



Pea Ridge National Military Park

Geologic and Soil Resources Inventory Summary



On this page: A 19th-century engraving detailing the last hour of the Battle of Pea Ridge on 8 March 1862. The scene depicts a wounded Major General Sterling Price (front center left) and the Confederate army as they prepare to retreat from the battlefield near Elkhorn Tavern (far right). Union forces occupy the distant fields (background left). The rocky bluffs of Elkhorn Mountain rise above the battlefield to the right and consist of the Mississippian Wedington Sandstone Member of the Fayetteville Shale. The mountain is a prominent geologic landform of the military park and played a major strategic element in the Battle of Pea Ridge. The engraving is based on paintings by Lt. Hunt P. Wilson. An annotated version of the engraving is provided in Johnson and Buel (1887).

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Please cite this report as:

Henderson, T. C. 2025. Pea Ridge National Military Park: Geologic and soil resources inventory summary. Unpublished report. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2308028>.

Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for Pea Ridge National Military Park. It also provides information on current geology and soil resources management concerns, with a focus on identified inventory needs related to geologic heritage, geohazards, and soil features and processes. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

The GRI hosted a baseline scoping meeting for Pea Ridge National Military Park in 2007. Baseline bedrock and surficial geologic maps were delivered to the parks in 2010 and updated in 2022. SRI delivered a legacy soil database and map to the park in 2005. The most up-to-date soil data for the park is available through [Web Soil Survey](#).

Pea Ridge National Military Park's geologic heritage is ingrained in its paleontological records, Indigenous connections, planetary analog potential, and its geologic connections to the landscape, strategy, and outcome of the Battle of Pea Ridge. The geologic and soil resources inventory needs for the park include various data and/or GIS information related to the inventory and monitoring of cave and karst resources, cultural resources, hydrological resources, and fossils, in addition to geologic mapping needs. Geologic hazards identified in the park include cave and karst, climate change, disturbed lands (e.g., abandoned mineral lands, overgrazing, surrounding development), flooding, mass wasting, radon, seismicity, swelling clays, and toxicological soil.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

Contents

Abstract	iii
List of Figures	vi
List of Tables	vii
Background of the GSRI	1
<i>Baseline GSRI Products</i>	<i>1</i>
Geology.....	1
Soils.....	2
<i>Possible Future GSRI Products.....</i>	<i>3</i>
Geologic Setting and History	4
<i>Park Establishment and Setting.....</i>	<i>4</i>
<i>Geologic History</i>	<i>4</i>
Paleozoic Era: Ancient Seas and Deltas.....	4
Cenozoic Era: Rivers, Karst, and Landslides.....	7
Geologic Heritage	8
<i>Paleontology.....</i>	<i>8</i>
<i>Indigenous Connections</i>	<i>9</i>
<i>Geology and the Battle of Pea Ridge</i>	<i>9</i>
The Federal Trenches.....	9
Elkhorn Mountain.....	10
Round Mountain or Roundtop.....	13
Ravines, Ridges, and Hollows.....	13
Welfley's Knoll.....	14
Memorials in Stone.....	17
<i>Pea Ridge, NASA, and Planetary Analog Studies.....</i>	<i>17</i>
Geologic Resource Management Issues and Inventory Needs	19
<i>Summary of Geologic and Soil Hazards</i>	<i>19</i>
Cave and Karst.....	23
Climate Change.....	24
Disturbed Lands.....	25
Flooding.....	28
Mass Wasting.....	28
Radon.....	30
Seismicity.....	30
Swelling Clays.....	30
Toxicological Soil.....	31
<i>Geologic Resource Protection</i>	<i>31</i>
Legislatively Required Geologic Inventories.....	31
Paleontological and Cultural Resources.....	31
Cave and Karst Resources.....	33
<i>Inventory Needs</i>	<i>34</i>
Acknowledgments	35
<i>2007 Scoping Participants.....</i>	<i>35</i>
<i>2025 Follow-up Meeting Participants.....</i>	<i>35</i>
<i>Summary Author.....</i>	<i>35</i>

<i>Summary Review</i>	35
<i>Summary Editing</i>	35
Literature Cited	36

List of Figures

<i>Figure 1. Exposure of the Hindsville Limestone Member of the Batesville Sandstone in PERI.</i>	6
<i>Figure 2. Sandstone bluffs of the Wedington Sandstone Member of the Fayetteville Shale in PERI.</i>	7
<i>Figure 3. View facing north toward Elkhorn Mountain from Cox's Field.</i>	10
<i>Figure 4. Bedrock geologic map of PERI showing troop movements during the Battle of Pea Ridge.</i>	12
<i>Figure 5. View from the eastern overlook looking west toward Round Mountain.</i>	13
<i>Figure 6. Bedrock geologic map of PERI showing troop movements during the Battle of Pea Ridge.</i>	16
<i>Figure 7. View from Welfley's Knoll facing northeast across the battlefield.</i>	17
<i>Figure 8. Photograph of the limestone cave near Elkhorn Tavern.</i>	24
<i>Figure 9. Aerial photograph taken in the 1960s along the Federal trenches.</i>	26
<i>Figure 10. Historic quarry site on the northwest flank of Round Mountain.</i>	27
<i>Figure 11. Photographs of the January 2008 landslide at the eastern overlook.</i>	29
<i>Figure 12. Photograph of the bedrock underlying the eastern overlook.</i>	29
<i>Figure 13. The Federal trenches along Little Sugar Creek.</i>	33

List of Tables

<i>Table 1. Web Soil Survey areas related to the military park.</i>	<i>2</i>
<i>Table 2. Geologic units mapped within the military park.</i>	<i>5</i>
<i>Table 3. Geologic hazards checklist.</i>	<i>20</i>
<i>Table 4. List of identified geologic and soil resources inventory needs for the military park.</i>	<i>34</i>

Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) facilitates the collection of new data or derives new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning.

In the 1990s, the NPS Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) programs were established as two of the original 12 baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, GRI scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, the Geologic and Soil Resources Inventory (GSRI), and will be integrated into the new Inventories & Assessment (I&A) program, in which parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Pea Ridge National Military Park (“PERI,” also referred to as the “military park” herein), were identified as missing a baseline GRI report.

This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the national park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for PERI and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The digital geologic map for PERI is available on the NPS DataStore accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/2171411>) and is adapted from multiple source maps created by the Arkansas Geological Survey. Additional GSRI documents include the NPS Scoping Report (Thornberry-Ehrlich 2007).

GSRI source maps:

- Chandler, A. K., and S. M. Ausbrooks (digital compilation by W. K. Mayfield). 2009a. Geologic map of the Garfield Quadrangle, Benton County, Arkansas: Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-AR-00320, scale 1:24,000.
https://ngmdb.usgs.gov/Prodesc/proddesc_86957.htm

- Chandler, A. K., and S. M. Ausbrooks (digital compilation by W. K. Mayfield). 2009b. Geologic map of the Pea Ridge Quadrangle, Benton County, Arkansas: Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-AR-00682, scale 1:24,000.
https://ngmdb.usgs.gov/Prodesc/proddesc_86956.htm

GSRI scoping report:

- Thornberry-Ehrlich, T. 2007. Geologic Resource Evaluation scoping summary: Pea Ridge National Military Park <https://irma.nps.gov/DataStore/Reference/Profile/2250411>

Soils

Soil maps provide information on soil types, including scores of different characteristics and management considerations, including linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the Natural Resources Conservation Service (NRCS) [Web Soil Survey](#) website along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The most up-to-date soils data for PERI is available via Web Soil Survey, which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data. The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name. PERI includes one soil survey area that is complete (Table 1). To view the soil data for PERI on the Web Soil Survey website, use the navigation pane on the left side of the homepage to select the soil survey “Area of Interest (‘AOI’)” tab. Under the “National Park Service” dropdown menu, select PERI to view the soil data for the military park. The AOI icon along the top of the screen allows users to select specific areas of the map and generate detailed soil data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view additional soil data, including linear extensibility and suitability for development. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

Additional soil mapping by the NPS Soil Resources Inventory (SRI) was updated for PERI in 2005 and is available on IRMA (<https://irma.nps.gov/DataStore/Reference/Profile/1048952>).

Table 1. Web Soil Survey areas related to the military park.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
AR007	Benton County, Arkansas	Complete

Possible Future GSRI Products

As the GSRI becomes integrated into the I&A, future GSRI products will be determined by the project proposals submitted by the parks. Moving forward, the GSRI program will fund inventory projects that include the following:

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Include features or processes on an individual feature- or landscape-scale.
- Include groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.
- Features and processes covered by other sources of funding and **not** eligible for GSRI funding are abandoned mineral lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will accept proposals for new baseline map products, such as funding a traditional geologic (bedrock or surficial) or soil mapping effort, especially at new or expanded parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need that the baseline data will support.

Geologic Setting and History

Park Establishment and Setting

Pea Ridge National Military Park is located about 5 km (3 mi) east of the town of Pea Ridge near the Arkansas–Missouri border in Benton County, northwestern Arkansas. Authorized on 20 July 1956, PERI preserves the battlefield landscape and resources associated with the Battle of Pea Ridge, a significant military engagement that turned the tide of the American Civil War west of the Mississippi River. Fought on 7–8 March 1862, the Battle of Pea Ridge resulted in a decisive Union victory that prevented the Confederacy from gaining control of Missouri and the lower Mississippi River Valley (National Park Service 2014, 2016). The military park is one of the most intact Civil War battlefields in the United States, encompassing approximately 1,740 hectares (4,300 acres), or nearly 90% of the battle’s core combat sites (National Park Service 2016). Historical and cultural resources within the military park are intimately associated with various themes related to the Civil War but also include Indigenous sites and remnants of old historic routes or trails. A portion of the northern route of the Trail of Tears National Historic Trail is preserved within PERI and commemorates the forcible removal and relocation of the Cherokee, Creek, Chickasaw, Choctaw, and Seminole nations from their homelands in Alabama, Georgia, North Carolina, and Tennessee. Additionally, the military park contains part of the Butterfield Overland Mail, a short-lived (1858 to 1861) stagecoach service that transported passengers and mail over 3,200 km (2,000 mi) between Tipton, Missouri, and San Francisco, California.

