National Park Service
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Natural Resource Stewardship and Science

Tallgrass Prairie National Preserve

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2462

ON THE COVER
The historic one-room schoolhouse was constructed out of the locally quarried limestone such as the Cottonwood Limestone Member of the Beattie Limestone and the Crouse Limestone. The building is situated on a hill in the native prairie landscape.
Photograph by Michael Barthelmes (Colorado State University).

THIS PAGE
Barely beneath the surface in some areas, the bedrock of the Flint Hills weathers to form rocky cobbles and gravel to create a landscape that was not hospitable to sod-busting pioneers looking for farmland. As a result, the area has retained its natural prairie character, a portion of the remaining 4% of prairie that once covered the North American interior.
Photograph by Katie KellerLynn (Colorado State University).

Tallgrass Prairie National Preserve

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Executive Summary

Comprehensive preserve management to fulfill the NPS mission requires an accurate inventory of the geologic features of a park unit, but preserve 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.

Tallgrass Prairie National Preserve, herein called the "preserve," preserves a portion of the remaining 4% of natural tallgrass prairie that once covered much of North America's interior. The preserve was established in 1993, but the geologic landscape both nurtured and protected the prairie ecosystem for thousands of years before that. Located in the Flint Hills of Kansas where the bedrock is at or near the surface and weathers to a blocky rubble and flint gravel, American pioneers found the landscape too difficult to till and thus spared it from the plows that turned the rest of the Great Plains into cultivated farmland.

Long before settlers broke their plows on the Flint Hills, the alternating layers of limestone and shale—deposited in shallow seas during the Permian Period about 280 million years ago—created natural reservoirs of underground water. The tallgrasses of the prairie extended their roots deep into cracks and fractures in the rock layers to find this water and thrive not only in the soil-rich valleys but on the rocky hill crests as well.

The limestone and shale preserve Permian marine life as fossils, some in the form of abundant chert, a hard sedimentary rock made up of quartz (SiO_2). The chert, or flint, weathered out of exposed limestone beds and has been used by Native Americans for making tools for thousands of years. The preserve provides an opportunity for visitors to reflect upon the human, ecological, and geologic history of the Great Plains while experiencing the relationship of Earth and sky, the feeling of vastness, and the openness of the landscape, which all contribute to a "sense of place" (NPS 2017, p. 8).

The preserve's bedrock is divided into a dozen formations. In geologic terminology, a formation is the fundamental rock-stratigraphic unit, meaning it is mappable (at a particular scale), lithologically distinct (with respect to rock type and other characteristics such as color, mineral composition, and grain size) from adjoining strata, and has a definable upper and lower contact (surface between two types or ages of rocks). A formation can be divided into "members" or combined into a "group." The Florence Limestone Member of the Barneston Limestone (formation), for instance, is exposed in the preserve and caps the highest hills along the preserve's northwest edge. Two other members of formations—the Kinney Limestone Member of the Matfield Shale and the Eiss Limestone Member of the Bader Limestone—also crop out in the preserve. The formations in the preserve are part of either the Chase or Council Grove Groups. All of the bedrock units in the preserve are formally recognized in the US Geologic Names Lexicon ("Geolex"), which is a national compilation of names and descriptions of geologic units maintained by the US Geological Survey (see "Additional References, Resources, and Websites"). As an indication of formal recognition, the terms are capitalized, for example, Eskridge Shale, which is composed of the oldest rocks exposed in the preserve.

This report contains the following chapters:

Introduction to the Geologic Resources Inventory—This chapter provides background information about the GRI, highlights the GRI process and products, and recognizes GRI collaborators. A geologic map in GIS format is the principal deliverable of the GRI. This chapter highlights the source maps used by the GRI team in compiling the GRI GIS data for the preserve 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 preserve preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories, such as the locally quarried building stone used in the historic structures, the use of flint by Native Americans, and the role of geology in preserving the natural prairie ecosystem.

Geologic History—This chapter describes the chronology of geologic events that formed the present landscape. In addition to an overview of Permian deposition, this chapter includes a geologic time scale and a table describing the GRI GIS units, paleontological resources, and the presence of springs.

Geologic Features and Processes and Resource Management Issues—This chapter describes the geologic features and processes of significance for the preserve, as well as potential management issues related to the preserve's geologic resources. Issues include (1) fluvial features and processes, especially related to Fox Creek and the many dammed stock ponds and springs in the preserve; (2) locally quarried, bedrock building stone, which is commonly fossiliferous; (3) the abundant paleontological resources of the preserve, including a possible type specimen (the specimen on which the description and name of a new species is based); (4) caves and karst features and processes, namely the alcoves formed in the Threemile Limestone Member of the Wreford Limestone; (5) eolian features and processes; (6) energy and mineral development, both past (oil and gas exploration and rock quarrying) and present (potential wind energy development); and (7) seismic activity, which has become increasingly common as a result of oil-field activity in Oklahoma and south-central Kansas.

Guidance for Resource Management—This chapter is a follow up to the "Geologic Features and Processes and Resource Management Issues" chapter. It provides resource managers with a variety of ways to find and receive management assistance with geologic resources.

Literature Cited—This chapter is a bibliography of references cited in this GRI report. Many of the cited references are available online, as indicated by an Internet address included as part of the reference citation. If preserve managers are interested in other investigations and/or a broader search of the scientific literature, the NPS Geologic Resources Division has collaborated with—and funded—the NPS Technical Information Center (TIC) to maintain a subscription to GeoRef (the premier online geologic citation database). Multiple portals are available for NPS staff to access this database. Monument staff may contact the GRI team or the NPS Geologic Resources Division for instructions to access GeoRef.

This report is supported by a GRI-compiled map of the bedrock geology of Tallgrass Prairie National Preserve. The GRI team used two source maps (Sawin 2008b; Sawin and Buchanan 2008) to compile the GRI GIS data. Geologic map units in the GRI GIS data are referenced in this report using map unit symbols.

Geology is a complex science with many specialized terms. This report provides definitions of geologic terms at first mention, typically in parentheses following the term.

Introduction to the Geologic Resources Inventory

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

GRI Products

The GRI team—which is a collaboration between the National Park Service's Geologic Resources Division and Colorado State University's Department of Geosciences—completed the following tasks as part of the GRI process for Tallgrass Prairie National Preserve (referred to as the "preserve" throughout this report): (1) conduct a scoping meeting and provide a scoping summary (KellerLynn 2008), (2) provide geologic map data in a geographic information system (GIS) format, (3) create a poster to display the GRI GIS data, and (4) provide 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 NPS Integrated Resource Management Applications (IRMA) portal (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 upon 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 (Sawin 2008b, Sawin and Buchanan 2008; 1:12,000) and *Map Accuracy Standards* (US Geological Survey 1999), geologic features represented in the GRI are horizontally within 6 m (20 ft) of their true locations.

Scoping Meeting

On 14 May 2008, the National Park Service held a scoping meeting at the preserve in Cottonwood Falls, Kansas. The scoping meeting brought together preserve staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report. A scoping summary (KellerLynn 2008) summarizes the findings of that meeting.

GRI GIS Data

Following the 2008 scoping meeting, the GRI team compiled the GRI GIS data for the preserve. The data was updated in 2022 and may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format. These data are the principal deliverable of the GRI.

Information about the GRI GIS data can be found in the files accompanying the data on IRMA. The GIS readme file explains the available file formats, how to use the data, and where to find more information about the GIS data model. The ancillary map information document lists the geologic maps or GIS data used to produce the GRI GIS data, the map units and map unit descriptions (including descriptions from all source maps), and additional information about the source maps.

The GRI team did not conduct original geologic mapping but compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data (fig. 1). Scoping participants and the GRI team identified the best available source maps based on coverage (area mapped), map scale, date of mapping, and compatibility of the mapping to the current geologic interpretation of an area.

The GRI GIS data for the preserve was compiled from the following two source maps:

- Surficial geology of the Tallgrass Prairie National Preserve (Sawin 2008b)
- Water-bearing units of the Tallgrass Prairie National Preserve (Sawin and Buchanan 2008)

GRI Poster

A poster of the GRI GIS data draped over a shaded relief image of the preserve and surrounding area is the primary figure referenced throughout this GRI report. The poster is not a substitute for the GIS data but is supplied as a helpful tool for office and field use and for users without access to ArcGIS. Not all GIS feature classes are included on the poster (table 1) 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.

Table 1. GRI GIS data layers for Tallgrass Prairie National Preserve.

Data Layers	On Poster?
Geologic cross section lines	No
Geologic attitude observation localities	No
Geologic observation localities	No
Geologic point features (springs)	Yes
Linear geologic units	Yes
Geologic contacts	Yes
Geologic units	Yes

GRI Report

On 8 December 2021, the GRI team hosted a follow-up conference call for preserve staff and interested geologic experts. The call provided an opportunity to get back in touch with preserve staff, introduce "new" (since the 2008 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.

The GRI report is a culmination of the GRI process. It synthesizes discussions from the scoping meeting in 2008, the follow-up conference call in 2021, 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 writing reflects the data and interpretation of the source map authors. Information from the preserve's foundation document (NPS 2017) was also included as applicable to the preserve's geologic resources and resource management.

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 Matfield Shale mapped in the preserve has the map symbol **Pm**. Capital letters indicate age; the following lowercase letters represent the unit's name. "**P**" represents the Permian Period (~298.9 million to 251.9 million years ago) and "**m**" represents Matfield Shale. A geologic time scale is provided as table in this report.

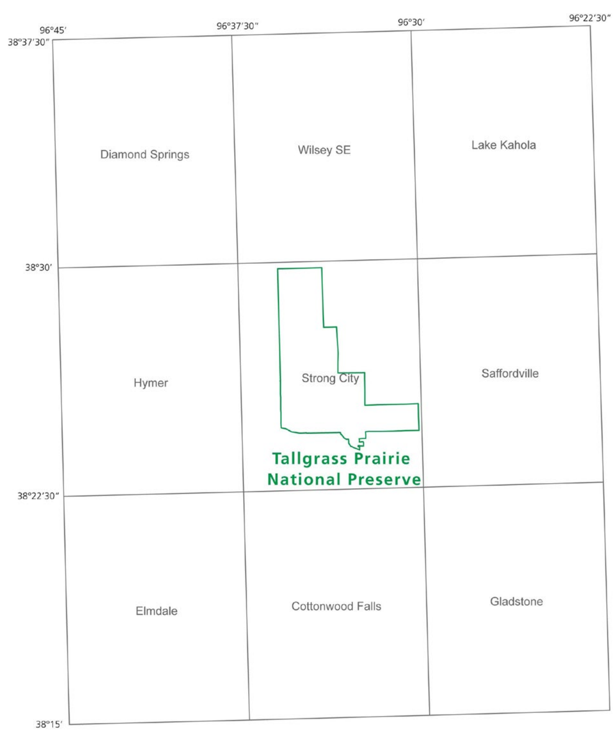

Figure 1. Index map of the GRI GIS data.
This map shows the GRI GIS data in the context of 7.5-minute quadrangles. The data extend only to the NPS boundary of Tallgrass Prairie National Preserve, outlined in green in the figure, and is entirely contained within the Strong City quadrangle. Index map by James Winter (Colorado State University).

Acknowledgements

The GRI team thanks the participants of the 2008 scoping meeting and 2021 follow-up conference call for their assistance in this inventory. The lists of participants are in alphabetical order and reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the Kansas Geological Survey for its maps of the area. This report and accompanying GIS data could not have been completed without them. Many thanks to Chris Buczko and Forrest Smith (NPS Geologic Resources Division) for their review of the Energy and Mineral Development section of this report. Thanks to Trista Thornberry-Ehrlich (Colorado State University) for producing many of the figures in this report.

