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George Washington Carver National Monument

Geologic Resources Inventory Report

The Boy Carver statue sits on a block of Burlington-Keokuk limestone. The block has been rotated 90 degrees so that the originally horizontal rock layers are nearly vertical. Visitors can observe fossil crinoids, brachiopods, and corals in the block of limestone.

MICHAEL BARTHELMES / COLORADO STATE UNIVERSITY

George Washington Carver National Monument: Geologic resources inventory report

Science Report NPS/SR—2024/201

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Abstract

Geologic Resources Inventory (GRI) reports provide information and resources to help park managers make decisions for visitor safety, the planning and protection of infrastructure, and the preservation of natural and cultural resources. Information in GRI reports may also be useful for interpretation. This report synthesizes discussions from a scoping meeting held in 2011 and a follow-up meeting in 2023. The chapters of this report discuss the geologic heritage, geologic history, geologic features and processes, and geologic resource management issues of George Washington Carver National Monument. Guidance for resource management and information about the previously completed GRI GIS data and poster (separate products) are also provided.

Acknowledgments

The GRI team thanks the participants of the 2011 scoping meeting and 2023 follow-up meeting for their assistance in this inventory. The lists of participants (below) reflect the names and affiliations of those participants at the times of the meetings. Because the GRI team does not conduct original geologic mapping, we are particularly thankful to the Missouri Geological Survey for its maps of the area. This report and accompanying GIS data could not have been completed without them. A big thank you to Doug Gouzie of Missouri State University and Christopher Reed (George Washington Carver National Monument) for their thoughtful and thorough reviews of this report. Thank you to Pat Seiser, Justin Tweet, Tony Gallegos, and Kyle Hinds of the Geologic Resources Division for reviewing sections of this report.

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Executive Summary

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

George Washington Carver National Monument (also referred to as the "monument" throughout this report) preserves the birthplace and childhood home of George Washington Carver, the African American scientist, agronomist, educator, and inventor who became known for his work at the Tuskegee Institute. Carver's diaries and accounts of his life recount the powerful impact that the natural setting of his youth had on his interest in agronomy and general curiosity.

This report is supported by a GRI-compiled map of the geology of the monument. The source map used to compile the GRI geographic information system (GIS) data was completed by the Missouri Geological Survey in 2015.

This report contains the following chapters:

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

Geologic Heritage—This chapter highlights the significant geologic features, landforms, landscapes, and stories of the monument, preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories, such as the landscape's role in George Washington Carver's adolescence and development.

Geologic History—This chapter describes, in the form of a geologic time scale, the chronology of geologic events that formed the present landscape.

Geologic Features, Processes, and Resource Management Issues—This chapter describes the geologic features and processes of significance for the monument and discusses any potential resource management issues associated with those features and processes. Issues include (1) disturbed lands, such as historic lead and zinc mining; (2) fluvial features and processes associated with the Carver Branch and its tributaries; (3) paleontological resources in the building stone; (4) caves and karst features, which manifest as Carver and Williams Springs; (5) eolian features and processes; (6) geothermal features at the visitor center; and (7) a table summarizing risks posed by geologic hazards at the monument.

Guidance for Resource Management—This chapter is a follow up to the “Geologic Features, Processes, and Resource Management Issues” chapter. It provides resource managers with a variety of methods to find and receive management assistance with geologic resources. A summary of laws, regulations, and policies which apply to geologic resources is also provided.

Additional References, Resources, and Websites—This chapter provides a thorough list of additional sources of information (e.g., websites, tools, publications, organizations) that may be useful to further explore the topics presented in this report.

Literature Cited—This is a bibliography of references cited in this GRI report. Many of the cited references are available online, as indicated by an Internet address included as part of the reference citation.

If monument managers are interested in other investigations and/or a broader search of the scientific literature, the NPS Geologic Resources Division has collaborated with—and funded—the NPS Technical Information Center (TIC) to maintain a subscription to GeoRef (the premier online geologic citation database). This database can be accessed by NPS staff through multiple portals. Monument staff may contact the GRI team or the NPS Geologic Resources Division for instructions.

Introduction

The purpose of this report is to familiarize readers with the geologic features, processes, history, and best practices for managing geologic resources for George Washington Carver National Monument (also referred to as the "monument" throughout this report). The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division (GRD) of the National Park Service (NPS) Natural Resource Stewardship and Science Directorate, provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is funded by the NPS Inventory and Monitoring Program.

Monument Background and Establishment

The monument, consisting of 85 hectares (210 acres) in southwestern Missouri, was established by Congress and signed into law by President Franklin D. Roosevelt on 14 July 1943 to preserve, protect, and interpret the "site of [George Washington Carver's] birthplace and childhood home to memorialize and interpret [his] life and legacy" (National Park Service 2016, p. 4).

Significant sites of the monument include the approximate location of the small cabin in which Carver was born (the cabin itself is no longer standing); the restored 1881 Moses Carver house; the Boy Carver statue; a bust of adult Carver; the graves of Moses and Susan Carver (George Washington Carver is buried at Tuskegee University in Alabama); and the visitor center which hosts a robust collection of interpretive and historical materials. These features are connected by the Carver Trail (see poster), a one-mile loop that can be self-guided or interpreted as part of a ranger-led tour. In 2022, the monument welcomed 26,725 recreational visitors (Ziesler and Spalding 2023).

The monument is located in the Springfield Plateau physiographic region (Figure 1), in the Interior Highlands province. The region is underlain by limestone bedrock with abundant cave and karst features, including springs, disappearing or sinking streams, and sinkholes. The Salem Plateau, to the east, is underlain by older bedrock as the landscape descends toward the Mississippi River valley. The bedrock of the Osage Plains to the north and west is younger. Once covered by prairie, the relatively level expanses of the Springfield and Salem Plateaus has been extensively developed for agriculture, and, more recently, urban growth.