The military park is situated on the Springfield Plateau of the Ozark Highlands physiographic province, a dissected foothill region predominantly underlain by sedimentary rocks dating to the Mississippian Period approximately 358.9 million to 323.2 million years ago (Guccione 1993; Haley et al. 1993; Chandler and Ausbrooks 2009a, b, 2010). Over millions of years, the gently rolling hills of the Springfield Plateau have been subject to erosion, karstification (the disintegration of carbonate bedrock such as limestone or dolostone), and incision to produce numerous ravines, hollows, caves, ridges, and isolated mountains. Many of these geologic features were strategic locations that significantly impacted the Battle of Pea Ridge (see “Geology and the Battle of Pea Ridge”).

Geologic History

Paleozoic Era: Ancient Seas and Deltas

The bedrock underlying PERI consists of Mississippian limestones, cherty limestones, sandstones, and shales originally deposited in and along an ancient shallow sea that formerly inundated northwestern Arkansas (Guccione 1993; Chandler 2009a, b, 2010). Today, these sedimentary strata are widely distributed across the Ozark Highlands and include (in order from oldest to youngest) the Boone Formation, Batesville Sandstone, and Fayetteville Shale (Table 2). The Ozark region has been above sea level and exposed to weathering and erosion since the Ouachita orogeny (mountain-building event) that occurred throughout the Late Mississippian and early Permian roughly 330 million to 300 million years ago (Thomas et al. 2021; Hudson and Turner 2022). Although the orogeny regionally deformed and uplifted the Ouachita Mountains to the south and the Ozark dome to the north, it has had minimal structural effect on the relatively flat-lying strata of the Springfield Plateau (Guccione 1993; Hudson and Turner 2022).

The Boone Formation (**Mb**) is the predominant bedrock in PERI and consists of fossiliferous limestone interbedded with chert or cherty limestone; these rocks underlie areas of lower elevation, including fields, hollows, and ravines. Carbonate rocks (e.g., limestone and dolostone) of the Boone Formation are susceptible to dissolution (chemical erosion or disintegration) and are associated with several karst features, including caves, springs, and seeps (see “Cave and Karst”; Adams and Ulrich 1905; Thornberry-Ehrlich 2007; Chandler and Ausbrooks 2010). Overlying the Boone Formation is the Hindsville Limestone Member of the Batesville Sandstone (**Mbv**), a sequence of limestone interbedded with shale, siltstone, and sandstone (Figure 1; Chandler and Ausbrooks 2009a, b, 2010). Within the military park, the member caps Welfley’s Knoll and forms the lower slopes of Elkhorn Mountain and Round Mountain (also referred to as “Round Top”). The lower and upper contacts of the Hindsville Limestone Member are unconformities, or gaps of “missing time” in the geologic record caused by erosion or non-deposition. Shales (**Mfl**) and sandstones of the Fayetteville Shale, which are found only in the highest hills or mountains within and surrounding the military park, are the youngest bedrock in PERI. The scenic bluffs atop Elkhorn Mountain consist of the Wedington Sandstone Member of the Fayetteville Shale (**Mfw**), an erosion-resistant, cross-bedded sandstone (Figure 2). Unlike the previously mentioned limestones and shales, the Wedington Sandstone Member was deposited in a deltaic setting along the margins of the inland sea and is known to contain both marine and terrestrial fossils (Chandler and Ausbrooks 2010; Xie et al. 2016). These deltas delivered an influx of coarser-grained, siliciclastic material (sediments rich in silica [SiO₂] such as quartz) shed from the developing uplifts associated with the Appalachian orogeny to the northeast (Guccione 1993; Xie et al. 2016; Thomas et al. 2021).

Table 2. Geologic units mapped within the military park.

GSRI map abbreviations for each time division and GSRI map unit symbols are in parentheses. Only geologic units mapped within PERI are included. Boundary ages follow the International Commission on Stratigraphy (2023).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Quaternary Period: Holocene (H) Pleistocene (PE)	2.58 million years ago to present	Landslide deposits Alluvium and terrace deposits (Qat)	Quaternary surficial deposits are the product of weathering, fluvial (river or stream) incision, and mass wasting processes that continue to shape the military park today.
Mississippian (M)	358.9 million to 323.2 million years ago	Fayetteville Shale, lower part (Mfl) Wedington Sandstone Member (Mfw) Batesville Sandstone Hindsville Limestone Member (Mbv) Boone Formation (Mb)	Limestones and shales of the Boone Formation, Batesville Sandstone, and Fayetteville Shale were deposited in a warm, shallow sea that formerly inundated northwestern Arkansas. The Wedington Sandstone Member of the Fayetteville Shale contains coarser siliciclastic material laid down in a deltaic setting along the sea margin. Following deposition, these rocks were subaerially exposed following the Late Paleozoic Ouachita orogeny that uplifted the Ozark dome and Ouachita Mountains.



Figure 1. Exposure of the Hindsville Limestone Member of the Batesville Sandstone in PERI. The member consists of limestone interbedded with shale, siltstone, and sandstone. For scale, the hammer is approximately 30 cm (1 ft) long. Figure 9B from Chandler and Ausbrooks (2010).



Figure 2. Sandstone bluffs of the Wedington Sandstone Member of the Fayetteville Shale in PERI. The resistant, cross-bedded sandstone caps the highest hills surrounding the military park—including Elkhorn Mountain and Round Mountain. Person for scale. Figure 11B from Chandler and Ausbrooks (2010).

Cenozoic Era: Rivers, Karst, and Landslides

The modern landscape of the military park has been predominantly shaped by fluvial incision coupled with karstification and mass wasting processes. According to Guccione (1993), glaciers never covered Arkansas during the previous Ice Age. Surficial geologic units in PERI include unconsolidated alluvium and terrace deposits (**Qat**) consisting of clay, silt, sand, and gravel (Chandler and Ausbrooks 2009a, b). Gravels are commonly comprised of chert sourced from the Boone Formation (Chandler and Ausbrooks 2010). Within PERI, these deposits are restricted to the Little Sugar Creek Valley south of the Federal trenches; they also occur north of the military park in Cross Timber Hollow. In addition to alluvium and terrace deposits, the Fayetteville Shale and Wedington Sandstone Member are susceptible to landslides; one incident occurred in PERI in 2008 and is mapped along the southeastern face of Elkhorn Mountain (see “Mass Wasting”; Chandler and Ausbrooks 2009a, 2010).

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. In 2015, the NPS GRD, in cooperation with the American Geosciences Institute, published a booklet introducing the American experience of geoheritage, geodiversity, and geoconservation: *America's Geologic Heritage: An Invitation to Leadership*. This publication introduces key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States. That booklet introduced the American experience of geologic heritage and outlined key principles and concepts, including the following five big ideas:

- 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.

Additional information about the geology of Arkansas state, including its geoheritage connections, can be found at the Arkansas Department of Energy and Environment website:

<https://www.geology.arkansas.gov/index.html> (accessed February 2025).

Paleontology

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any 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 rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone.

Fossils preserved in PERI record ancient marine and terrestrial environments that existed over 300 million years ago (see “Geologic History”). On the northern slopes of Elkhorn Mountain, gastropod fossils (*Platyceras compressum*) have been reported from ravine exposures consisting of interbedded sandstone and limestone of the Batesville Sandstone (**Mbv**; USGS locality 2840 of Gordon 1969). Hunt et al. (2008) reported additional fossils, tentatively identified as “coral” and “plant” specimens, in association with a rockslide that occurred near the eastern overlook of Elkhorn Mountain in January 2008. The plant fossils were sourced from the Wedington Sandstone Member of the Fayetteville Shale (**Mfw**) and identified as *Lepidodendron* (or “scale tree”), a large tree-like plant approximately 30 m (100 ft) tall with distinctive diamond-shaped leaf scars (Hunt et al. 2008; Chandler and Ausbrook 2010). Additional investigation into the identification and source of the coral specimen is merited.

All bedrock units present within PERI are known to be fossiliferous outside the park boundary. Additional investigations may lead to future fossil discoveries within the military park.

Indigenous Connections

The military park is located in the archeologically rich Ozark Highlands, an uplifted region of northern Arkansas and southern Missouri with a history of human occupation dating back 10,000 years. The bedrock underlying PERI predominantly consists of limestone and interbedded chert of the Mississippian Boone Formation (**Mb**). Ancient chert quarries found throughout the Ozark region attest to Indigenous Peoples using the chert to make tools and trade implements (Sabo and Early 1988; Thornberry-Ehrlich 2007). According to Carlson-Drexler et al. (2008) and National Park Service (2014), PERI contains several Indigenous sites that include three lithic scatters (human-modified rock debris) and additional lithic materials recovered from Winton Spring. These cultural resources are valuable windows into the past and demonstrate that the local bedrock was valuable to adaptation and survival in the Ozark Highlands. In addition to these sites, PERI staff have documented several rock structures that merit additional archeological investigation (see “Inventory Needs”; Shelley Todd and Nolan Moore, NPS PERI, personal communication 9 April 2025).

Geology and the Battle of Pea Ridge

Geology is often a critical factor that dictates the terrain, tactics, and outcome of military engagements. Several geologic landforms played a crucial role in the Battle of Pea Ridge—including the namesake “Pea Ridge”—which refers to the broad plateau or tableland that slopes gently south from Elkhorn Mountain toward Little Sugar Creek (Shea and Hess 1992). The geologic features described below were instrumental to the battlefield and are described in an order that helps convey the strategy of the Union and Confederate armies.

The Federal Trenches

The Federal (Union) trenches are a system of earthen fortifications constructed along the steep northern bluffs flanking Little Sugar Creek. In the weeks leading up to the battle, the Union army, led by Brigadier General [Samuel Curtis](#), was advancing southwest across the Missouri–Arkansas border in pursuit of the secessionist Missouri State Guard led by Major General [Sterling Price](#). On 5 March 1862, Curtis decided to take a defensive stance and moved his headquarters to the north bank of Little Sugar Creek, where Telegraph Road forded the stream (Shea and Hess 1992; Catton 2024). According to Catton (2024, p. 139), assuming the enemy attacked from the south, it would “...encounter a rampart of rocky limestone bluffs running east and west perpendicular to the north-south road.” The bluffs are underlain by fluvially incised limestone and chert of the Mississippian Boone Formation (**Mb**) that rise 24 m (80 ft) to 36 m (120 ft) above the valley floor and are separated by narrow hollows and intermittent streams. Curtis amassed his army along the bluffs in a south-facing line and ordered them to dig into the rocky soils. The Union forces built rifle pits halfway down the slopes and above the bluffs, as well as two blufftop artillery redoubts on either side of Telegraph Road (Shea and Hess 1992). These earthen fortifications offered protection from anticipated rebel fire but also provided an elevated vantage point to survey the approach of the Confederate troops. Remnants of the Federal trenches are the only remaining structural elements related to the Battle of Pea Ridge (National Park Service 2016). Although the fortifications were never used for their intended purpose, they were instrumental in causing Confederate leadership to alter their plan of attack, thus determining where and how the Battle of Pea Ridge would be fought (National Park Service 2016; Catton 2024).