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Geologic Heritage

America's geologic heritage, also referred to as "geoheritage," encompasses the significant geologic features, landforms, and landscapes characteristic of the nation that are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, and economic. This chapter highlights the geologic features, landforms, landscapes, and stories of Tallgrass Prairie National Preserve valued for their geologic heritage qualities. It also draws connections between geologic resources and other park resources and stories.

Currently, the United States has no comprehensive national registry that includes all geoheritage sites, but all NPS areas possess at least some aspect of geologic heritage, and many are worthy of conservation so that their lessons and beauty will remain as a legacy for future generations. Though park units are not currently established specifically for geoheritage values, any geologic component of a park's enabling legislation or planning and management documents can be considered a part of America's geoheritage. Geoheritage sites generally have great potential for scientific studies, use as outdoor classrooms, and enhancing public understanding and enjoyment. Such sites are fundamental to understanding dynamic earth systems, the succession and diversity of life, climatic changes over time, evolution of landforms, and the origin of mineral deposits.

Preserve Establishment and Setting

The preserve was established by Congress on 12 November 1996 to "preserve, protect, and interpret for the public an example of a tallgrass prairie ecosystem, the historic resources, and cultural and social values represented within the preserve, in the Flint Hills of Kansas." The preserve represents a portion of the less than 4% of remaining tallgrass prairie in the world (KellerLynn 2008). In 1997, the preserve was listed as a national historic landmark for its association with the Cattlemen's Empire period of the late 19th century (NPS 2017).

The establishment of the preserve was the culmination of more than 70 years of interest in and work toward (and opposition to) the creation of a national prairie park (NPS 2017). The entire property is managed jointly by The Nature Conservancy and the National Park Service as a unit of the National Park System; however, of the 4,409 ha (10,894 ac), only 13 ha (33 ac) are owned outright by the National Park Service. The rest is privately owned by The Nature Conservancy. Legislative champion, then-Senator Nancy Kassebaum (R-KS) touted the preserve as a "model for the nation" as a public-private partnership.

In 2021, the preserve welcomed 35,001 recreational visitors (Ziesler and Spalding 2022). This was the highest annual number since its establishment in 1996.

The preserve is in eastern-central Kansas, immediately north of Strong City (fig. 2) in the Flint Hills region (fig. 3) of the Central Lowland physiographic province. The Central Lowlands are a transitional area where the boundary between grasslands and woodlands has shifted over time. Still today, periods of prolonged drought can cause an eastward shift of the shortgrass prairie in western Kansas (Mandel 2006).

The Flint Hills region is a north-south stretch of west-dipping beds of limestone and shale. The limestone contains abundant bands of chert, or flint, which is much less soluble than the encasing limestone and remains as fragmented gravel as the limestone weathers to soil (Wilson 1978).

The preserve's foundation document (NPS 2017) justifies the designation as a unit of the National Park System with the following significances:

- Tallgrass Prairie Ecosystem
- Cultural History of the Prairie
- Legacy of Ranching in the Flint Hills
- Outstanding Stone Architecture
- Scenery
- Management Model

Although none of these values explicitly mention geology, this chapter about geologic heritage explores the connections between geology, the preserve's cultural and ecological history, and the value placed upon them.

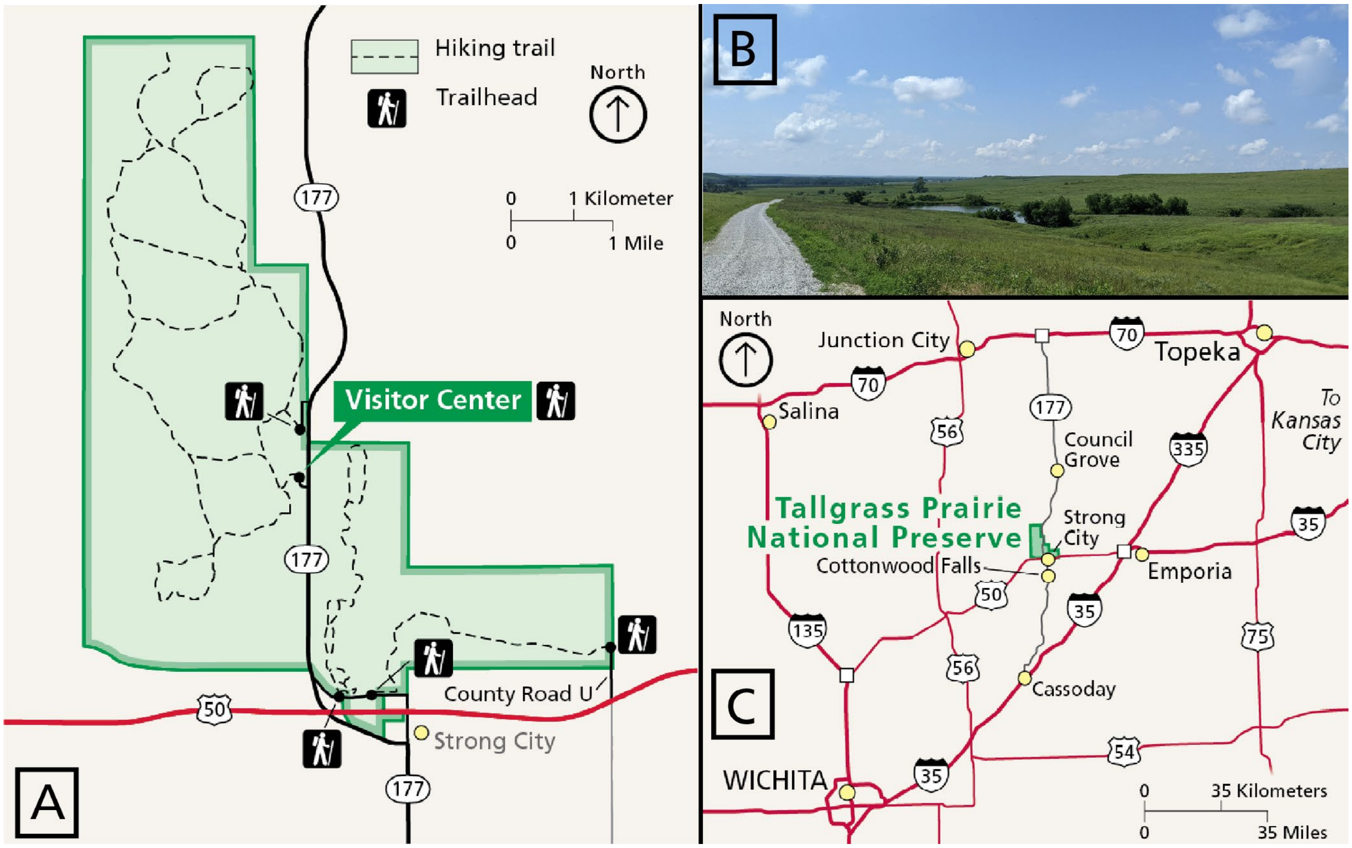

Figure 2. Maps of Tallgrass Prairie National Preserve.
The preserve is located immediately north of Strong City, Kansas, and about halfway between Wichita and Topeka (C). The preserve is crossed by many walking trails (A, B) as well as the historic house, barn, and schoolhouse. The visitor center offers interpretive information about the history, ecology, and geology of the preserve. NPS maps (A, C), photograph (B) by Michael Barthelmes (Colorado State University).

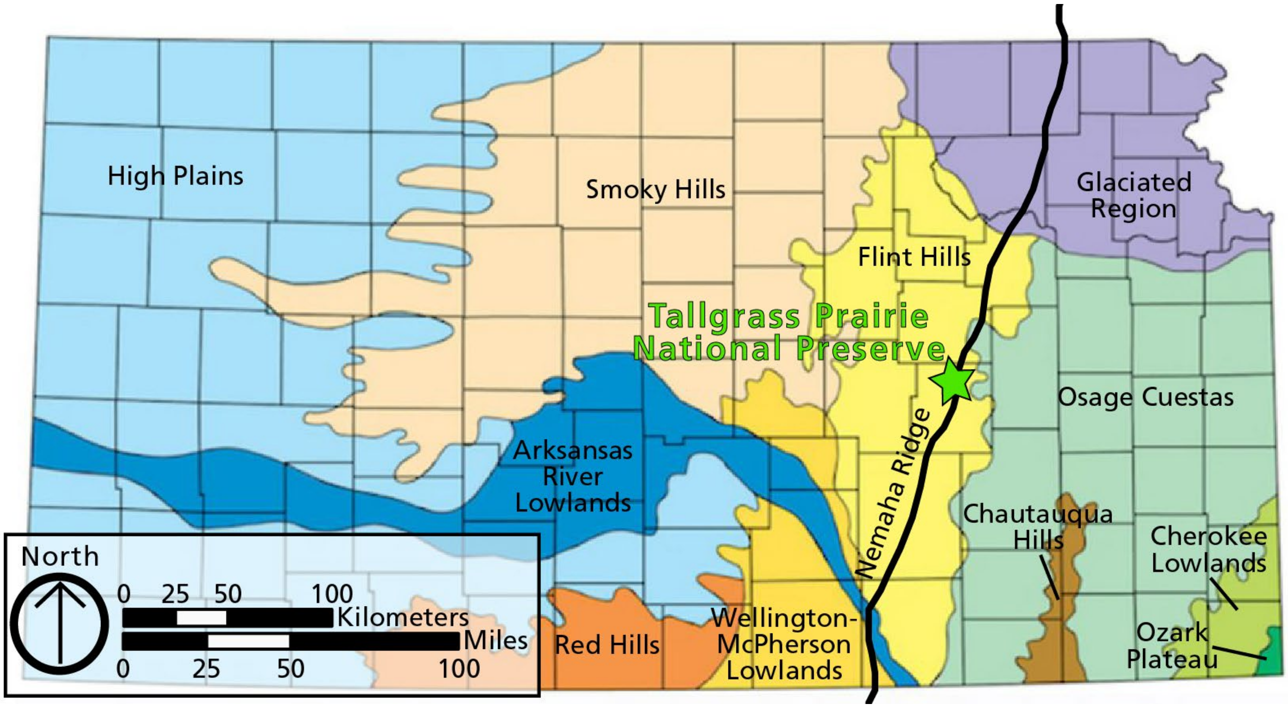

Figure 3. Map of the physiographic regions of Kansas.
The preserve is in the Flint Hills physiographic region of Kansas, named for the abundance of flint in the limestone layers that form the hills. Flint is harder than limestone and remains as jagged gravel as the limestone weathers. The glaciated region in northeast Kansas represents the maximum extent of glacial ice during the Pleistocene Epoch. Although not mapped in the preserve, the windblown glacial dust (loess) forms wide deposits throughout Kansas. The preserve falls directly above the Nemaha Ridge, a buried uplift (large fold [bend] in the strata) composed of rocks as old as Archean and as young as Mississippian (see fig. 5). Graphic adapted by Michael Barthelmes (Colorado State University) from a Kansas Geological Survey map at https://geokansas.ku.edu/physiographic-regions (accessed 17 August 2022).

Cultural Geoheritage

Geoheritage is the connection between geology and human experience. In 2015, the NPS Geologic Resources Division in cooperation with the American Geosciences Institute published a booklet—*America's Geologic Heritage: An Invitation to Leadership* (National Park Service and America's Geosciences Institute 2015)—introducing the American experience of geoheritage, geodiversity, and geoconservation. That publication highlights key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States (see "Additional References, Resources, and Websites").

Native American Culture

In a region named for a geologic feature—the Flint Hills—one does not have to look very far to find geoheritage connections to the preserve's story and resources. A cultural landscape report (Bahr Vermeer & Haecker Architects et al. 2004) was completed for the preserve in 2004 and included a historical timeline of human activity in the region. The following information is based on that timeline and an archeological overview and assessment (Jones 1999).

