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Washita Battlefield National Historic Site

Geologic Resources Inventory Report



Unobstructed views—like the one that looks northeast from the overlook down to the Washita River and the Horseshoe Hills beyond—add to the “sense of place” at the historic site.
NPS

Washita Battlefield National Historic Site: Geologic resources inventory report

Science Report NPS/SR—2024/188

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Abstract

Geologic Resources Inventory (GRI) reports provide 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 GRI reports may also be useful for interpretation. This report synthesizes discussions from a scoping meeting held in 2011 and a follow-up conference call in 2023. Chapters of this report discuss the geologic heritage, geologic history, geologic features and processes, and geologic resource management issues of Washita Battlefield National Historic Site. Guidance for resource management and information about the previously completed GRI GIS data and poster (separate products) are also provided.

Acknowledgments

The GRI team thanks the participants of the 2011 and 2023 meetings for their assistance with this inventory. Because the GRI team does not conduct original geologic mapping, we are particularly thankful to the Geological Society of America, GeoCorps America program, with funding from the GRI program, and the Oklahoma Geological Survey for producing geologic maps of the area. This report and accompanying GRI GIS data could not have been completed without them.

Thanks to Trista Thornberry-Ehrlich (Colorado State University) for producing many of the graphics in this report. Thanks to Kenny Points (Washita Battlefield National Historic Site) for taking photographs that help to illustrate many locations in the historic site. Thanks to Suzanne McKetta (Colorado State University) for her "time-saving" assistance in converting radiocarbon ages to calendar years. Thanks to Forrest Smith (NPS Geologic Resources Division) and Richard Zahm (Washita Battlefield National Historic Site) for information about the gas pipeline that runs through the historic site. Thanks to Jason Kenworthy (NPS Geologic Resources Division) for generating reports using the DOI Strategic Hazard Identification and Risk Assessment (SHIRA) and NRCS Web Soil Survey (WSS) for use in this report. Finally, thanks again to Richard Zahm for his continued help during the review stage of this report.

The following lists of people reflect the names and affiliations of participants at the time of those meetings. The lists of participants and reviewers are organized alphabetically by last name. The other lists are organized hierarchically with respect to their relative contribution to a project.

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Executive Summary

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

Washita Battlefield National Historic Site (referred to as the "historic site" throughout this GRI report) is in Roger Mills County, western Oklahoma. It is near the town of Cheyenne.

The historic site became part of the National Park System in 1997. It preserves and protects the site of the "Battle of the Washita," where, just before dawn on 27 November 1868, the 7th US Cavalry under the command of Lieutenant Colonel George Armstrong Custer attacked the winter camp of Cheyenne (Tsistsistas) Peace Chief Black Kettle. The NPS is the steward of 127.6 ha (315.2 ac) in what scholars believe to be the core area of the battlefield landscape.

The historic site's bedrock and surficial deposits represent 300 million years of Earth's history. Many park resources integral to the historic site's history and cultural identity—such as the Washita River and Custer's Knoll—are geologic resources. The GRI highlights historical, cultural, natural, and geologic connections among resources.

This GRI report compiles and summarizes park-specific geologic information and research. It is based on the most accurate, up-to-date geologic mapping known at the time of writing. It was written with park management in mind and incorporates the historic site's significance as expressed in its foundation document.

The following information is included in the GRI report:

Acknowledgments—This report is the culmination of the GRI process, which began in 2011 during a scoping meeting at the historic site. Over the ensuing years, many individuals and organizations have helped to complete the GRI process. These people and their associated organizations are recognized in this chapter.

Introduction—This chapter summarizes the establishment of the historic site. It also orients readers to the historic site's location and various settings (geologic, physiographic, and NPS network). Additionally, it provides background information about the GRI program and highlights GRI products. The principal deliverable of the GRI is a geologic map compiled in a geographic information system (GIS) format; this product is referred to as the "GRI GIS data" in this report. Source maps used in compiling the GRI GIS data were prepared by Julian Stahl, a GeoCorps America participant (a program of the Geological Society of America), and Robert O. Fay, a geologist at the Oklahoma Geological Survey. This report incorporates geologic information and interpretations from both of these geologic maps. Mapping by Stahl predominates because it is more

detailed. Mapping by Fay covers a greater area. The chapter also calls attention to the poster, which displays the GRI GIS data compiled from the geologic map by Stahl.

Geologic Heritage—Geologic heritage exists at the overlap of geology and human experiences and values. This chapter highlights the historic site's geologic heritage, which includes significant geologic features for interpreting and understanding the "Battle of the Washita." The chapter draws connections between geologic resources and other park resources such as landscape features (e.g., Black Kettle's winter camp, the pony kill site, and Custer's Knoll) and building stone (i.e., stone markers/memorials) as well as the historic site's sense of place.

Geologic History—This chapter describes the chronology of geologic events that led to the present-day landscape. These events include assembly of the supercontinent Pangea when deposition of the historic site's bedrock took place, filling the Anadarko basin (also associated with the historic site's bedrock), a notable unconformity (gap in the rock record), the Laramide Orogeny (mountain-building event), deposition of the Ogallala Formation (in the vicinity of the historic site), development of the Washita River valley (which cut through the Ogallala Formation), and the development of sand dunes. The chapter also provides a geologic time scale that organizes these events in the context of geologic time (eras, periods, and epochs, as well as associated numerical ages) and connects them to the GRI GIS data via geologic map units. Three paleogeographic maps and three block diagrams help to orient readers to the settings where the historic site's bedrock was deposited.

Geologic Features and Processes—This chapter describes the following geologic features and processes of significance for the historic site: Permian red beds, which enhance the scenery, underlie the historic site, comprise conical hills, and make up the greater battlefield landscape; Ogallala Formation, which tops nearby mesas; the development of the Washita River, which is the defining feature of the landscape; and paleodunes and other eolian features, which are commonly underrepresented on geologic maps but blanket extensive swaths of the landscape.

Geologic Resource Management Issues—This chapter discusses management issues related to the historic site's geologic resources (features and processes). The issues are organized alphabetically, not with respect to management priorities. The geologic issues are climate change and geologic resources; energy development; erosion; flood control projects and flooding; geologic hazards; paleontological resource inventory, monitoring, and protection; and restoration of the railroad grade.

Guidance for Resource Management—This chapter provides resource managers with a variety of ways to find and receive management assistance for the issues discussed in the "Geologic Resource Management Issues" chapter or other geologic issues, as needed. The chapter includes a compilation of laws, regulations, and policies relevant to managing NPS geologic resources.

In addition to these chapters, "Additional References, Resources, and Websites" lists online and other publications that may be useful for geologic resource management at the historic site. "Literature Cited" provides a bibliography of all the references cited in this GRI report and serves as a source of park-specific geologic information.

Introduction

This chapter orients readers to the historic site and introduces them to the Geologic Resources Inventory (GRI). The GRI is administered by the Geologic Resources Division (GRD) of the National Park Service (NPS) Natural Resource Stewardship and Science (NRSS) Directorate. The GRI provides geologic map data and pertinent geologic information to support resource management and science-informed decision making. The GRI is funded by the NPS Inventory and Monitoring Program.

