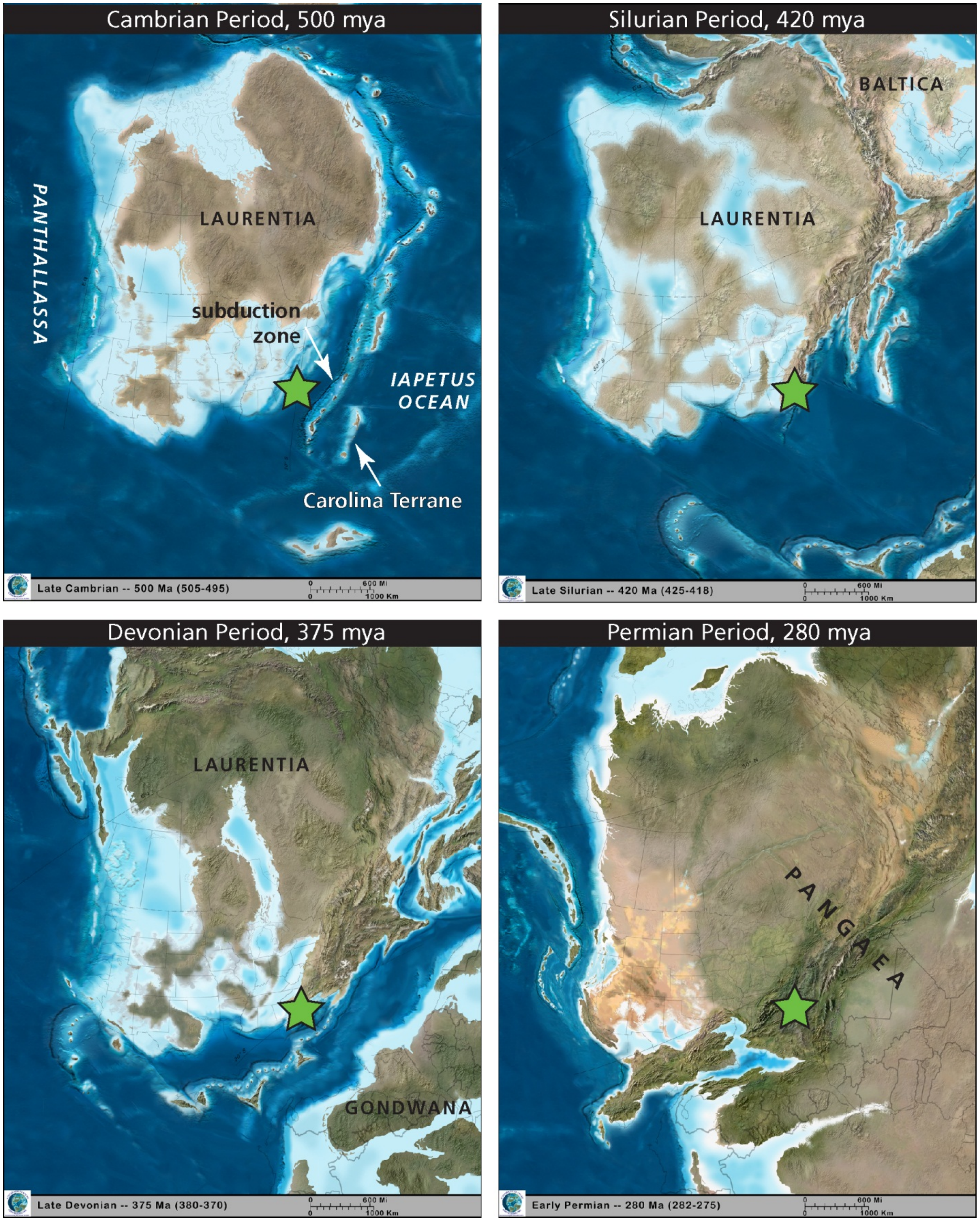

Figure 19. Paleozoic paleogeographic maps of North America. Tectonic collisions on the eastern margin of Laurentia (proto–North America) generated mountain chains that paralleled the coast and added land to the continent. The Avalonian Orogeny is represented by the Late Cambrian map, the Taconic Orogeny by the Late Silurian map, the Acadian Orogeny by the Late Devonian map, and the Alleghenian (Appalachian) Orogeny by the Early Permian map. See text for details. Green stars approximate the present location of Congaree National Park. Mya = million years ago. Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 25 November 2013), and annotated by Jason Kenworthy (NPS Geologic Resources Division).

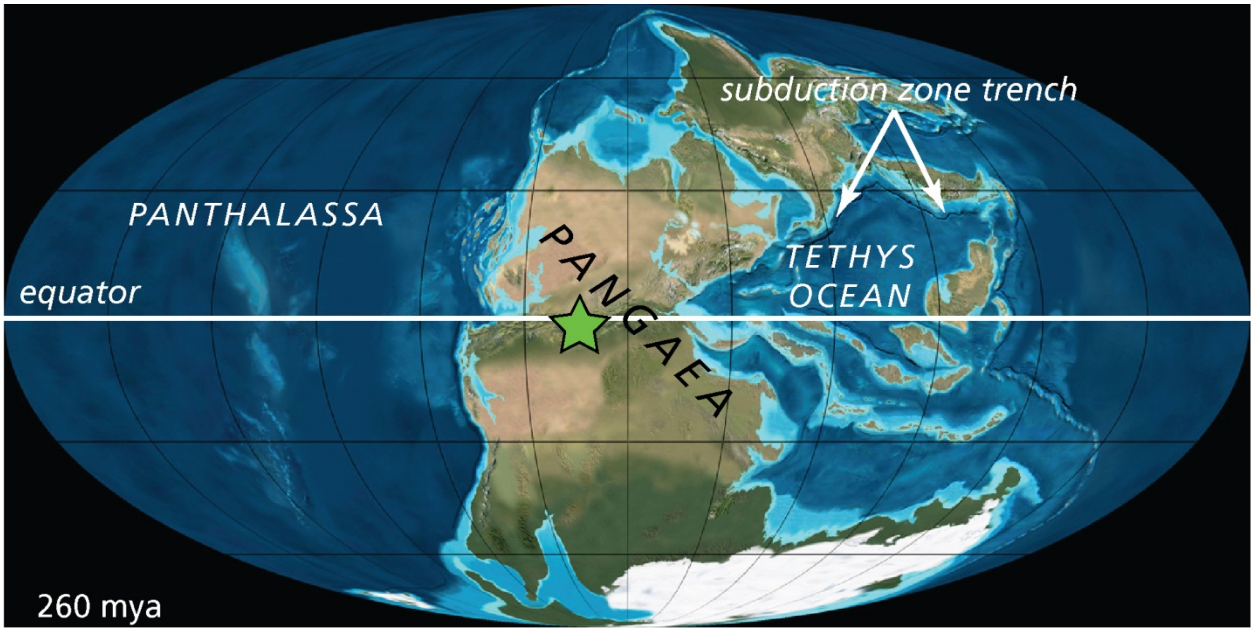

Figure 20. Pangaea. By the end of the Paleozoic, the major global landmasses had sutured together to form the supercontinent Pangaea. Much of Earth's surface was covered by a large ocean called Panthalassa. The green star marks the approximate present-day location of Congaree National Park. Mya = million years ago. Base paleogeographic map created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 25 November 2013), and annotated by Jason Kenworthy (NPS Geologic Resources Division).

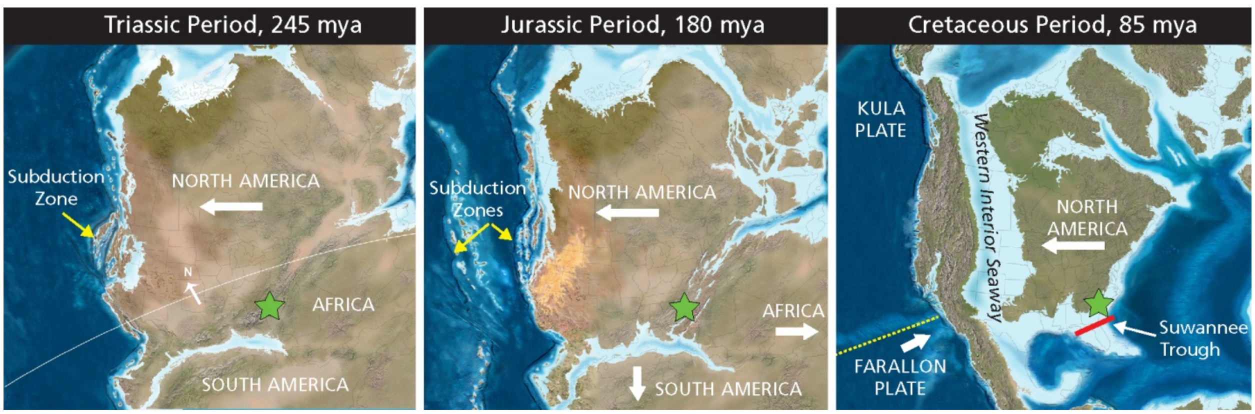

Figure 21. Mesozoic paleogeographic maps of North America. During the Triassic, Pangaea began to split apart and rift basins formed along the eastern seaboard as the Atlantic Ocean began to open and the region of present-day South Carolina became coastal. Green stars mark the approximate present-day location of Congaree National Park. The white line across the Early Triassic graphic represents the approximate location of the equator. White arrows represent the directions of plate movement. Mya = million years ago. Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 25 November 2013), and annotated by Jason Kenworthy (NPS Geologic Resources Division).

reactivated as a normal fault. Extension produced additional fault-bounded rift valleys (called grabens) beneath what is now the Coastal Plain east and south of the park. Eventually, the rift basins filled with as much as 3,500 m (11,000 ft) sediment eroded from the Piedmont and Blue Ridge provinces (fig. 22; Chowns and Williams 1983; Daniels et al. 1983; Clendenin et al. 1999).