For thousands of years, beginning at the end of the last glacial advance in North America, and the beginning of the Holocene Epoch (11,700 years ago), humans intermittently inhabited the area. Native American hunter-gatherers used the readily available chert (flint) to make weapons and tools, hunting extant Pleistocene megafauna and other wildlife, as well as engaging in subsistence farming in the thick bottomland soils (Jones 1999).

Archeological evidence from 10,000 years ago to 2,000 years ago—the so-called "Paleoindian" tradition and the Archaic Period—is scarce. Archeological evidence is often preserved by being buried, which is unlikely to occur in areas like the preserve where the bedrock is near or at the surface. Archeological evidence will likely only be found in alluvial deposits (Mandel 1995), which are map units **Qal** and **Qc** (see poster). The thick accumulations of river- and stream-borne sediments are the only depositional environments where tools or weapons could be buried. Many radiocarbon dates of bone fragments and burned wood and charcoal from these settings, including from Fox Creek within the preserve (Mandel 2006), confirm this prediction.

Archeological evidence throughout the Flint Hills from 2,000 years ago to ~200 years ago (calendar year 1825) record a gradual shift toward stationary lifestyle, supported by trade and horticulture (Jones 1999). Hunting and gathering still played an important role in subsistence however, with the introduction of bow and arrow hunting that was supported by the abundant flint resources. Weapons and tools are predominantly made of flint from the Florence Limestone Member of the Barneston Limestone (**Pb**; Jones 1999). The scope of the trading networks is revealed in the provenance of materials, including pipestone (catlinite; see the GRI report about Pipestone National Monument by Graham 2017) and copper from Minnesota as well as Puebloan pottery and obsidian from New Mexico (Jones 1999).

Euro-American Culture

By the year 1541, when the first European explorers encountered the Native American people living in the Great Plains, the Flint Hills region was associated with the rich cultures of the Wichita, Osage, Pawnee, and Kansa Nations (Jones 1999). The next several hundred years are characterized by European and Euro-American colonization, and displacement of the Native American people through treaties and massacres. Kansas became a state in 1861, officially opening the door to settlers eager to explore the farming and ranching potential of the landscape. Stephen Jones, the original owner and builder of the Spring Hill Ranch, purchased land in the area in 1878 (Jones 1999).

The near-surface bedrock and flint-rich gravelly soil made plowing impractical and protected the native prairie of the Flint Hills from being turned into farmland, as happened to most of the Great Plains. Instead, ranching became the primary economy, with cattle grazing filling the niche left by the displaced and hunted bison. Stephen Jones quarried local limestone to construct “the best improved ranch” in Kansas (Bahr Vermeer & Haecker Architects et al. 2004, p. 2-35), consisting of a large house, barn, and outbuildings, and surrounded his land with miles of stone fencing (see the “Bedrock Building Stone” section). Jones also donated the land on which the limestone schoolhouse was built. The cultural landscape report (Bahr Vermeer & Haecker Architects et al. 2004) provides a detailed timeline of the development of Strong City and the surrounding area. Of geologic note is the fact that Barney Lantry, who purchased the Spring Hill Ranch from Jones in 1888, had made his fortune quarrying and shipping the local limestone.

Today, the prairie landscape of the preserve is an opportunity for visitors to reflect on the history of inhabitation and exploration. The Great Plains are a fixture of American culture and history—Laura Ingalls Wilder’s *Little House on the Prairie* takes place in the Flint Hills south of the preserve and William Least Heat-Moon’s “deep map” *PrairyErth* explores the culture, ecology, and geography of Chase County—and, thanks to the underlying geology, the preserve is a place where visitors can experience the native prairie landscape as it has existed for thousands of years.

Geologic History

This chapter describes the geologic events that formed the present landscape. Events are discussed more-or-less in order of geologic age (oldest to youngest; table 2).

Table 2. Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2022). Items in parentheses include GRI map abbreviations for geologic time units. For example, "K" in a map unit symbol means that a map unit was deposited during the Cretaceous Period. "T" in a map unit symbol stands for Tertiary, which is a widely used but no longer formally recognized term for the geologic period from 66.0 million to 2.6 million years ago (Paleogene and Neogene Periods). Where no geologic time subdivision exists, "n/a" indicates not applicable.

Eon	Era(s)	Period(s)	Epoch(s)	MYA
Phanerozoic	Cenozoic	Quaternary (Q)	Holocene (H)	0.0117–today
Phanerozoic	Cenozoic	Quaternary (Q)	Pleistocene (PE)	2.6–0.0117
Phanerozoic	Cenozoic	Neogene (N)	Pliocene (PL)	5.3–2.6
Phanerozoic	Cenozoic	Neogene (N)	Miocene (MI)	23.0–5.3
Phanerozoic	Cenozoic	Paleogene (PG)	Oligocene (OL)	33.9–23.0
Phanerozoic	Cenozoic	Paleogene (PG)	Eocene (E)	56.0–33.9
Phanerozoic	Cenozoic	Paleogene (PG)	Paleocene (EP)	66.0–56.0
Phanerozoic	Mesozoic	Cretaceous (K)	Upper, Lower	145.0–66.0
Phanerozoic	Mesozoic	Jurassic (J)	Upper, Middle, Lower	201.3–145.0
Phanerozoic	Mesozoic	Triassic (TR)	Upper, Middle, Lower	251.9–201.3
Phanerozoic	Paleozoic	Permian (P)	Lopingian, Guadalupian, Cisuralian	298.9–251.9
Phanerozoic	Paleozoic	Pennsylvanian (PN)	Upper, Middle, Lower	323.2–298.9
Phanerozoic	Paleozoic	Mississippian (M)	Upper, Middle, Lower	358.9–323.2
Phanerozoic	Paleozoic	Devonian (D)	Upper, Middle, Lower	419.2–358.9
Phanerozoic	Paleozoic	Silurian (S)	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
Phanerozoic	Paleozoic	Ordovician (O)	Upper, Middle, Lower	485.4–443.8
Phanerozoic	Paleozoic	Cambrian (C)	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic (Z)	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
Proterozoic	Mesoproterozoic (Y)	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic	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

Except for surficial deposits such as alluvium and colluvium (**Qal**, **Qc**) that were deposited in the Quaternary Period (2.6 million years ago–today; see table 2), the geologic units mapped in the preserve were all deposited in the Permian Period (298.9 million to 251.9 million years ago). During the early Permian Period—around 280 million years ago (fig. 4)—the climate was warm, and the area was submerged by a shallow tropical sea (Tolsted and Swineford 1986). Alternating layers of shale and limestone were deposited in this sea, corresponding to fluctuations in sea level; that is, limestone is deposited in deeper water whereas shale is deposited in shallower water. Limestone is formed by the precipitation of calcium carbonate ($CaCO_3$), usually through biological processes from the accumulation of corals and shells. Shale, also generally called mudstone, is formed through the accumulation and compaction of fine-grained quartz (SiO_2), and calcite ($CaCO_3$) minerals. These sediments represent the finest grains that are derived from onshore erosion.

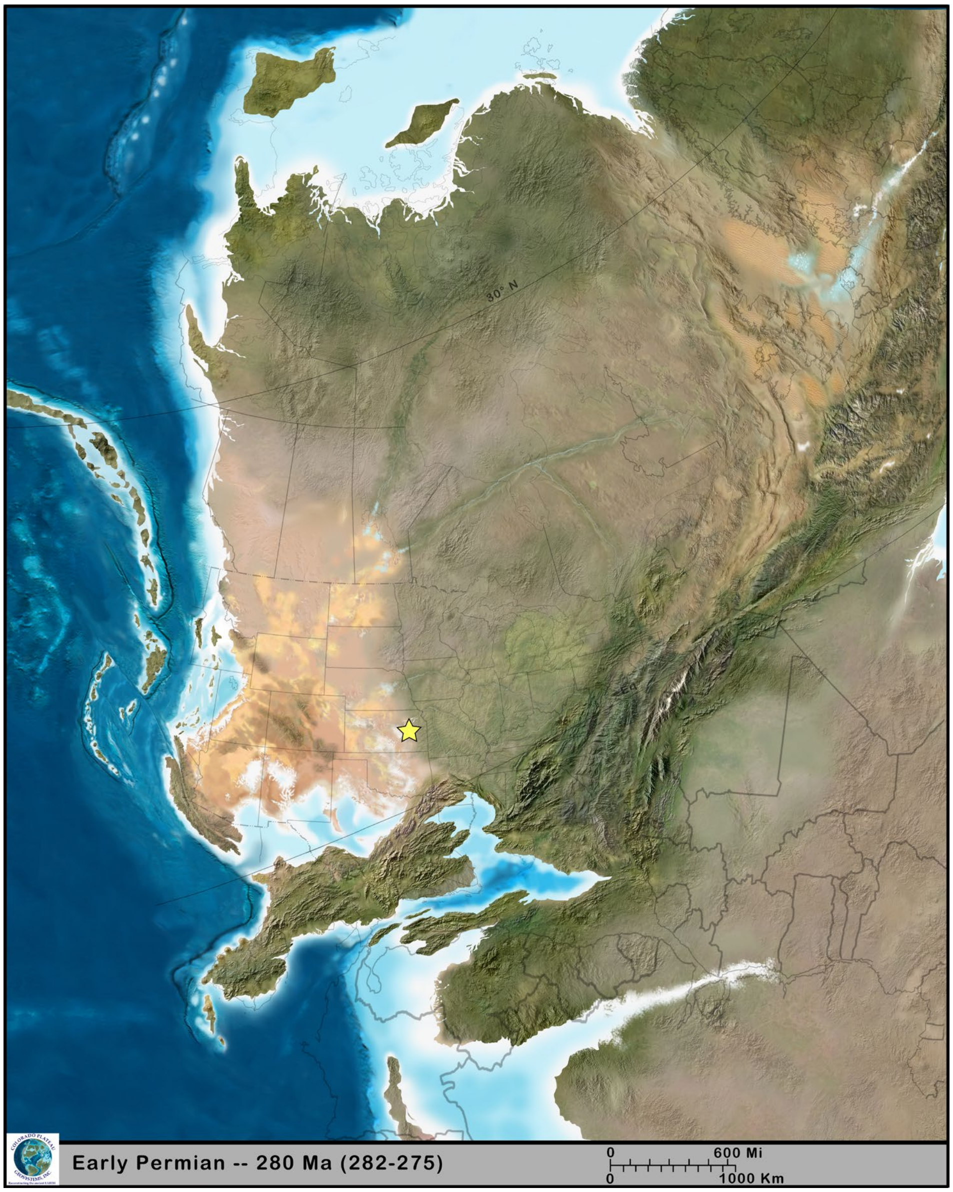

Figure 4. Paleogeographic map of North America during the early Permian Period.
About 280 million years ago, the area of the preserve (yellow star) was submerged beneath shallow tropical seas. Fluctuations in sea level resulted in alternating layers of mud—when the sea was shallower and deposition was closer to shore—and fine-grained remains of calcareous sea life when the water level was higher. Over (a lot of) time, these layers were lithified into the alternating layers of limestone and shale that are exposed at the preserve today. 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).

Within the preserve, three of the limestone units—the (1) Schroyer and (2) Threemile Limestone Members of the Wreford Limestone (**Pw**) and the (3) Florence Limestone Member of the Barneston Limestone (**Pb**)—mapped in the preserve contain prominent bands of chert, or flint. Chert is a fine-grained rock made up of silicate minerals (composed of silicon [Si] and oxygen [O] plus an element or elements, for example, quartz, which is composed of silica [SiO_2]) that are either chemically precipitated or accumulated remains of siliceous (silica-rich) organisms. While most of the organisms that inhabit shallow seas precipitate calcium carbonate ($CaCO_3$), some, such as sponge spicules and the single-celled radiolarians, are silica based. When these accumulate as sediments and are lithified, the silicate minerals form nodules of chert within the limestone. As might be expected in rocks formed from the accumulation of sea life, both the limestone and shale units mapped in the preserve contain abundant fossils (see table 3; Hunt et al. 2008).