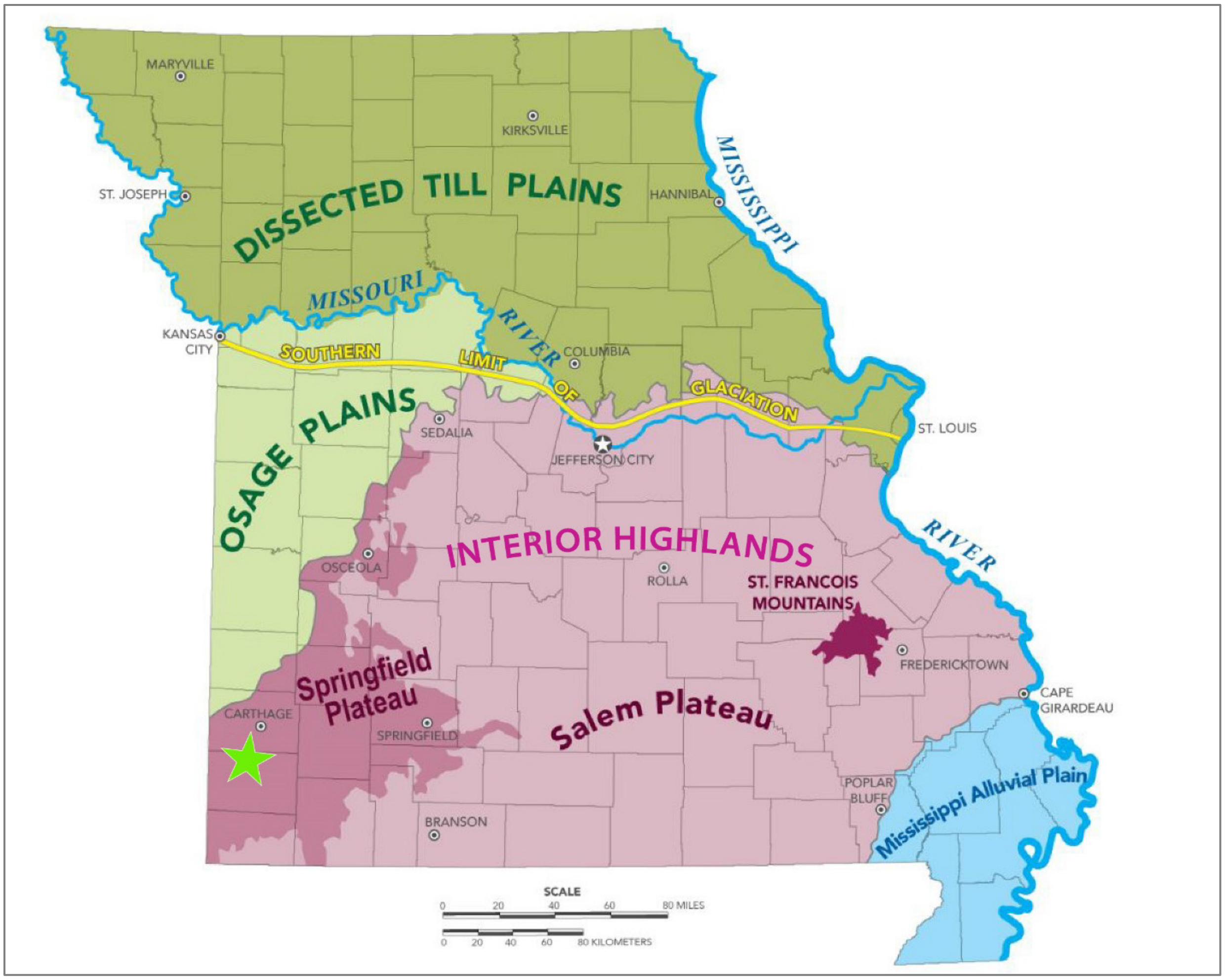

Figure 1. Map of the physiographic regions of Missouri. The state of Missouri is generally characterized by relatively flat-lying beds of sedimentary rock deposited in the Paleozoic Era, between 539 million years and 252 million years ago. In the northern part of the state—the Dissected Till Plains—the bedrock is covered by thick layers of glacially deposited sediment (till) that has been carved and shaped by rivers and streams. The Springfield Plateau region, where the monument is located (indicated by a green star), and the Salem Plateau were not flattened by glaciers and the topography is a mix of rolling hills interspersed by steep escarpments. Graphic adapted from the Missouri Department of Natural Resources.

According to the monument's foundation document (National Park Service 2016), the following factors warrant the monument's inclusion in the National Park System:

- Preserving the site of the birthplace of George Washington Carver, the Moses Carver farm.
- George Washington Carver's childhood experiences on the farm and surrounding area cultivated his spirituality, love of nature, and thirst for knowledge—factors that contributed to his successes in life.

Although neither of these values explicitly mentions geology, the "Geologic Heritage" chapter explores the connection between geology and the significance of the monument.

Geologic Resources Inventory

The GRI was established in 1998 by the GRD and the NPS Inventory and Monitoring Program [Division] to meet the NPS need for geologic mapping and related information. Geologic maps were identified as one of 12 natural resource data sets critical for long term science-informed park management. From the beginning, the GRI has worked with long-time NPS partner Colorado State University to ensure products are scientifically accurate and utilize the latest in geographic information system (GIS) technology. For additional information regarding the genesis of the program and its early focus, refer to National Park Service (1992, 1998, 2009).

GRI Products

The GRI team—which is a collaboration between the GRD of the NPS, Colorado State University's Department of Geosciences, and University of Alaska Fairbanks Museum of the North—completed the following tasks as part of the GRI process for the monument: (1) conducted a scoping meeting and provided a scoping summary (Graham 2011); (2) provided geologic map data in a GIS format; (3) created a poster to display the GRI GIS data; and (4) provided a GRI report (this document).

GRI products—GIS data, map posters, scoping summaries, and reports—are available on the "Geologic Resources Inventory—Products" website and through the DataStore (see "Access to GRI Products"). Information provided in GRI products is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based on the information provided in GRI products. Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features in the GRI GIS data or on the poster. Based on the source map scale (Scherlinck 2015; 1:24,000) and US National Map Accuracy Standards, geologic features represented in the GRI GIS data are horizontally within 12 m (40 ft) of their true locations.

<u>Scoping Meeting</u>

On 6 April 2011, the NPS held a scoping meeting for the monument at the visitor center. The scoping meeting brought together monument 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 for inclusion in the final GRI report. A scoping summary (Graham 2011) summarizes the findings of that meeting.

<u>GRI GIS Data</u>

Following the scoping meeting, the GRI team compiled the GRI GIS data for the monument. These data are the principal deliverable of the GRI. At the time of scoping, the only geologic map of the region was the state geologic map at 1:500,000 produced by the Missouri Geological Survey (Middendorf 2003). The GRI team does not conduct original geologic mapping but in this instance did fund a Geocorps America project to complete mapping of the monument and surrounding area at 1:24,000 scale (Figure 2; Scherlinck 2015).

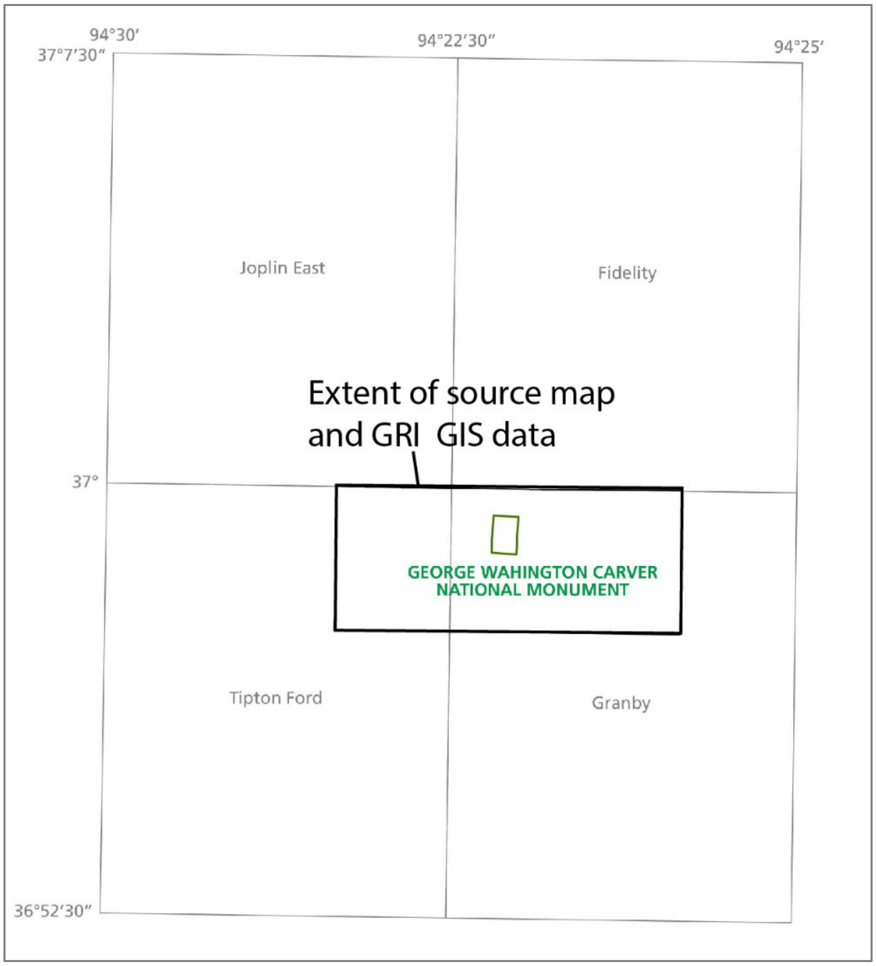

Figure 2. Index map of the GRI GIS data. This map shows the extent of the GRI GIS data in the context of 7.5-minute quadrangles. These data, compiled from a source map by Scherlinck (2015), extend beyond the boundaries of the monument to include parts of Granby and Tipton Ford quadrangles and provide regional geologic context. The monument is located in the Granby quadrangle. Index map by Stephanie O'Meara (Colorado State University).