Elkhorn Mountain

As Price's Missouri State Guard retreated south into Arkansas, they sought shelter in the Boston Mountains south of PERI and rendezvoused with the Confederate army under the command of Major General [Earl Van Dorn](#). With a combined rebel force of nearly 16,000 troops, Van Dorn ordered the joint armies to advance north on 4 March 1862 with plans for a general assault against Curtis and his Union forces (Shea and Hess 1992; Huggard 1997; Annis et al. 2011). The next day, Van Dorn was informed of Curtis' fortified position at the Federal trenches. Discouraged by a frontal attack against the trenches, Van Dorn seized an opportunity to stealthily advance his army north around the Union's right flank via the Bentonville Detour Road. The Bentonville Detour was a gravelly road that branched from Little Sugar Creek and proceeded in a northeasterly arc for roughly 13 km (8 mi) around Elkhorn Mountain; the road intersected Telegraph Road approximately 8 km (5 mi) north of the Federal trenches (Shea and Hess 1992). Elkhorn Mountain is an elongate, 4 km (2.5 mi)-long mountain that marks the northern limit of the battlefield and the northern boundary of PERI (Figure 3). As a prominent geologic landform in the military park, Elkhorn Mountain rises roughly 60 m (200 ft) above the adjacent plateau and consists of the Mississippian Hindsville Limestone Member of the Batesville Sandstone (**Mbv**), the lower Fayetteville Shale (**Mfl**), and is capped by the resistant sandstone of the Wedington Sandstone Member of the Fayetteville Shale (**Mfw**). If Van Dorn could secretly lead his army around Elkhorn Mountain, he would effectively envelop the enemy and have the element of surprise.



Figure 3. View facing north toward Elkhorn Mountain from Cox's Field. Elkhorn Mountain defines the northern boundary of the military park and is the prominent geologic feature of the battlefield landscape. The eastern overlook can be seen on the mountain in the distance. NPS photograph.

As Van Dorn ordered the rebel army to march throughout the night of 6–7 March 1862, his troops were hindered by blizzard conditions, fatigue, hunger, disorganization, and a maze of felled trees (see “Ravines and Ridges”; Shea and Hess 1992; Catton 2024). By morning, the Confederates were strung out for miles along the Bentonville Detour Road—an issue that eroded their numerical superiority. In a calculated gamble to allow his army to catch up, Van Dorn split his forces in half along the western limit of Elkhorn Mountain and attempted a two-pronged attack that would convene on Elkhorn Tavern. These two prongs included (1) soldiers led by Van Dorn and Price along the Bentonville Detour Road north of Elkhorn Mountain and (2) troops led by Brigadier Generals [Benjamin McCulloch](#), [James McIntosh](#), and [Albert Pike](#) along Ford Road to the south of Elkhorn Mountain (Figure 4). Although the mountain initially disguised the movements of the rebels, it proved to be a formidable obstacle that severed the Confederate army and hindered internal command. As an elevated vantage point, the mountain was used by both Union and Confederate troops, who fortified or stationed troops along its commanding bluffs (Johnson and Buel 1887; Shea and Hess 1992). In the final hours of the Battle of Pea Ridge, the geology of Elkhorn Mountain would play into the strategy of the Union artillery positioned at Welfley’s Knoll (see “Welfley’s Knoll”).

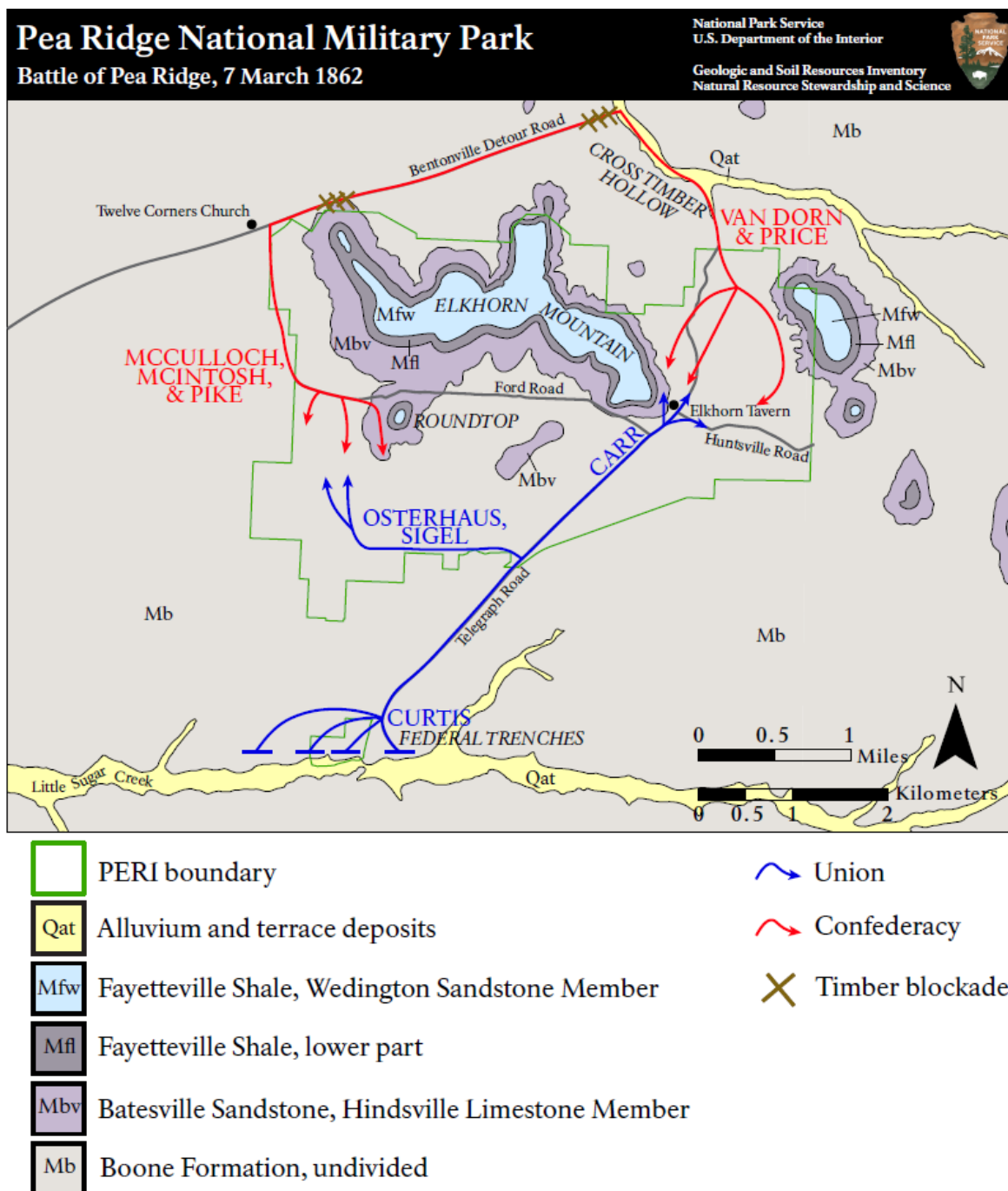


Figure 4. Bedrock geologic map of PERI showing troop movements during the Battle of Pea Ridge, 7 March 1862. In the days leading up to the battle, the Union fortified the limestone bluffs overlooking Little Sugar Creek. The Confederate army used the Bentonville Detour Road to sneak north past Union positions. The rebels split into two attack prongs at the western edge of Elkhorn Mountain and attempted to reconvene at Elkhorn Tavern. To slow the advance of the enemy, the Union forces constructed two timber blockades along the ravines of the Bentonville Detour Road. As fighting commenced near Leetown, the Confederates used Round Mountain to survey the battlefield prior to their disorganized retreat. At Elkhorn Tavern, the Union fortified the crest of Elkhorn Mountain and the surrounding plateau, which offered strategic high ground. The rebels had to fight uphill to get out of Cross Timber Hollow, a daunting task made more difficult by the frozen, chert-rich limestone bedrock. Figure created by Tim C. Henderson (Colorado State University).

Round Mountain or Roundtop

On 7 March 1862, the Battle of Pea Ridge began as two separate battles fought simultaneously on either side of Elkhorn Mountain. As McCulloch, McIntosh, and Pike traversed Ford Road toward their intended goal of Elkhorn Tavern, they were ambushed by Union forces in a clearing of fields immediately west of Round Mountain (also referred to as “Roundtop”; Carlson-Drexler et al. 2008; Annis et al. 2011; Catton 2024). Round Mountain is another prominent geologic landform that stands roughly 45 m (150 ft) above the surrounding agricultural landscape and is lithologically similar to Elkhorn Mountain (Figure 5; see “Elkhorn Mountain”). During the skirmish, mounted Confederate scouts (3rd Texas Cavalry) utilized Round Mountain to survey the battlefield following an initial engagement that left both McCulloch and McIntosh dead (Shea and Hess 1992). The sudden loss of two high-ranking officers left the rebels in disarray and without clear leadership—a significant factor that led to their defeat on the western end of the battlefield.



Figure 5. View from the eastern overlook looking west toward Round Mountain. In the distant center, Round Mountain rises approximately 45 m (150 ft) above the surrounding wooded fields. The mountain was strategically utilized by Confederate soldiers during the Battle of Pea Ridge on 7 March 1862. Figure 4-1 from National Park Service (2014).