Table 3. GRI GIS Permian bedrock geologic units of the preserve.

Table 3 describes the preserve's bedrock including paleontological resources and whether any springs are associated with a geologic unit. Not all members of a formation occur within the preserve (see poster). The alternating layers of permeable (limestone) and impermeable (shale) rock units create a landscape with abundant springs which are ecologically significant; see "Springs and Seeps" section. All of the bedrock units in the preserve were deposited in the Permian Period (298.9 million–251.9 million years ago; see table 2) and are presented here stratigraphically.

Geologic Unit	Description	Paleontologic Resources	Springs
Barneston Limestone, Florence Limestone Member (**Pb**)	Around 4.5 m (15 ft) of the Florence Limestone Member of the Barneston Limestone caps the highest hills in the preserve. **Pb** is light gray/yellow-gray and contains nodules of light- to dark-gray chert which weathers out to accumulate on slopes and create distinctive rounded hilltops.	• Echinoid spines and crinoids are present in outcrops outside of the preserve.	None
Matfield Shale (**Pm**)	The Matfield Shale is 20 m (65 ft) thick and is composed of three members: the Wymore Shale, the Kinney Limestone, and the Blue Springs Shale Members; the base of the Kinney Limestone Member (**Pkin**) is included in the GRI GIS data as a linear feature. • The Blue Springs Shale Member is about 7 m (22 ft) thick and is poorly exposed in the preserve. • The Kinney Limestone Member ranges in thickness from 3 to 7 m (9 to 22), and averages about 5 m (16 ft). The limestone weathers to elongated blocks that accumulate on slopes. • The Wymore Shale Member is about 8 m (27 ft) thick, multicolored, and may contain a boxwork (honeycomb structure that forms in jointed sedimentary rocks) limestone.	Blue Springs Shale Member • No paleontological resources have been recorded from within the preserve, where the unit is poorly exposed. Outside of the preserve, near Manhattan, Kansas, bivalves, gastropods, brachiopods, ostracods, and burrows have been found. Kinney Limestone Member • Bivalves • Gastropods • Brachiopods (*Composita* and *Derbyia*) • Crinoids • Ostracods • Tentaculitids (worm-tubes) • Foraminifera Wymore Shale Member • Bivalves • Brachiopods (*Derbyia*)	None

Table 3, continued. GRI GIS Permian bedrock geologic units of the preserve.

Geologic Unit	Description	Paleontologic Resources	Springs
Wreford Limestone (**Pw**)	The Wreford Limestone is composed of three members: the Schroyer Limestone, Havensville Shale, and Threemile Limestone Members, although these are not individually mapped in the GRI GIS data. • The Schroyer Limestone Member is about 4 m (13 ft) thick and contains layers of flint up to 0.5 m (1 ft) thick. • The Havensville Shale Member is about 3 m (9 ft) thick of yellow-brown-green mudstone, interbedded with fossiliferous limestones. • The Threemile Limestone Member is 5.5 m (18 ft) thick, with flint layers up to 0.5 m (1 ft) thick. It is prominent at the preserve, forming a bench that caps most of the flat-topped hills.	Schroyer Limestone Member • Broken shell fragments • Bryozoans • Brachiopods (*Composita*, *Wellerella*, chonetids, and productids) • Echinoid spines and plates • Crinoids • "Algal" coatings Havensville Shale Member • Bryozoans • Bivalves (*Aviculopecten*, *Wilkingia*, and myalinids) • Brachiopods (*Composita)* • Echinoids and crinoids are present, but less common Threemile Limestone Member • Shell fragments, with well-preserved shells near the base (bryozoans, brachiopods, and crinoids) • Horn corals • Brachiopods (*Neochonetes*, *Meekella*, *Wellerella*, and productid spines)	• Some springs occur at the base of the Schroyer limestone member. • Springs are commonly associated with the Threemile limestone member.
Speiser Shale (**Psp**)	The Speiser Shale is about 5 m (17 ft) thick, contains thin limestone layers, and ranges from gray-green to red, purple, and green from the upper part to the lower part.	• Bryozoans • Bivalves (*Aviculopecten*, *Acanthopecten*, and myalinids) • Brachiopods (*Neochonetes*, *Chonetinella*, *Derbyia*, and productinids) • Crinoids	None
Funston Limestone (**Pf**)	The Funston Limestone averages about 6 m (20 ft) thick with a range from 5 to 7 m (15 to 24 ft). **Pf** can generally be divided into an upper and lower limestone unit, separated by a mudstone. The upper part is rarely exposed; the bottom part is massive and crops out on hillsides, forming a prominent bench with thin plates and sharp, angular edges.	• Bivalves (*Aviculopecten*, *Pseudomonotis*, *Aviculopinna*, myalinids, and algal-coated specimens) • Broken shell fragments (bivalves and brachiopods) and burrows	• Springs are abundant from the upper and lower limestones.
Blue Rapids Shale (**Pbr**)	The Blue Rapids Shale averages 4.5 m (17 ft) thick with a range from 4 to 7 m (14 to 24 ft). **Pbr** is gray, green, and yellow brown, with a thin limestone layer and/or limestone boxwork in the lower part of the unit.	No fossils from **Pbr** have been found in the preserve to date. Tetrapod material reported in Cowley County appears to be from **Pbr**.	None
Crouse Limestone (**Pc**)	The Crouse Limestone ranges from 2 to 4 m (7 to 15 ft) thick with an average of 3 m (11 ft). The upper part is yellow gray clayey limestone that weathers to thin plates. The lower part is gray or yellow brown and contains geodes and iron deposits (limonite).	• Gastropods • Bivalves (*Permophorus*, *Aviculopectn*, *Acanthopecten*, *Pseudomonotis*, *Septimyalina*, and myalinids) • Ostracods	• Springs occur at the base of the lower limestone.

Table 3, continued. GRI GIS Permian bedrock geologic units of the preserve.

Geologic Unit	Description	Paleontologic Resources	Springs
Easly Creek Shale (**Pec**)	The Easly Creek Shale is about 7 m (23 ft) thick and consists of two mudstones separated by as much as <1 m (2 ft) of limestone; this layer is informally called the "Easly Creek limestone."	• Fragments of bryozoans, brachiopods (*Composita*, *Derbyia*, *Neochonetes*, and productids), gastropods (*Straparollus*), trilobites (*Ditomopyge*), and crinoids. • Limestone contains bivalves (*Aviculopecten*, *Acanthopecten*, and *Pseudomonotis*), brachiopods (*Composita*, *Derbyia*, and productids) and bryozoans (e.g., *Acanthocladia*). • "Algal" coating on shells • Invertebrate burrows	• Some springs are associated with the "Easly Creek limestone."
Bader Limestone (Eiss Limestone Member; **Pba**)	The Bader Limestone is about 26 ft (8 m) thick and consists of three members: the Middleburg Limestone, the Hooser Shale, and the Eiss Limestone Members. The base of the Eiss Limestone Member is included in the GRI GIS data as a linear unit (**Ptei**). • The Middleburg Limestone Member is about 6 ft (2 m) thick and is composed of gray limestone, green mudstone, and a black shale. • The Hooser Shale Member is about 5 ft (1.5 m) thick and is a gray green mudstone that is red at the base. • The Eiss Limestone Member averages about 15 ft (4 m) thick and is composed of and upper and lower limestone and middle mudstone. The upper limestone is gray and contains gypsum (a soft, evaporite sulfate mineral) nodules; outcrops of the lower limestone are rare.	Middleburg Limestone Member • Bivalves (*Aviculopecten*, *Acanthopecten*, *Pseudomonotis*, and myallinids) • Brachiopods (productids) • Gastropods (*Bellerophon* and high-spired snails) • Crinoids Hooser Shale Member • None to date Eiss Limestone Member • Bivalves (*Aviculopecten*, *Acanthopecten*, *Pseudomonotis*, *Schizodus*, *Aviculopinna*, and myalninids) • Bryozoans (e.g., *Tabulipora*, *Rhombopora*, and *Acanthacladia*) • Brachiopods (*Neochonetes*, *Meekella*, *Derbyia*, *Composita*, *Juresania*, and *Reticulatia*) • Echinoid spines and plates • Crinoids • Trilobites (*Ditymopyge*)	• The Middleburg Limestone Member yields some springs. • Springs are common from the upper limestone of the Eiss Limestone Member.
Stearns Shale (**Psp**)	The Stearns Shale ranges from 2.5 to 4 m (8 to 14 ft) thick with an average of 3 m (12 ft). It is a green, red, purple, and gray mudstone that may contain thin or boxwork limestone.	The Stearns Shale is not fossiliferous.	None

Table 3, continued. GRI GIS Permian bedrock geologic units of the preserve.

Geologic Unit	Description	Paleontologic Resources	Springs
Beattie Limestone (**Pbe**)	The Beattie Limestone is about 7 m (21 ft) thick and consists of three members: the Morrill Limestone, the Florena Shale, and the Cottonwood Limestone Members. • The Morrill Limestone Member is about 1.5 (5 ft) thick and contains thin mudstone beds. In some places, the limestone forms prominent outcrops. • The Florena Shale Member is gray-green and about 3 m (11 ft) thick. • The Cottonwood Limestone Member is about 1.5 m (5 ft) thick and is light gray to yellow-white, with a blocky appearance.	Morrill Limestone Member • Rare brachiopods and echinoderms Florena Shale Member • Fenestrate bryozoans • Brachiopods (*Neochonetes*, *Meekella*, *Derbyia*, *Composita*, and productids) • Echinoid spines • Crinoids Cottonwood Limestone Member • Fusulinids (*Schubertella*, *Schwagerina*, and *Triticites*) • Crinoids • Echinoid spines • Brachiopods • Bryozoans	None
Eskridge Shale (**Pe**)	The Eskridge Shale is the bottommost bedrock unit exposed in the preserve; it crops out as a gray green mudstone along Fox Creek in a few localities. The maximum exposed thickness is 4 m (14 ft).	• Plant material (tree bark and leaves), bivalves, and gastropods have been discovered in **Pe** outside of the preserve.	None

The layers of rock dip gently westward, a result of the underlying Nemaha Ridge (Wilson 1978), an uplifted ridge of Precambrian (older than 538.8 million years) granite in the rocks that form the basement of the Kansas landscape (fig. 5).

Any rocks that had been deposited in the preserve area between the Permian and Quaternary Periods (~280 million years ago–2.6 million years ago) have since been eroded from the land's surface, a process that is continuing today. Differential erosion of the shales and limestones creates the topography of the Flint Hills. The softer material of the shale erodes readily, while the harder limestone remains to form hills and benches. The chert fragments in the limestone layers are resistant to erosion and weather out to form angular gravel that covers the surface. This gravel has armored the limestone beds against erosion and armored the prairie landscape from the plows of would-be "sodbusters."