The GRI GIS data for the monument were compiled from the following source map:

- Geologic mapping of George Washington Carver National Monument and surrounding area, Missouri (Scherlinck 2015)

GRI Poster

A poster of the GRI GIS data draped over a shaded relief image of the monument and surrounding area is the primary figure referenced throughout this GRI report. The poster is not a substitute for the GIS data but is supplied as a helpful tool for office and field use and for users without access to ArcGIS. Not all GIS feature classes are included on the poster (strike and dip symbology are not shown on the poster), and geographic information and selected park features have been added. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

GRI Report

On 4 December 2023, the GRI team hosted a combined follow-up meeting for both Wilson's Creek National Battlefield and George Washington Carver National Monument staff and interested geologic experts. The meeting provided an opportunity to get back in touch with park staff, introduce "new" (since the 2011 scoping meeting) staff to the GRI process, and update the list of geologic features, processes, and resource management issues for inclusion in the final GRI report.

This GRI report is the culmination of the GRI process. It synthesizes discussions from the scoping meeting in 2011, the follow-up meeting in 2023, and additional geologic research. The selection of geologic features and processes highlighted in this report was guided by the previously completed GRI map data, and the writing reflects these data and the interpretation of the source map author. When applicable to the monument's geologic resources and resource management, information was also included from the monument's foundation document (National Park Service 2016).

Geology is a complex science with many specialized terms. This report provides definitions of complex geologic terms at first mention, typically in parentheses following the term. Additionally, the GRI report links the GRI GIS data to the geologic features and processes discussed in the report using map unit symbols; for example, the Warsaw Formation mapped in the monument has the map symbol **Mw**. Capital letters indicate age, and the lowercase letters that follow symbolize the unit name. "**M**" represents the Mississippian Period (~358.9 million to 323.2 million years ago), and "**w**" represents the Warsaw Formation. A geologic time scale, which lists all the map units in the monument, is provided as a table in this report (see "Geologic History" chapter).

Geologic Heritage

Geologic heritage (also called "geoheritage") evokes the idea that the geology of a place is an integral part of its history and cultural identity. Geologic heritage exists at the overlap of geology and humanity, and encompasses important aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific qualities. This chapter highlights the geologic features, landforms, landscapes, and stories of the monument valued for their geologic heritage qualities. It also draws connections between geologic resources and other park resources and stories.

In 2015, in cooperation with the American Geosciences Institute (AGI), the GRD, which administers the GRI (see "Introduction" chapter), published, *America's Geologic Heritage: An Invitation to Leadership* (National Park Service and American Geosciences Institute 2015). That booklet introduced the American experience of geologic heritage and included five key principles and concepts:

- America's geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America's geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America's geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America's geologic heritage benefits from established conservation methods developed around the world and within the United States.
- America's geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Geologic heritage connections at the monument include local bedrock used as building stone, fossils in the stone base of the Boy Carver statue and some building stones, and the influence geology had on Carver's childhood interests in the natural world and painting. These connections could be explored through interpretative programming or signage at the monument.

Story of George Washington Carver

George Washington Carver was highly influenced by the environmental surroundings in his youth. The dynamic natural setting of his birth and adolescence in southwestern Missouri, where the interplay of the Ozarks, plains, and glaciated regions creates habitat for rich plant biodiversity, is the product of geologic processes.

The rocks themselves fostered Carver's curiosity about the natural world, and in his writings, he recalls collecting choice specimens from the Carver Branch. Carver painted throughout his life, mixing his own pigments from clays that he found when he lived in Alabama. The "From Pebbles to Painting" waysign at the monument connects his fascination with colors to the brightly colored pebbles he collected in his youth.

Building Stone

Locally sourced stone—primarily chunks of chert that weathered out of the limestone bedrock—was used as building material throughout the monument, including the foundation of the Moses Carver house, low walls along the trail and surrounding the Carver cemetery, and the amphitheater surrounding the Boy Carver statue (Figure 3). Chert is a silicate (SiO_2) rock that is more resistant to erosion than the carbonate ($CaCO_3$) limestone that makes up the bedrock in the region. As the limestone erodes, the pieces of chert remain on the surface and are easily collected and used for building. The historical foundation of the Moses Carver house is built entirely from these irregularly shaped pieces, whereas the low walls throughout the monument are a mix of the local chert and purchased sandstone blocks of unknown provenance (Christopher Reed, George Washington Carver National Monument, 18 June 2024, personal communication). Both the local limestone stone and the imported sandstone contain fossils of marine invertebrate animals. See the "Paleontological Resources" section for more information about fossils in the building stone and the "Geologic History" chapter for more information about the origins of the bedrock.

Figure 3. Photographs of building stone throughout the monument. Clockwise from top left: photo of the rounded amphitheater walls that surround the Boy Carver statue, with a park visitor completing a Junior Ranger activity; photo of the stone foundation of the Moses Carver house; photo of the stone wall that surrounds the Carver cemetery; photo of a low wall that lines part of the trail. Except for the house foundation, the stone used in the walls is a mix of locally sourced chert (irregular shaped pieces) and purchased sandstone of unknown provenance (tops of walls and larger, regularly shaped pieces). Photographs by Michael Barthelmes (Colorado State University).

Fossils

Fossils (preserved evidence of past life; see the "Paleontological Resources" subsection of the "Geologic Features, Processes and Resource Management Issues" chapter) are present in building stone (the foundation of the Moses Carver house and the stone wall that borders the cemetery) and decorative stone (the base of the Boy Carver statue and surrounding amphitheater) throughout the monument. Although there is no record of George Washington Carver being particularly impacted by the fossil record of the region, these pieces are evidence of a time when southern Missouri was under a shallow prehistoric sea and may be an opportunity for monument visitors to explore their own geoheritage.

Geologic History

This chapter describes the geologic events that formed the present landscape of the monument and surrounding area. The geologic story at the monument is fairly straightforward yet it is long, beginning hundreds of millions of years ago. In the Mississippian Period of the Paleozoic Era (358.9 million years to 323.2 million years ago; Table 1), Laurentia (the landmass that would become the North American continent) was covered in a warm, shallow sea (Figure 4). The calcium carbonate ($CaCO_3$) shells of invertebrate creatures like crinoids and brachiopods were among the marine sediments that were deposited in the area. Over time, these sediments hardened into horizontal beds of limestone.

Table 1. Geologic time scale. The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Colors correspond to USGS suggested colors for geologic maps. Letters in parentheses are abbreviations for geologic time units. Where no geologic time subdivision exists, “n/a” indicates not applicable. The rocks in the GRI GIS data for the monument are from the Mississippian Period (M) of the Paleozoic Era.

Eon	Era(s)	Period(s)	Epoch(s)	MYA [A]
Phanerozoic	Cenozoic	Quaternary (Q)	Holocene (H)	0.0117–today
	Cenozoic	Quaternary (Q)	Pleistocene (PE)	2.6–0.0117
	Cenozoic	Neogene (N)	Pliocene (PL)	5.3–2.6
	Cenozoic	Neogene (N)	Miocene (MI)	23.0–5.3
	Cenozoic	Paleogene (PG)	Oligocene (OL)	33.9–23.0
	Cenozoic	Paleogene (PG)	Eocene (E)	56.0–33.9
	Cenozoic	Paleogene (PG)	Paleocene (EP)	66.0–56.0
	Mesozoic	Cretaceous (K)	Upper, Lower	145.0–66.0
	Mesozoic	Jurassic (J)	Upper, Middle, Lower	201.4–145.0
	Mesozoic	Triassic (TR)	Upper, Middle, Lower	251.9–201.4
	Paleozoic	Permian (P)	Lopingian, Guadalupian, Cisuralian	298.9–251.9
	Paleozoic	Pennsylvanian (PN)	Upper, Middle, Lower	323.2–298.9
	Paleozoic	Mississippian (M)	Upper, Middle, Lower	358.9–323.2
	Paleozoic	Devonian (D)	Upper, Middle, Lower	419.2–358.9
	Paleozoic	Silurian (S)	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
	Paleozoic	Ordovician (O)	Upper, Middle, Lower	485.4–443.8
	Paleozoic	Cambrian (C)	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic (Z)	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8

[A] Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023).