Ravines, Ridges, and Hollows

The bedrock underlying PERI predominantly consists of limestone and cherty limestone of the Mississippian Boone Formation (**Mb**). Streams have heavily dissected the bedrock, creating a network of hollows, ravines, and ridges. Immediately north of Elkhorn Tavern, the plateau descends into a series of ravines and ridges that

constitute Cross Timber Hollow and Williams Hollow (Shea and Hess 1992). Prior to the Battle of Pea Ridge, Curtis ordered Union soldiers to preemptively fell trees along the Bentonville Detour to prevent or delay rebel movements. Two separate tree blockades were established at the following locations: (1) along a ravine about 1.6 km (1 mi) east of Twelve Corners Church; and (2) at Cross Timber Hollow (see Figure 4; Shea and Hess 1992; Huggard 1997). These precautionary measures ultimately hindered the progress of Van Dorn and Price's militia along the Bentonville Detour and provided the Union precious time to reconfigure and resupply its troops at Elkhorn Tavern.

By late morning of 7 March 1862, the Confederate infantry had advanced upon Elkhorn Tavern but faced the arduous task of fighting uphill to ascend Cross Timber Hollow. Union forces commanded by Colonels [Eugene Carr](#) and [Grenville Dodge](#) deployed their troops along the northern edge of the plateau and stretched their defensive line over the crest of Elkhorn Mountain to protect troop movements (Shea and Hess 1992). The Union position offered superior high ground, level terrain, and a direct communication line with the rest of the army via Telegraph Road (Shea and Hess 1992). Carr positioned several artillery pieces on Narrow Ridge, a ridgeline that descends north into Cross Timber Hollow. The Union utilized the topography of Narrow Ridge to successfully scout the approaching rebels and attack their susceptible, downslope positions. As fighting commenced, the Confederates heavily fortified the ridges (e.g., Broad Ridge) located on the opposite side of Cross Timber Hollow from the Union artillery. However, the bedrock beneath the Confederacy's offensive pushback impeded the rebel troops' progress as they stumbled over cherty limestone that covered Narrow Ridge and slipped on ice-covered rocks in the ravines on either side (Shea and Hess 1992). According to Shea and Hess (1992), some of the fiercest fighting during the Battle of Pea Ridge occurred as the rebels fought their way uphill out of the hollow and onto the plateau.

Welfley's Knoll

As the Union retreated south from Elkhorn Tavern, Curtis established a new line of position along Ruddick's Field and Cox's Field on either side of Telegraph Road. The western edge of Cox's Field is defined by Welfley's Knoll, a gently rounded hill or knoll underlain by the Hindsville Limestone Member of the Batesville Sandstone (**Mbv**) that rises approximately 15 m (50 ft) above the surrounding fields (Figures 6–7; National Park Service 2014; Shea and Hess 1992). The knoll is named after Union Captain Martin Welfley, who positioned his Independent Missouri Battery at the crest of Welfley's Knoll during the artillery duel that commenced the morning of 8 March 1862. During the final hours of the Battle of Pea Ridge, Union Brigadier General [Franz Sigel](#) commanded several artillery pieces stationed on Welfley's Knoll to inflict serious damage on the Confederate army positioned along the sandstone bluffs of Elkhorn Mountain:

After Hart's battery fled the scene, Sigel directed three of his six batteries to rake the woods on either side of Telegraph Road and three to shift their fire toward the southeastern corner of Big Mountain [Elkhorn Mountain]. The bare, rocky promontory was the most distinctive physical feature on the battlefield. Huge, free-standing columns of sandstone thirty feet high dominated the slope below the crest. Because of the absence of vegetation along this part of the slope the Federals could see the infantrymen of the 2nd Missouri Brigade in line and a battery being hauled toward the crest.

When the Federal gunners opened fire, the imposing promontory became a deathtrap. Incoming artillery rounds smashed into the stone and sent fragments flying in all directions. Infantrymen who sought shelter among the massive formations discovered their error too late. Artillerymen and their horses, standing exposed to the terrible fire, were mowed down. Sigel reported with no exaggeration that “the rocks and stones worked as hard as the shells and shot” to slay the enemy. Within half an hour the Confederate right flank on Big Mountain crumbled, and Van Dorn ordered a withdrawal. (Shea and Hess 1992, pp. 234–235)

According to Shea and Hess (1992), the battle-tested bluffs represent an area along the eastern face of Elkhorn Mountain referred to as the “Point of Rocks.” As the right flank of the Confederate army collapsed due to artillery fire, the rebels realized their lack of available ammunition and retreated from the battlefield via Huntsville Road and Telegraph Road.

Pea Ridge National Military Park

Battle of Pea Ridge, 8 March 1862

National Park Service
U.S. Department of the Interior

Geologic and Soil Resources Inventory
Natural Resource Stewardship and Science

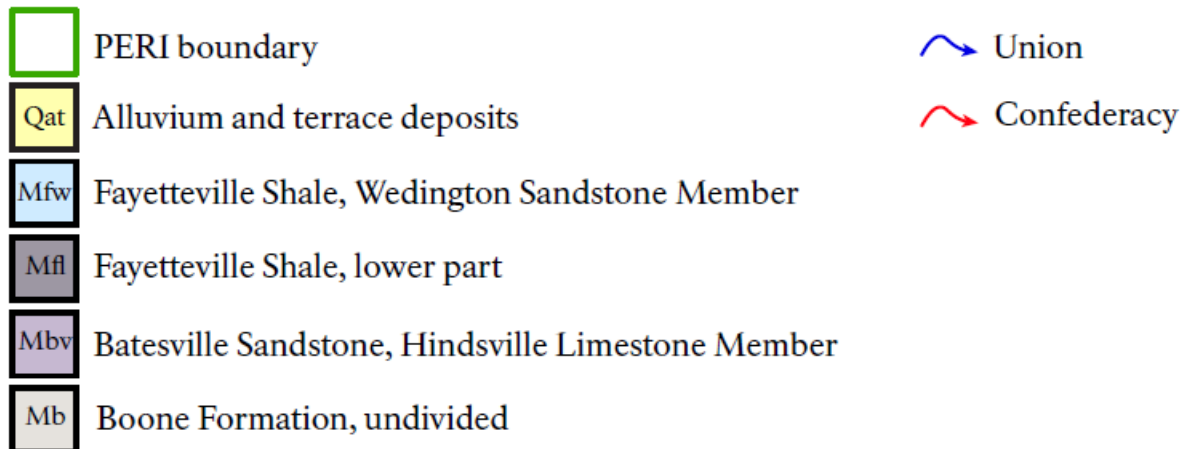
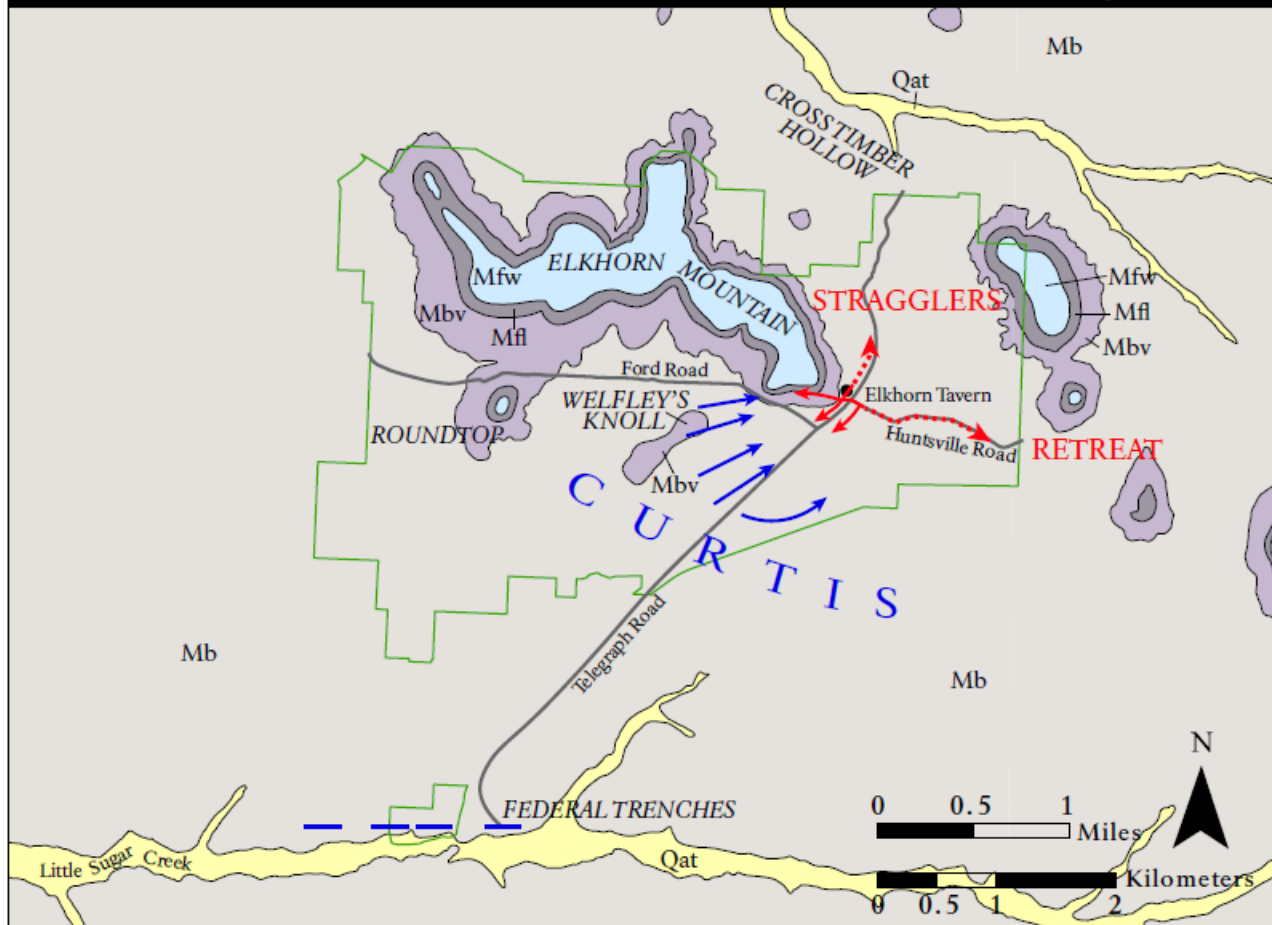


Figure 6. Bedrock geologic map of PERI showing troop movements during the Battle of Pea Ridge, 8 March 1862. Following the rebel defeat near Leetown, the Union consolidated its troops in the fields south of Elkhorn Tavern. Union artillery stationed at Welfley's Knoll inflicted significant damage on rebel soldiers along the bluffs of Elkhorn Mountain. After running low on available ammunition, the rebels retreat via Huntsville Road and along Telegraph Road. Figure created by Tim C. Henderson (Colorado State University).