Continental extension ended approximately 150 million years ago, during the Late Jurassic, as the North American Plate was pushed farther away from the Atlantic spreading center (Clendenin et al. 1999). As the divergent boundary moved offshore, the high heat flow that accompanies plate tectonic extension decreased. This thermal subsidence (lowering of the land) created more space to accommodate sediment eroded from the highlands (Dewey 1982; Clendenin et al. 1999). As the continental margin subsided, relative sea level rose and the newly formed Atlantic Ocean advanced farther onto the Coastal Plain and deposited marine sediments over a wider area (McKenzie 1978; Dewey 1982; Clendenin et al. 1999).

Phase III: Upper Cretaceous to Middle Eocene Growth of the Coastal Plain

Upper Cretaceous (fig. 21) sediments on the Coastal Plain represent a range of fluvial, deltaic, and open-shelf depositional environments. Four major regional marine sequences are recorded on the Coastal Plain, with deposition of progressively younger Cretaceous

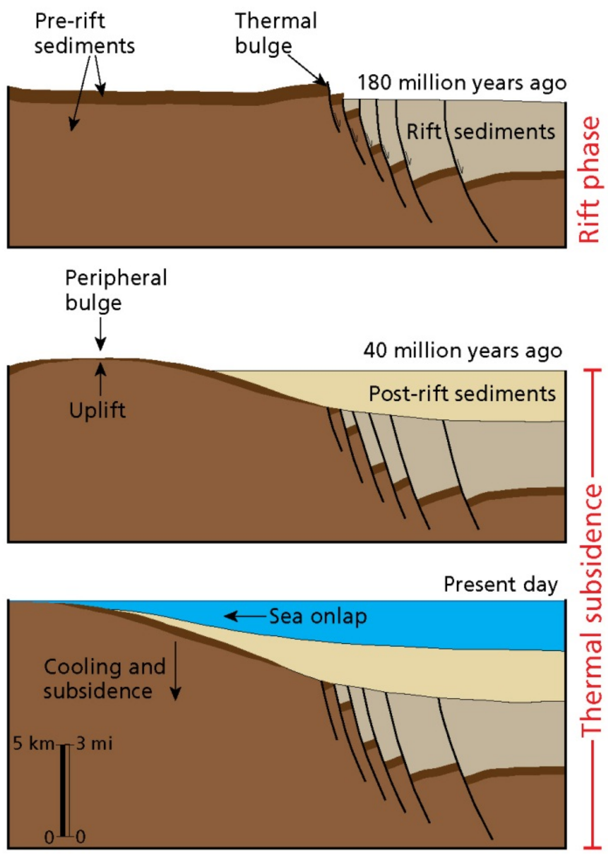

Figure 22. Evolution of the Atlantic coast from rift extension to thermal subsidence. Sediments began to fill rift basins in the Triassic. As the spreading ridge moved offshore, the coastal region subsided, causing relative sea level to rise and onlap the Coastal Plain. Original graphic from Dewey (1982, fig. 17), modified by Trista Thornberry-Ehrlich (Colorado State University).

sediments farther inland (Sohl and Owens 1991; Clendenin et al. 1999). The sand, silt, and clay of the Upper Cretaceous Sawdust Landing Formation (geologic map unit Ksl) represent deposition on the upper portion of a delta that formed along the coastline of present-day South Carolina (Nystrom et al. 1991; Shelley 2007b).

Episodic transgressions and regressions caused the coastline to fluctuate throughout the Upper Cretaceous and into the Paleogene and Neogene. From the Late Cretaceous to the Miocene, the Suwannee Current (also called the Gulf Trough Current), which was the precursor of the Gulf Stream, flowed eastward from the Gulf of Mexico across the region of present-day southern Georgia to South Carolina (Pinet and Popenoe 1985; Popenoe et al. 1987; Murphy 1995; Clendenin et al. 1999).

The Upper Paleocene Lang Syne Formation (Tls) unconformably overlies Upper Cretaceous sediments in the Coastal Plain, but depositional environments in the Paleocene were similar to those in the Cretaceous (Colquhoun and Muthig 1991; Nystrom et al. 1991). The Lang Syne Formation was deposited on the lower portion of a delta.

A major transgression during the Middle Eocene, approximately 50 million years ago, is associated with widespread carbonate and clastic sediments across the Coastal Plain (fig. 23; Willoughby et al. 1999). In the vicinity of Congaree National Park, these sediments include the clastic, sandy deposits of the Congaree Formation (Tc). The quartz sand, glauconite pellets, shark teeth, and mollusks in the Congaree Formation accumulated on a marine shelf adjacent to a coastal highland that provided a major source of sediment (Nystrom et al. 1991). The presence of abundant glauconite pellets in the overlying Warley Hill Formation (Twh) suggests that the unit was deposited below low tide in water depths exceeding 10 m (33 ft) (Porrenga 1967; Nystrom et al. 1991). The shallow marine limestone of the Santee Limestone (Ts), which accumulated above the Warley Hill Formation east and southeast of the park, indicates that the environment in the region of present-day South Carolina was warm, tropical, or subtropical during the Middle Eocene.

Phase IV: Late Eocene to Miocene Landscape

An unconformity separates Middle Eocene units from the Upper Eocene Dry Branch Formation (Tdb) and the Tobacco Road Sand (Ttr; Nystrom et al. 1991). Abundant quartz sand, trace fossils, leaves, shark and ray teeth, corals, oysters, and other mollusk fossils indicate that the units were deposited in marginal marine coastal environments (Nystrom et al. 1991). The distinctive bed of quartz pebbles at the base of the Tobacco Road Sand marks a regional shift from transgression to regression along the southern Atlantic Coastal Plain (Huddlestun and Hetrick 1979; Nystrom et al. 1991; Mazza et al. 2014).

In the Oligocene, glaciers developed on Antarctica, which had drifted into the polar regions, triggering a major global sea-level fall (Eyles 1993; Miall 1997; Clendenin et al. 1999). In the region of present-day South Carolina, sea-level fall (regression) shifted the shoreline at least 200 km (120 mi) to the east-southeast across the Coastal Plain (Harris and Zullo 1991).

Subsequent regressions are regionally recorded in the Early to Middle Miocene, approximately 23 and 14 million years ago, respectively (fig. 23; Miller et al. 1985; Eyles 1993; Clendenin et al. 1999). Enormous amounts of sediment were eroded and spread southward from the Piedmont over the Coastal Plain. Fluvial systems developed, and sand and conglomerate of the Middle Miocene Altamaha Formation (Tal) covered the Congaree National Park region. At this time, the Coastal Plain was tilted seaward (Zoback and Zoback 1981, 1991; Watts et al. 1982; Cloetingh and Kooi 1990; Nystrom et al. 1991). Recent fieldwork in the southern Appalachians supports the occurrence of post-orogenic regional uplift of greater than 150% in the Miocene (Gallen et al. 2013).

Phase V: Pliocene–Pleistocene Formation of the Orangeburg Scarp and Middle Coastal Plain Terraces

A subsequent sea-level rise (transgression) in the Pliocene inundated the Miocene fluvial systems and