Park Establishment

On 12 November 1996, Congress passed legislation (Public Law 104-333) that established Washita Battlefield National Historic Site (referred to as the "historic site" throughout this report). The law recognized the importance of the "Battle of the Washita" as a nationally significant element of frontier military history and as a symbol of the struggle of the Plains Tribes to maintain control of their traditional use areas.

The area covered during the Battle of the Washita encompasses 3,108 ha (7,680 ac) or 31 km^2 (12 mi^2). That entire area was designated a national historic landmark in 1966, 30 years before the historic site was established. Notably, the national historic landmark is 24 times larger than the historic site's present-day boundary, which encompasses 127.6 ha (315.2 ac).

The national historic landmark was listed in the National Register of Historic Places when the register came into existence in 1966 (National Park Service 2022). At that time, the Oklahoma Historic Society owned the land that would become the historic site (Mendinghall 1976). These lands were formally transferred to the NPS in 1997. Today, the historic site encloses what scholars believe to be the core area of the Battle of the Washita. Notably, some landscape features that contribute to the events that took place during the Battle of the Washita are beyond the historic site's boundaries (see "Landscape Features").

The following significance statements (slightly modified) from the historic site's foundation document (National Park Service 2016) express why the historic site's resources and values are important enough to merit designation as a unit of the National Park System:

- The attack on Chief Black Kettle's (Moxtaveto [spelling from Gardner 2002]) winter camp along the Washita River (Hooxeeohe in Cheyenne [spelling from Gardner 2002]) was the first implementation of a strategy resulting from the failures of the treaty system adopted by the US Army to strike encampments of Plains Tribes during the winter months when they were most vulnerable.
- The attack was a pivotal point for the Cheyenne and other Plains Tribes in that it symbolized their struggles to maintain the freedom of their traditional way of life and the realization that their lives were changing.
- The events at Washita greatly impacted two prominent leaders. First, Chief Black Kettle (1803–1868), who was widely known for his pursuit of peaceful coexistence with settlers,

was killed during the attack. Second, Lieutenant Colonial George Armstrong Custer (1839–1876), who was already known for his exploits during the Civil War, acquired a reputation as an aggressive "Indian fighter." Custer was later killed during the "Battle of the Little Bighorn," also known as the "Battle of Greasy Grass" (see GRI report about Little Bighorn Battlefield National Monument by KellerLynn 2011b).

- Washita is a deeply meaningful place and has spiritual significance to the Cheyenne and Arapaho. It is a place to show respect for all the lives that were lost and offers opportunities for education, healing, and reconciliation.
- The natural and physical resources of the Washita site, including the topography, scenic views, and vegetation, retain the character of the landscape at the time of the attack, enabling visitors to visualize the event.

Park Setting

The historic site is in Roger Mills County, western Oklahoma, about 1.6 km (1.0 mi) west of the "town" (unincorporated, populated place) of Cheyenne (Figure 1). The county takes its name from Texas politician Roger Quarles Mills. The state takes its name from two Choctaw words—okla (meaning "people") and humma (meaning "red"). The word "Cheyenne" is a modification of the Lakota word šahiyena, meaning "red speakers," which is thought to have been given to the Cheyenne by the Lakota because of the difference in their two languages (Campbell and Campbell 2022).

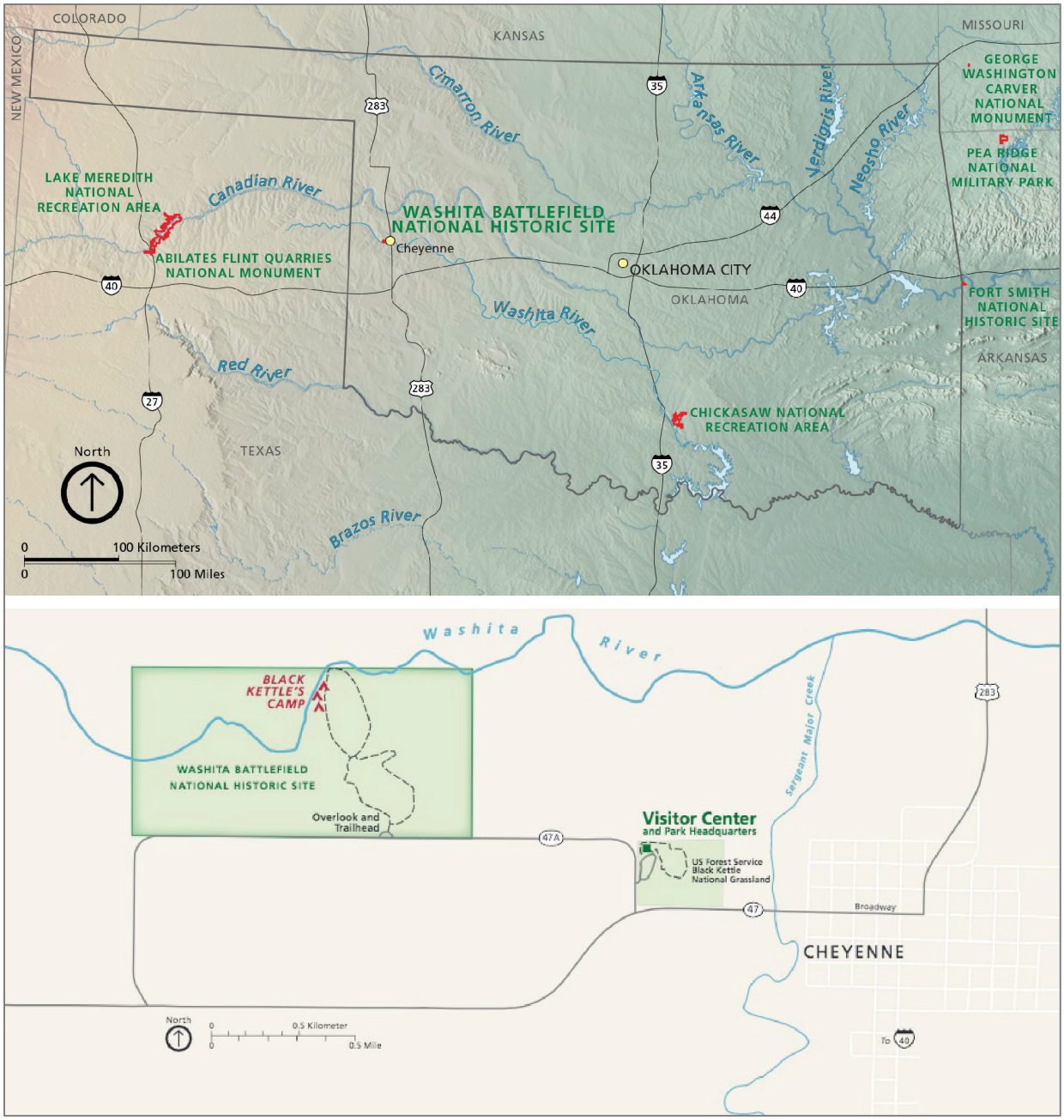


Figure 1. Location maps. Washita Battlefield National Historic Site (referred to as the "historic site" throughout this report) is in western Oklahoma, near the town of Cheyenne. The NPS and USDA Forest Service share a visitor center that houses administrative services and provides information about the historic site and Black Kettle National Grassland. Top: Map by Trista L. Thornberry-Ehrlich (Colorado State University). Base map by Tom Patterson (National Park Service). Bottom: NPS map by Harpers Ferry Center, available at https://www.nps.gov/subjects/gisandmapping/nps-maps.htm (accessed 21 May 2024).