Figure 7. View from Welfley’s Knoll, facing northeast across the battlefield. The knoll is a gentle hill along the west side of Cox’s Field where limestone of the Boone Formation is overlain by the Hindsville Limestone Member of the Batesville Sandstone. During the Battle of Pea Ridge, the topographic rise was used by Union artillery during the morning duel of 8 March 1862. The eastern face of Elkhorn Mountain rises above the fields to the left. Figure 3-14 of National Park Service (2014).

Memorials in Stone

The military park contains three stone monuments that commemorate the Battle of Pea Ridge, which date back to the late 19th and early 20th centuries. Two of the oldest monuments—the Reunited Soldiery Monument and the Monument to the Brave Confederate Dead—were constructed in the 1880s and are located near Elkhorn Tavern. Both monuments consist of a slender limestone pillar approximately 5 m (15 ft) in height (National Park Service 2014). The Reunited Soldiery Monument is mounted on top of sandstone blocks cut from a local outcrop on Elkhorn Mountain and features a female figure (“Miss Goddess of Liberty”) cut from statuary marble (Catton 2024). The youngest monument in PERI, the US Army Headquarters Monument, was built in 1935 using rough masonry fieldstone (National Park Service 2014; Catton 2024). The monument is located along National Park Drive, just inside the park entry off of US Highway 62.

Pea Ridge, NASA, and Planetary Analog Studies

In 2025, planetary scientists working with the National Aeronautics and Space Administration (NASA), the Planetary Sciences Institute, and other academic institutions performed a field study at PERI to investigate

potential terrestrial analog sites (see <https://news-dev.uark.edu/articles/74360/department-of-geosciences-hosts-mars-scientists-to-look-at-arkansas-rocks>; accessed May 2025). These analog sites are valuable natural laboratories that demonstrate either biological, environmental, or geological conditions similar to those on the Moon, Mars, and beyond. The field workshop focused their study on the Mississippian Wedington Sandstone Member of the Fayetteville Shale, a deltaic sandstone containing sedimentary structures (e.g., crossbedding, ripple-bedding) indicative of channelized flow strength and direction (see “Geologic History”; Chandler and Ausbrooks 2010). Analyses of the Wedington Sandstone Member can provide insight into the depositional conditions that once possibly existed on Mars during an earlier stage in its planetary evolution. Several inferred deltas have been reported for Mars, suggesting the planet once contained more liquid water at its surface—including an ancient Martian ocean (De Toffoli et al. 2021).

Geologic Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified by discussions with SAGA staff. Geologic resource management issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure good management of SAGA. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the Guidance for Resource Management SharePoint for more information regarding geologic resource management.

The NPS GRD has developed an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>; accessed December 2024) that summarizes the laws, regulations, and policies that specifically apply to geologic and soil resources or processes. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or anthropogenic activity.

Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The battlefield landscape presents a variety of geologic hazards, or “geohazards”—naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. The *Addressing Climate Change and Natural Hazards Handbook* (National Park Service 2015, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with environmental change hazards and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management (e.g., [Climate-Smart Planning Principles](#) and [Recommended Practices](#)) has been developed to support effective decision-making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 3) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 3 includes selected geologic and soil hazards listed in Part 1 of the handbook (National Park Service 2023). The GSRI team has added additional hazards where appropriate for the park. If needed, Part 2 of the handbook could inform the completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

Table 3. Geologic hazards checklist.

This summary table is a synthesis of existing GSRI-compiled map data and information, as well as published US Geological Survey and other government agency information. It is suitable 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, 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the military park.

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Earthquake	Falling objects Collapsing structures Inoperability of major building systems (e.g., power, sewer, water) Trigger to other hazards (e.g., landslides) Human injury or casualty	Potential hazard (low; DOI SHIRA)	Arkansas Seismic Network (accessed February 2025) Ausbrooks and Johnston (2024) Earthquakes in Arkansas (accessed February 2025) Guccione (1993) US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper United State Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)
Slope movements (also called “mass wasting”)	Landslides (e.g., rockfalls, slumping or creep) Damage or destruction of park infrastructure Damage to or loss of natural or cultural resource sites or features Human injury or casualty	Known hazard (very high; DOI SHIRA)	Chandler and Ausbrooks (2009b; 2010) DOI SHIRA Risk Mapper Report GSRI GIS hazard layers or slope movement deposits (e.g., “landslide deposits”) Thornberry-Ehrlich (2007)
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Surface collapse Ceiling collapse Rock fall Human injury or casualty	Known hazard (high; DOI SHIRA)	Annis et al. (2011) Chandler and Ausbrooks (2010) DOI SHIRA Risk Mapper Report National Park Service (2014, 2016) Thornberry-Ehrlich (2007)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Shrink/swell soils	Sinking or lateral shifting of the ground beneath roads, trails, or structures The tour road has been repaired numerous times since its construction in 1963 due to unstable substrate problems attributable to underlying clays. Shifting of the roadway generates tension cracks in the pavement surface that allow water to penetrate and further weaken the road base. Damage to infrastructure (e.g., buildings, utility systems) Increased susceptibility to slope movements Human injury or casualty	Known hazard (moderate to very high; USDA Web Soil Survey)	Huggard (1997) Thornberry-Ehrlich (2007) USDA Web Soil Survey
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	Flooding (driven by storms, prolonged rainfall or snowmelt) capable of generating mass wasting events Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Stream channel migration Stream bank erosion Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites Human injury or casualty	Known hazard (extreme; DOI SHIRA)	Annis et al. (2011) DOI SHIRA Risk Mapper Report Federal Emergency Management Agency (FEMA) Map Service Center National Park Service (2014) Thornberry-Ehrlich (2007)
Flash Flood	Sudden rising water and rapid inundation Enhanced mass wasting susceptibility Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Stream channel migration Stream bank erosion Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites Human injury or casualty	Known hazard	2025 follow-up meeting (Shelley and Nolan Moore, NPS PERI, personal communication 9 April 2025) Federal Emergency Management Agency (FEMA) Map Service Center
Volcanic eruption	Not applicable	Not applicable	Not applicable
Hydrothermal activity	Not applicable	Not applicable	Not applicable

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Radon	Health hazard	Potential hazard (moderate – zone 2; DOI SHIRA and US EPA).	DOI SHIRA Risk Mapper Report Otton (1992) US Environmental Protection Agency (EPA) Map of Radon Zones
Toxicological soil (arsenic ¹ , <i>Bacillus anthracis</i> [causes anthrax] ² , cadmium ¹ , lead ¹ , and selenium ²)	Health hazard	¹ Potential hazard (high; DOI SHIRA) ² Potential hazard (low; DOI SHIRA)	DOI SHIRA Risk Mapper Report

Cave and Karst

Karst topography develops in limestone, dolostone, gypsum, and other rocks by dissolution, as the rock is chemically and physically eroded by rainwater containing dissolved carbonic acid. Over time, dissolution can create open spaces or voids that develop into larger interconnected cavities or passages. Karst topography presents several hazards (e.g., surface collapse, ceiling collapse, rock fall), as the dissolution of bedrock often weakens its structural integrity. The military park is predominantly underlain by limestone and cherty limestone of the Mississippian Boone Formation (**Mb**). These rocks are susceptible to karstification and contain an abundance of caves, sinkholes, sinkhole ponds, seeps, sinking streams, and dissolution holes (Thornberry-Ehrlich 2007; Annis et al. 2011; Chandler and Ausbrooks 2010, National Park Service 2014, 2016). In Benton County, the Boone Formation is fractured and contains many cracks that promote water flow and dissolution (Chandler and Ausbrooks 2010). In addition to the Boone Formation, sinkholes in the area surrounding PERI contain rock debris from the overlying Batesville Sandstone (**Mbv**; Thornberry-Ehrlich 2007). According to Thornberry-Ehrlich (2007), as increased urbanization and population growth stress local groundwater aquifers, there is an increased potential for karst collapse as the water table is lowered.

The military park contains one known cave that is located within the hillside of Elkhorn Mountain to the west of Elkhorn Tavern. The limestone cave measures approximately 3 m (10 ft) by 9 m (30 ft) with a clearance of about 2 m (6 ft; Thornberry-Ehrlich 2007; National Park Service 2014). The cave is part natural landform and part man-made structure, with its entrance shaped into a formal square opening (Figure 8; National Park Service 2014). According to National Park Service (2014), it is possible the cave was used for storage during the Battle of Pea Ridge. Due to a partial collapse, the cave is closed to visitors (National Park Service 2016). Several additional caves are rumored to exist in PERI but merit additional investigation (see “Inventory Needs”; Thornberry-Ehrlich 2007). Winton Spring, located along the tour road immediately west of the visitor center, is a karst-related spring originating from the Boone Formation. During the 19th century, the spring was a valuable source of drinking water and was used by Union troops during the Battle of Pea Ridge; Indigenous lithic materials have been recovered from the spring, suggesting the spring was used long before the battle as well (National Park Service 1989; Carlson-Drexler et al. 2008; Catton 2024). Sinking streams within the military park typically appear as dry creek beds and only flow immediately after storms or other large precipitation events. (Thornberry-Ehrlich 2007).



Figure 8. A historic photograph of the limestone cave near Elkhorn Tavern. The cave is situated along the eastern slope of Elkhorn Mountain and contains a carved entrance shaped into a formal square opening. The cave ceiling clearance is about 2 m (6 ft). Due to a partial collapse, the cave is off-limits to the public. Figure 3-144 from National Park Service (2014).

Climate Change

Although climate change planning is beyond the scope of this GSRI summary, a discussion of climate change is included because of the potential disruption it may cause to the military park's resources, including geologic resources. The climate at PERI is already changing; all future climate model projections include temperatures above the recent historical average (1979–2012), and the average annual precipitation is anticipated to be highly variable (Climate Change Response Program 2024). Projected increases in several variables (air temperatures, evaporation rates, droughts, and precipitation) may negatively affect aquifer recharge as well as watershed quality and flow. These changes in water availability are likely to impact geologic processes (e.g., floods, landslides, erosion), in addition to ecological processes (e.g., invasive species, phenology), wildfire occurrence, visitation, and park management procedures (Climate Change Response Program 2024).