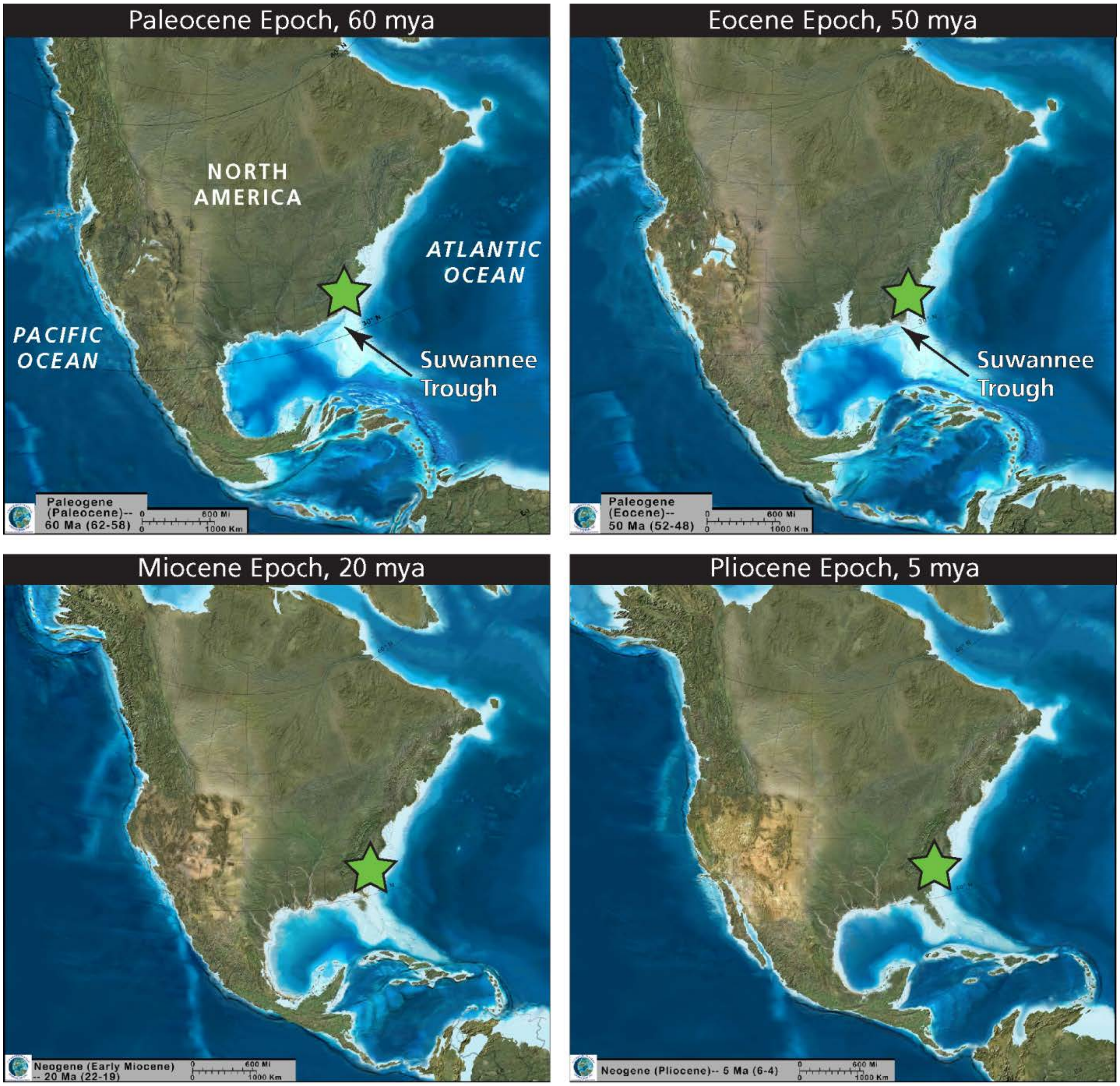

Figure 23. Cenozoic paleogeographic maps of North America. Green stars mark the approximate present-day location Congaree National Park. The location of the Suwannee Trough, which was eliminated in the Miocene, is indicated. Mya = million years ago. Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 25 November 2013), and annotated by Jason Kenworthy (NPS Geologic Resources Division).

established nearshore marine environments only a few miles from the present-day location of the park. The sand and clay of the Duplin Formation (Tdl) record deposition in an estuary formed at the mouth of a river (Shelley 2007b, 2007c, 2007f). Sea level progressively rose sufficiently for waves to cut the Orangeburg Scarp, which marks the inland limit of the Middle Pliocene Atlantic Ocean (Cronin 1981; Murphy 1995; Clendenin et al. 1999; Shelley 2007a). Approximately 13 km (8 mi) north of the park, the Orangeburg Scarp locally trends southwest, parallel to the Congaree River, indicating that the Congaree River Valley was a physiographic embayment during the Pliocene.

The CRVTC (Tt12–Tt13) developed following the maximum Pliocene sea-level rise and subsequent glacial–interglacial fluctuations. As sea level dropped, the Congaree River incised the Coastal Plain, creating the CRVTC. Southeast of the park, fluctuating sea level produced at least 10 depositional sequences that record episodic cycles of sea-level rise followed by sea-level fall through the Pliocene (Colquhoun 1974; Soller and Mills 1991; Clendenin et al. 1999).

Approximately 5 million years ago, at the beginning of the Pliocene, the Isthmus of Panama formed and separated the Atlantic from the Pacific Ocean (Keigwin 1978; Clendenin et al. 1999). This new barrier changed the directions and intensities of ocean currents. The collision of India with Eurasia, which began in the Middle Miocene, continued to uplift the Himalayan Mountains, causing regional cooling of the Northern

Hemisphere. These events helped to trigger Northern Hemisphere glaciation in the Middle Pliocene and Pleistocene.

Fossil pollen suggests that the Coastal Plain was cooler and drier than presently during the Pleistocene ice ages (Prentice et al. 1991; Leigh et al. 2004; Shelley 2007a). An open savanna environment developed in the region of today's Congaree National Park, and boreal forests grew in higher elevations (Jackson and Whitehead 1993; Cohen et al. 2004; Shelley 2007a). The transition to the Holocene was marked by climate and sea-level shifts. Precipitation increased after 18,000 years ago, and sea level rose dramatically by about 17,000–15,000 years ago when the Laurentide Ice Sheet melted (Colquhoun 1995; Shelley 2007a). River systems during the Pleistocene alternated between braided systems chocked with sediment and single-thread systems like the modern Congaree. Both types of deposit are found in the CRVTC. The braided systems seem to be associated with full glacial conditions, and the single-thread systems seem to be associated with interglacials, but the driving mechanisms are still being explored (Leigh et al. 2004; Leigh 2006). For example, regional braided stream systems began to change to meandering river systems by around 17,000 years ago, during the last glacial–interglacial transition; by 14,000–12,000 years ago, the meandering patterns of modern rivers in the southeastern Coastal Plain had been established (Leigh et al. 2004; Leigh 2006; Shelley 2007a).

Phase VI: Late Pleistocene–Holocene Landscape

Continued tilting of the Coastal Plain brought subtle changes to the landscape. Rivers dissected the uplands, and asymmetrical valleys formed as river channels were deflected to the southeast (Clendenin et al. 1999). Incision by the Congaree and Wateree rivers continued to develop terrace complexes on the Coastal Plain (Qt1–Qt11b and Qtw1–Qtw2).

Approximately 8,500–8,000 years ago, the generally dry climate of the Coastal Plain began to transition to a wetter climate (Colquhoun 1995; Colquhoun et al. 1995; Cohen et al. 2006; Shelley 2007a). Wetlands expanded and shallow depressions flooded. The alluvial fan complex in the Congaree River floodplain (Qaf) may have formed at this time (Shelley 2007a). Throughout the Holocene, aeolian sand (Qe) and alluvium (Qa) were deposited on the Coastal Plain. About 6,000 years ago, modern estuaries and floodplains began to form near the coast. Groundwater rimswamps (Qfw) in the Congaree River floodplain began forming at or before about 4,000 years ago (Cohen et al. 2005b; Shelley 2007a; David Shelley, NPS Congaree National Park, Education Coordinator, written communication, 26 June 2014).

Permanently flooded conditions became periodically flooded conditions from 5,000 to 3,000 years ago in the region of present-day South Carolina (Brooks et al. 1986, 1996; Brooks and Sassaman 1990; Cohen et al. 2004, 2005b, 2006). The region returned to a wetter climate from 3,000 to 1,000 years ago, which may have coincided with sea level stabilization (Hussey 1993; Shelley 2007a). Approximately 1,000 years ago, regional conditions became drier (Hussey 1993).

Phase VII: Holocene Anthropogenic Impacts

Humans have used the Congaree River Valley for thousands of years. Since Europeans began arriving in the 16th century, however, the landscape has been significantly altered (Shelley 2007a). Activities associated with the timber industry, agriculture, and urbanization have changed the landscape, increased sedimentation rates, and altered upstream groundwater and surface water flow. Once-clear Piedmont rivers are now "brown water" rivers (see inside cover, Shelley et al. 2012).

Today, Congaree National Park preserves a portion of pristine floodplain character and includes roughly 4,500 ha (11,000 ac) of true old-growth forest. This swamp-cypress and broadleaf forest provides a modern analog for the similar Early–Middle Eocene vegetation that is found today in the Canadian Arctic (Eberle and Greenwood 2012).

Geologic Map Data

This section summarizes the geologic map data available for Congaree National Park. A poster (in pocket) displays the map data draped over imagery of the park and surrounding area. The Map Unit Properties Table (in pocket) summarizes this report's content for each geologic map unit. Complete GIS data are included on the accompanying CD and are also available at the GRI publications website: http://go.nps.gov/gripubs.

Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, these maps portray the spatial distribution and temporal relationships of rocks and unconsolidated deposits. Geologic maps can be divided into two primary types: surficial and bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type.

Geologic maps often depict geomorphic features, structural interpretations (such as faults or folds), and locations of past geologic hazards that may be susceptible to future activity. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website, http://www.agiweb.org/environment/publications/mapping/index.html, provides more information about geologic maps and their uses.