Table 1 (continued). Geologic time scale. The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Colors correspond to USGS suggested colors for geologic maps. Letters in parentheses are abbreviations for geologic time units. Where no geologic time subdivision exists, "n/a" indicates not applicable. The rocks in the GRI GIS data for the monument are from the Mississippian Period (M) of the Paleozoic Era.

Eon	Era(s)	Period(s)	Epoch(s)	MYA [A]
Proterozoic (continued)	Mesoproterozoic (Y)	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic (continued)	Paleoproterozoic (X)	Statherian, Orosirian, Rhyacian, Siderian	n/a	2,500–1,600
Archean	Neo-, Meso-, Paleo-, Eo-archean	n/a	n/a	4,000–2,500
Hadean	n/a	n/a	n/a	4,600–4,000

[A] Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023).

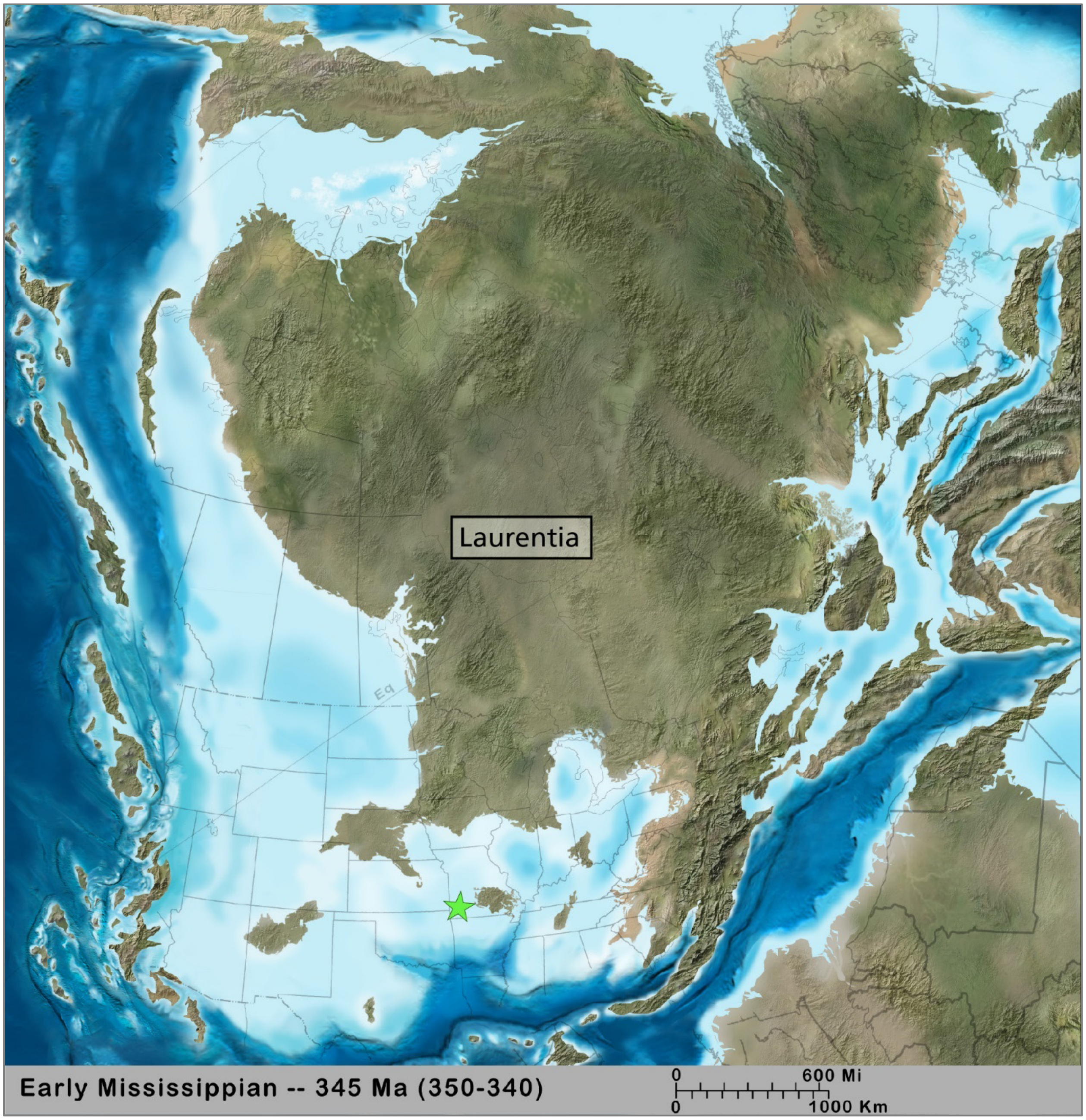

Figure 4. Paleogeographic map of North America during the Early Mississippian Period. The bedrock that underlies southwestern Missouri and the monument (marked with green star) is sedimentary rock that was deposited during the Mississippian Period (359 million to 323 million years ago), when Earth's climate was much warmer, and a shallow sea covered much of the proto-North American continent. Limestone, formed from the slow accumulation of sediments including the remains of organisms, was deposited beneath these seas. Paleogeographic map by Ron Blakey, North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., used under license with annotation by Michael Barthelmes (Colorado State University).

In the considerable time since the Mississippian Period (more than 300 million years; Table 1)—which saw the rise and fall of the dinosaurs, the formation and breaking apart of Pangea, and the eventual assembly of the North American continent and the uplift of the Rocky Mountains—any additional rocks deposited on top of the Mississippian limestones have been eroded away.

During the Pleistocene Epoch (2.6 million to 10,000 years ago) of the Quaternary Period (2.6 million years ago to present), glaciers advanced over much of North America, although the extent of ice did not reach the monument's location in southern Missouri (see Figure 1). Therefore, the region is not characterized by the features typical of a glaciated landscape. However, the glaciers ground the rocks and sediments beneath them into fine dust. As the glaciers retreated, these sediments were blown by the wind and deposited as loess beyond the extent of glaciation, including the region of the monument. Agricultural development has reworked or removed the loess deposits in the area, and the GRI GIS data does not map them. However, the former presence of loess contributed to the rich soil and rural tradition that characterized the region in George Washington Carver's youth.

Today, bedrock is now exposed primarily on slopes and in valleys where rivers and streams of the Missouri and Mississippi watersheds incise and rework surficial deposits. Karst processes, which dissolve limestone and create features such as caves and sinkholes, shape the landscape into low rolling hills.

Geologic Features, Processes, and Resource Management Issues

The geologic features and processes highlighted in this chapter are significant to the monument's landscape and history. Selection of these features and processes was based on input from scoping and follow-up meeting participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports.

Some geologic features, processes, or human activities may require management for human safety, the protection of infrastructure, and the preservation of natural and cultural resources. The GRD provides technical and policy assistance for these issues (see "Guidance for Resource Management"). The issues are discussed along with the features and processes that they are associated with. The geologic hazards in the park are summarized at the end of this chapter.

Since the GRI scoping meeting in 2008, the NPS has completed a foundation document (National Park Service 2016), a cultural landscape report and environmental assessment (Bahr Vermeer and Haecker Architects et al. 2015), and a natural resource condition assessment (Annis et al. 2011) for the monument. Because these documents are primary sources of information for resource management, they were used to draw connections between geologic features and fundamental resources and values.