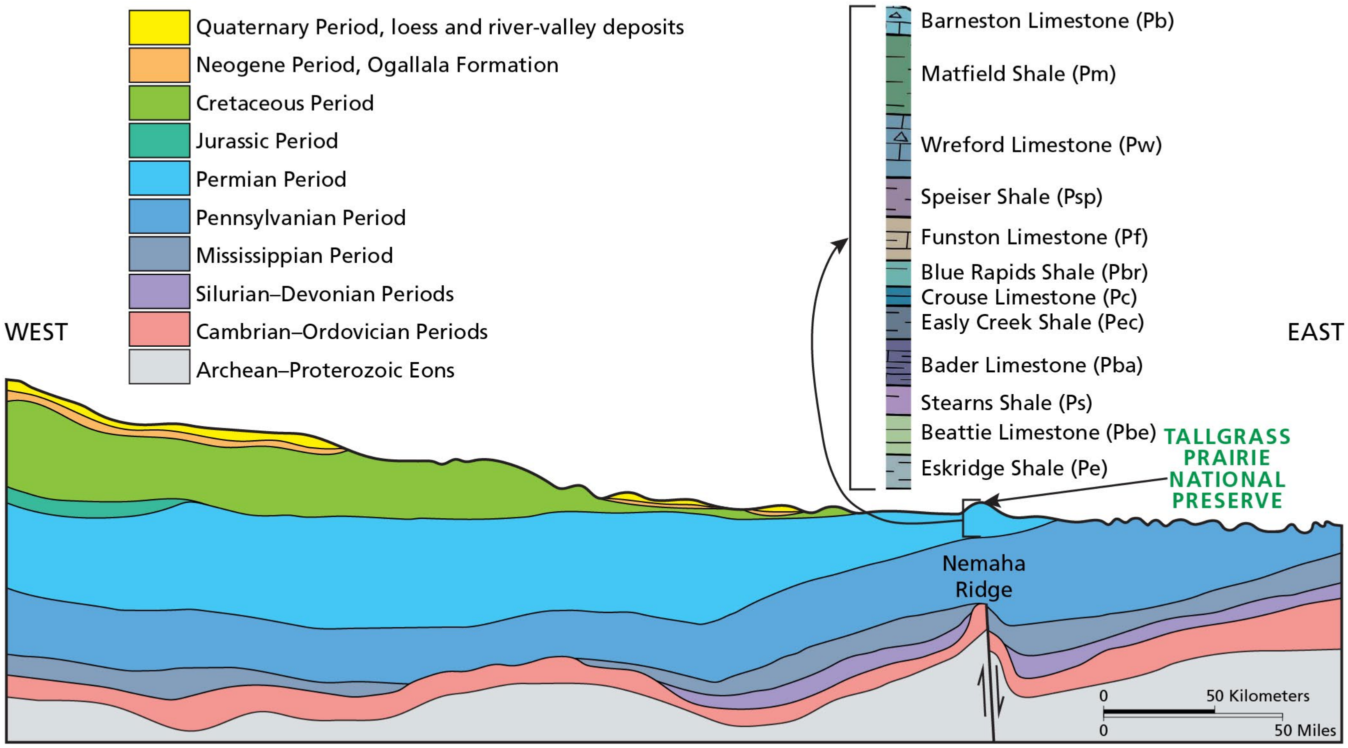

Figure 5. Generalized cross-section of the geology of Kansas.
The bedrock of Kansas consists of generally horizontal layers of sedimentary rocks. The farther east in Kansas, and the closer to the Missouri River, more of the surface has been eroded to reveal older rocks. The preserve is in the area called the "Permian system" for the rocks exposed there; these rocks were deposited during the Permian Period (298.9 million–251.9 million years ago). Alternating layers of shale and limestone, like those in the preserve, characterize this region. The Nemaha Ridge, which is underneath the preserve, is an uplift (large fold or bend in strata) created by movement along a near-vertical fault during the Pennsylvanian Period. Pennsylvanian and Permian rocks have since buried the uplift. Graphic by Trista Thornberry-Ehrlich (Colorado State University) adapted from Tolsted and Swineford (1986) and Sawin (2008b).

Geologic Features, Processes, and Resource Management Issues

The geologic features and processes highlighted in this chapter are significant to the preserve's landscape and history. Selection of these features and processes was based on input from scoping and conference-call participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues (see the "Guidance for Resource Management" chapter). The issues are ordered with respect to management priority.

Since scoping in 2008, the National Park Service has completed a foundation document (NPS 2017) and a natural resource condition assessment (Jones et al. 2019) for the preserve. Because these documents are a primary source of information for resource management, they were used in preparation of this report to draw connections between geologic features and "core components" such as "fundamental resources and values" and "other important resources and values."

In 2021, a follow-up conference call with preserve staff, Kansas Geological Survey geologists, and GRD staff (see the "Introduction to the Geologic Resources Inventory" chapter) verified the present-day pertinence of issues identified in 2008. The call helped to update the list of geologic resource management issues, in particular the increase in seismic activity related to fluid injection in Oklahoma and Kansas, and to guide research of this report.

The following list of geologic features and processes and resource management issues is based on the 2008 scoping summary, 2017 foundation document, and 2021 conference call discussion, and report reviewers' comments.

- Fluvial Features and Processes
- Bedrock Building Stone
- Paleontological Resources
- Caves and Karst Features and Processes
- Eolian Features and Processes
- Energy and Mineral Development
- Seismic Activity

Fluvial Features and Processes

Fluvial features and processes are related to flowing water in rivers and streams. Fluvial features in the preserve include Fox and Palmer Creeks and their unnamed tributaries, other unnamed intermittent and perennial streams, springs and seeps, and several dammed stock ponds. Fluvial processes are the main driver of landscape evolution in the preserve. Fox Creek, the primary drainage of the preserve and a tributary of the Cottonwood River, flows generally north–south through the preserve east of the visitor center and historic farmstead. Palmer Creek, a tributary of Fox Creek, flows west–east across the northern extent of the preserve.

Alluvial deposits (e.g., **Qal**) are those deposited by running water; colluvial deposits (e.g., **Qc**) are those deposited at the foot of slopes, often as a result of rain or sheet flow. Some deposits in the preserve are both alluvial and colluvial (**Qc**).

More than 20,000 years of alluvial and colluvial deposition and features are found in the Fox Creek valley (Mandel 2006). The Fox Creek valley is around 1,000 m (3,280 ft) wide and consists of four Quaternary (2.6 million years ago–today) features: (1) a low floodplain, (2) a high floodplain, (3) an alluvial terrace, and (4) a series of colluvial fans (fig. 6; Mandel 2006). The low floodplain is frequently flooded whereas the high floodplain floods only occasionally. The terrace represents an older floodplain surface and slopes gently away from the valley walls where it merges with alluvial/colluvial fans. The fans consist of a mix of fine and coarse-grained sediment derived from the uplands.

The preserve's foundation document (NPS 2017) lists "upland prairie streams" as a fundamental resource or value (FRV), citing their contribution to the diverse hydrological character of the tallgrass prairie. The streams are habitat to more than 30 species of fish and aquatic invertebrates, including the federally endangered Topeka shiner (*Notropis topeka*) and several state-listed fish species. The streams and springs are also a water source for terrestrial species, and a narrow ribbon of riparian forest adjacent to Fox Creek provides food and habitat to woodland fauna (Mandel 2006).

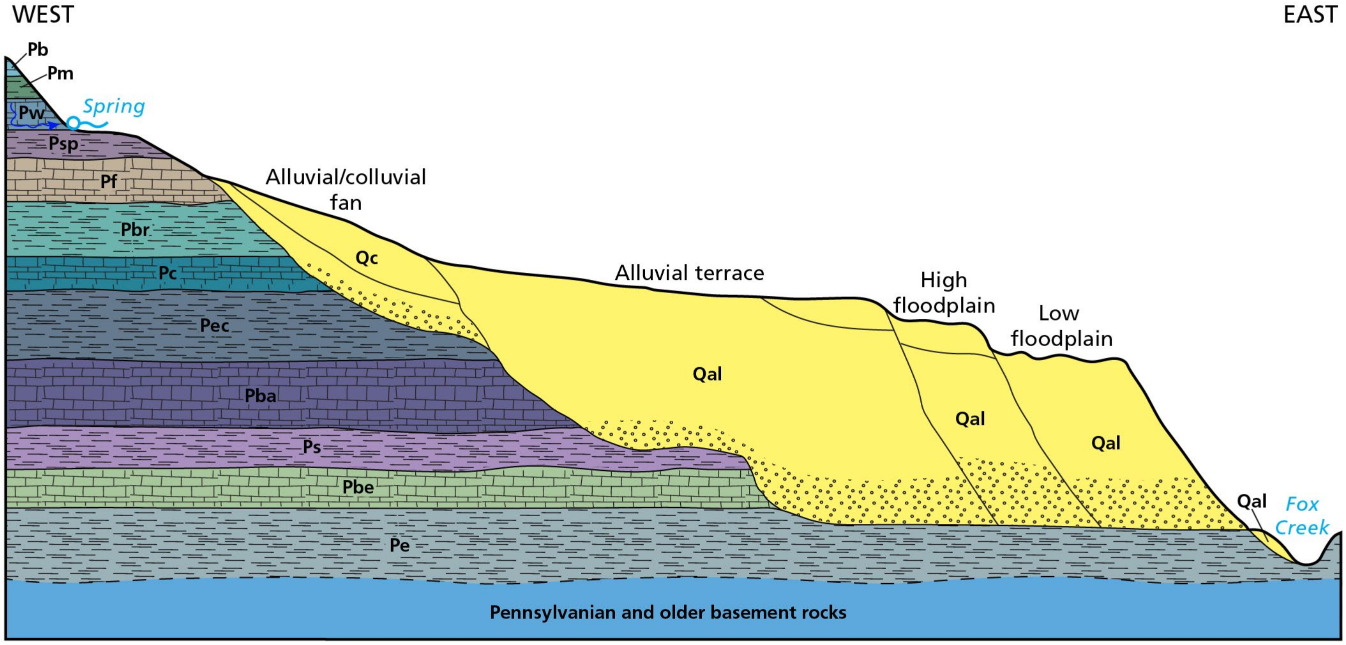

Figure 6. Generalized cross section of the preserve and Fox Creek valley.
The Fox Creek valley contains four distinct recent depositional features: two floodplains, a terrace, and an older alluvial/colluvial fan. These are deposited on top of the eroded Permian bedrock which crops out elsewhere in the preserve. The alternating layers of limestone and shale in the Permian rocks create seeps and springs throughout the preserve. Groundwater percolates through the permeable limestone layers (e.g., Wreford Limestone, Pw) until it encounters an impermeable shale layer (e.g., Speiser Shale, Psp), at which point it travels horizontally until it intersects with the land surface as a spring. Springs are an important source of water for wildlife in the preserve, and water bearing limestone units form reservoirs that the long tallgrass roots access. Graphic by Trista Thornberry-Ehrlich after Mandel (2006, figure 4) and Sawin (2008b).

Potential management concerns associated with fluvial features and processes include erosion, flooding, and the preservation of habitat. Fluvial erosion is a management concern for the protection of archeological and paleontological sites along streams (KellerLynn 2008); land modification, such as removal of agricultural terraces to restore natural drainage, may threaten buried cultural resources (Mandel 2006). Erosion along streams is exacerbated by cattle and bison going to the streams (KellerLynn 2008). The historic or contemporary removal of gravel from Fox and Palmer Creeks (outside the preserve), and channelization of streams at road crossings may be leading to bank instability along stream reaches within the preserve (Kristen Hase, Tallgrass Prairie National Preserve, superintendent, conference call, 8 December 2021).

Flooding is common in the preserve and affects trails, water crossings, and restoration fields; however, flooding is not considered a significant issue (Kristen Hase, conference call, 8 December 2021). The 28 dammed ponds in the preserve, which were built in 1930s, are associated with springs and streams (KellerLynn 2008). These ponds are habitat for the Topeka shiner and are occasionally affected by algal blooms, likely a result of over 100 years of pond use by cattle. Many of the dams are not properly engineered and several have breached in the last several years (Kristen Hase, conference call, 8 December 2021), resulting in minor flooding and erosion (fig. 7). Cattle traffic around the ponds also causes erosion (KellerLynn 2008).