Source Maps

The GRI team digitizes paper maps and converts digital data to conform to the GRI GIS data model. The GRI digital geologic map product includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, references, and figures. The GRI team used the following sources to produce the digital geologic data set for Congaree National Park. These sources also provided information for this report.

Meitzen, K. M., C. S. Howard, and P. G. Nystrom. 2009. Geologic map of the Poinsett State Park 7.5-minute quadrangle. Geologic quadrangle map GQM-46 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Nystrom, P., 2009. Geologic map of the Wedgefield 7.5-minute quadrangle, South Carolina. Geologic quadrangle map GQM-47 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Shelley, D. C. 2007b. Geologic map of the Congaree 7.5-minute quadrangle. Geologic quadrangle map GQM-31 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Shelley, D. C. 2007c. Geologic map of the Eastover 7.5-minute quadrangle. Geologic quadrangle map GQM-30 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Shelley, D. C. 2007d. Geologic map of the Gadsden 7.5-minute quadrangle, Calhoun and Richland counties, South Carolina. Geologic quadrangle map GQM-37 (scale 1:24,000). South Carolina Department of Natural Resources Geological Survey, Columbia, South Carolina.

Shelley, D. C. 2007e. Geologic map of the Saylors Lake 7.5-minute quadrangle, Calhoun, Lexington, and Richland counties, South Carolina. Geologic quadrangle map GQM-38 (scale 1:24,000). South Carolina Department of Natural Resources Geological Survey, Columbia, South Carolina.

Shelley, D. C. 2007f. Geologic map of the Wateree 7.5-minute quadrangle, Lexington, Richland, and Sumter counties, South Carolina. Geologic quadrangle map GQM-36 (scale 1:24,000). South Carolina Department of Natural Resources Geological Survey, Columbia, South Carolina.

Willoughby, R. H. 2003a. Geologic map of the Fort Motte 7.5-minute quadrangle. Geologic quadrangle map GQM-10 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Willoughby, R. H. 2004. Geologic map of the Lone Star 7.5-minute quadrangle. Geologic quadrangle map GQM-15 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

Willoughby, R. H. 2003b. Geologic map of the Elloree 7.5-minute quadrangle. Geologic quadrangle map GQM-27 (scale 1:24,000). South Carolina Geological Survey, Columbia, South Carolina.

GRI GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available at http://science.nature.nps.gov/im/inventory/geology/Geo logyGISDataModel.cfm. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Congaree National Park using data model version 2.1. The GRI Geologic Maps website, http://www.nature.nps.gov/geology/inventory/geo_maps.cfm, provides more information about GRI map products.

GRI digital geologic data are included on the attached CD and are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Search?SearchType=Q). Enter "GRI" as the search text and select a park from the unit list.

The following components are part of the data set:

- A GIS readme file (PDF) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information.
- Data in ESRI geodatabase GIS format
- Layer files with feature symbology (table 4)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- An ancillary map information document (PDF) that contains information captured from source maps, such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures
- An ESRI map document (.mxd) that displays the digital geologic data
- A KML/KMZ version of the data viewable in Google Earth (table 4).

Table 4. Geology data layers in the Congaree National Park GIS data.

Data Layer	Data Layer Code	On Poster?	Google Earth Layer?
Geologic Cross-Section Lines	SEC	No	No
Geologic Observation Localities	GOL	No	No
Mine Point Features	MIN	No	No
Observation, Observed Extent, and Trend Lines (floodplain confluence)	LIN	Yes	Yes
Geologic Line Features (escarpments)	GLF	Yes	Yes
Map Symbology	SYM	Yes	No
Faults	FLT	Yes	Yes
Mine Area Feature Boundaries	MAFA	Yes	Yes
Mine Area Features	MAF	Yes	Yes
Geologic Contacts	GLGA	Yes	Yes
Geologic Units	GLG	Yes	Yes

GRI Map Poster

A poster of the GRI digital geologic data draped over aerial imagery of the park and surrounding area is included with this report. Not all GIS feature classes are included on the poster (table 4). 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 set, but are available online from a variety of sources. Contact GRI for assistance in locating these data.

Map Unit Properties Table

The Map Unit Properties Table lists the geologic time division, symbol, and a simplified description for each of the geologic map units in the GRI GIS data. Following the structure of the report, the table summarizes the geologic features, processes, resource management issues, and history associated with each map unit.

Use Constraints

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

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

Glossary

This section contains brief definitions of selected geologic terms relevant to this report. Definitions are based on those in the American Geosciences Institute Glossary of Geology *(5th edition; 2005). Additional terms are defined at http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

absolute age. The geologic age of a fossil, rock, feature, or event in years; commonly refers to radiometrically determined ages.

active margin. A tectonically active margin where lithospheric plates come together (convergent boundary), pull apart (divergent boundary), or slide past one another (transform boundary). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism. Compare with "passive margin."

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountainous area into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

asthenosphere. Earth's relatively weak layer or shell below the rigid lithosphere.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

batture. An elevated part of a riverbed, formed by gradual accumulation of alluvium, especially the land between low-water stage and a levee along the banks.

braided stream. A sediment-clogged stream that forms multiple channels which divide and rejoin.

carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).

carbonate rock. A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).

clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts).

clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

claystone. Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented, rounded clasts larger than 2 mm (0.08 in).

continental crust. Crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

continental rifting. Process by which a region of crust undergoes extension (pulling apart), resulting in the formation of many related normal faults, and often associated with volcanic activity.

continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths less than 200 m (660 ft).

continental slope. The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

convergent boundary. A plate boundary where two tectonic plates are colliding.

CRFC. Congaree River Floodplain Complex.

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

crust. Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

CRVTC. Congaree River Valley Terrace Complex.

cutbank. A steep, bare slope formed by lateral erosion of a stream.

deformation. A general term for the processes of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

delta. A sediment wedge deposited where a stream flows into a lake or sea.

diabase. An intrusive igneous rock consisting primarily of the minerals labradorite and pyroxene.

dike. A narrow igneous intrusion that cuts across bedding planes or other geologic structures.

divergent boundary. An active boundary where tectonic plates are moving apart (e.g., a spreading ridge or continental rift zone).

downcutting. Stream erosion process in which the cutting is directed in primarily downward, as opposed to lateral erosion.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

eolian. Describes materials formed, eroded, or deposited by or related to the action of the wind. Also spelled "Aeolian."

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

escarpment. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement. Also called a "scarp."

estuary. The seaward end or tidal mouth of a river where freshwater and seawater mix; many estuaries are drowned river valleys caused by sea-level rise (transgression) or coastal subsidence.

eustatic. Relates to simultaneous worldwide rise or fall of sea level.

extension. A type of strain resulting from forces "pulling apart." Opposite of compression.

extrusive. Describes molten (igneous) material that has erupted onto Earth's surface.

fault. A break in rock along which relative movement has occurred between the two sides.

feldspar. A group of abundant (more than 60% of Earth's crust), light-colored to translucent silicate minerals found in all types of rocks. Usually white and gray to pink. May contain potassium, sodium, calcium, barium, rubidium, and strontium along with aluminum, silica, and oxygen.

floodplain. The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.

footwall. The mass of rock beneath a fault surface (also see "hanging wall").

formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.

glauconite. A green mineral, closely related to the micas. It is an indicator of very slow sedimentation.

graben. A down-dropped structural block bounded by steeply dipping, normal faults (also see "horst").

granule. A rock fragment larger than a very coarse sand grain and smaller than a pebble, or a size between that of the head of a small wooden match and that of a small pea, being somewhat rounded or otherwise modified by abrasion in the course of transport.

hanging wall. The mass of rock above a fault surface (also see "footwall").

incision. The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.

kaolinite. A common clay mineral with a high aluminum oxide content and white color.

limestone. A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

liquefaction. The transformation of loosely packed sediment into a more tightly packed fluid mass.

lithology. The physical description or classification of a rock or rock unit based on characters such as its color, mineral composition, and grain size.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50 to 100 km (31 to 62 miles) thick, that encompasses the crust and uppermost mantle.

magma. Molten rock beneath Earth's surface capable of intrusion and extrusion.

meander. Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

member. A lithostratigraphic unit with definable contacts; a member subdivides a formation.

metamorphic. Describes the process of metamorphism or its results. One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

mid-ocean ridge. The continuous, generally submarine and volcanically active mountain range that marks the divergent tectonic margin(s) in Earth's oceans.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

overbank deposit. Alluvium deposited outside a stream channel during flooding.

oxbow. A closely looping stream meander resembling the U-shaped frame embracing an ox's neck; having an extreme curvature such that only a neck of land is left between two parts of the stream.

paleogeography. The study, description, and reconstruction of the physical landscape from past geologic periods.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

parabolic dune. Crescent-shaped dune with horns or arms that point upwind.

passive margin. A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America (compare to "active margin").