Bedrock Features

The GRI GIS data and poster show three distinct rock units in the area of the monument: The Burlington limestone and Keokuk limestone, undifferentiated (Burlington-Keokuk limestone; **Mbk**); the Burlington limestone, Short Creek Oolite member (**Mbs**); and the Warsaw Formation (**Mw**). These rock units are described in detail in Table 2, including where they are mapped in relation to the monument.

The entire monument is underlain by the Burlington-Keokuk limestone (**Mbk**; Figure 5 and see poster). Bedrock does not crop out within the monument, except for one small, "desk-sized" area at the site of Carver Spring (Doug Gouzie, Missouri State University, December 4, follow-up meeting). The source of the Carver Spring is near the walkway that includes the Boy Carver statue; however, the exact location is overgrown, and snakes are common, so visitors are not encouraged to explore the area.

Table 2. Geologic units in the GRI GIS data. This table describes the bedrock and surficial geologic units that are included in the GRI GIS data. The bedrock units underlying the monument and surrounding area were deposited in the Mississippian Period (359 million to 323 million years ago); the units are presented here stratigraphically (oldest at the bottom). All unit descriptions are from Scherlinck (2015).

Period	Geologic Unit	Description	Locations
Mississippian (359 million to 323 million years ago)	Warsaw Formation (**Mw**)	The Warsaw Formation is a thick-bedded, gray stone that contains chert and a small number of marine fossils including crinoids, brachiopods, and bryozoans.	**Mw** is mapped in the areas surrounding the monument but does not exist within the monument boundaries.
	Burlington limestone, Short Creek Oolite member (**Mbs**)	The Short Creek Oolite member of the Burlington limestone is the boundary between the Burlington-Keokuk (**Mbk**) and the Warsaw Formation (**Mw**). Oolite is a sedimentary rock that forms from ooids, which are spheres that form when a mineral, usually calcium carbonate ($CaCO_3$) precipitates out of supersaturated water to coat a fragment of shell or piece of sand that is suspended in the water.	**Mbs** only appears in the far southwest corner of the GRI GIS data and is not mapped within the monument boundaries.
	Burlington limestone and Keokuk limestone, undifferentiated (**Mbk**)	The Burlington-Keokuk limestone consists of thick-to-thin beds of gray and light gray stone that contain abundant fossils of crinoids. Other marine invertebrate fossils, including brachiopods and bryozoans, are present. Although the Burlington and Keokuk limestones are two different units with very similar lithologies, the Burlington grades into the Keokuk and a contact is often impossible to identify; thus, the two units are combined as “undifferentiated,” and referred to in this report as “the Burlington-Keokuk limestone.”	**Mbk** underlies the entire area of the monument, although it is only exposed in one small area, off-trail at the site of the Carver Spring.

Figure 5. Photograph of Burlington-Keokuk limestone outcrop. Although the entire monument is underlain by Burlington-Keokuk limestone (Mbk), it is not exposed within the NPS boundary except in one small, concealed area at the site of Carver Spring. This photograph of a roadcut just to the west of the monument at the turn off from US Highway 71 onto State Highway V shows the same type of horizontal limestone beds that exist beneath the surface of the monument. Photograph by Michael Barthelmes (Colorado State University).

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism's activity such as nests, burrows, tracks, or feces). Fossils may occur *in situ* (in rocks or unconsolidated deposits), in museum collections, or in other cultural contexts such as building stone. All fossils are nonrenewable resources.

Because there is little to no bedrock exposed at the monument, there are no *in situ* paleontological resources. However, the Mississippian-age bedrock (**Mbk**, **Mw**) that underlies the monument and surrounding area contains invertebrate marine fossils that reflect the ancient shallow sea in which those rocks were deposited. These types of fossils (brachiopods and crinoids) are abundant in the region, however, visitors should be aware that collection of fossil resources from NPS land is illegal. Currently, fossil theft is not a pressing concern at the monument.

The foundation of the Moses Carver house was constructed using the Mississippian-age bedrock (**Mbk**, **Mw**), and fossils are abundant in the stone upon close inspection (Figure 6). Fossils are also present in the stone wall surrounding the Carver family cemetery (Figure 7), although this stone is partially sourced from unknown locations outside the monument. Additionally, the block of limestone that the Boy Carver statue sits upon also contains invertebrate marine fossils (Figure 8). The exact provenance of this block of stone is unknown, however it is similar to the local bedrock.

Figure 6. Photographs of fossils in house foundation. The foundation of the Moses Carver house (top photograph) is made up of chunks of chert from the local bedrock that are fossiliferous. Close inspection (bottom photographs) reveals jumbles of fragmented fossils including bryozoan fronds; pocket knife for scale. Photographs by Michael Barthelmes (Colorado State University).

Figure 7. Photographs of fossils in Carver cemetery wall. The stone wall that borders the Carver cemetery (top photograph) is made up of fossiliferous rock. Close inspection (bottom photograph) reveals brachiopod shells. The sandstone that these fossils are in was commercially acquired by the monument and its provenance is unknown. Photograph of cemetery wall by Michael Barthelmes (Colorado State University), photograph of brachiopod fossil by Mattison Shreero (National Park Service).

Figure 8. Photographs of fossils in the base of the Boy Carver statue. The block of limestone that the Boy Carver statue sits on is local bedrock, although its exact provenance is unknown. Crinoid and brachiopod fossils are abundant throughout the block. In the top left photo, fragments of crinoid stalks are circled on the left and center, and a brachiopod is circled in the upper right. In the top right photograph, pieces of crinoid stalks are circled right beneath the seat of the statue. In the bottom photograph, a piece of brachiopod is circled. Pocket knife for scale. Photographs by Michael Barthelmes (Colorado State University).

Disturbed Lands

Disturbed lands are those areas where the natural conditions and processes have been directly impacted by human activities such as mining, oil and gas production, development, agriculture, overuse, or inappropriate use. Historical and modern land disturbing activities at the monument have included lead and zinc mining, agriculture, and streambank management. Disturbed land features associated with these activities include riprap along the Carver Branch stream and an abandoned and plugged mineshaft. Additionally, the Williams Spring was impounded to create a scenic pond near the Moses Carver house (see poster).

The area has a history of mineral exploration beginning prior to the turn of the 20th century, particularly lead, iron, and zinc mining. In fact, when the Park Service acquired the land of the monument in 1951, it acquired only 210 acres of the 240-acre farm because the remaining 30 acres contained zinc ore, and the purchase price was prohibitive (Dilebo 1972). The rest of the property was donated to the George Washington Carver Birthplace Association, and then to the NPS, in 2004 (National Park Service 2016). The Shartell property mine, on the donated land, was plugged and capped with several feet of dirt in 2005 (Christopher Reed, George Washington Carver National Monument, December 4, follow-up meeting). Tailings, or the material that is leftover once the valuable fraction is separated from an ore, from the Shartell mine were removed in 2006.

Shortly after the National Park Service acquired the property, in the 1970s, riprap was placed along the outside of a meander bend in Carver Creek to control erosion. The material for the riprap was stone from structures that were removed at around the same time (Bahr Vermeer and Haecker architects et al. 2015). No streambank restoration has been conducted since then (Christopher Reed, George Washington Carver National Monument, 20 June 2024, personal communication).

Fluvial Features and Processes

Fluvial refers to the features and processes associated with flowing water. Fluvial features in the monument include streams and springs. Fluvial processes in the park include stream channel erosion, deposition of stream sediments, and flooding. Resource managers interested in monitoring fluvial processes may find the “fluvial geomorphology” chapter (Lord et al. 2009) of *Geological Monitoring* (Young and Norby 2009) useful.

Streams

The streams in the monument— the Carver Branch (Figure 9), Williams Branch, and Harkins Branch—are an aspect of the “Cultural Landscape” fundamental resource or value (FRV) identified in the monument’s foundation document because “The native vegetation, waterways, and natural resources… help today’s park visitors connect to Carver’s early experiences” (National Park Service 2016, p. 6). The cultural landscape report and environmental assessment of the monument (Bahr Vermeer and Haecker architects et al. 2015) found the stream condition to be “generally good, though there may be mild impairment from threats outside of the park boundaries” (p. 203). The outside threats are agricultural runoff, including herbicides and pesticides, which may kill native plants and negatively impact the water quality within the monument (National Park Service 2016).