Springs and Seeps

Sawin and Buchanan (2008) inventoried 236 springs and seeps within the preserve; these are included in the GRI GIS data and on the poster. Springs occur where water-bearing rock units intersect with the land surface. The alternating layers of shale and limestone that underlie the preserve create a landscape with abundant springs. Limestone is a permeable rock type—water from precipitation seeps through joints and fractures in limestone, which are widened over time by the flowing water. When the water encounters a less-permeable layer of shale, it flows horizontally until it encounters the hillside (see fig. 6). Many of the springs mapped in the GRI GIS data occur at or near contacts between limestone and shale units (see poster).

Figure 7. Photographs of stock ponds and related erosion.
(A) Dammed stock pond, as seen from a walking trail. (B and C) Examples of erosion caused by flooding of the stock ponds. The ponds provide an important source of habitat, including for the endangered Topeka Shiner, and a source of water for cattle, bison, and other wildlife. The historic dams are not properly engineered and when they fail can cause flooding and erosion. Cattle moving around the edge of the ponds can also cause erosion. Photographs by Michael Barthelmes (A; Colorado State University) and Katie KellerLynn (B and C; Colorado State University).

Springs are an important source of year-round water for wildlife in the preserve. Springs are also an important source of year-round water for cattle and bison, especially where the springs are dammed to form ponds. Water-bearing rock units also act as reservoirs, providing water to the vegetation. In some places, this results in species of grasses growing in unexpected locations. In prairie landscapes, the soil is thinnest on hilltops and around rocky outcrops and these areas are generally populated with “shortgrass” vegetation whereas the “tallgrass” species are found in the thicker and wetter soil of the lowlands (KellerLynn 2008). However, the presence of water-bearing limestone underlying hills allows tallgrasses to grow everywhere in the preserve—the tallgrasses extend roots into fractures in limestone to find reserves of water (Hoy 2006).

Water-bearing limestone, springs, and seeps are a part of the natural character and cultural history of the preserve, for example, Stephen F. Jones named his Spring Hill Farm and Stock Ranch for the features; however, the destructive power of running water is also a management concern. The foundation document (NPS 2017) identifies water infiltration as a threat to historic structures. Scoping participants discussed an intermittent spring that runs through the crawl space beneath the ranch house (KellerLynn 2008), and Sawin (2008b) identified likely water-bearing limestone intersecting with the house’s foundation. A 2021 project stabilized the house and improved the drainage at and around the house (Kristen Hase, written communication, 28 June 2022).

Bedrock Building Stone

More than 60 structures and over 50 km (30 mi) of fencing in the preserve are constructed of local bedrock. The Cottonwood Limestone Member of the Beattie Limestone (**Pbe**) weathers into large blocks and was quarried to construct the main ranch house and many outbuildings (KellerLynn 2008). The Cottonwood Limestone Member was also used to form the corners of the three-story barn and the schoolhouse (fig. 8), but Crouse Limestone (**Pc**) quarried south of the preserve was used for the walls (Hunt et al. 2008).

The extensive stone fencing in the preserve is one of the most definitive features and records the evolution of farming and ranching life in 19th and 20th century Kansas. The limestone was used in part for its availability—quarry locations are pointed out during interpretive bus tours—and in part for its durability as a building material. The bedrock building stone does not pose any outstanding management concerns although potential exists for the development of interpretative themes tying the geologic and cultural resources together; additionally, much of the building stone (e.g., **Pc**) is fossiliferous (see “Paleontological Resources”).

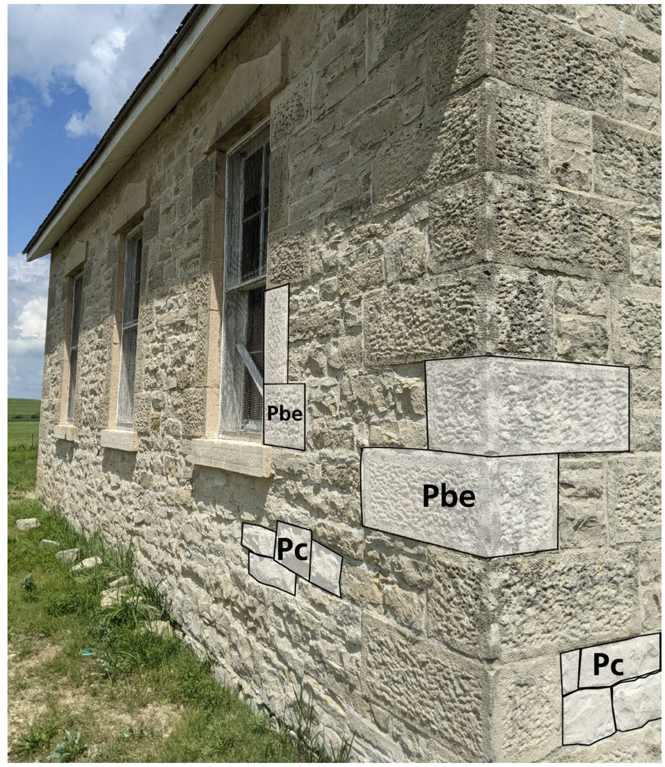

Figure 8. Photograph of schoolhouse rock. The historical schoolhouse, north of the farmstead, was built from locally quarried stone. The Cottonwood Limestone Member of the Beattie Formation (Pbe), which weathers to large blocks and was also used in construction of the house and barn, forms the corners and window and doorframes. The Crouse Limestone (Pc), quarried south of the preserve, forms the walls. Examples of each stone are marked on the photograph. Photograph and annotations 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 (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 situ (in rocks or unconsolidated deposits), or in museum collections or other cultural contexts. All fossils are nonrenewable resources.

The alternating layers of limestone and shale that underlie the preserve were deposited in shallow seas and contain abundant fossils of marine organisms with shells (Bennet 1984). Of the 12 bedrock geologic units included in the GRI GIS data, all but one—the Stearns Shale (**Psp**)—are known to contain fossils; three others—the Barneston Limestone (**Pb**), the Blue

Rapids Shale (**Pbr**), and the Eskridge Shale (**Pe**)—are fossiliferous elsewhere but are not known to be fossiliferous within the preserve (Hunt et al. 2008, Sawin and West 2008; see table 3). Hunt (2008), Sawin (2008), and Sawin and West (2008) documented the paleontological resources of the preserve, which include corals, brachiopods, bryozoans, bivalves, gastropods, ostracodes, trilobites, echinoids, and crinoids (fig. 9). Scoping participants (see KellerLynn 2008) mentioned the presence of stromatolites—layered domes of limestone built by marine algae and bacteria—though this remains unconfirmed, but "algal" coatings of shells and other clasts are common in some strata.

A type specimen is the specimen on which the description and name of a new species is based. Newell (1937) documented the type specimen for the bivalve *Clavicosta echinata* as being from "the lower Eiss [**Ptei**, member of **Pba**] limestone just west of the cemetery northwest of Strong City, Kan." If the cemetery documented by Newell (1937, p. 80) is the St. Anthony cemetery, then this type specimen may have been discovered within what is now the preserve, depending on how far "just west" of the location was.

Figure 9. Photographs of paleontological resources at the preserve.
All but four units (Pb, Pbr, Psp, and Pe) in the preserve have recorded occurrences of fossils. Many fossils can be observed in outcrops along trails. (A) Brachiopod from the Bader Limestone (Pba) observed near the historic schoolhouse. (B) Cluster of brachiopods and brachiopod fragments in the Crouse Limestone (Pc). Pc was used to construct the historic buildings, and fossils can be observed in the walls. (C) Echinoid fragments and (D) crinoid fragments in the Schroyer Member of the Wreford Limestone (Pw). Photographs by Michael Barthelmes (A; Colorado State University), Tim Connors (B; NPS Geologic Resources Division), and Katie KellerLynn (C and D; Colorado State University).

The abundance of fossils known within the preserve means that the potential is excellent for continued discovery of additional paleontologic resources. The paleontological resource inventory and monitoring report (Hunt et al. 2008) recommended that preserve staff observe erosional surfaces (e.g., river and stream banks, cliffs, and other exposed bedrock) for fossil material while conducting their usual duties. Discovered fossils should remain in place and be photographically documented. Many fossils are observable in the historic building stone. A brief inventory in April 2022 identified examples of horn corals, bryozoans, brachiopods, bivalves, gastropods, and crinoids, as well as ubiquitous rice-grain-like fusulinid foraminifera (Justin Tweet, NPS Geologic Resources Division, associate, written communication, 8 June 2022). Conference call participants expressed interest in the possibility of a Scientists in Parks (SIP) participant conducting a thorough fossil inventory (see "Guidance for Resource Management" for SIP information).

Collecting fossils from NPS land is illegal; however, scoping and conference call participants expressed that fossil theft or vandalism is not considered a management concern at the preserve. As Rex Buchanan of the Kansas Geological Survey said during scoping, "anything you can get here [i.e., on the preserve], you can get somewhere else easier" (KellerLynn 2008, p. 7). Nevertheless, "casual" fossil theft from the preserve still has potential.

Caves and Karst Features and Processes

Karst is a landscape that forms through the dissolution of soluble rocks, commonly carbonate rocks such as limestone or dolomite (Toomey 2009). Caves are naturally occurring underground voids such as solutional caves (commonly associated with karst), lava tubes (tunnel-like caves in a lava flow after the lava has stopped flowing), sea caves (clefts or cavities in a sea cliff), talus caves (a void among collapsed boulders), regolith caves (formed by soil piping), and glacier caves (ice-walled caves) (Toomey 2009).

The landscape at the preserve is 97% karst (Land et al. 2013), a statistic that reflects the abundance of soluble limestone and manifests itself in the presence of springs throughout the preserve (see "Springs and Seeps"). However, although other areas in the Flint Hills are known to contain caves, the layers of bedrock within the preserve are not thick enough to support large-scale caves (KellerLynn 2008). Scoping participants observed small alcoves in the Threemile Limestone Member of the Wreford Limestone (**Pw**) that formed through karst processes (fig. 10). Conference call participants confirmed the existence of these alcoves and expressed that, while a formal inventory would likely be useful, the alcoves are too small to be considered a management issue.

Figure 10. Photographs of alcoves in the Threemile Limestone Member.
The alcoves in the Threemile Limestone Member of the Wreford Limestone (Pw) formed through karst processes—the dissolution of soluble rock material by running water. While the alcoves at the preserve are small and chances are small that a visitor would become lost exploring them, they are an interpretive opportunity to learn about caves and karst at the preserve and elsewhere in the Flint Hills. Photographs by Katie KellerLynn (Colorado State University).

Eolian Features and Processes

Eolian (also spelled “aeolian” from Aeolus, Greek goddess of the wind) refers to windblown erosion, transportation, and deposition of sediments (Lancaster 2009). Features created by eolian processes include depositional landforms and deposits such as dunes, loess, and sand sheets, as well as erosional forms such as desert pavement, yardangs, and ventifacts.

Loess, or fine-grained windblown sediment that was commonly initially ground by glaciers, forms extensive deposits across the Midwest dating to the Pleistocene ice ages (2.6 million years ago to 11,700 years ago). However, any loess that was deposited within the boundaries of the preserve has since been eroded or reworked into valley sediments (KellerLynn 2008). Because loess deposits in Kansas are regional, Mandel (2006) used them as “markers” to stratigraphically correlate the alluvium and colluvium (**Qal** and **Qc**) in the Fox Creek valley.

Consistent winds blow across the prairie, and high winds do occur, but the namesake vegetation stabilizes the sediment and wind erosion is not a management concern at the preserve. Windblown ash may inhibit air quality after controlled (or uncontrolled) burning, but this is short lived (KellerLynn 2008).