Oklahoma is the traditional home of the nomadic Plains Tribes. As noted by best-selling author Simon Winchester in his book *Land: How the Hunger for Ownership Shaped the Modern World*: "These were Plains Indians, not homesteaders and farmers, not designated as civilized by the

government, but instead feared for being fearless and splendid—tepee dwellers, ever moving, magnificent horsemen, masters of animals that the colonizing Spanish had imported by the sixteenth century" (Winchester 2021, p. 142).

A fundamental resource and value of the historic site is Tribal relationships. The enabling legislation for the historic site stresses the importance of partnering with traditionally associated Tribes in planning, management, interpretation, and education. Traditionally associated Tribes of the historic site are the Cheyenne (Tsistsistas, meaning "People" in Cheyenne; spelling from Cheyenne and Arapaho Tribes 2022) and Arapaho (Hinono'ei, meaning "People" in Arapaho; spelling from Cheyenne and Arapaho Tribes 2022). Today, the Cheyenne and Arapaho Tribes function as one nation (Cheyenne and Arapaho Tribes 2022). In addition to the Cheyenne and Arapaho Tribes, other traditionally associated Tribes of the historic site are the Comanche Nation, Oklahoma; the Northern Cheyenne Tribe of the Northern Cheyenne Indian Reservation, Montana; and the Quapaw Tribe of Indians, Oklahoma (National Park Service 2016).

Lands owned by local ranchers interspersed with land associated with Black Kettle National Grassland surround the historic site. The grassland is managed by the USDA Forest Service, Cibola National Forest, and was named for Peace Chief Black Kettle. The grassland encompasses 12,700 ha (31,300 ac) in Oklahoma and Texas. Most of the grassland (12,435 ha [30,726 ac]) is near the historic site, though Lake Marvin Recreation Area, which encompasses 233 ha (576 ac), is near Canadian, Texas (USDA Forest Service, n.d.).

The NPS and Forest Service share a facility that serves as the NPS park headquarters/visitor center and the Forest Service district office. The facility is located 0.8 km (0.5 mi) east of the historic site (Figure 1).

Various settings provide context for the historic site. Classified with respect to Oklahoma's geology, the historic site is in the Western Red-Bed Plains geomorphic province, which consists of gently rolling hills of nearly flat-lying red sandstone and shale that was deposited during the Permian Period (298.9 million to 251.9 million years ago; Curtis et al. 2008). From oldest to youngest, the red-bedded rock units in this region are the Cloud Chief Formation, Doxey Formation (formally referred to as the Doxey "Shale"), and Elk City Sandstone (see "Permian Red Beds"). Due to the distinctive color of these rocks, the region is known as "red carpet country" (Figure 2).



Figure 2. Photographs of "red carpet country" species and substrate. Red is a characteristic feature of the landscape at the historic site. From its geologic foundation of red beds, vibrantly colored soils, blanket of dust, and extant species, all is awash in red. NPS photographs (n.d.) available at https://www.nps.gov/waba/learn/photosmultimedia/photogallery.htm (accessed 21 May 2024).

With respect to physiographic provinces (Fenneman 1928; see also National Park Service 2017), the historic site is part of the Interior Plains, which is a broad region of rolling terrain that lies at the heart of the North American landscape. In the continental United States, this region is composed of the Central Lowland and the Great Plains. The historic site is the most westerly unit of the National Park System within the Central Lowland (Figure 3). The Central Lowland covers an area of about 941,500 km^2 (585,000 mi^2), extending from western New York to North Dakota and south to Texas. Elevations in the region are 610 m (2,000 ft) or less, though the province is bounded by higher relief. Characteristic features are flat lands with geomorphic remnants of glaciation (National Park Service 2017), though continental scale glaciers extended only as far south as Kansas, not into Oklahoma or the historic site.