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

piedmont. An area, plain, slope, glacier, or other feature at the base of a mountain.

plagioclase. An important rock-forming group of feldspar minerals.

plate tectonics. The concept that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid asthenosphere.

pluvial. Describes geologic processes or features resulting from rain.

point bar. A low ridge of sand and gravel deposited in a stream channel on the inside of a meander where flow velocity slows.

potassium feldspar. A feldspar mineral rich in potassium (e.g., orthoclase, microcline, sanidine, adularia).

pull-apart basin. A topographic depression created by an extensional bend or extensional overstep along a strike-slip fault.

radiometric age. An age expressed in years and calculated from the quantitative determination of radioactive elements and their decay products.

regression. A long-term seaward retreat of the shoreline related to a relative drop in sea level.

reverse fault. A contractional high-angle (greater than 45°) dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").

rift. A region of crust where extension results in formation of many related normal faults, often associated with volcanic activity.

rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

scarp. A steep cliff or topographic step resulting from displacement on a fault, or by mass movement, or erosion. Also called an "escarpment."

seafloor spreading. The process by which tectonic plates pull apart and new lithosphere is created at oceanic ridges.

sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

sill. An igneous intrusion that is of the same orientation as the surrounding rock.

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

spreading center. A divergent boundary where two lithospheric plates are spreading apart. It is a source of new crustal material.

spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow in a clearly confined channel.

stream channel. A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

stream terrace. Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault. Said to be "sinistral" (left-lateral) if relative motion of the block opposite the observer appears to be to the left. "Dextral" (right-lateral) describes relative motion to the right.

structural geology. The branch of geology that deals with the description, representation, and analysis of structures, chiefly on a moderate to small scale. The subject is similar to tectonics, but the latter is generally used for the broader regional or historical phases.

structure. The attitude and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusions.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

subsidence. The gradual sinking or depression of part of Earth's surface.

suture. The linear zone where two continental landmasses become joined via obduction.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

terrace. A relatively level bench or step-like surface breaking the continuity of a slope (also see "stream terrace").

terrane. A large region or group of rocks with similar geology, age, or structural style.

thrust fault. A contractional dip-slip fault with a shallowly dipping fault surface (less than 45°) where the hanging wall moves up and over relative to the footwall.

transgression. A long-term landward migration of the shoreline related to a relative rise in sea level.

unconformity. An erosional or non-depositional surface bounded on one or both sides by sedimentary strata. An unconformity marks a period of missing time.

undercutting. The removal of material at the base of a steep slope or cliff or other exposed rock by the erosive action of falling or running water (such as a meandering stream), of sand-laden wind in the desert, or of waves along the coast.

underfit stream. A stream that appears to be too small to have eroded the valley in which it flows; a stream whose whole volume is greatly reduced or whose meanders show a pronounced shrinkage in radius.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

volcanic. Describes anything related to volcanoes. Can refer to igneous rock crystallized at or near Earth's surface (e.g., lava).

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Additional References

This section lists additional references, resources, and websites that may be of use to resource managers. Web addresses are valid as of September 2014. Refer to the appendix for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

NPS Geologic Resources Division (Lakewood, Colorado): http://nature.nps.gov/geology/

NPS Geologic Resources Inventory: http://www.nature.nps.gov/geology/inventory/index.cfm

NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://www.nature.nps.gov/geology/gip/index.cfm

NPS Views program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://www.nature.nps.gov/views/

NPS Resource Management Guidance and Documents

1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf

Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html

NPS-75: Natural resource inventory and monitoring guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural resource management reference manual #77: http://www.nature.nps.gov/Rm77/

Geologic monitoring manual (Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado): http://nature.nps.gov/geology/monitoring/index.cfm

NPS Technical Information Center (TIC; Denver, Colorado; repository for technical documents): http://www.nps.gov/dsc/technicalinfocenter.htm

Climate Change Resources

NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm

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

Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Geological Surveys and Societies

South Carolina Geological Survey http://www.dnr.sc.gov/geology/

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.agiweb.org/

Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

National geologic map database (NGMDB): http://ngmdb.usgs.gov/

Geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/

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

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

Tapestry of time and terrain (descriptions of physiographic provinces): http://tapestry.usgs.gov/Default.html

Appendix: Geologic Resource Laws, Regulations, and Policies

The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to National Park Service 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. Information is current as of September 2014. Contact the NPS Geologic Resources Division for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC § 5937** 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. Regulations in association with 2009 PRPA are being finalized (May 2014).	**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.
Rocks and Minerals	**NPS Organic Act**, **16 USC § 1 *et seq.*** directs the NPS to conserve all resources in parks (including 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 CFR § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 CFR § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 CFR § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, or 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.
Nonfederal minerals other than oil and gas	**NPS Organic Act, 16 USC §§ 1 and 3** **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.	**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**. **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.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1** and **5**.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Exception:** 16 USC §90c 1(b) the non-wilderness portion of Lake Chelan National Recreation Area, where sand, rock and gravel may be made available for sale to the residents of Stehekin for local use as long as such 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.

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.

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).

NPS 178/126781, October 2014

National Park Service
US Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™

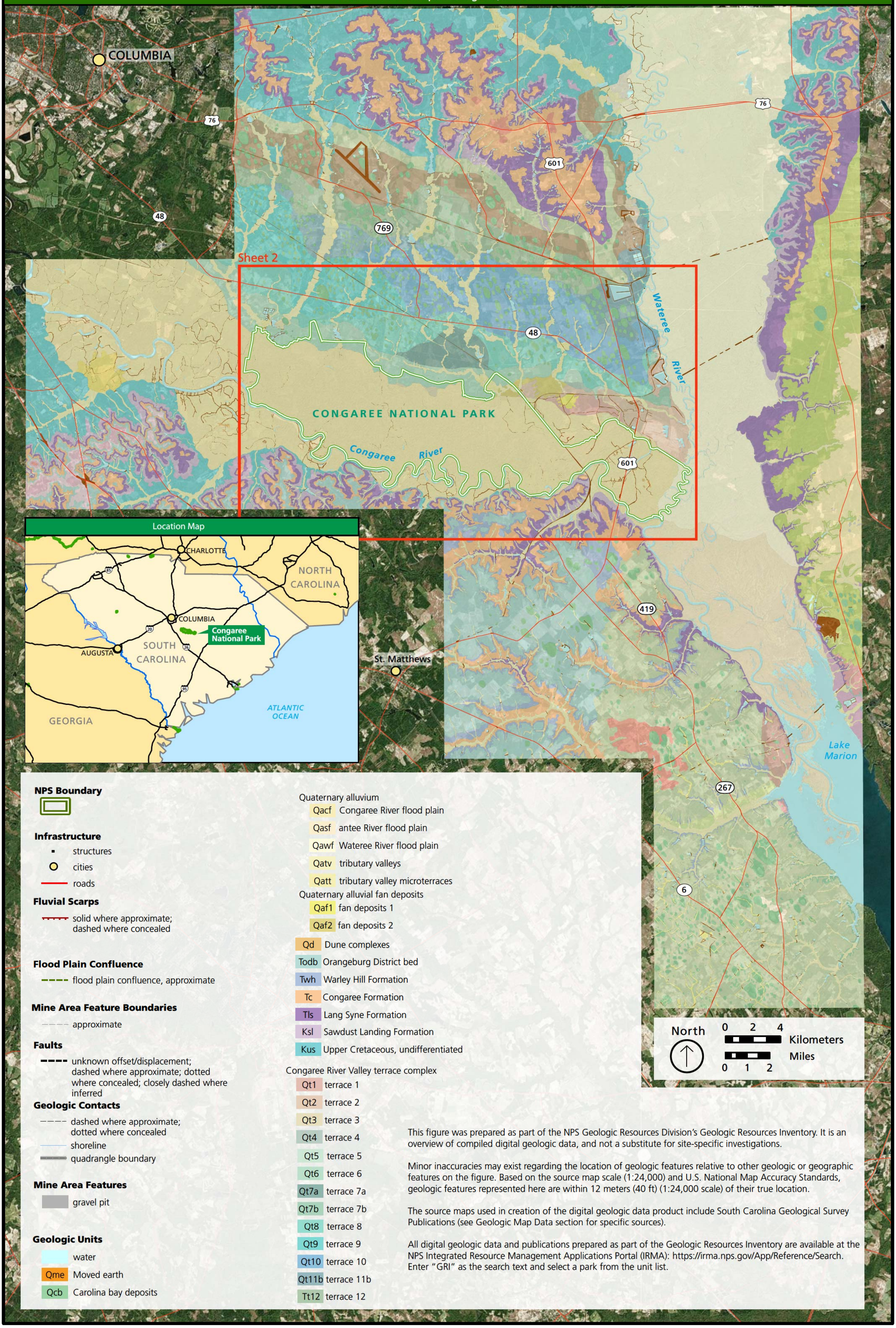
Geologic Map of Congaree National Park

South Carolina

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

Sheet 1: Extent Map and Legend, Area of Detail in Red



This figure was prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. It is an overview of compiled digital geologic data, and not a substitute for site-specific investigations.

Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the figure. Based on the source map scale (1:24,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 12 meters (40 ft) (1:24,000 scale) of their true location.

The source maps used in creation of the digital geologic data product include South Carolina Geological Survey Publications (see Geologic Map Data section for specific sources).