Energy and Mineral Development

Oil and Gas Resources

The preserve and surrounding area have nearly a century of “poorly documented history” of oil and gas production (Carr 1998, p. 2). The underlying Nemaha Ridge (uplift feature), which crosses Kansas north–south, is the most important factor in trapping of oil and gas in the area of the preserve. The uplift formed an anticline, or arch-shaped fold in the overlying sedimentary rocks, which traps oil and gas (fig. 11). The El Dorado oil field south of the preserve in Butler County is one of the oldest and richest in Kansas (Wilson 1978). Indeed, discovery of oil in Butler County in the 1920s sparked a boom of drilling activity that extended along the Nemaha Ridge into Chase County, and the first well in what is now the preserve was drilled in 1929 (Carr 1998).

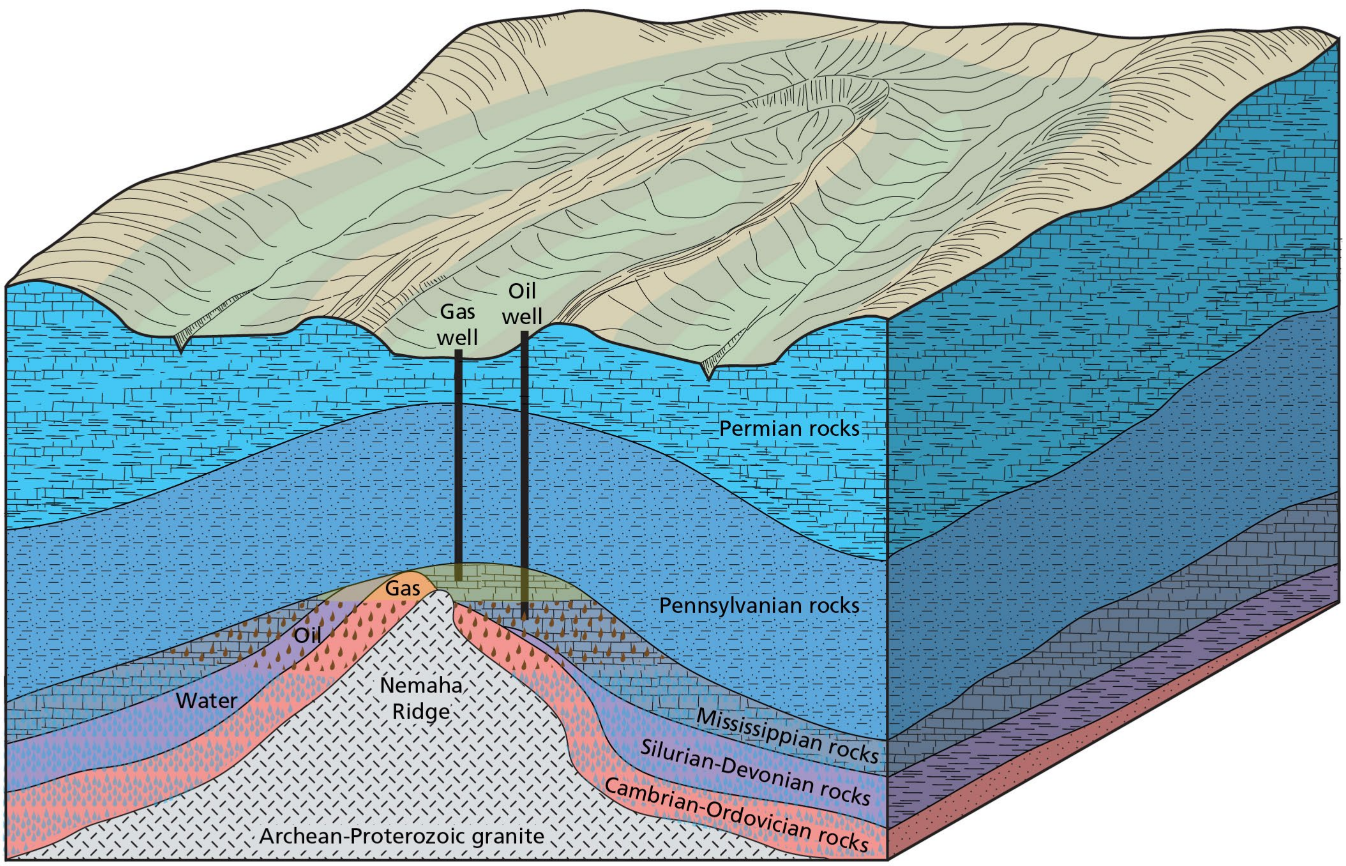

Figure 11. Block diagram of oil and gas stratigraphy in Kansas.
The underlying Nemaha Ridge creates a trap for oil and gas where the overlying sedimentary rocks are bowed upward into an anticline. Natural gas and oil “float” on top of the trapped water, filling tiny openings in sandstone or other rocks; the oil and gas are trapped beneath less-porous rock types above. Wells drilled from the surface can find oil, gas, or water, depending on where they are drilled. Graphic by Trista Thornberry-Ehrlich after Wilson (1978, figure 6).

Oil and gas extraction in Chase County was developed primarily from shallow (60–120 m [200–400 ft]) reservoirs and used locally on the ranch as well as in Strong City and Cottonwood Falls (Carr 1998). Because reporting was not historically required on these small wells, the existing documentation regarding location, production, and eventual abandonment is scattered and incomplete. Heather Brown (Tallgrass Prairie National Preserve, chief of Interpretation and Visitor Services, conference call, 8 December 2021) recalled that a collection of historical ranch papers, including gas records, had recently been donated to the preserve, although these are currently held in curatorial storage in Kansas City. A GRD trip report (O'Dell 2000) documented 25 active gas wells within the preserve; however, as of the 2021 conference call, all the gas wells within the preserve had been plugged and are not producing. Participants discussed some legacy features of the gas wells, such as bare and weedy ground (i.e., not the native prairie landscape) and above-ground pipes (fig. 12). Some of this piping has been repurposed by park staff into the new bison handling facility; some of the remaining pipe on the ground is incorporated into the historical themes along interpretative bus tours.

Further remediation of these small, abandoned gas wells was not considered a high priority by preserve staff on the 2021 conference call. The primary known issue associated with these sites is the increased erosion of sediments not stabilized by vegetation, which is exacerbated by cattle. Preserve staff can request assistance from GRD for assistance in reclamation (see "Guidance for Resource Management" chapter).

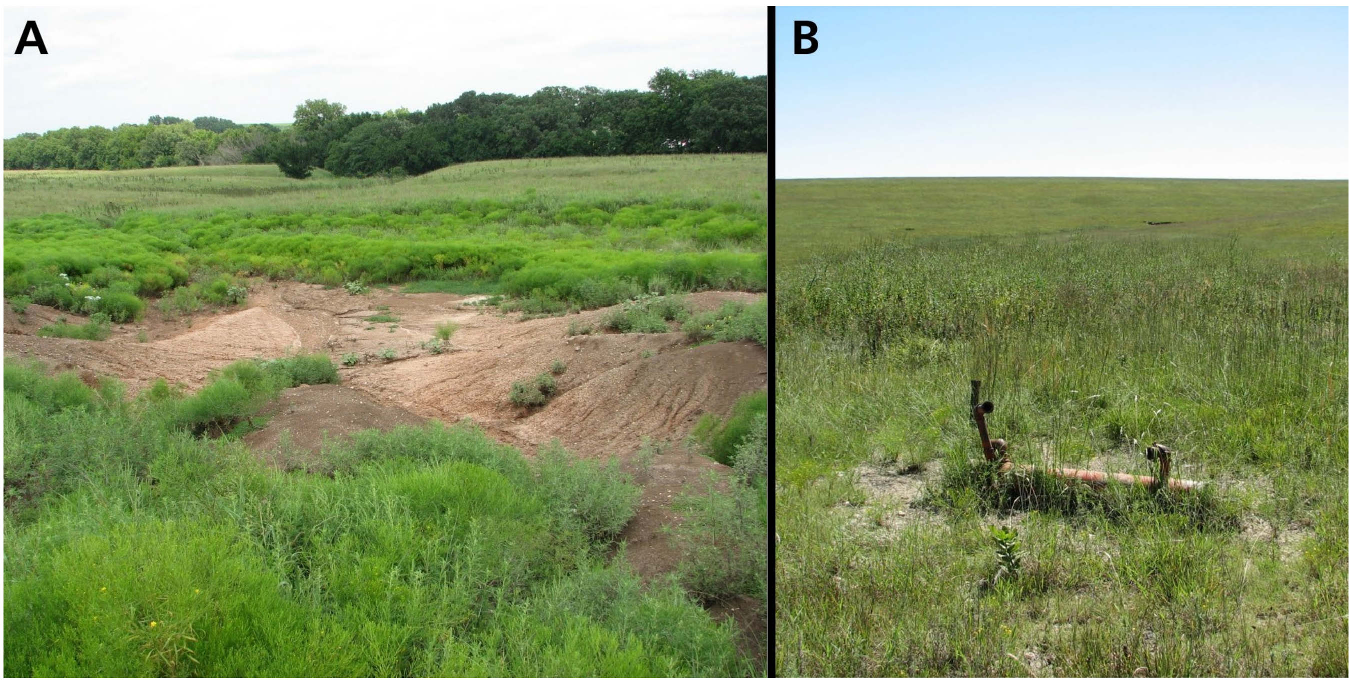

Figure 12. Photographs of abandoned gas wells and disturbed land.
Various features document a legacy of gas extraction at the preserve. (A) Bare and weedy ground remains where some gas wells have been plugged; this erosion can be exacerbated by cattle. (B) Piping that was part of a gas well. Some of this piping has been repurposed into the new bison handling facility; other piping has been left in place and is included in interpretative tours of the preserve. Photographs by Kristen Hase (Tallgrass Prairie National Preserve).

Quarries

Many small, historical quarries throughout the preserve yielded limestone building material for the ranch house, barn, and fencing (see "Bedrock Building Stone"). These are included in some interpretative themes and can be viewed from the paths (fig. 13).

A large active quarry lies just north of the preserve. Also outside of the preserve, gravel mining from streambeds affects downstream bank stability (see "Fluvial Features and Processes").

Quarries, with their exposed bedrock surfaces, are likely locations for paleontological resources.

Wind Energy

The landscape and weather of Kansas make the area a prime location for wind energy development. Construction of wind turbines near the preserve boundary would impact the viewshed of the natural prairie ecosystem and threaten the foundation document's "Scenery" significance (NPS 2017). The governors of Kansas have historically used executive power to discourage wind development in the core of the Flint Hills (i.e., the area of the preserve), but as this is not done legislatively it could change with any future governor. Power transmission lines already run across the eastern section of the preserve; the associated energy company has said that burying the lines is cost and effort prohibitive (Kristen Hase, Tallgrass Prairie National Preserve, superintendent, conference call, 8 December 2021).

Figure 13. Photograph of historic quarry.
In places where bedrock crops out at the surface, which is common in the preserve, access to raw materials and building stone was made easily. The historic quarry of the Schroyer Member of the Wreford Limestone (Pw), which yields flint as well as building stone, was likely used by Native Americans in addition to Euro-American settlers. Small quarries like these are scattered throughout the preserve and are an opportunity for historical interpretation. Fresh exposures may also yield new fossil discoveries. Photograph by Katie KellerLynn (Colorado State University).

Seismic Activity

The 2008 scoping summary (KellerLynn 2008) identified the risk of seismic activity affecting the preserve as "low." Although this is generally true, when the subject was discussed 13 years later as part of the conference call, Rex Buchanan (Kansas Geological Survey) explained that "things have changed a lot since 2008" (fig. 14). Although no epicenters have been placed within the preserve, the potential for shaking related to induced seismicity originating from Oklahoma and elsewhere in Kansas has greatly increased because of fluid injection of saltwater in Oklahoma (Peterie et al. 2018). Injection-induced seismicity has been associated with earthquakes up to 90 km (55 mi) away from the injection site. Elevated seismic activity in Kansas since 2013 is related to fluid injection in Oklahoma and Kansas.