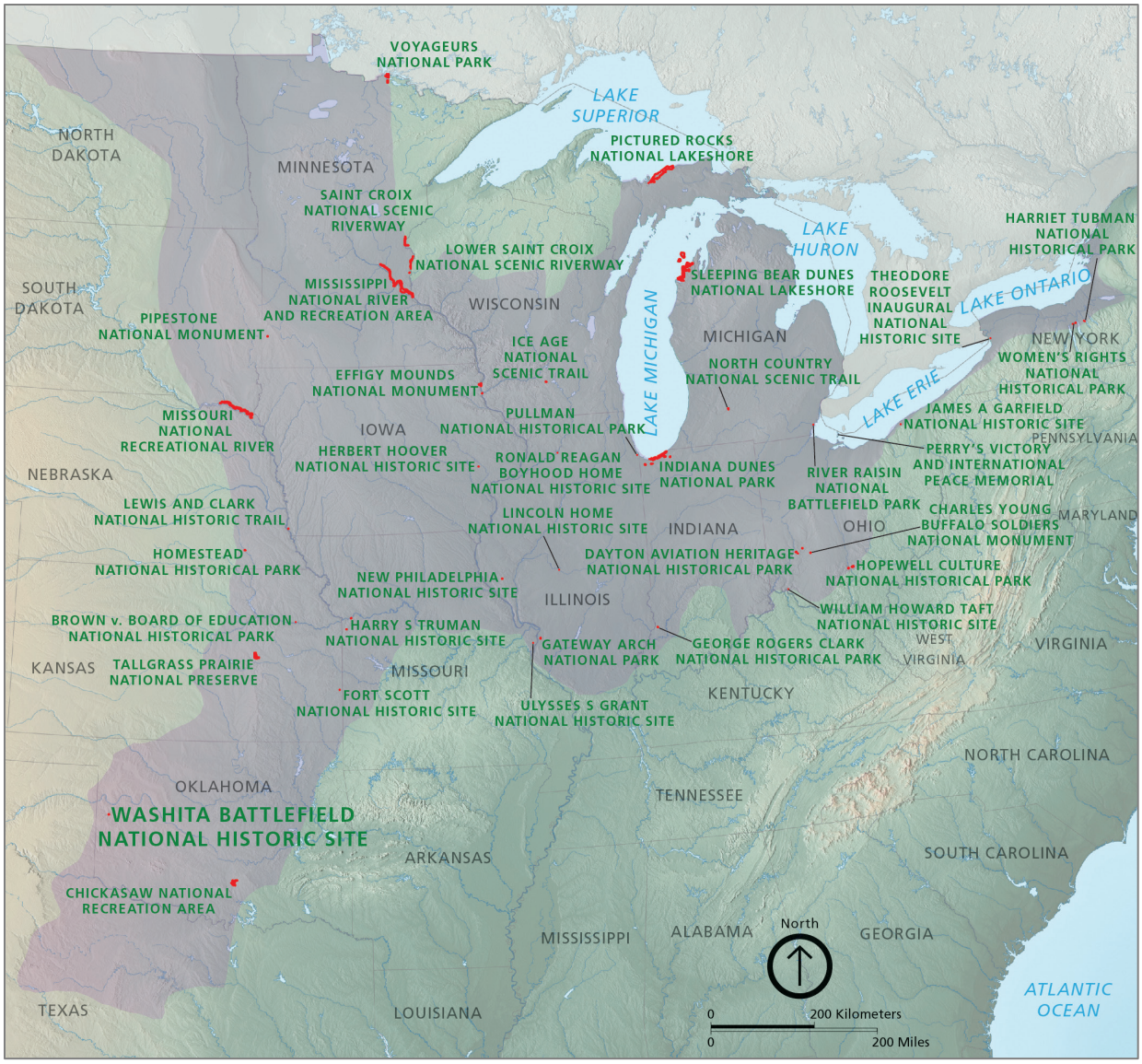


Figure 3. Map of the Central Lowland physiographic province. The historic site is part of the Central Lowland physiographic province (lavender shading). On the north, this large province extends from western New York to North Dakota, and on the south, to Texas. The historic site is the farthest west National Park System unit in the province. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using USGS physiographic province map data at https://water.usgs.gov/GIS/metadata/usgswrd/XML/physio.xml#stdorder and NPS boundaries data at https://irma.nps.gov/DataStore/Reference/Profile/2224545?Inv=True (accessed 20 September 2023). Base map by Tom Patterson (National Park Service).

Although the High Plains are typically considered a subregion of the Great Plains, some investigators (e.g., Willett et al. 2018) use the term "High Plains" for the region that includes the historic site. In general, the High Plains cover eastern Montana, southeastern Wyoming, southwestern South Dakota, western Nebraska, eastern Colorado, western Kansas, and eastern New Mexico. However, western

Oklahoma and western Texas may be included as part of the High Plains. Notably, the "High Plains aquifer," also known as the "Ogallala aquifer," underlies this region.

With respect to the 32 NPS inventory and monitoring networks, the historic site is in the Southern Plains Network. The 11 parks in the network are distributed across five states—Colorado, Kansas, New Mexico, Oklahoma, and Texas—and range in size from 127 ha (315 ac) to more than 16,795 ha (41,500 ac). The network comprises four national historic sites, two national recreation areas, three national monuments, and two national historical parks (National Park Service 2019).

GRI Program

The GRI was established in 1998 by the GRD and the NPS Inventory and Monitoring Program [Division] to meet the NPS need for geologic mapping and related information (National Park Service 1992, 1998, 2009). Geologic maps were identified as one of 12 natural resource data sets critical for long-term science-informed park management. From the beginning, the GRI has worked with longtime NPS partner Colorado State University to ensure products are scientifically accurate and utilize the latest in GIS technology. Because NPS units in Alaska are at a much larger scale than those in the continental United States and have distinctive resource management challenges, the GRI partners with the NPS Alaska Regional Office and, starting in 2021, the University of Alaska Museum of the North, to develop GRI products.

GRI Products

The GRI team completed the following tasks as part of the GRI for the historic site: (1) conduct a scoping meeting and provide a scoping summary, (2) provide a geologic map in GIS (referred to as the "GRI GIS data" throughout this report), (3) create a poster to display the GRI GIS data, and (4) provide a GRI report. GRI products are available on the NPS DataStore through the Integrated Resource Management Applications (IRMA) Data Store (see "Access to GRI Products").

Information provided in GRI products is not a substitute for site-specific investigations. The information in GRI products should neither permit nor deny ground-disturbing activities. 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 scales—Fay (2010; 1:100,000) and Stahl (2012; 1:24,000)—and US National Map Accuracy Standards, geologic features represented in GRI products are horizontally within 51 m (167 ft) and 12 m (40 ft) of their true locations on 1:100,000-scale maps and 1:24,000-scale maps, respectively. The locations of significant landscape features (see "Geologic Heritage: Landscape Features") are not part of the GRI GIS data; they were "hand labeled" on the geologic poster of the historic site.

Scoping Meeting

On 13 May 2011, the NPS held a scoping meeting at the historic site. The meeting brought together historic site 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 2011a) summarizes the findings of that meeting.

GRI GIS Data

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. The GRI team standardizes map deliverables using a data model that dictates GIS data structure, including layer architecture, feature attribution, and relationships within Esri ArcGIS software (see "Access to GRI Products"). The GRI GIS data may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format.

Using the following source maps, the GRI team compiled two GRI GIS data sets for the historic site:

- Fay, R. O. 2010. Preliminary geologic map of the Foss Reservoir 30' × 60' quadrangle, Beckham, Custer, Dewey, Ellis, and Roger Mills Counties, Oklahoma (scale 1:100,000). Oklahoma Geologic Quadrangle OGQ-78A. Oklahoma Geological Survey, Norman, Oklahoma.
- Stahl, J. 2012. Geologic map of the Washita Battlefield National Historic Site, Cheyenne, Oklahoma (scale 1:24,000). Unpublished map by GeoCorps America participant. Geological Society of America, Boulder, Colorado.

Fay (2010) is the source map for the wbar_geology data set. Only a portion of the original map was used in compiling the GRI GIS data (Figure 4), but all geologic features within that extent were captured. This GRI GIS data set covers two 7.5′ quadrangles—Cheyenne NW and Cheyenne—of the larger Foss Reservoir 30' × 60' quadrangle.