All digital geologic data and publications prepared as part of the Geologic Resources Inventory are available at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. Enter "GRI" as the search text and select a park from the unit list.

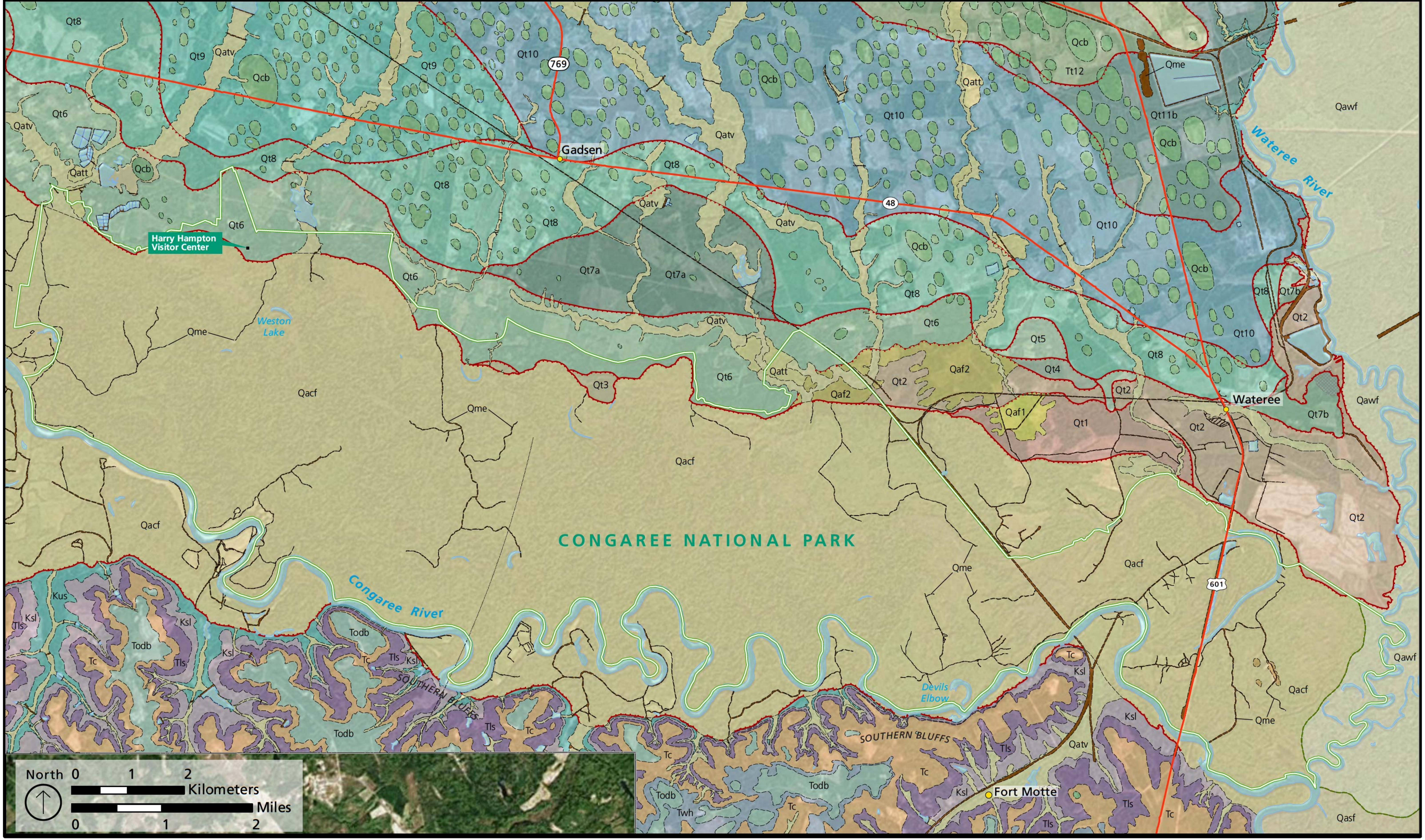
Geologic Map of Congaree National Park

South Carolina

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

Sheet 2: Geology of Congaree National Park



Map Unit Properties Table: Congaree National Park

Colored map units are mapped within Congaree National Park. **Bold text** refers to report sections.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Holocene)	Moved earth (Qme)	Man-made construction material. Includes dams, causeways, embankments, dikes, roads, railroads, and other fill.	Man-made (not geologic) features related to agriculture, urbanization, logging, and other earth moving activities.	**Moved Earth** Construction projects modify the flow of surface water.	**Phase VII: Holocene Anthropogenic Impacts** Human alterations to the landscape.
	Freshwater marsh and swamp deposits (Qfw)	Black, silty clay and peat deposited in stream valleys. Includes silty, clayey, and organic-rich deposits accumulating in man-made drainage ditches. Likely present in the park, although at extents too limited to map at the source map scale.	None documented.	None documented.	**Phase VI: Pleistocene–Holocene Landscape** Development of marsh and swamp deposits. Sand deposited in lakebeds and savannahs.
QUATERNARY (Pleistocene–Holocene)	Sandhills lakebed deposits (Qslk)	White to light-gray quartz sand and gray to black quartz sand in lakebeds or savannahs. Contains clay. Deposits are surrounded by aeolian sand.			
	Carolina bay deposits (Qcb)	Light-gray to black quartz sand and organic-rich peat deposits. Contains clay. Coarser sand and granules rim the bays. Agriculture masks many bays, but their form is recognizable by their topographic depression, orientation, and soil-moisture conditions.	**Carolina Bays** Shallow, elliptical depressions.	Bays are important seasonal depressional wetlands, but the vast majority of bays have been erased by land development. This unit is not mapped in the park, and thus poses no significant resource management issue for park staff.	**Phase VI: Pleistocene–Holocene Landscape** Charcoal fragments indicate the occurrence of fire events during dry periods, whereas peat formed under wet conditions. Most bays began to form during the Wisconsin glaciation (85,000–11,000 years ago), but some may have started to form 100,000–200,000 years ago.
	Eolian sand (Qe)	White to light-tan, moderately sorted, fine- to very coarse-grained quartz sand with negligible clay. In central Fort Motte quadrangle.	None documented.	None documented.	**Phase VI: Pleistocene–Holocene Landscape** Aeolian sand was deposited on the Coastal Plain.
	Eolian sand of East Bethel (Qeeb)	Same lithology as **Qe**. Overlies the Duplin Formation (**Td**). Up to 6 m (20 ft) thick.			
	Eolian sand of Manchester State Forest (Qem)	Same lithology as **Qe**. Overlies **Td** and is overlain by modern alluvium and **Qfw**. Up to 11 m (35 ft) thick. Ranges from 3 to 6 m (10–20 ft) thick in southeastern Poinsett Park quadrangle.			
	Alluvium, Congaree River floodplain (Qacf)	Light-tan to dark-brown, fine- to very coarse-grained sand, silt, clay, and organic-rich peat deposits. Similar in composition and texture to **Qasf** and **Qawf**.	**Congaree River Floodplain Complex** Consists of a complex array of intra-floodplain terraces, meander belts, alluvial fans, dune fields, and rimswamps. Floodplain may also contain infilled abandoned channels, floodplain streams, natural levee deposits, and back swamps. **Congaree River Channel** The Congaree River meanders across **Qacf**, forming sinuous loops and curves. **Tributary Channel Features** Tributaries to the Congaree River flow across **Qacf**. Fluvial processes and features are similar to those associated with the Congaree River. **Rimswamps** Seepage wetlands found in units **Qacf** and **Qawf**. **Oxbow Lakes** Cutoff meander loop that fills with water and sediment. Weston Lake and Devils Elbow are oxbow lakes.	**Flooding** About 10 floods occur annually in the park. Floods may inundate boardwalks, but they also provide necessary nutrients and water to floodplain habitats. **Climate Change** Global climate change is expected to increase the frequency and intensity of drought in South Carolina, which may impact groundwater flow. Flooding may increase due to increased hurricane activity. **Groundwater Hydrology** Groundwater is critical for maintaining the park's wetlands, oxbow lakes, and rimswamps. **Hurricanes** Hurricanes are potential threats to the landscape, sediment, vegetation, and infrastructure of the park. **Earthquakes** The floodplain lies in an area with a low potential for earthquake-caused liquefaction.	**Phase VI: Pleistocene–Holocene Landscape** Landforms in these floodplains represent varied environmental conditions that existed from the Late Pleistocene to the present.
	Alluvium, Wateree River floodplain (Qawf)	Fine- to very coarse-grained, light-tan to dark-brown sand, silt, clay, and organic-rich peat deposits. Alluvium is 20 m (66 ft) thick in drill hole 43-167 and overlies a stiff gray Cretaceous clay.			
	Alluvium, Santee River floodplain (Qasf)	Lithology similar to **Qacf** and **Qawf**. The Santee River floodplain begins at the confluence of the Congaree and Wateree rivers, which shifts with flooding events.	None documented.	None documented.	**Phase VI: Pleistocene–Holocene Landscape** Late Pleistocene dates for similar tributaries in the Savannah River Valley are assumed to be applicable in the Congaree River Valley.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Pleistocene–Holocene)	Alluvium, tributary valleys (Qatv)	Small stream valleys containing saturated brown, red, and black sand and clay. Active streambeds contain sand, gravel, and cobbles. May include a series of 2–3 moderately preserved fluvial terraces.	**Tributary Channel Features** Tributaries to the Congaree River flow across **Qacf**. Fluvial processes and features are similar to those associated with the Congaree River. Tributary channel beds primarily contain coarse, recycled Pliocene–Pleistocene sand transported from the terrace complex.	**Flooding** About 10 floods occur annually in the park. During floods events the lower portions of tributary channels may receive water, sediment, and coarse woody debris from the Congaree River. Floods may inundate microterraces. **Climate Change** Global climate change is expected to increase drought in South Carolina, which may impact groundwater flow. Flooding may increase due to increased hurricane activity. **Groundwater Hydrology** Groundwater is critical for maintaining the park's wetlands, oxbow lakes, and rimswamps. **Hurricanes** Hurricanes are potential threats to the landscape, sediment, vegetation, and infrastructure of the park.	**Phase VI: Pleistocene–Holocene Landscape** Late Pleistocene dates for similar tributaries in the Savannah River Valley are assumed to be applicable in the Congaree River Valley.
	Alluvium, tributary valley microterraces (Qatt)	Blonde to red-brown quartz sand with abundant heavy minerals.	**Congaree River Floodplain Complex** Transition from the Congaree River Floodplain Complex to the Congaree River Valley Terrace Complex. Small, scattered, fragmentary steps between active, swampy tributary valleys and the true upland terrace surface.		**Phase VI: Pleistocene–Holocene Landscape** These features may reflect post–18th century changes in hydrology and sediment supply due to land use, Holocene climate changes, or abandoned, erosional benches, rather than constructional terraces.
	Alluvial fan deposits (Qaf, Qaf1, Qaf2) **Qaf2** is mapped in the park.	**Qaf**: Varicolored, poorly sorted, fine- to very coarse-grained speckled sand with local red, micaceous, silty clay lenses. Up to 5 m (17 ft) thick. **Qaf1**: Fan deposits.	**Alluvial Fans** In the Saylors Lake quadrangle, at least two fining-upward sequences suggest lobe switching.	**Flooding** Floods may inundate subtle alluvial fans. **Climate Change** Flooding may increase due to increased hurricane activity resulting from global climate change. **Hurricanes** Hurricanes are potential threats to the landscape, sediment, vegetation, and infrastructure of the park.	**Phase VI: Pleistocene–Holocene Landscape** These fan deposits are similar to robust fans in the lower Mississippi River Valley.
		Qaf2: Fan deposits adjacent to McKenzie Creek in Wateree quadrangle. Up to 1.2 m (4 ft) thick	**Alluvial Fans** Upper fans on Griffin's and McKenzie creeks.		**Phase VI: Pleistocene–Holocene Landscape** Approximately 8,500–8,000 years ago, the generally dry conditions of the Coastal Plain began to shift toward a wetter landscape. Wetlands expanded and shallow depressions flooded. The alluvial fan complex in the Congaree River floodplain (**Qaf**) may have formed at this time.