Damage to structures within the preserve has not been directly correlated to seismic activity. However, the unreinforced masonry of the ranch house is potentially susceptible to damage associated with shaking. The preserve has a history of seismic activity: at least 25 earthquakes are documented between 1867 and 1976, and seismographs recorded more than 100 between 1977 and 1989 in Kansas (Steeples and Brosius 1996). The largest recorded earthquake in Kansas hit the Manhattan area in 1867, toppling chimneys and cracking foundations (Steeples and Brosius 1996).

Any seismic activity originating in or near the preserve would likely be associated with the 300-million-year-old Nemaha Ridge (see figs. 3 and 5). The faults bounding the uplift are still active today, especially the Humboldt fault zone that passes through east-central Kansas (KellerLynn 2008).

The Kansas Geological Survey maintains an interactive map of recent earthquakes, which may be of interest and use for resource managers at the preserve (see "Guidance for Resource Management"). In addition, the "Monitoring Seismic Activity" chapter (Braile 2009) in *Geological Monitoring* (Young and Norby 2009) discusses the relevance and rationale for seismic monitoring and provides vital signs and methods.

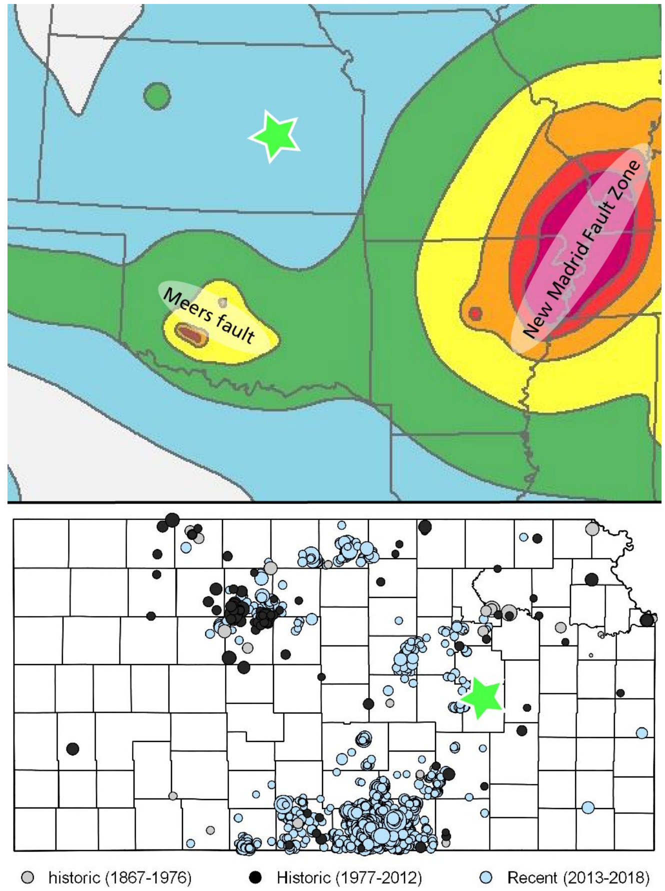

Figure 14. Seismic hazard map of central United States and earthquake map of Kansas.
Top: The map is a portion of the 2018 long term national seismic hazard map (US Geological Survey, https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map; accessed 17 August 2022), with the preserve location marked by a green star. Blue indicates almost no hazard; red indicates greater hazard. The preserve is far enough to the west of the New Madrid Fault Zone and to the north of the active Meers fault to be at low risk. Bottom: The map of historic and recent earthquakes in Kansas (Kansas Geological Survey, https://www.kgs.ku.edu/Geophysics/Earthquakes/overview.html; accessed 17 August 2022) shows a recent (2013–2018; blue circles) increase in seismic activity near the preserve and to the south. Peterie et al. (2018) tied this to increased seismic activity to fluid injection in Oklahoma and Kansas. Preserve location and labels added by Michael Barthelmes (Colorado State University).

Guidance for Resource Management

These references, resources, and websites may be of use to resource managers. The laws, regulations, and policies apply to NPS geologic resources. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), National Park Service 2006 Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75).

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) portal: https://irma.nps.gov/. Enter "GRI" as the search text and select a park from the unit list.

Four Ways to Receive Geologic Resource Management Assistance

- Contact the NPS Geologic Resources Division (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. Park managers can formally request assistance via https://irma.nps.gov/Star/ (available on Department of the Interior [DOI] network computers only).
- Formally request assistance at the Solution for Technical Assistance Requests (STAR) webpage: https://irma.nps.gov/Star/ (available on DOI network computers 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 (SIP) program: 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 Geologic Resources Division can provide guidance and assistance with submitting a proposal. The Geological Society of America and Environmental Stewards are partners of the SIP program.
- Refer to *Geological Monitoring* (Young and Norby 2009), which provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Chapters are available online at https://www.nps.gov/subjects/geology/geological-monitoring.htm.

Park-Specific Documents

The park's foundation document (NPS 2017) is one of the primary sources of information for resource management within the preserve. This document guided the writing of this GRI report.

NPS Natural Resource Management Guidance and Documents

- NPS *Management Policies 2006* (Chapter 4: Natural Resource Management): https://www.nps.gov/policy/index.cfm
- 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 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 (Schuurman et al. 2020): https://doi.org/10.36967/nrr-2283597

Geologic Resource Laws, Regulations, and Policies

Table 4 was developed by the NPS Geologic Resources Division. It summarizes laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water

Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act) but does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**Archaeological Resources Protection Act of 1979, 16 USC §§ 470aa – mm Section 3 (1) Archaeological Resource—**nonfossilized and fossilized paleontological specimens, or any portion or piece thereof, shall not be considered archaeological resources, under the regulations of this paragraph, unless found in an archaeological context. Therefore, fossils in an archaeological context are covered under this law. **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309 Section 3 (5) Cave Resource—**the term "cave resource" includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems. Therefore, every reference to cave resource in the law applies to paleontological resources. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands.	**36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted. **43 CFR Part 49** will contain the DOI regulations implementing the Paleontological Resources Preservation Act.	**Section 4.8.2 requires NPS to protect geologic features from adverse effects of human activity.** **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Caves and Karst Systems	**Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/ Agriculture to identify "significant caves" on Federal lands, regulate/ restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources. **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.	**36 CFR § 2.1** prohibits possessing/ destroying/ disturbing…cave resources…in park units. **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.	**Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts. **Section 4.8.2 requires NPS to protect geologic features from adverse effects of human activity.** **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact cave environment, and to remove existing developments if they impair caves. **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.
Recreational Collection of Rocks Minerals	**NPS Organic Act, 54 USC. § 100101 et seq.** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c) – Pipestone National Monument enabling statute**. Authorizes American Indian collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources… in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

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

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

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims (Locatable Minerals)	**Mining in the Parks Act of 1976, 54 USC § 100731 et seq.** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6** and **9A**. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.
Nonfederal Oil and Gas	**NPS Organic Act, 54 USC § 100751 et seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: **16 USC § 230a** (Jean Lafitte NHP & Pres.) **16 USC §450kk** (Fort Union NM), **16 USC § 459d-3** (Padre Island NS), **16 USC § 459h-3** (Gulf Islands NS), **16 USC § 460ee** (Big South Fork NRRA), **16 USC § 460cc-2(i)** (Gateway NRA), **16 USC § 460m** (Ozark NSR), **16 USC§698c** (Big Thicket N Pres.), **16 USC §698f** (Big Cypress N Pres.)	**36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights outside of Alaska to -demonstrate bona fide title to mineral rights; -submit an Operations Permit Application to NPS describing where, when, how they intend to conduct operations; -prepare/submit a reclamation plan; and -submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators to comply with 9B regulations.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil, Gas, and Solid Minerals)	**The Mineral Leasing Act, 30 USC § 181 et seq.**, and the **Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq.** do not authorize the BLM to lease federally owned minerals in NPS units. **Combined Hydrocarbon Leasing Act, 30 USC §181,** allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in GLCA, which is the only park unit that contains a STSA. **Exceptions**: Glen Canyon NRA (**16 USC § 460dd et seq.**), Lake Mead NRA (**16 USC § 460n et seq.**), and Whiskeytown-Shasta-Trinity NRA (**16 USC § 460q et seq.**) authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. **American Indian Lands Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108,** all minerals on American Indian trust lands within NPS units are subject to leasing. **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.	**36 CFR § 5.14** states prospecting, mining, and… leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing. **Regulations re: Native American Lands within NPS Units:** **25 CFR Part 211** governs leasing of tribal lands for mineral development. **25 CFR Part 212** governs leasing of allotted lands for mineral development. **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development. **25 CFR Part 224** governs tribal energy resource agreements. **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**). **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases. **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases. **30 CFR §§ 1206.50-1206.62** and **§§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases. **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases. **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal minerals other than oil and gas	**NPS Organic Act, 54 USC §§ 100101 and 100751**	**NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a **§ 5.3** business operation, and **§ 5.7** – Construction of buildings or other facilities, and to comply with the solid waste regulations at **Part 6**.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1** and **5**.
Coal	**Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq.** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation , and employee protection. **Part 7** of the regulations states that National Park System lands are unsuitable for surface mining.	None Applicable.
Uranium	**Atomic Energy Act of 1954:** Allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.	None Applicable.	None Applicable.
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	None Applicable.	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change, as put forth by Beavers et al. (in review). **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.

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

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

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1)**	None applicable.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding. **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams. **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas. **16 USC §90c-1(b)** authorizes sand, rock and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area, for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: -only for park administrative uses; -after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; -after finding the use is park's most reasonable alternative based on environment and economics; -parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; -spoil areas must comply with **Part 6** standards; and -NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Additional References, Resources, and Websites

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- NPS Climate Change Response Program: https://www.nps.gov/orgs/ccrp/index.htm
- NPS Climate Change, Sea Level Change: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- NPS Level 3 Handbook—Addressing Climate Change and Natural Hazards: Facility Planning and Design Considerations (NPS 2015): https://www.nps.gov/dscw/publicforms.htm#df
- NPS Policy Memorandum 15-01—Addressing Climate Change and Natural Hazards for Facilities (Jarvis 2015): https://www.nps.gov/policy/PolMemos/policymemoranda.htm
- NPS Sea Level Rise Map Viewer: https://maps.nps.gov/slr/
- US Global Change Research Program: http://www.globalchange.gov/home

Earthquakes

- Kansas Geological Survey, recent earthquakes: https://www.kgs.ku.edu/index.html
- ShakeAlert: An Earthquake Early Warning System for the West Coast of the United States (USGS sponsored): https://www.shakealert.org/
- USGS Earthquake Hazards Program, Unified Hazard Tool: https://earthquake.usgs.gov/hazards/interactive/

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geoparks: https://en.unesco.org/global-geoparks
- US Geoheritage & Geoparks Advisory Group: https://www.americasgeoheritage.com/

Geologic Maps

- American Geosciences Institute, Meeting Challenges with Geologic Maps: http://www.americangeosciences.org/environment/publications/mapping
- *General Standards for Geologic Maps* (Evans 2016)
- National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geological Surveys and Societies

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

Kansas Geology

- Kansas Geological Survey: https://www.kgs.ku.edu/index.html

NPS Geology

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

NPS Reference Tools

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

Relevancy, Diversity, and Inclusion

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

Soil

- 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/2190427. *Note*: The PDF is contained within SRI_Detailed_Soils.zip, which also contains an index map of parks where an SRI has been completed. Download and extract all files.

US Geological Survey Reference Tools

- Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- Geographic Names Information System (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Tapestry of Time and Terrain (descriptions of physiographic provinces; Vigil et al. 2000): http://pubs.usgs.gov/imap/i2720/
- USGS Publications Warehouse (many publications available online): http://pubs.er.usgs.gov
- 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 Geologic Resources Division for assistance in obtaining them.

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The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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