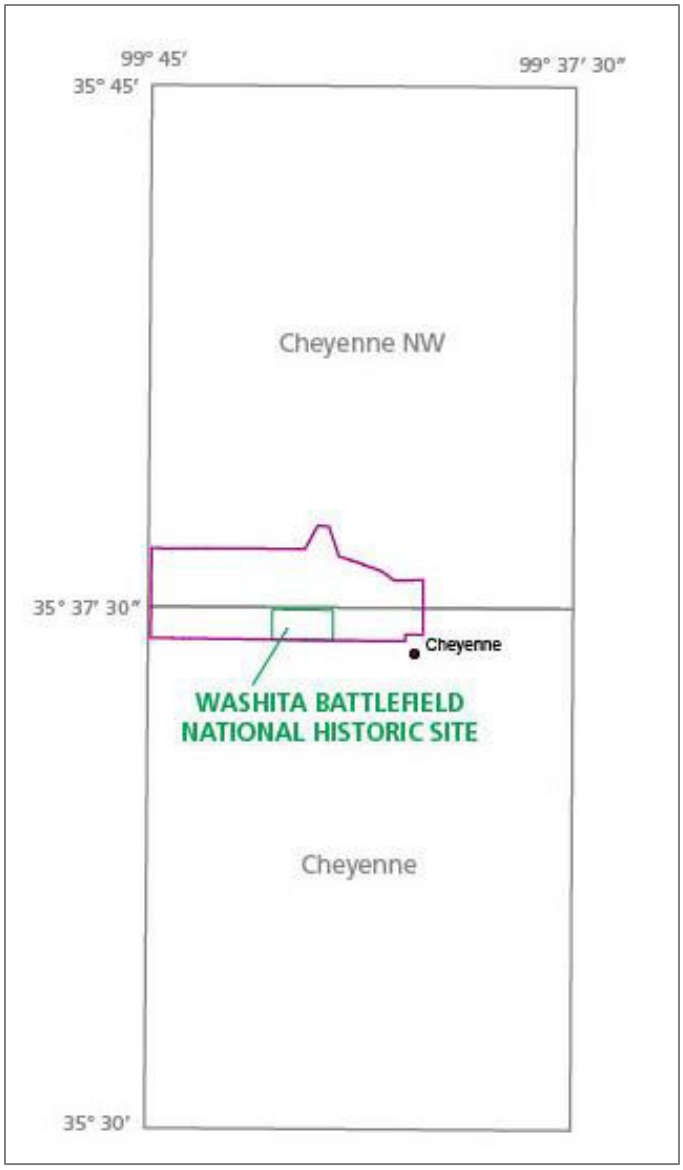


Figure 4. Index map of the GRI GIS data. The boundary for the historic site (as of August 2022) is outlined in green. The historic site lies in the Cheyenne 7.5' quadrangle. The map displays the location of the nearby town of Cheyenne, Oklahoma. The GRI team compiled two data sets for the historic site. The purple outline represents the extent of the GRI GIS data in the waba_geology data set; the source map is Stahl (2012; scale 1:24,000). These are the data displayed on the poster. The gray outline represents the extent of the GRI GIS data in the wbar_geology data set; the source map is Fay (2010; scale 1:100,000). Notably, original mapping by Fay (2010) covers the entire Foss Reservoir 30' × 60' quadrangle; only two 7.5' quadrangles (Cheyenne NW and Cheyenne) are included in the GRI GIS data. Graphic by Stephanie O'Meara (Colorado State University).

Stahl (2012) is the source map for the waba_geology data set. The GRI GIS data capture the full extent of the area mapped and all of the geologic features presented on that source map (Figure 4).

More information about the GRI GIS data can be found in the files accompanying the data on the DataStore. The "GIS readme document" explains the available file formats for the GRI GIS data, how to use the different file formats, and where to find more information about the GIS data model. The "ancillary map information document" that corresponds to the GRI GIS data includes essential elements of the source maps: a map unit list; map unit descriptions from all source maps; map legends, references, and cross sections from each source map; correlation charts and/or schematic diagrams that show correlations of rock units; and an index map of the GRI GIS data (Figure 4).

GRI Poster

The poster displays the GRI GIS data set of the source map by Stahl (2012). The data are draped over a shaded relief image of the historic site and surrounding area. The poster is the primary figure referenced throughout this 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, and geographic information and selected park features have been added to it. Specifically, the landscape features of significance for the Battle of the Washita (see "Geologic Heritage: Landscape Features") were identified and labeled on the poster; a GIS layer does not exist for these features. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

GRI Report

In preparation for writing this GRI report, the GRI team hosted a follow-up meeting for historic site staff and others interested in the geologic resources of the historic site (see "Acknowledgments"). The meeting, which took place on 28 March 2023, provided an opportunity to get back in touch with historic site staff; introduce "new" staff (since the 2011 scoping meeting) to the GRI process; and update the list of geologic features, processes, and resource management issues for inclusion in the GRI report.

This report is a culmination of the GRI process. It uses geologic interpretations displayed in the GRI GIS data, summarizes additional geologic research, and synthesizes discussions from the 2011 and 2023 meetings. In addition, the report incorporates reviewers' comments and many follow-up discussions, via email and audio calls, with historic site staff.

The primary audience of GRI reports is park resource managers, but GRI products may also be appealing and useful to other audiences such as park interpreters, maintenance staff, and visitors. To that end, GRI reports attempt to avoid technical terms and provide a writing style that is accessible to readers without a background in geology. Nevertheless, like other sciences, geology encompasses complex concepts and is full of jargon. Although GRI reports use geologic terminology, the terms are defined at their first instance, usually in parentheses following the term. Commonly, graphics are provided to help illustrate unfamiliar concepts.

The names of map units used in the GRI report primarily reflect the source maps. However, where nomenclature differs between the source maps and the formal nomenclature found 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 (USGS; see "Additional References, Resources, and Websites"), those differences are noted. The main difference for the historic site is that the source maps use Doxey "Formation," whereas the formal name in Geolex is the Doxey "Shale."

GRI reports follow spellings recorded in the Geographic Names Information System (GNIS), which contains geographic terms that the US Board on Geographic Names has formally accepted. The US Board on Geographic Names is a federal body designed to maintain uniform usage of geographic names throughout the federal government. In 1947, the Secretary of the Interior was given joint authority with the US Board on Geographic Names and has final approval of the board's actions. The online GNIS database is maintained by the USGS (see "Additional References, Resources, and Websites").

In some cases, park maps and other publications use names that are not recorded in GNIS but are used by park staff and others living in the area. In these cases, variant names and spellings are noted in the GRI report.

Geologic Heritage

This chapter highlights the geologic heritage of the historic site. Geologic heritage exists at the overlap of geology and human experiences and values.

The historic site's foundation document (National Park Service 2016) identifies core components—park description, park purpose, significance statements, fundamental resources and values, other important resources and values, and interpretive themes—that help guide planning and management efforts. Core components typically do not change over time. This GRI report draws connections between the core components and geologic resources and values.

The following resources are an integral part of the historic site's history and cultural identity; they are also part of its geologic heritage:

Landscape Features

The battlefield landscape and the landscape setting are two of the historic site's four fundamental resources and values:

> *Battlefield Landscape. The battlefield landscape consists of all of the cultural and natural landscape elements located within the historic site's boundary associated with the 1868 attack. This includes particular sites associated with the Washita conflict, including Black Kettle's winter camp, the pony kill site, Custer's Knoll, and the escape routes used by fleeing Cheyenne, as well as the general topography, grassland and riparian vegetation, and the Washita River (National Park Service 2016, p. 6).*

> *Landscape Setting. Broader aspects of the cultural landscape that may extend outside the historic site's boundaries are encompassed in the landscape setting. Important components that contribute to the landscape setting include views, the surrounding topography, dark night skies, and the rangeland setting, as well as the sites of actions related to the attack, nearby encampments, 7th Calvary troop movements, and the site related to Major Joel Elliot's engagement (National Park Service 2016, p. 6).*

Geology is the foundation of both the battlefield landscape and the landscape setting. Table 1 highlights the specific landscape features of the area that are geologically and culturally significant. The poster displays these features on the geologic map by Stahl (2012). The map units of Fay (2010) listed in Table 1 appear in the GRI GIS data (wbar_geology).

Table 1. Geology of significant landscape features.