Climate change manifestations that may intensify geologic hazards include the following:

- Increased average temperatures
- More frequent and intense storms
- Increased frequency and magnitude of fires
- Increased susceptibility to mass wasting events
- Increased extreme weather scenarios, including drought and flooding
- Decreased water availability during extremely dry weather scenarios

Disturbed Lands

Disturbed lands are places where the natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; and overuse or inappropriate use. Restoration aims to restore a site, watershed, or landscape to a previous condition, typically a desirable historic baseline. Human activity often disturbs lands, leading to unintended and long-lasting issues that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities.

Abandoned Mineral Lands

The military park contains two inactive quarries that postdate the Battle of Pea Ridge. According to Catton (2024), the Federal trenches were negatively impacted by railroad construction in the years following the Civil War. To build portions of the St. Louis-San Francisco Railway, rock was quarried from the bluffs flanking Little Sugar Creek, which obliterated a central section of the Federal trenches (Figure 9; Chandler and Ausbrooks 2009b; Catton 2024). On the northwest flank of Round Mountain is an abandoned quarry that was used during the 1950s construction of Arkansas State Highway 72 (Thornberry-Ehrlich 2007; Chandler and Ausbrooks 2009b; National Park Service 2014, 2016). The quarry is situated within the Mississippian Hindsville Limestone Member of the Batesville Sandstone (**Mbv**). The oval-shaped quarry is about 15 m (50 ft) wide in its longest dimension and is filled with water (Figure 10; National Park Service 2014, 2016).



Figure 9. Aerial photograph taken in the 1960s along the Federal trenches. The view is facing northwest across Little Sugar Creek toward the northern bluffs flanking the creek. The bluffs were quarried during railroad construction (railway in the lower foreground), which damaged a central portion of the trenches. NPS/PERI.



Figure 10. Historic quarry site on the northwest flank of Round Mountain. The quarry is situated in the Hindsville Limestone Member of the Batesville Sandstone and was active during the construction of Arkansas State Highway 72. Today the quarry is filled with water. Figure 3-76 from National Park Service (2014).

Historic Overgrazing

In the early years following the establishment of PERI, special use grazing permits were granted to four neighboring property owners, which accounted for 567 acres of the military park (Huggard 1997). These historic grazing practices were associated with soil erosion problems, including gully formation and topsoil loss during periods of heavy precipitation (Huggard 1997). Although the NPS banned grazing in many of its parks (including PERI) in 1978 due to erosion concerns, the results serve as a valuable lesson in the possible repercussions of vegetative removal on the surrounding landscape.

Surrounding Developments

The military park is located within 10 km (6 mi) of the Bentonville/Rogers metropolitan area and is susceptible to intense development pressure. Regional population growth and increased traffic are stressing the park's resources and have affected the battlefield landscape and visitor experience (Annis et al. 2011; National Park Service 2014). According to National Park Service (2016), the increased traffic at PERI is generating pollution (e.g., sulfur dioxide gas emissions, acid rain) that is causing commemorative monuments and other cultural resources to deteriorate. As nearby residential or commercial developments continue to expand, there is a greater chance that groundwater will become contaminated due to increased surface runoff and septic system installation (Thornberry-Ehrlich 2007). The military park is underlain by

carbonate bedrock that is susceptible to karstification and contains groundwater aquifers and springs that are vulnerable to contamination and increased water usage. As population growth continues to stress available groundwater resources, there is an increased potential for karst collapse as the water table is lowered (see “Cave and Karst”; Thornberry-Ehrlich 2007).

Flooding

The battlefield landscape of PERI is crossed by numerous streams and drainages that include Little Sugar Creek, Lee Creek, Winton Spring Run, and Pratt Creek (Annis et al. 2011; National Park Service 2014, 2016). Little Sugar Creek is the only perennial stream within the military park and bounds the southern edge of the Federal trenches. The 100-year floodplain of Little Sugar Creek extends into this area and is prone to flooding and flash flooding following major storms (Thornberry-Ehrlich 2007; National Park Service 2014). Hydrologic processes such as flooding help govern landform development in PERI (e.g., erosion, sedimentation, stream incision, or migration) but also present several hazards, including inundation, infrastructure damage, riverbank erosion, and washouts. In the mid-1970s, the majority of Lee Creek Road—a historic earthen road dating back to the Battle of Pea Ridge—was washed out by a flood along Lee Creek (National Park Service 2014). Several projects have repaired flood-related damages to culverts, curbs, and other infrastructure along the tour road (Shelley Todd, NPS PERI, personal communication 9 April 2025). As climate change is forecasted to deliver more extreme weather scenarios, there is a concern that the tour road infrastructure is not large enough to accommodate intense storms and prolonged precipitation events (see “Climate Change”).

The frequency and size of floods in PERI affect the supply of water, sediment, and debris to stream channels, which in turn modifies flow and reshapes channel dimensions (Annis et al. 2011). Additionally, floods help transport nutrients, salts, and contaminants that impact ecological habitats. Climate change predictions for PERI include increased temperatures, highly variable precipitation, and an increased occurrence of extreme weather events (e.g., drought or storms) that may influence the frequency, magnitude, and impact of flooding (see “Climate Change”).

Mass Wasting

The term “mass wasting” is used to describe downhill movements of rock, soil, or ice and includes several types of landslide phenomena, including debris (or snow) avalanches, debris flows, slumping or slope creep, and rockfalls. The military park is susceptible to slope creep and landslides, especially along the steep slopes and bluffs of Elkhorn Mountain and Round Mountain. Although these mountains are capped by the Wedington Sandstone Member (**Mfw**), these erosion-resistant sandstones are underlain by shales of the lower Fayetteville Shale (**Mfi**), which are unstable and prone to landslides (Thornberry-Ehrlich 2007). Several large blocks of the Wedington Sandstone Member have detached or spalled off Elkhorn Mountain near the eastern overlook, leaving massive (roughly 5 m [15 ft]-diameter) boulders along the base of the mountain (Figures 11–12; see also Figure 2). Some of these detached boulders predate the Civil War and were used for defensive cover during the Battle of Pea Ridge; it is also quite possible some boulders were dislodged by the artillery duel that took place on 8 March 1862 (see “Welfley’s Knoll”). In January 2008, a large rockfall occurred near the eastern overlook; several large boulders of the Wedington Sandstone Member dislodged, fragmented into smaller blocks, and slid downslope below the overlook (Chandler and Ausbrooks 2010).

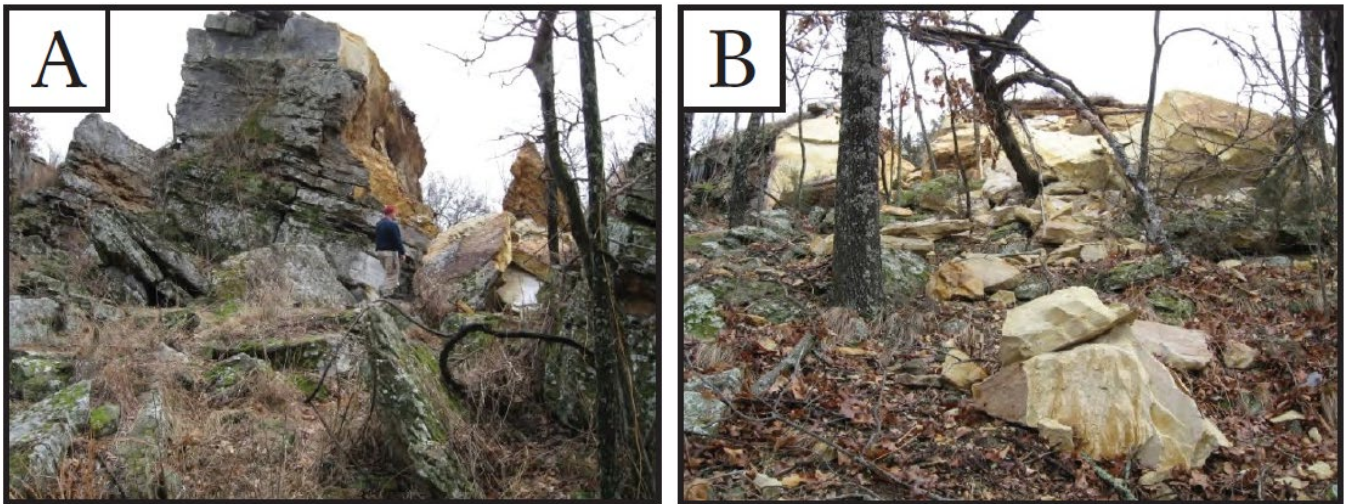


Figure 11. Photographs of the January 2008 landslide at the eastern overlook. A) Large blocks of the Wedington Sandstone Member of the Fayetteville Shale have spalled off the bluffs capping Elkhorn Mountain. A person stands next to the rockfall debris for scale. (B) Smaller pieces of sandstone that have broken and rolled downslope. Figures 13A and 13B of Chandler and Ausbrooks (2010).



Figure 12. Photograph of the rockslide, taken in 2010, showing the bedrock underlying the eastern overlook. The rocks consist of sandstone and siltstone of the Wedington Sandstone Member of the Fayetteville Shale. NPS photograph.

Radon

Radon is a naturally occurring gas created by the decay of radioactive elements present in many rocks. Although radon is almost always present in small amounts in soil and rocks, some types of rock (e.g., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above-average amounts of radon gas that can pose a known health risk (Otton 1992). According to the EPA map of radon zones, Benton County is identified as a zone of moderate potential (zone 2) for elevated indoor radon levels between 2 and 4 pCi/L (see <https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state>; accessed February 2025). The EPA has guidance for radon mitigation.

Seismicity

The Springfield Plateau in northwestern Arkansas is an area of relatively low seismic risk compared to the rest of the country (Petersen et al. 2023). Although Benton County has had several earthquakes—seven of which occurred during the spring and summer of 2010—these were all minor events less than magnitude 3.0 on the Richter scale (Ausbrooks and Johnston 2024; see also [Earthquakes in Arkansas](#); accessed February 2025). However, portions of northern Arkansas have experienced powerful, high magnitude earthquakes related to the New Madrid seismic zone, an active fault system that extends across northeastern Arkansas, southwestern Kentucky, southeastern Missouri, and northwestern Tennessee. The seismic zone represents a failed rift (Reelfoot Rift) formed at the end of the Proterozoic Eon approximately 560 million years ago (Guccione 1993; Elling et al. 2022). During 1811 and 1812, over 1,800 earthquakes were recorded across the seismic zone, four of which are estimated to be greater than magnitude 8 (Guccione 1993). The closest seismic monitoring station to PERI is located approximately 19 km (12 mi) south in Hobbs State Park. The station is part of the [Arkansas Seismic Network](#), a collection of nine broadband seismic stations established in 2010 that are cooperatively operated by the Arkansas Geological Survey, University of Memphis, and Arkansas State Parks.