QUATERNARY (Upper Pleistocene)	Dune complexes (Qd)	Brown, well-sorted sand with locally abundant heavy minerals and very little clay. Consists of three sand dune complexes (Green Hill Mound, Muller's Barn Ridge, and Solomon Island) within **Qacf**.	Vegetated mounds of sand, <9 m (<30 ft) high. The dunes tower above the swampy floodplain.	None documented.	**Phase VI: Pleistocene–Holocene Landscape** Dunes probably formed 15,000–30,000 years ago, although some may be as old as 80,000 years.
	Packs Landing beds (Qpl)	Tannish-orange to light-gray, medium-grained quartz sand and pebbles. Subordinate brown to gray cohesive clay matrix. Beds are 5–11 m (16–37 ft) thick in the subsurface. Unconformably overlie **Ksl** and **Tls** in the Lone Star quadrangle.	None documented.		**Phase VI: Pleistocene–Holocene Landscape** Alluvium of an ancient Santee River terrace was deposited approximately 29,720–23,390 years before present.
QUATERNARY (Pleistocene)	Congaree River Valley Terrace Complex: terraces 1–11b (Qt1–Qt11b)	Series of estuarine to fluvial deposits that are Pliocene (**Tt12**–**Tt13**) to recent (**Qt1**–**Qt11b**) in age. Multiple sequences of white to pink, massive, poorly to moderately sorted, medium- to very coarse-grained sand with interstitial clay grading upward into red clay and sandy clay. Gravel is common at the base, followed by a sheet of sand. Local relief is up to 4.6 m (15 ft). Many younger terraces are concentrated in the lowermost valley. **Qt2**, **Qt3**, **Qt6**, and **Qt8** have been mapped in the park.	**Congaree River Valley Terrace Complex** Fourteen terrace surfaces (the current floodplain is terrace 0). Alluvial, colluvial, aeolian, and groundwater processes have modified terrace surfaces and scarps. Terraces are complex features of various sizes that developed at different times.	**Hurricanes** Hurricanes are potential threats to the landscape, sediment, vegetation, and infrastructure of the park. **Climate Change** Destructive potential of Atlantic hurricanes is expected to increase.	**Phase VI: Pleistocene–Holocene Landscape** Tectonic tilting of the Coastal Plain caused the deflection of rivers to the southeast, generating asymmetrical valleys. The Congaree River incised the Congaree River Valley to produce the terrace complex.
	Wateree River Valley Terrace Complex: terrace 1 (Qtw1, Qtw2)	At least two fragmentary terraces in Wateree River Valley. **Qtw2**: younger Wateree River Valley terraces. **Qtw1**: older Wateree River Valley terraces.	General character and architecture of individual terrace deposits are similar to those in the Congaree River Valley.	None documented.	**Phase VI: Pleistocene–Holocene Landscape** Tilting of the Coastal Plain caused the deflection of rivers to the southeast, generating asymmetrical valleys. The Wateree River incised the Wateree River Valley to produce the terrace complex.
QUATERNARY (Lower Pleistocene)	Wicomico Formation Toney Bay Member (Qwtb)	Varicolored, mottled, partly laminated, medium- to coarse-grained quartz sand in a silt to clay matrix. Layer of coarse-grained quartz sand and pebbles at the base. Unconformably overlies **Tls**, and abuts and unconformably terminates **Qm**. Unconformably overlain by **Qpl**, modern alluvium, and **Qfw**.	None documented.		**Phase V: Pliocene–Pleistocene Formation of the Orangeburg Scarp and Middle Coastal Plain Terraces** The Pleistocene Coastal Plain was cooler and drier than it is today. A braided stream system dominated the Coastal Plain during the Pleistocene. Terraces formed.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Lower Pleistocene)	Fluvial terrace deposits of Halfway Swamp (Qhs)	Varicolored quartz sand; reddish-orange, orange, and tan sandy conglomerate; and brown and gray, sandy clay matrix. Conglomerate is at or near the bases of the deposits. Maximum known thickness is 8.5 m (28 ft). The deposits unconformably overlie **Twh** and **Tc** and are truncated by modern alluvium.	None documented.	None documented.	**Phase V: Pliocene–Pleistocene Formation of the Orangeburg Scarp and Middle Coastal Plain Terraces** The Pleistocene Coastal Plain was cooler and drier than it is today. A braided stream system dominated the Coastal Plain during the Pleistocene. Terraces formed.
	Terrace sediments of Low Falls Landing (Qlf)	Varicolored, cohesive quartz sand, mixed quartz sand and clay, quartz-pebble to feldspar-pebble conglomerate, and minor stiff clay. Unit is more than 3 m (10 ft) thick by the parking lot at Low Falls Landing. The terrace sediments unconformably overlie **Tls**, abut and unconformably terminate **Td**, and are overlain by modern alluvium and **Qfw**.	The Low Falls terrace is a fluvial terrace deposited by Santee River.		
	Marietta unit (Qm)	Varicolored, medium- to very coarse-grained quartz sand with minor amounts of heavy minerals and clay matrix. Abuts **Td** and overlies **Twh** and **Tls**. **Qm** is exposed in a narrow terrace in southeastern Lone Star quadrangle.	None documented.		**Phase V: Pliocene–Pleistocene Formation of the Orangeburg Scarp and Middle Coastal Plain Terraces** Sea level fluctuated throughout the Neogene, causing the shoreline to advance (transgress) and retreat (regress) onto the Coastal Plain. When sea level fell, rivers incised the Coastal Plain, developing the Congaree River Valley Terrace Complex. **Qm** was deposited during a marine transgression.
NEOGENE (Pliocene)	Congaree River Valley Terrace Complex: terraces 12, 13 (Tt12, Tt13)	Terraces 12 and 13 of the Congaree River Valley Terrace Complex are the same as those described above (**Qt1**–**Qt11b**).	**Congaree River Valley Terrace Complex** Fourteen terrace surfaces (the current floodplain is terrace 0). Alluvial, colluvial, aeolian, and groundwater processes have modified terrace surfaces and scarps. Terraces are complex features of various sizes that developed at different times.		
	Duplin Formation (Td)	Directly correlated with **Tt12** and **Tt13**, and bounded upsection by the Orangeburg Scarp, one of the best-preserved scarps in the Coastal Plain and the inland limit of the Middle Coastal Plain.	**Paleontological Resources** Outside of the park, fossils of foraminifera, corals, bryozoans, gastropods, bivalves, scaphopods, chitons, barnacles, ostracodes, echinoids, sharks, reptiles, whales, and terrestrial mammals have been discovered in the Duplin Formation.		**Phase V: Pliocene–Pleistocene Formation of the Orangeburg Scarp and Middle Coastal Plain Terraces** Sea level rose in the early Pliocene, and estuaries formed at the mouths of rivers. **Td** represents deposition in an estuary that formed at an oblique angle to the northeast–southwest-trending Orangeburg Scarp.
	Duplin Formation: Upper part (Tdu)	Red, orange, brown, and yellow, medium-grained quartz sand, quartz granules, and local interstitial clay. Contact with beds of **Tdl** is gradational. Upper contact is abrupt. Overlain by **Qe**, **Qfw**, **Qcb**, **Qm**, or **Qlf**.			
	Duplin Formation: Lower part (Tdl)	Moderately cohesive, dark gray-green, fossiliferous, moderately calcareous clay with abundant shell fragments. May also have well-sorted quartz sand. Overlies **Tls**, **Twh**, or **Todb** in drill holes.			
NEOGENE (Miocene)	Altamaha Formation (Tal)	Red to orange, weathered, heterogeneous, poorly sorted, coarse-grained sand and gravel with abundant interstitial clay and local quartz cobbles. Sand-sized white clay clasts are common and locally give this unit a speckled appearance.	None documented.		**Phase IV: Late Eocene to Miocene Landscape** Sea level fluctuated throughout the Neogene, causing the shoreline to advance (transgress) and retreat (regress) onto the Coastal Plain. Sea level fell during deposition of **Tal**, which represents fluvial conglomerates deposited by braided systems on the Coastal Plain.
PALEOGENE (Eocene)	Tobacco Road Sand (Ttr)	Red, orange, brown, moderately to poorly sorted, fine- to medium-grained, dominantly quartz sand. Pebbles are commonly found at the base. Maximum thickness is approximately 4.9 m (16 ft).			**Phase IV: Late Eocene to Miocene Landscape** Sea level fluctuated throughout the Paleogene, causing the shoreline to advance (transgress) and retreat (regress) onto the Coastal Plain. **Ttr**, **Tdb**, and **Todb** were deposited in marginal marine coastal environments. **Ttr**: Deposited in a nearshore to littoral marine environment. **Tdb**: Represents a transgressive, nearshore shelf deposit. **Todb**: Considered to be a shallow marine deposit.
	Dry Branch Formation (Tdb)	Orange, red, brown, moderately well-sorted, fine- to coarse-grained quartz sand. Rare blue quartz and garnet. Interstitial clay varies from rare to abundant. Very coarse sand and pebbles at the lower contact. Maximum thickness is approximately 4.9 m (16 ft), but thickens to 16 m (52 ft) in Georgia.			
	Orangeburg District bed (Todb)	Red, orange, yellow sand and clay. Quartz grains in clayey sand beds are poorly sorted with granules and scattered pebbles. Contains dark heavy minerals and muscovite flakes that impart a sheen to the smeared sediment. Molluscan fossils occur locally.			