Feature	Map Unit (Stahl 2012; scale 1:24,000)	Map Unit (Fay 2010; scale 1:100,000)	Location with Respect to Black Kettle's Winter Camp in 1868	Within the Historic Site?
Washita River channel	Floodplain (**Qfp**)	Alluvium (**Qa**)	Flows north of the camp	Yes
Ravines leading to/from the Washita River	Tributary floodplain (**Qtf**) Fluvial terrace 1 (**Qt1**)	Terrace deposits (**Qt**)	Both north and south of the river channel	Yes
Black Kettle's winter camp	Floodplain (**Qfp**)	Alluvium (**Qa**)	1868: South of meander bend Today: North of meander bend	Yes
Other winter camps	Beyond map extent	Beyond the extent of the GRI GIS data. Note: The original map by Fay (2010) shows either terrace deposits (**Qt**) or the Cloud Chief Formation (**Pcc**) underlying the locations of the other winter camps.	3–8 km (2–5 mi) east of Black Kettle's winter camp	No
Scout observation ridge	Possibly fluvial terrace 2 (**Qt2**)	Possibly Cloud Chief Formation (**Pcc**)	~1.6 km (1.0 mi) northwest of Black Kettle's winter camp	No
Place where Black Kettle and Medicine Woman Later were killed	Floodplain (**Qfp**)	Alluvium (**Qa**)	A short distance downstream from (east of) Black Kettle's winter camp	Yes
Pony kill site	Probably fluvial terrace 1 (**Qt1**) but possibly paleodunes (**Qd**)	Terrace deposits (**Qt**)	~800 m (0.5 mi) downstream from Black Kettle's winter camp, north of the railroad grade	Yes
Custer's Knoll/Hill	Doxey Formation (**Pd**)	Cloud Chief Formation (**Pcc**)	~600 m (0.4 mi) southeast of Black Kettle's winter camp, cut by the railroad grade	Yes
Twin Knolls	Beyond map extent	Cloud Chief Formation (**Pcc**)	~900 m (0.6 mi) southwest of Black Kettle's winter camp	No
Place where Major Elliott and other troops were killed	Floodplain (**Qfp**)	Terrace deposits (**Qt**)	~2.5 km (1.5 mi) east of Black Kettle's winter camp, near the present-day confluence of the Washita River and Sergeant Major Creek	No

Washita River and Ravines

Map units associated with the river: **Qfp**—floodplain of Stahl (2012). **Qa**—alluvium of Fay (2010). Map units associated with ravines: **Qtf**—tributary floodplain and **Qt1**—fluvial terrace 1 of Stahl (2012). **Qa**—alluvium and **Qt**—terrace deposits of Fay (2010).

The Washita River is the dominant and defining natural feature within the historic site (Cowley 1999). It is known as Hooxeeohe (meaning the "Lodge Pole River") by the Cheyenne because of the practice of leaving lodge (i.e., tepee) poles leaning against trees between stays. It is known as "Buffalo Creek" by the Comanche. The Spanish called it the "Rio Negro" (Black River). The French called it the "False Washita" to distinguish it from the Ouachita River that they had encountered farther east (Warde 2005).

Because of its meandering nature (see "Geologic Features and Processes: Washita River"), the course of the Washita River has changed over time. Based on aerial images, the source map by Stahl (2012) and the GRI GIS data show five locations of the channel: 1873, 1936, 1950, 1966, and 2012. The most probable location of the Washita River in 1868 is close to the position traced on the General Lands Office Survey of 1873, which was conducted by H. C. F. Hackbusch (Stahl 2012). For simplicity and to emphasize "then and now," the poster shows only the 1873 and 2012 locations. Changes in the channel's location over time affect descriptions of the location of Black Kettle's winter camp (see "Black Kettle's Winter Camp" subsection).

The stream channel, in 1868 and at present, is about 3–4 m (10–13 ft) wide with steep banks that are exposed during low-flow conditions, such as in November when the attack on Black Kettle's camp took place (Barde 1900; Marston and Halihan 2007). The valley walls rise 76 to 122 m (250 to 400 ft) above the floodplain to craggy red shale cliffs of Permian age (National Park Service 2016). Ravines (small, intermittent tributary drainages) leading down to the river were used by the Cheyenne for retreat and as hiding places during the attack. Ravines also provided routes for US troops in pursuit of Cheyenne men, women, and children. Some of these ravines have filled in with sediment since 1868 (Rea 1997).

Black Kettle's Winter Camp

Map units: **Qfp**—floodplain of Stahl (2012). **Qa**—alluvium of Fay (2010).

Black Kettle's winter camp was situated within a meander bend of the Washita River (Haecker 2000). According to a map by Barde ca. 1900, the location of the camp was south of a meander bend (see poster). However, because the Washita River is a naturally meandering river, the channel has migrated across the site of Black Kettle's camp. Sixty-eight years after the attack (ca. 1936), the camp was within the active channel. Now, the location of Black Kettle's camp is on the north side of the river (Marston and Halihan 2007).

Black Kettle's winter camp covered approximately 10 ha (25 ac) (Marston and Halihan 2007). The camp was home to approximately 250 men, women, and children (Greene 2001) residing in 51 lodges (Lees et al. 2001).

The low-lying position of the camp with its bordering fluvial terraces (former floodplains) had apparently been selected to offer a modicum of protection from the winter winds prevalent on the Southern Plains and because it was close to a water supply sufficient for the camp and its horses (Figure 5). Also, a canopy of cottonwood trees, which would have enclosed the camp at that time, provided shelter and fuel for winter fires (Reber et al. 1999; Lees et al. 2001). Until the morning of 27 November 1868, defending the location had never been necessary (John Milner Associates, Inc., and Susan Maxman Architects 2003). Besieged by four US Cavalry battalions, however, the location became a deadly trap within the narrow Washita River valley (Cowley 1999).



Figure 5. Photograph of the Washita River in winter. The wintery waters of the Washita River harken back to the time of the attack—referred to as the "Battle of the Washita"—that took place on 27 November 1868. NPS photograph by Richard Zahm (Washita Battlefield National Historic Site), taken 2006; modified to fit report format.

Winter Camps of Other Tribes

Map unit: **Qt**—terrace deposits and/or **Pcc**—Cloud Chief Formation of Fay (2010). *Note*: These winter camps are beyond the extent covered by the GRI GIS data, but the full extent of the map by Fay (2010) includes them.

Black Kettle's winter camp was located upstream (west) of Apache, Arapaho, Comanche, Kiowa, and other Cheyenne winter camps. An estimated 6,000 people and their horses inhabited those camps (Gardner 2002). Like Black Kettle's camp, these other camps met their water needs by being close to the Washita River.

Scout Observation Ridge

Map units: **Qt2**—fluvial terrace 2 of Stahl (2012). **Pcc**—Cloud Chief Formation of Fay (2010).

During the night of 26–27 November 1868, Osage scouts Little Beaver and Hard Rope (Osage spellings unknown) first observed Black Kettle's winter camp from rising ground about 1.6 km (1.0 mi) northwest of the camp. According to Ben Clark (7th US Cavalry, chief of scouts), Custer and his officers "lay on this very spot and spied out the village and the lay of the land" (Greene 2001, p. 282).