Swelling Clays

Swelling clays, or shrink-swell clays, include minerals such as smectites that are physically altered by the presence of water and tend to swell when wet and shrink when dry. As swelling clays expand or contract, the change in volume can undermine the integrity of the substrate, increase the susceptibility of slope failure, and cause infrastructure problems along roadways or trails. According to the USDA NRCS Web Soil Survey, several soils mapped within the military park are rated “medium” and “high” in linear extensibility (a determination of shrink-swell potential). Linear extensibility ratings are based on the percentage of volume change as soil dries and include four assessment categories: (1) low, <3%; (2) medium, 3–6%; (3) high, 6–9%; and (4) very high, >9%. The ratings for PERI indicate that swelling clays can cause significant volume change capable of damaging buildings, roads, and other structures. A continuous zone of soils rated high in swelling potential defines the lower slopes of Elkhorn Mountain; these regions correlate to areas underlain by the Mississippian Fayetteville Shale (lower part, **Mfi**) and the Hindsville Limestone Member of the Batesville Sandstone (**Mbv**). One of the highest linear extensibility ratings is for the Summit silty clay (“SsD2”) mapped along the eroded slopes of Round Mountain.

Deeply weathered limestone deposits in PERI contain shrink-swell clay horizons that create hazardous road or trail conditions and damage resources (Thornberry-Ehrlich 2007). Since its construction in 1963, the tour road has been susceptible to damage stemming from erosion and foundational support problems that may be

related to swelling clays. Sections of the roadway are prone to sinking or laterally shifting, which generate tension cracks in the pavement surface (Thornberry-Ehrlich 2007; Huggard 1997). According to Huggard (1997, p. 221), during the 1980s the Federal Highway Commission (FHWA) concluded that weak foundations are “...restricted to certain areas where the road base is resting on a gray fissured clay, typically interbedded with rock in the area.” Water that penetrates the cracked pavement can disintegrate the clay material into a soft mass, leaving the subsurface in a weakened state (Huggard 1997). Further investigation and core drilling performed by the FHWA have revealed damaged sections of the roadway are persistently underlain by saturated soils that will continue to deteriorate without substrate or groundwater remediation (Huggard 1997).

Toxicological Soil

According to the DOI SHIRA (accessed February 2025), soils within PERI have potentially high amounts of arsenic, cadmium, lead, selenium, and *Bacillus anthracis*—a naturally occurring soil pathogen known to cause anthrax. Soil maps show that potentially hazardous concentrations of arsenic, cadmium, lead, and selenium occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, selenium, and their potential health impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see <https://www.atsdr.cdc.gov/>; accessed February 2025).

The bacteria *Bacillus anthracis* causes the rare, naturally occurring disease anthrax, which can cause severe illness in both humans and livestock exposed to spores. For more information on the public health risks associated with anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see <https://www.cdc.gov/anthrax/about/index.html>; accessed February 2025).

Geologic Resource Protection

Legislatively Required Geologic Inventories

The core responsibility of the NPS is to preserve and protect park resources, processes, systems, and values unimpaired for present and future generations. According to National Park Service (2006), the NPS will preserve and protect geologic resources, features, and processes as integral components of park natural systems. The goals of the NPS are to assess the impacts of natural processes and human activities on geologic resources; maintain and restore the integrity of existing geologic resources; integrate geologic resources management into NPS operations and planning; and interpret geologic resources for the benefit and enjoyment of park visitors (National Park Service 2006). Various management protection policies applicable to geologic resources, features, and processes are included in National Park Service (2006) and are also organized at the following website: <https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm> (accessed February 2025).

Paleontological and Cultural Resources

The paleontological and cultural resources of PERI are invaluable and provide a unique window into the geologic and historic past. Fossils and Civil War-related relics are susceptible to erosion, vandalism, and looting (Carlson-Drexler et al. 2008; Thornberry-Ehrlich 2007; National Park Service 2014, 2016). Since the mid-1990s there have been at least five violations of the Archeological Resource Protection Act of 1979—the most recent of which occurred in 2013 and 2022 (Carlson-Drexler et al. 2008; Shelley Todd and Nolan

Moore, NPS PERI, personal communication 9 April 2025). In each instance, looters dug holes in search of battlefield or Indigenous items; the most audacious violation included 104 looter holes (Carlson-Drexler et al. 2008). In addition to looting, several graves in PERI need to be reset or have sunken (National Park Service 2014). Although no geologic mechanism is provided, it may be worth investigating the cause of these shifting grave sites (see “Inventory Needs”). Historic structures, roads, and trails (e.g., Federal trenches, Trail of Tears, Butterfield Overland Mail) within the military park are also susceptible to surface runoff and erosion problems. Since the Battle of Pea Ridge, the Federal trenches have degraded and are now overgrown with vegetation and partially infilled with soil or rocky debris (Figure 13; Thornberry-Ehrlich 2007; Catton 2024). Historic quarry operations along Little Sugar Creek also negatively impacted a central section of the Federal trenches (see “Disturbed Lands”; Chandler and Ausbrooks 2009b; Catton 2024). Many of the historic roads or trails, such as the Trail of Tears, Butterfield Overland Mail, Lee Creek Road, and Leetown Road, have been damaged by erosion related to drainage or flooding (National Park Service 2014, 2016).

All paleontological and cultural resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation. Protection measures for fossils are outlined by the 2009 Paleontological Resources Preservation Act (PRPA). For additional information regarding paleontological resource laws, regulations, and policies, the NPS GRD developed the following summary article: <https://www.nps.gov/articles/paleontology-legal-instruments.htm> (accessed February 2025).



Figure 13. The Federal trenches along Little Sugar Creek. Union troops constructed the trenches atop bluffs underlain by the Boone Formation. Today, these earthen fortifications are muted by surface runoff, erosion, and vegetative overgrowth. The two individuals to the left are standing in the remnants of the trenches. NPS photograph.

Cave and Karst Resources

The military park contains a diverse collection of cave and karst resources that include caves, sinkholes, sinkhole ponds, seeps, sinking streams, and dissolution holes. Many of these features are associated with cultural resources and are vulnerable to population pressures that increase the likelihood of vandalism, pollution, or groundwater withdrawal (Thornberry-Ehrlich 2007). Although one cave is reported within PERI, it is rumored that several others may exist, and the military park has never completed a cave and karst resource inventory (see “Inventory Needs”). Winton Spring is a karst-related spring that was utilized by Union soldiers during the Battle of Pea Ridge and is also associated with Indigenous lithic materials (National Park Service 1989; Carlson-Drexler et al. 2008; Catton 2024). Additionally, the cave located by Elkhorn Tavern may have been used for storage during the battle (National Park Service 2014).

For additional information regarding cave and karst resource laws, regulations, and policies, the NPS GRD developed the following summary article: <https://www.nps.gov/articles/caves-and-karst-systems-legal-instruments.htm> (accessed February 2025).

Inventory Needs

The following table (Table 4) presents geologic and soil resources inventory needs that were identified during the 2025 follow-up meeting, in NPS planning documents, or through literature review.

Table 4. List of identified geologic and soil resources inventory needs for the military park.

Subject	Inventory Need(s)	Reference(s)
Cave and karst resources	Complete a cave and karst resource inventory. Winton Spring and the cave adjacent to Elkhorn Tavern have cultural connections related to the Civil War and early Indigenous occupants. Additional caves have been rumored to exist within PERI. Currently, the military park is planning to conduct a cave inventory during the fall or winter of 2025.	Thornberry-Ehrlich (2007); 2025 follow-up meeting; Nolan Moore (NPS PERI, written communication May 2025)
Cultural resources	Conduct subsurface stability investigations of cemetery sites in PERI. Several tombstones and grave sites have shifted or sunken within the military park. An investigation into the possible mechanism (e.g., karstification, swelling clays) is merited.	National Park Service (2014)
Cultural resources	Complete ground-penetrating radar investigations for burial sites and old historic road traces, including the Trail of Tears, Butterfield Overland, and Telegraph Road.	National Park Service (2016)
Cultural resources	Create an earthworks management plan. The Federal trenches are the only remaining structure related to the Battle of Pea Ridge and have degraded due to surface runoff and erosion. The military park may want to decide how to preserve and maintain these earthworks without damaging them in a hardwood canopy forest.	National Park Service (2016)
Cultural resources	Incorporate historical land use evolution and delineation studies and the effects of geology on the park's history into interpretive programs.	Thornberry-Ehrlich (2007)
Cultural resources	Perform an archeological investigation on the rock structures in PERI. Further investigation is needed to help determine the age and association of these rock structures.	2025 follow-up meeting
Hydrology	Perform dye studies to understand groundwater flow in PERI and its immediate surrounding area.	Thornberry-Ehrlich (2007)
Hydrology	Establish baseline flow conditions for local springs and monitor changes to see if any surrounding developments are impacting the hydrogeologic system.	Thornberry-Ehrlich (2007)
Mapping	The park boundary of PERI needs to be surveyed. A segment of the boundary line is uncertain along the Federal trenches where erosion has occurred along Little Sugar Creek.	National Park Service (2016)
Mapping	Perform detailed mapping of all cave and karst features in the military park.	Thornberry-Ehrlich (2007)
Paleontology	Conduct provenance investigation of tentatively identified "coral" and "plant" fossils. These paleontological resources were observed following the January 2008 rockslide.	Hunt et al. (2008)
Paleontology	Perform a comprehensive paleontological inventory of PERI and establish a plan to deal with potential illegal sampling and collecting.	Thornberry-Ehrlich (2007)

Acknowledgments

The GSRI team thanks the participants of the 2007 scoping meeting and 2025 follow-up meeting for their assistance in this inventory. The lists of participants reflect the names and affiliations of these participants at the time of the meeting and call.