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
PALEOGENE (Eocene)	Santee Limestone (Ts)	Cream to light-tan, moderately indurated, microfossiliferous lime mudstone to wackestone and packstone. Contains the fossil oyster *Cubitostrea sellaeformis* and associated fossils.	None documented.	None documented.	**Phase III: Upper Cretaceous to Middle Eocene Growth of the Coastal Plain** Sea level fluctuated throughout the Paleogene, causing the shoreline to advance (transgress) and retreat (regress) onto the Coastal Plain. In the middle Eocene, a transgression spread marine carbonate and clastic sediments across the Coastal Plain. **Ts** accumulated in a shallow marine environment. **Twh** was deposited below low tide. **Tc** was deposited on a marine shelf.
	Warley Hill Formation (Twh)	Olive-green (fresh) to orange, pale-green, red to dark-brown (weathered), stiff, clayey, fine- to coarse-grained quartz sand. Some clay beds. Includes glauconite pellets and rare occurrences of shark teeth. Color differences are due to the weathering of glauconite. Averages 4.0 m (13 ft) thick.	Black, phosphatic shark teeth. Dark-green glauconite pellets (glauconite occurs only in marine environments).		
	Congaree Formation (Tc)	Varicolored, loose to moderately cohesive, medium-grained quartz sand with local lenses of glauconitic sand, interstitial clay, granules, and weak silica and carbonate cement. Lower part may have burrowed to laminated green claystone with the molluscan bivalve *Anodontia augustana*. The most obvious lithologic contact in the area is the lower contact with the waxy black clay of **Tls.** Incised channels in **Tc** are several meters deep and contain sand, clay, and small [2–3 mm (0.08–0.1 in)] bivalves.	**Southern Bluffs** Upper unit of the strata exposed in the bluffs along the Congaree River. No fossil is identifiable near the park, but the large molluscan bivalve *Anodontia augustana* occurs in parts of Calhoun County, South Carolina, and Alabama. **Paleontological Resources** Microfossils and shell fragments.	**Erosion of the Southern Bluffs** The Congaree River erodes the southern bluffs at an approximate rate of 2.46 m (8.07 ft)/1,000 years. Bluff erosion is an episodic process that includes hillslope processes, river erosion, and slope movement (mass wasting).	
PALEOGENE (Paleocene)	Lang Syne Formation (Tls)	Extremely variable in color (black, red, orange, gray, white, buff, brown) and lithology. Ranges from thin-bedded clay and sand to massive claystone and iron-oxide cemented sandstone. Local trace fossils and silicified shell fragments ("Buyck's Bluff Chert"). Capped by a distinct, cohesive, plastic, waxy, black clay referred to as the "Tavern Creek bed".	**Southern Bluffs** Exposed in the bluffs along the Congaree River. "Buyck's (pronounced 'bikes') Bluff Chert" contains abundant bivalves and turritellid gastropods and was used for projectile points by prehistoric people. Some sand beds contain clay-lined burrows. **Paleontological Resources** Microfossils (palynomorphs).	**Erosion of the Southern Bluffs** The Congaree River erodes the southern bluffs at an approximate rate of 2.46 m (8.07 ft)/1,000 years. Bluff erosion is an episodic process that includes hillslope processes, river erosion, and slope movement (mass wasting). **Potential Mining Impacts** Fuller's earth was mined from **Tls**. Potential impacts on the park are unknown.	**Phase III: Upper Cretaceous to Middle Eocene Growth of the Coastal Plain** Sea level fluctuated throughout the Paleogene and Neogene, causing the shoreline to advance (transgress) and retreat (regress) onto the Coastal Plain. **Tls** represents a lower delta-plain depositional environment. Palynological analysis of black clay samples indicated Late Paleocene (Thanetian) and Early Paleocene (Danian) ages.
CRETACEOUS (Late)	Sawdust Landing Formation (Ksl)	Gray, cream, and orange interbedded sand, conglomerate, and clay. Capped by a distinct, stiff, cohesive, varicolored clay with abundant granules.	**Southern Bluffs** Exposed in the bluffs along the Congaree River. Cross-bedded sand. The clay is a secondary matrix and consists of pale-green illite and smectite (in the upper part), gray to white kaolin, and abundant accessory minerals. **Paleontological Resources** Microfossils (palynomorphs).	**Erosion of the Southern Bluffs** The Congaree River erodes the southern bluffs at an approximate rate of 2.46 m (8.07 ft)/1,000 years. Bluff erosion is an episodic process that includes hillslope processes, river erosion, and slope movement (mass wasting).	**Phase III: Upper Cretaceous to Middle Eocene Growth of the Coastal Plain** By the Late Cretaceous, the Coastal Plain contained fluvial, deltaic, and open-shelf depositional environments. Episodic transgressions and regressions caused the coastline to fluctuate throughout the Upper Cretaceous and into the Paleogene and Neogene. The Suwannee Trough separates South Carolina and Georgia from the offshore continental shelf. **Ksl**: Interpreted as an upper delta plain deposit. **Kus**: Reflects marginal to shallow marine environments and may be correlative with the Cape Fear Formation or the Black Creek Group.
	Upper Cretaceous, undifferentiated (Kus)	White, purple, and red highly weathered clay, sandy clay, clayey sand, sand, and conglomerates with local iron oxide cement.	**Southern Bluffs** Exposed in the bluffs along the Congaree River. Sedimentary structures include ripple marks, cross beds, parallel laminations, and stream channels. Iron oxide–cemented sandstone forms "pipes" at the base of the bluffs and is attributed to recent groundwater/surface water interactions.		