The historic resource study (Greene 2001, pp. 281–282) describes the observation spot as being on "rising ground in the northeast quarter of Section 2, Township 13 North, Range 24 West, about one mile northwest of the village site." Based on that description, an approximate location is marked on the poster. This location (a "high point" on a fluvial terrace [**Qt2**]) has not been verified in the field, however.

Staging Area and Sugar Loaf

Map units: **Pd**—Doxey Formation of Stahl (2012). **Pcc**—Cloud Chief Formation of Fay (2010).

Several conical hills composed of the Doxey Formation (**Pcc**) rise above the plain north of the historic site (see poster). Two of these hills mark the pre-attack staging area of an estimated 800 men of the 7th Cavalry (see poster). Another prominent landmark is known as "Sugar Loaf" (Figure 6). Custer and his men congregated in this area, waiting for daybreak to attack.



Figure 6. Photograph of Sugar Loaf. Sugar Loaf is a prominent landmark north of the historic site. This red bed knoll is composed of the Doxey Formation, which is formally known as the Doxey Shale, map unit Pd (see poster). NPS photograph by Christian Schroll, n.d.

Troops were divided into four contingents: (1) Custer's command approached the village from the northwest, (2) Major Joel H. Elliott's command from the northeast, (3) Captain Edward Myers from the west, and (4) Captain William Thompson from the south (Figure 7). The four battalions encircled Black Kettle's winter camp, reducing the chance of escape (Cowley 1999).

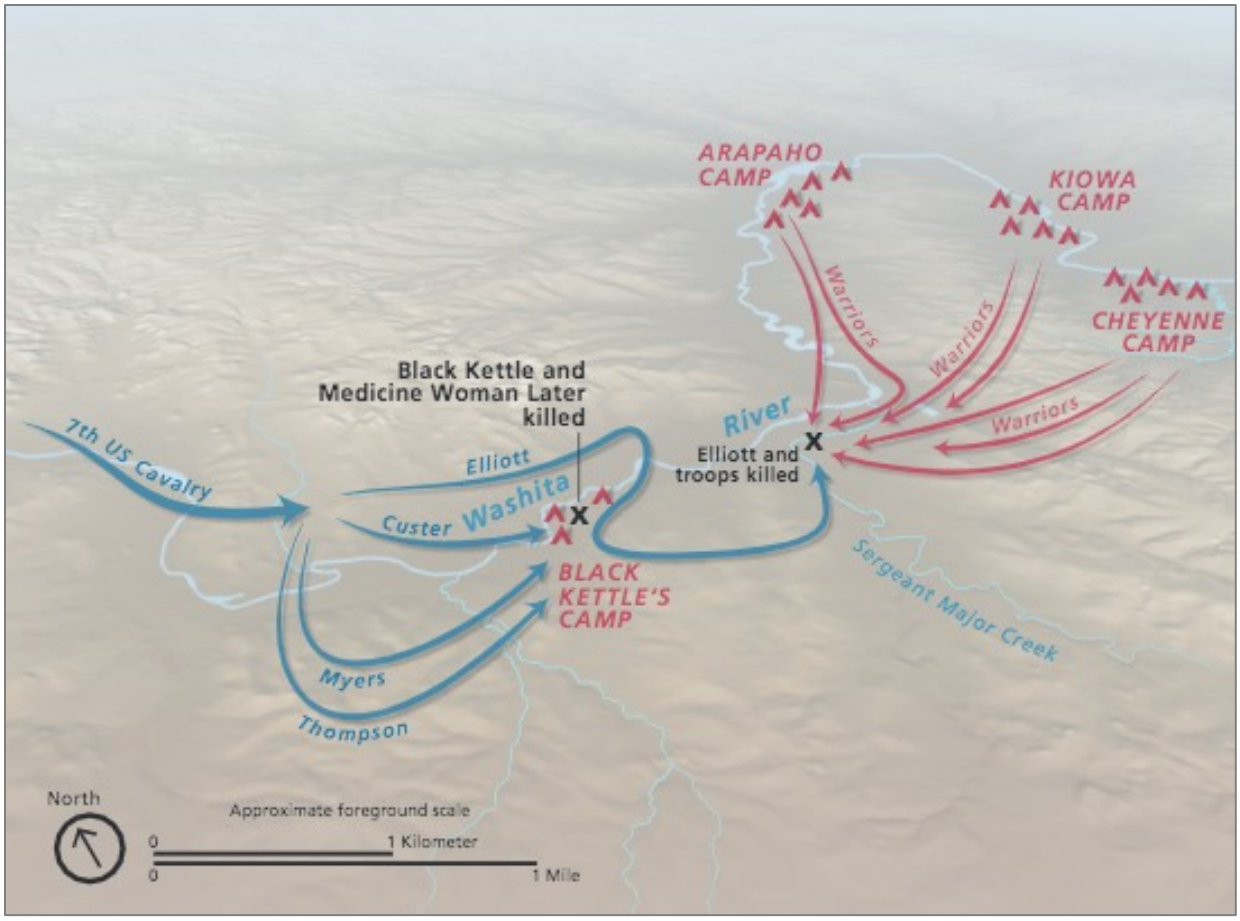


Figure 7. Map of 7th US Cavalry maneuvers. Divided into four contingents, the 7th Cavalry attacked Black Kettle's camp from all sides: Custer's command approached from the northwest. Major Joel H. Elliott's command approached from the northeast. Captain Edward Myers approached from the west. Captain William Thompson approached from the south. Attempts at escape occurred eastward along or through the river and up the ravines and hills to the south of the river. Once the attack started, the camp was overrun within 10 minutes, but fighting continued until about 3 o'clock that afternoon because warriors from camps downstream rode up the valley to aid Black Kettle. Scattered fighting and killing took place along the floodplain and in the hills to the south. Historic accounts describe how Black Kettle and his wife, Medicine Woman Later, were killed while trying to cross the river. NPS graphic available at https://www.nps.gov/subjects/gisandmapping/nps-maps.htm (accessed 21 May 2024).

As Major Elliott led his troops into position, they encountered a very steep conical hill—Sugar Loaf (see poster and Figure 6)—which stands about "one-half mile north of the village site, in the northwest quarter of Section 1" (Greene 2001, pp. 284–285). From the vantage point on Sugar Loaf, Elliott reconnoitered the village during the night. Before opening the assault at daybreak, Elliott descended the butte and led his troops down a draw, or "canyon," east of Sugar Loaf toward Black Kettle's camp.

Following the initial attack, Cheyenne, Arapaho, Kiowa, and Comanche warriors from the nearby villages watched from Sugar Loaf. They taunted the soldiers, hoping to draw some of them away, but

could not attack for fear of harming the 53 women and children that had been taken captive (National Park Service 2021b).

Place Where Black Kettle and Medicine Woman Later Were Killed

Map units: **Qfp**—floodplain of Stahl (2012). **Qa**—alluvium of Fay (2010).