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Literature Cited

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

Adams, G. I., and E. O. Ulrich. 1905. Description of the Fayetteville quadrangle. US Geological Survey. Folios of the Geologic Atlas 119. <https://pubs.usgs.gov/publication/gf119>

Annis, G. M., M. D. Debacker, D. D. Diamond, L. E. Elliott, A. J. Garringer, P. A. Hanberry, K. M. James, R. D. Lee, M. E. Morey, and D. L. Pursell. 2011. Pea Ridge National Military Park natural resource condition assessment. Natural Resource Report. NPS/HTLN/NRR—2011/426. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado <https://irma.nps.gov/DataStore/Reference/Profile/2172828>

Ausbrooks, S. M., and D. H. Johnston. 2011 (revised 2024). Three centuries of earthquakes in Arkansas from 1699 through 2023. Arkansas Geological Survey Digital Geohazard Map GH-EQ-ARK-001. Scale 1:500,000. https://www.geology.arkansas.gov/maps-and-data/geohazard_maps/GH-EQ-ARK-001-three-centuries-of-earthquakes.html

Carlson-Drexler, C. G., D. D. Scott, and H. Roeker. 2008. 'The battle raged...with terrible fury': battlefield archeology of Pea Ridge National Military Park. National Park Service, Midwest Archeological Center. Lincoln, Nebraska. <https://irma.nps.gov/DataStore/Reference/Profile/2198537>

Catton, T. 2024. "When the war come up": historic resource study, Pea Ridge National Military Park, Arkansas. National Park Service, Midwest Regional Office (Regions 3, 4, 5). Omaha, Nebraska. <https://irma.nps.gov/DataStore/Reference/Profile/2304854>

Chandler, A. K., and S. M. Ausbrooks (digital compilation by W. K. Mayfield). 2009a. Geologic map of the Garfield Quadrangle, Benton County, Arkansas: Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-AR-00320, scale 1:24,000. https://ngmdb.usgs.gov/Prodesc/proddesc_86957.htm

Chandler, A. K., and S. M. Ausbrooks (digital compilation by W. K. Mayfield). 2009b. Geologic map of the Pea Ridge Quadrangle, Benton County, Arkansas: Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-AR-00682, scale 1:24,000. https://ngmdb.usgs.gov/Prodesc/proddesc_86956.htm

Chandler, A. K., and S. M. Ausbrooks. 2010. Geology of the Pea Ridge and Garfield Quadrangles, Benton County, Arkansas. Arkansas Geological Survey Information Circular IC-41. <https://www.geology.arkansas.gov/publication/information-circulars/IC-41-information-circular.html>

Climate Change Response Program. 2024. Pea Ridge National Military Park climate futures summary. National Park Service. Fort Collins, CO. <https://irma.nps.gov/DataStore/Collection/Profile/9441>

Elling, R., S. Stein, C. A. Stein, and K. Gefek. 2022. Three major failed rifts in central North America: similarities and differences. GSA Today, 32(6). <https://doi.org/10.1130/GSATG518A.1>

- Gordon, M. Jr. 1969. Revision of some of Girty's invertebrate fossils from the Fayetteville Shale (Mississippian) of Arkansas and Oklahoma—Introduction. US Geological Survey Professional Paper 606-A. <https://pubs.usgs.gov/publication/pp606>
- Guccione, M. J. 1993. Geologic history of Arkansas through time and space. Arkansas and Regional Studies Center, Fayetteville, Arkansas. <https://www.geology.arkansas.gov/education/geology-resources.html>
- Haley, B. R., E. E. Glick, W. V. Bush, B. E. Clardy, C. G. Stone, M. B. Woodward, and D. L. Zachry. 1993. Geologic map of Arkansas. US Geological Survey, Reston, Virginia. Special Geologic Map. Scale 1:500,000. https://ngmdb.usgs.gov/Prodesc/proddesc_16308.htm
- Hudson, M. R., and K. J. Turner. 2022. Late Paleozoic flexural extension and overprinting shortening in the southern Ozark Dome, Arkansas, USA: evolving fault kinematics in the foreland of the Ouachita orogen. *Tectonics*, 41, e2021TC006706. <https://doi.org/10.1029/2021TC006706>
- Huggard, C. J. 1997. Pea Ridge National Military Park: an administrative history. National Park Service History Electronic Library and Archive. <https://www.npshistory.com/publications/peri/index.htm#documents>
- Hunt R., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring—Heartland Network. Natural Resource Technical Report. NPS/NRPC/NRTR—2008/132. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/660631>
- International Commission on Stratigraphy. 2023. International chronostratigraphic chart (v2023/09). Drafted by K. M. Cohen, D. A. T. Harper, P. L. Gibbard, and N. Car. International Union of Geological Sciences (IUGS), International Commission on Stratigraphy (ICS), Durham, England [address of current ICS chair]. <https://stratigraphy.org/chart>
- Jarvis, J. E. 2015. Addressing climate change and natural hazards for facilities. Policy Memorandum 15-01 to All Employees (National Park Service), 20 January 2015. US Department of the Interior, National Park Service, Washington DC Support Office, Washington DC. <https://www.nps.gov/policy/PolMemos/policymemoranda.htm>
- Johnson, J. R., and C. C. Buel. 1887. Battles and leaders of the Civil War: being for the most part contributions by Union and Confederate officers. The Century Company, New York. <https://archive.org/details/battlesleadersof01john/mode/2up>
- National Park Service. 1989. Pea Ridge National Military Park: official map and guide. National Park Service.
- National Park Service. 2014. Cultural landscape report and environmental assessment. National Park Service, Midwest Regional Office. <https://irma.nps.gov/DataStore/Reference/Profile/2217977>

- National Park Service. 2015. Addressing climate change and natural hazards: facility planning and design considerations, January 2015. Level 3 Handbook. National Park Service, Park Planning Facilities and Lands, Construction Program Management Division, Denver, Colorado.
<https://www.nps.gov/dscw/publicforms.htm#df>
- National Park Service. 2016. Pea Ridge National Military Park, Arkansas. National Park Service Foundation Document. <https://www.npshistory.com/publications/foundation-documents/index.htm>
- National Park Service. 2023. Addressing climate change and natural hazards handbook: checklist for assessment of environmental change and effects on National Park Service facilities, version 2, April 2023. NPS Park Planning, Facilities, and Lands Directorate. Washington, DC.
- National Park Service and American Geosciences Institute. 2015. America's geologic heritage: an invitation to leadership. NPS 999/129325. National Park Service, Geologic Resources Division, Denver, Colorado, and American Geosciences Institute, Alexandria, Virginia.
<https://www.nps.gov/subjects/geology/americas-geoheritage.htm>
- Otton, J. K. 1992. The geology of radon. US Geological Survey Unnumbered Series, General Interest Publication. <https://www.usgs.gov/publications/geology-radon>
- Perrone, S. 2023. Report: state of soils information at the National Park Service, WASO level. National Park Service. <https://irma.nps.gov/DataStore/Reference/Profile/2307328>
- Petersen, M. D., A. M. Shumway, P. M. Powers, E. H. Field, M. P. Moschetti, K. S. Jaiswal, K. R. Milner, S. Rezaeian, A. D. Frankel, A. L. Llenos, A. J. Michael, J. M. Altekruze, S. K. Ahdi, K. B. Withers, C. S. Mueller, Y. Zeng, R. E. Chase, L. M. Salditch, N. Luco, K. S. Rukstales, J. A. Herrick, D. L. Girot, B. T. Aagaard, A. M. Bender, M. L. Blanpied, R. W. Briggs, O. S. Boyd, B. S. Clayton, C. B. DuRoss, E. L. Evans, P. J. Haeussler, A. E. Hatem, K. L. Haynie, E. H. Hearn, K. M. Johnson, Z. A. Kortum, N. S. Kwong, A. J. Makdisi, H. B. Mason, D. E. McNamara, D. F. McPhillips, P. G. Okubo, M. T. Page, F. F. Pollitz, J. L. Rubinstein, B. E. Shaw, Z-K. Shen, B. R. Shiro, J. A. Smith, W. J. Stephenson, E. M. Thompson, J. A. Thompson Jobe, E. A. Wirth, and R. C. Witter. 2023. The 2023 US 50-State National Seismic Hazard Model: overview and implications. *Earthquake Spectra* 40(1):5–88.
<https://journals.sagepub.com/doi/10.1177/87552930231215428>
- Sabo, G. III, and A. M. Early. 1988 (revised 2003). Prehistoric culture history. Pages 34–120 in G. Sabo III, A. M. Early, J. C. Rose, B. A. Burnett, L. Vogele, Jr., and J. P. Harcourt, editors. *Human adaptation in the Ozark and Ouachita Mountains*. Arkansas Geological Survey Research Series No. 31. Fayetteville, Arkansas. <https://archeology.uark.edu/learn-discover/publications/>
- Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 in R. Young, and L. Norby, editors. *Geological Monitoring*. Geological Society of America. Boulder, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2203105>
- Shea, W. L., and E. J. Hess. 1992. *Pea Ridge: Civil War campaign in the West*. University of North Carolina Press, Chapel Hill, North Carolina. <https://archive.org/details/pearidgecivilwar0000shea>

- Thomas, W. A., G. E. Gehrels, K. E. Sundell, and M. C. Romero. 2021. Detrital-zircon analyses, provenance, and late Paleozoic sediment dispersal in the context of tectonic evolution of the Ouachita orogen. *Geosphere* 17(4). <https://pubs.geoscienceworld.org/gsa/geosphere/article/17/4/1214/598714/Detrital-zircon-analyses-provenance-and-late>
- Thompson, J. A., S. Kienast-Brown, T. D’Avello, J. Philippe, and C. Brungard. 2020. Soils2026 and digital soil mapping – A foundation for the future of soils information in the United States. *Geoderma Regional* 22, e00294. <https://doi.org/10.1016/j.geodrs.2020.e00294>
- Thornberry-Ehrlich, T. 2007. Geologic Resource Evaluation scoping summary: Pea Ridge National Military Park. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2250411>
- De Toffoli, B., A.-C. Plesa, E. Hauber, and D. Breuer. 2021. Delta deposits on Mars: a global perspective. *Geophysical Research Letters* 48. <https://doi.org/10.1029/2021GL094271>
- Xie, X., W. Cains, and W. L. Manger. 2016. U–Pb detrital zircon evidence of transcontinental sediment dispersal: provenance of Late Mississippian Wedington Sandstone member, NW Arkansas. *International Geology Review* 58(15). <https://doi.org/10.1080/00206814.2016.1193775>