Figure 9. Photograph of Carver Branch. View of the Carver Branch as it flows under a wooden bridge along the walking trail just past the Boy Carver statue. The stream condition is rated “good” and provides habitat for flora and fauna. Photograph by Michael Barthelmes (Colorado State University).

The majority of the water in the pond and streams comes springs, therefore it is generally of good quality (Michael DeBacker, Heartland Network, December 4, follow-up meeting). The recharge rate and groundwater flow rate are rapid and flushes out any contaminants relatively quickly; the groundwater quality in southern Missouri karst regions is superior to anywhere else in the state (Graham 2011).

Flooding is not considered a threat, although high water levels during storms can approach the picnic areas. Climate change trends and predictions for the area include increased precipitation and an increased quantity and severity of storms, which could increase and intensify flooding (Gonzalez 2015).

Springs

The abundance of soluble limestone manifests itself in the presence of springs in and around the monument. Springs occur where water-bearing rock units intersect with the land surface. The GRI GIS data and the GRI poster include five springs in the Burlington-Keokuk limestone (**Mbk**), two of which are within the monument’s boundaries. Bowles (2013) found that the “water quality, habitat, and invertebrate community metrics were well within the range for unimpaired streams in the region" (p. 25).

Carver Spring is near the walkway that includes the Boy Carver statue, and it is the site of the only bedrock exposure within the monument (see the "Bedrock Features" section for more information). Carver Spring feeds a short stream that flows into Carver Branch.

Williams Spring is located along the Carver Trail. The spring itself is currently impounded to create Williams Pond, which can be accessed and appreciated via the contemplative loop trail. The pond drains into Williams Branch, which also feeds into Carver Branch before flowing out of the monument.

Karst

Karst is a landscape formed by the dissolution of soluble rocks, commonly carbonate rocks such as limestone or dolomite (Toomey 2009). The monument's landscape is 100% karst (Land et al. 2013). Springs and disappearing streams (discussed in the "Fluvial Features and Processes" section of this chapter) are features of karst landscapes, as are sinkholes. Sinkholes are common in southwestern Missouri and primarily form through "cover collapse" processes, where the overlying cover of weathered rock and soil collapses into a subterranean opening and is washed away by groundwater, causing the hole to gradually expand upward. Gentle dolines, which form as almost imperceptible movements of soil through cracks in limestone until the surface has washed away without a noticeable "collapse," are also common in the region (Doug Gouzie, Missouri State University, 2 July 2024, personal communication).

Although sinkholes can damage structures and present "falling-into" hazards to visitors, the monument is not currently affected by sinkhole formation which is more prevalent to the east in the area of Springfield and Wilson's Creek National Battlefield (Graham 2011). Resource managers may find the "caves and associated landscapes" chapter (Toomey 2009) of *Geological Monitoring* (Young and Norby 2009) useful.

Eolian Features and Processes

Eolian refers to the windblown erosion, transportation, and deposition of sediments (Lancaster 2009). Features created by eolian processes may include depositional landforms and deposits such as dunes, loess, and sand sheets (sand that is too large, or wind velocity too low, for dunes to form), as well as erosional forms.

Today, loess (windblown silt that is often derived from the crushed material created by glaciers) is present in the area north of the monument but is not mapped within the monument itself (Graham 2011). However, they were likely present on the original farm when George Washington Carver lived in Missouri but have been lost due to years of agricultural use. Loess deposits are generally fertile and lend themselves to robust vegetation and growing crops.

Geologic Hazards

The dynamic landscapes preserved at many National Park System units present a variety of natural hazards that pose a threat to NPS facilities, staff, and visitors. Many of these natural hazards are geologic in nature (e.g., volcanoes, earthquakes, and landslides). NPS Policy Memorandum 15–01 (Jarvis 2015) directs NPS managers and their teams to proactively identify and document facility vulnerabilities to climate change and other natural hazards.

The GRI process identified flooding as the primary geologic hazard for the monument; however, the risk of infrastructure or resources being damaged by flooding is low. Other potential hazards at the monument include earthquakes associated with the New Madrid Fault Zone (low hazard); shrink/swell soils, which occur when changes in moisture cause pronounced changes in soil volume (low hazard); and radon, which occurs from the natural breakdown of uranium in soil and rocks and emits carcinogenic particles (medium hazard). The Guidance for Resource Management and Additional References, Resources and Websites chapters provide additional information and resources for managing and understanding these hazards. Table 3 summarizes the geologic hazards at the historic site.

Table 3. Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the battlefield.

Hazard Type	Best Professional Judgement	Risk or Secondary Hazard	Sources of Geohazard Information
Earthquake	Potential Hazard	• Falling objects. • Collapsing structures.	• International Building Code • United State Geological Survey (USGS) Earthquake Probability Map • Missouri Department of Natural Resources
Slope movements (landslide/avalanche)	Not applicable	• Not applicable	• Not applicable
Permafrost	Not applicable	• Not applicable	• Not applicable
Cave/karst	Not applicable	• Not applicable	• Not applicable

Table 3 (continued). Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the battlefield.

Hazard Type	Best Professional Judgement	Risk or Secondary Hazard	Sources of Geohazard Information
Shrink/swell soils	Potential Hazard	• Damage to structure • "Heaving" of ground beneath structure	• NPS Soil Resources Inventory • Web Soil Survey • Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic (gSSURGO) datasets
Coastal storm surge/ sea or lake level change/shoreline erosion	Not applicable	• Not applicable	• Not applicable
Tsunami	Not applicable	• Not applicable	• Not applicable
Riverine Flood	Potential Hazard	• Flooding (i.e., snowmelt, rainfall, etc.) • Destruction of infrastructure. • Stream channel migration. • Stream bank erosion.	• Federal Emergency Management Agency (FEMA) Map Service Center • State geological surveys • Natural Resource Condition Assessment (NRCA) (Annis et al. 2011)
Flash Flood	Potential Hazard	• Sudden rising water (i.e., dry wash) • Loss of life due to unexpected flooding • Destruction of infrastructure	• FEMA Map Service Center • State geological survey • NPS Technical Support • NRCA (Annis et al. 2011)
Volcanic eruption	Not applicable	• Not applicable	• Not applicable
Hydrothermal activity	Not applicable	• Not applicable	• Not applicable

Table 3 (continued). Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the battlefield.

Hazard Type	Best Professional Judgement	Risk or Secondary Hazard	Sources of Geohazard Information
Radon	Potential Hazard	• Health hazard	• Missouri Department of Natural Resources • Missouri Department of Health and Human Services • EPA Map of Radon Zones

Guidance for Resource Management

This chapter provides information to assist resource managers in addressing geologic resource management issues and applying NPS policy. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), NPS 2006 Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75).

Access to GRI Products

- GRI products (scoping summaries, GIS data, posters, and reports): http://go.nps.gov/gripubs
- GRI products are also available through the NPS Integrated Resource Management Applications (IRMA) DataStore portal: https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.
- GRI GIS data model: http://go.nps.gov/gridatamodel
- Additional information regarding the GRI, including contact information: https://www.nps.gov/subjects/geology/gri.htm

Three Ways to Receive Geologic Resource Management Assistance

- Contact the GRD (https://www.nps.gov/orgs/1088/contactus.htm). GRD staff members provide coordination, support, and guidance for geologic resource management issues in three emphasis areas: (1) geologic heritage, (2) active processes and hazards, and (3) energy and minerals management. GRD staff can provide technical assistance with resource inventories, assessments, and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; laws, regulations, and compliance; resource management planning; and data and information management.
- Formally request assistance at the Solution for Technical Assistance Requests (STAR) webpage: https://irma.nps.gov/Star/ (available on the Department of the Interior [DOI] network only). NPS employees (from a park, region, or any other office outside of the Natural Resource Stewardship and Science [NRSS] Directorate) can submit a request for technical assistance from NRSS divisions and programs.
- Submit a proposal to receive geologic expertise through the Scientists in Parks program (SIP; see https://www.nps.gov/subjects/science/scientists-in-parks.htm). Formerly the Geoscientists-in-the-Parks program, the SIP program places scientists (typically undergraduate students) in parks to complete science-related projects that may address resource management issues. Proposals may be for assistance with research, interpretation and public education, inventory, and/or monitoring. The GRD can provide guidance and assistance with submitting a proposal. The Geological Society of America and Environmental Stewards are partners of the SIP program. Visit the internal SIP website to submit a proposal at https://doimspp.sharepoint.com/sites/nps-scientistsinparks (only available on DOI network computers).

Geological Monitoring

Geological Monitoring (Young and Norby 2009) provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Chapters are available online at https://www.nps.gov/subjects/geology/geological-monitoring.htm.

Park-Specific Documents

The park's Foundation Document (National Park Service 2016), Natural Resource Condition Assessment (Annis et al. 2011), and Cultural Landscape Report/Environmental Assessment (Bahr Vermeer and Haecker Architects et al. 2015) are primary sources of information for resource management within the monument boundaries. These documents guided the writing of this GRI report.

NPS Natural Resource Management Guidance and Documents

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

Geologic Resource Laws, Regulations, and Policies

The following sections, which were developed by the GRD, summarize laws, regulations, and policies that specifically apply to NPS geologic resources, geologic processes, energy, and minerals. The first section summarizes law and policy for geoheritage resources, which includes caves, paleontological resources, and geothermal resources. The energy and minerals section includes abandoned mineral lands, mining, rock and mineral collection, and oil and gas operations. Active processes include geologic hazards (e.g., landslides), coastal processes, soils, and upland and fluvial processes (e.g., erosion). Laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, NEPA, or the National Historic Preservation Act) are not included, but the NPS Organic Act is listed when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

Geoheritage Resource Laws, Regulations, and Policies

Caves and Karst Systems

Resource-specific Laws:

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

Resource-specific Regulations:

- **36 CFR § 2.1** prohibits possessing/destroying/disturbing…cave resources…in park units.
- **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.

NPS Management Policies 2006:

- **Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts.
- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact the cave environment, and to remove existing developments if they impair caves.
- **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.

Geothermal

Resource-specific Laws:

- **Geothermal Steam Act of 1970, 30 USC. § 1001** et seq. as amended in 1988, states:
    - No geothermal leasing is allowed in parks.
    - "Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead).

  - NPS is required to monitor those features.
  - Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects.
- **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.

Resource-specific Regulations:

- **43 CFR Part 3200** requires BLM to include stipulations when issuing, extending, renewing, or modifying leases or permits to protect significant thermal features in NPS-administered areas (see 43 CFR §3201.10), prohibit the bureau from issuing leases in areas where geothermal operations are reasonably likely to result in significant adverse effects on significant thermal features in NPS-administered areas (see 43 CFR §3201.11 and §3206.11), and prohibit BLM from issuing leases in park units.

NPS Management Policies 2006:

- **Section 4.8.2.3** requires NPS to:
  - Preserve/maintain integrity of all thermal resources in parks.
  - Work closely with outside agencies.
  - Monitor significant thermal features.

<u>Paleontological Resources</u>

Resource-specific Laws:

- **Archaeological Resources Protection Act of 1979, 16 USC §§ 470aa – mm Section 3 (1)** Archaeological Resource—nonfossilized and fossilized paleontological specimens, or any portion or piece thereof, shall not be considered archaeological resources, under the regulations of this paragraph, unless found in an archaeological context. Therefore, fossils in an archaeological context are covered under this law.
- **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309 Section 3 (5)** Cave Resource—the term "cave resource" includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems. Therefore, every reference to cave resource in the law applies to paleontological resources.
- **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects.
- **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa** et seq. provides for the management and protection of paleontological resources on federal lands.

Resource-specific Regulations:

- **36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof.
- **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted.
- **43 CFR Part 49** contains the DOI regulations implementing the Paleontological Resources Preservation Act, which apply to the NPS.

NPS Management Policies 2006:

- **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.

Energy and Minerals Laws, Regulations, and Policies

<u>Abandoned Mineral Lands and Orphaned Oil and Gas Wells</u>

Resource-specific Laws:

- **The Bipartisan Infrastructure Law**, **Inflation Reduction Act**, and **NPS Line Item Construction** program all provide funding for the reclamation of abandoned mineral lands and the plugging of orphaned oil and gas wells.

Resource-specific Regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

<u>Coal</u>

Resource-specific Laws:

- **Surface Mining Control and Reclamation Act (SMCRA) 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.

Resource-specific Regulations:

- **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.

NPS Management Policies 2006:

- None applicable.

<u>Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)</u>

Resource-specific Laws:

- **Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.
- **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas.
- **16 USC §90c-1(b)** authorizes sand, rock, and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.

Resource-specific Regulations:

- None applicable.

NPS Management Policies 2006:

- **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 the 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.

Federal Mineral Leasing (Oil, Gas, and Solid Minerals)

Resource-specific Laws:

- **The Mineral Leasing Act, 30 USC § 181** et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq. do not authorize the BLM to lease federally owned minerals in NPS units.
- **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in Glen Canyon National Recreation Area, which is the only park unit that contains a STSA.
- **Exceptions:** Glen Canyon National Recreation Area (NRA) (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.) authorize the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration.
- **American Indian Lands** Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108, all minerals on American Indian trust lands within NPS units are subject to leasing.
- **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.

Resource-specific Regulations:

- **36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law.
- **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing.
- Regulations re: Native American Lands within NPS Units:
  - **25 CFR Part 211** governs leasing of tribal lands for mineral development.
  - **25 CFR Part 212** governs leasing of allotted lands for mineral development.
  - **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development.
  - **25 CFR Part 224** governs tribal energy resource agreements.
  - **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC §§ 2101-2108).
  - **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases.

    - **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases.
    - **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases.
    - **30 CFR § 1206.450** governs the valuation of coal from Indian Tribal and Allotted leases.
    - **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.

NPS Management Policies 2006:

- **Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

<u>Mining Claims (Locatable Minerals)</u>

Resource-specific Laws:

- **Mining in the Parks Act of 1976, 54 USC § 100731** et seq. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas.
- **General Mining Law of 1872, 30 USC § 21** et seq. allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA.
- **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.

Resource-specific Regulations:

- **36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law.
- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9**, Subpart A requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability.
- **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 CFR Parts 6 and 9A.
- **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

<u>Nonfederal Minerals other than Oil and Gas</u>

Resource-specific Laws:

- NPS Organic Act, 54 USC §§ 100101 and 100751

Resource-specific Regulations:

- **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 business operation (§ 5.3) or for construction of buildings or other facilities (§ 5.7), and to comply with the solid waste regulations at Part 6.

NPS Management Policies 2006:

- **Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.

<u>Nonfederal Oil and Gas</u>

Resource-specific Laws:

- **NPS Organic Act, 54 USC § 100751** et seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- Individual Park Enabling Statutes:
    - 16 USC § 230a (Jean Lafitte NHP & Pres.)
    - 16 USC § 450kk (Fort Union NM)
    - 16 USC § 459d-3 (Padre Island NS)
    - 16 USC § 459h-3 (Gulf Islands NS)
    - 16 USC § 460ee (Big South Fork NRRA)
    - 16 USC § 460cc-2(i) (Gateway NRA)
    - 16 USC § 460m (Ozark NSR)
    - 16 USC § 698c (Big Thicket N Pres.)

    - 16 USC § 698f (Big Cypress N Pres.)

Resource-specific Regulations:

- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights in parks outside of Alaska to:
    - Demonstrate valid right to develop mineral rights;
    - Submit an Operations Permit Application to NPS describing where, when, and how they intend to conduct operations;
    - Prepare/submit a reclamation plan; and
    - Submit financial assurance to cover reclamation and potential liability.
- **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 8.7.3** requires operators to comply with 9B regulations.

<u>Recreational Collection of Rocks and Minerals</u>

Resource-specific Laws:

- **NPS Organic Act, 54 USC. § 100101** et seq. directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law.
- **Exception: 16 USC. § 445c (c)**—Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).

Resource-specific Regulations:

- **36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units.
- **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown National Recreation Area.
- **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.

NPS Management Policies 2006:

- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Transpark Petroleum Product Pipelines

Resource-specific Laws:

- The **Mineral Leasing Act, 30 USC § 181** et seq., and the **Mineral Leasing Act for Acquired Lands, 30 USC § 351** et seq. authorize new rights of way across some federal lands for pipelines, excluding NPS areas.
- The only parks with the legal authority to grant new rights of way for petroleum product pipelines are:
    - Natchez Trace Parkway (16 USC §460a)
    - Blue Ridge Parkway (16 USC §460a-8)
    - Great Smoky Mountains National Park (P.L. 107-223 – 16 U.S.C. §403 notes)
    - Klondike Gold Rush National Historical Park (16 USC §410bb(c) (limited authority for the White Pass Trail unit)
    - Gulf Islands National Seashore - enabling act authorizes rights-of-way for pipelines for oil and gas transported across the seashore from outside the unit (16 USC §459h-3)
    - Gateway National Recreation Area - enabling act authorizes rights-of-way for gas pipelines in connection with the development of methane gas owned by the City of New York within the unit (16 USC §460cc-2(i))
    - Denali National Park—2013 legislation allows for issuance of right-of-way permits for a natural gas pipeline within, along, or near the approximately 7-mile segment of the George Parks Highway that runs through the park (Public Law 113–33)

Resource-specific Regulations:

- NPS regulations at **36 CFR Part 14 Rights of Way**

NPS Management Policies 2006:

- **Section 8.6.4** states that new rights of way through, under, and across NPS units may be issued only if there is specific statutory authority and there is no practicable alternative.

Uranium

Resource-specific Laws:

- **Atomic Energy Act of 1954** allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.

Resource-specific Regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Active Processes and Geohazards Laws, Regulations, and Policies

<u>Coastal Features and Processes</u>

Resource-specific Laws:

- **NPS Organic Act, 54 USC § 100751** et. seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- **Coastal Zone Management Act, 16 USC § 1451** et. seq. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone.
- **Clean Water Act, 33 USC § 1342/Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit.
- **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs.
- **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.

Resource-specific Regulations:

- **36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands.
- **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.

NPS Management Policies 2006:

- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/park facilities/historic properties.
- **Section 4.8.1.1** requires NPS to:

- Allow natural processes to continue without interference,
- Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions,
- Study impacts of cultural resource protection proposals on natural resources,
- Use the most effective and natural-looking erosion control methods available, and
- Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.

Geologic Hazards

Resource-specific Laws:

- **National Landslide Preparedness Act, 43 USC §§ 3101–3104** strengthens the mandate to identify landslide hazards and reduce losses from landslides. Established the National Landslide Hazards Reduction Program. "…the United States Geological Survey and other Federal agencies, shall—identify, map, assess, and research landslide hazards;" Reduce landslide losses, respond to landslide events.

Resource-specific Regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.8.1.3**, Geologic Hazards
- **Section 9.1.1.5**, Siting Facilities to Avoid Natural Hazards
- **Section 8.2.5.1**, Visitor Safety
- **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.

Soils

Resource-specific Laws:

- **Soil and Water Resources Conservation Act, 16 USC §§ 2001–2009** 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 ensure 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).

Resource-specific Regulations:

- **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.

NPS Management Policies 2006:

- **Section 4.8.2.4** requires NPS to (1) prevent unnatural erosion, removal, and contamination; (2) conduct soil surveys; (3) minimize unavoidable excavation; and (4) develop/follow written prescriptions (instructions).

<u>Upland and Fluvial Processes</u>

Resource-specific Laws:

- **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**).

Resource-specific Regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems.
- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.

- **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding.
- **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams.
- **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes.
- **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Additional References, Resources, and Websites

Missouri Resources

- Missouri Department of Health and Human Services (radon): https://health.mo.gov/living/environment/radon/index.php
- Missouri Department of Natural Resources: https://dnr.mo.gov/land-geology

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- NPS Climate Change Response Strategy (2023 Update): https://www.nps.gov/subjects/climatechange/response-strategy.htm
- NPS Green Parks Plan: https://www.nps.gov/subjects/sustainability/green-parks.htm
- NPS National Climate Change Interpretation and Education Strategy: https://www.nps.gov/subjects/climatechange/nccies.htm
- NPS Policy Memorandum 12-02—Applying NPS Management Policies in the Context of Climate Change: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Policy Memorandum 15-01—Addressing Climate Change and Natural Hazards for Facilities: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- U.S. Global Change Research Program: http://www.globalchange.gov/home

Days to Celebrate Geology

- Geologist Day—the first Sunday in April (marks the end of the winter and beginning of preparation for summer field work; formally celebrated in Ukraine, Kazakhstan, Belarus, Kyrgyzstan, and Russia)
- National Cave and Karst Day—6 June, also known as International Day of Caves and Subterranean World
- International Geodiversity Day—6 October: https://www.geodiversityday.org/
- Earth Science Week—typically the second full week of October: https://www.earthsciweek.org/
- National Fossil Day—the Wednesday of Earth Science Week: https://www.nps.gov/subjects/fossilday/index.htm

Disturbed Lands Restoration

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

Earthquakes

- Missouri Department of Natural Resources: http://dnr.mo.gov/land-geology/hazards/earthquakes
- USGS Did You Feel It? reporting system: https://earthquake.usgs.gov/data/dyfi/
- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/
- USGS ShakeMap: https://earthquake.usgs.gov/data/shakemap/
- Seismic Monitoring (Braile 2009) in *Geological Monitoring* (Young and Norby 2009)

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- NPS Geoheritage Sites - Examples on Public Lands, Natural Landmarks, Heritage Areas, and The National Register of Historic Places: https://www.nps.gov/subjects/geology/geoheritage-sites-listing-element.htm
- NPS Museum Collection (searchable online database): https://museum.nps.gov/ParkPList.aspx
- NPS National Natural Landmarks Program: https://www.nps.gov/subjects/nnlandmarks/index.htm
- NPS National Register of Historic Places: https://www.nps.gov/subjects/nationalregister/index.htm
- NPS Stratotype Inventory: https://www.nps.gov/subjects/geology/nps-stratotype-inventory.htm
- UNESCO Global Geoparks: https://en.unesco.org/global-geoparks

Geologic Maps

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

Geological Surveys and Societies

- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/

- Association of American State Geologists: http://www.stategeologists.org/
- Geological Society of America: http://www.geosociety.org/
- Missouri Geological Survey: https://dnr.mo.gov/about-us/missouri-geological-survey
- US Geological Survey: http://www.usgs.gov/

NPS Geology

- NPS America's Geologic Legacy: http://go.nps.gov/geology. This primary site for information about NPS geology includes a geologic tour, news, and other information about geology in the NPS, and resources for educators and park interpreters.
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm. The NPS Geodiversity Atlas is a collection of park-specific webpages containing information about the park's geology and links to additional resources.
- NPS Geologic Resources Inventory: http://go.nps.gov/gri

NPS Reference Tools

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

Relevancy, Diversity, and Inclusion

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

Soils

- Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS): https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

- WSS_four_steps (PDF/guide for how to use WSS): https://irma.nps.gov/DataStore/Reference/Profile/2305342.

USGS Reference Tools

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

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These references are cited in this report. Contact the GRD for assistance in obtaining them.

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