Black Kettle was alerted of imminent danger by a woman of his Tribe running through the camp. Black Kettle fired a shot from his rifle to awaken those still sleeping, then reached for the pony tethered at his lodge. A man named Bearmeat Face (Cheyenne spelling unknown) described the chief and his wife, Medicine Woman Later (Ar-no-ho-wok; spelling from Greene 2001, p. 203), "mounting an iron-gray horse, 'but the horse was badly frightened by the great firing and the morning excitement' so much that they could not get away quickly. They tried to make it to the ford to cross to the north side, but the soldiers were already storming through the brush near the stream. Then the horse they were riding was shot in the right hind leg, and Black Kettle and his wife were killed. The chief was hit in the stomach, and another shot struck him in the back, between the shoulder blades. Nonetheless, they fell in the water, the horse struggling to reach the far bank, where it died" (Greene 2001, p. 203).

Pony Kill Site

Map units: **Qd**—paleodunes or **Qt1**—fluvial terrace 1 of Stahl (2012). **Qt**—terrace deposits of Fay (2010).

During the attack, the cavalry rounded up an estimated 875 Cheyenne ponies, then drove the horses to a point below a high bluff southeast of the winter camp, possibly on a paleodune (**Qd**; "inactive dune," though the meaning is unclear; see "Eolian Features and Processes"). The ponies were "bunched against the steep bank" and shot to death by four companies of cavalry (Greene 2001, p. 291). The killing required a full two hours to complete (Gardner 2002). Custer was determined to kill the horses because if he took them with him, not only would they delay his withdrawal from Black Kettle's camp (and proximity of the downriver winter camps), but they would remain an enticing prize for warriors who might follow. Moreover, the killing of the horses would devastate the people and cripple their future mobility. Some ponies were spared to serve as mounts for the women and children taken prisoner; a few were given to Osage scouts (Greene 2001).

The bones of the slain animals lay on the ground for many years. By 1891, some had been placed around the base of the first historic marker at the site (see "Geologic Heritage: Building Stone"). By ca. 1902, locals had gathered up the bones for sale to a Texas fertilizer company (Greene 2001, p. 275). Some bones were there in 1935 (National Park Service 2024).

Custer's Knoll/Hill

Map units: **Pd**—Doxey Shale of Stahl (2012). **Pcc**—Cloud Chief Formation of Fay (2010).

After leading the charge into the valley and across the river, Custer then rode southward out of the valley to a prominent knoll where he could better direct the attack (Figure 8). The knoll, which stands

an estimated 12 m (40 ft) above the floodplain, was a significant observation post, including after Custer gained word that other winter camps lay downstream (Greene 2001).



Figure 8. Photograph of Custer's Knoll. The photograph shows the northwestern side of the knoll, looking toward the southeast. Lieutenant Colonel George Armstrong Custer used this location as an observation post during the attack. The side of the knoll was excavated in 1928–1929 as part of the construction of a railroad grade of the Panhandle and Santa Fe Railroad (see poster). NPS photograph by Kenny Points (Washita Battlefield National Historic Site), taken February 2024.

Referred to as either "Custer Hill" (Cowley 1999) or "Custer's Knoll" (Greene 2001; National Park Service 2016), Custer ascended this feature following the opening charge into the winter camp. The knoll is southeast of Black Kettle's winter camp and slightly northwest of the present overlook (see poster). The north side of the knoll was torn away during construction of the railroad grade (Greene 2001; see "Restoration of the Railroad Grade").

Twin Knolls

Map unit: Beyond map extent of Stahl (2012). **Pcc**—Cloud Chief Formation of Fay (2010).

During the attack, many Cheyenne women and children fled across the prairie in the direction of two buttes known as "Twin Knolls" (Figure 9). These buttes are about 0.8 km (0.5 mi) south of the

location of Black Kettle's winter camp and rise about 30 m (100 ft) above the floodplain (see poster). The women and children encountered Myers's squadron at Twin Knolls, where according to Ben Clark, soldiers began to pursue them and kill them "without mercy" (Greene 2001, p. 288). Clark brought Custer's attention to the matter, and "he ordered me to stop the slaughter, which I did" (Greene 2001, p. 288). The captives were ushered back to the camp and placed under guard in one or more tepees (Greene 2001).



Figure 9. Photograph of Twin Knolls. During the attack, women and children from Black Kettle's camp fled toward Twin Knolls, which rise above the plain (south of the historic site; see poster). These fleeing Cheyenne were either killed or taken prisoner by the 7th Cavalry. Note the wind turbines on the horizon. NPS photograph by Kenny Points (Washita Battlefield National Historic Site), taken February 2024.

Twin Knolls are beyond the map extent of Stahl (2012), but mapping by Fay (2010) identifies them as being composed of the Cloud Chief Formation (**Pcc**). Notably, at a scale of 1:100,000, Fay (2010) does not distinguish the conical hills in the area from the surrounding Cloud Chief Formation. Because other conical hills in the area—including Custer's Knoll, Sugar Loaf, and those around the staging area—are mapped as Doxey Formation by Stahl (2012), it seems likely that Twin Knolls also may be composed of the Doxey Formation (see "Origin of Conical Hills").

Place Where Major Elliott and Other Troops Were Killed

Map units: **Qfp**—floodplain of Stahl (2012). **Qt**—terrace deposits of Fay (2010).

In an attempt to corral some Cheyenne boys seen fleeing from the winter camp through the unclosed gap between his command and that of Captain William Thompson (see Figure 7), Major Joel Elliott, along with regimental Sergeant Major Walter Kennedy and a group of cavalrymen joining in, took off downstream in pursuit. As reported by Ben Clark, Elliott exclaimed, "There's a lot of escaping Indians; come on boys, let's take 'em in." Those who joined the major "did so of their own accord" (Greene 2001, p. 190).

Arapaho reinforcements, arriving from their winter camp located to the east (see Figure 7), overcame and killed the pursuing cavalry at a point along the Washita River about 4.0 km (2.5 mi) east of Black Kettle's camp (see poster). That location is near the present-day confluence of Sergeant Major Creek and the Washita River (Figure 10). Since that day in 1868, however, the configuration of Sergeant Major Creek in this area has drastically changed (Figure 11); its course has been diverted directly north into the Washita River (Greene 2001). The diversion (straightening and channelizing of the creek) took place because flooding repeatedly impacted State Route 283 and the railroad bridge over the highway (Richard Zahm, Washita Battlefield National Historic Site, park ranger, audio call, 15 April 2024). According to a map by Brill (1938; see p. 37 in Crowley 1999), the creek in this area used to flow to the east and parallel to the Washita River. As such, the confluence of the two streams is now about 0.6 km (1 mi) west of where it was in 1868 (Figure 11).



Figure 10. Photograph of the “witness tree.” For many years, this tree marked the location where Major Joel H. Elliott and other troops were killed following their attack on Black Kettle’s winter camp. The location is near the present-day confluence of the Washita River and Sergeant Major Creek (east of the historic site). In 2023, a tornado demolished the tree. Photograph by Charles J. Brill, taken 1938, courtesy of Richard Zahm (Washita Battlefield National Historic Site).

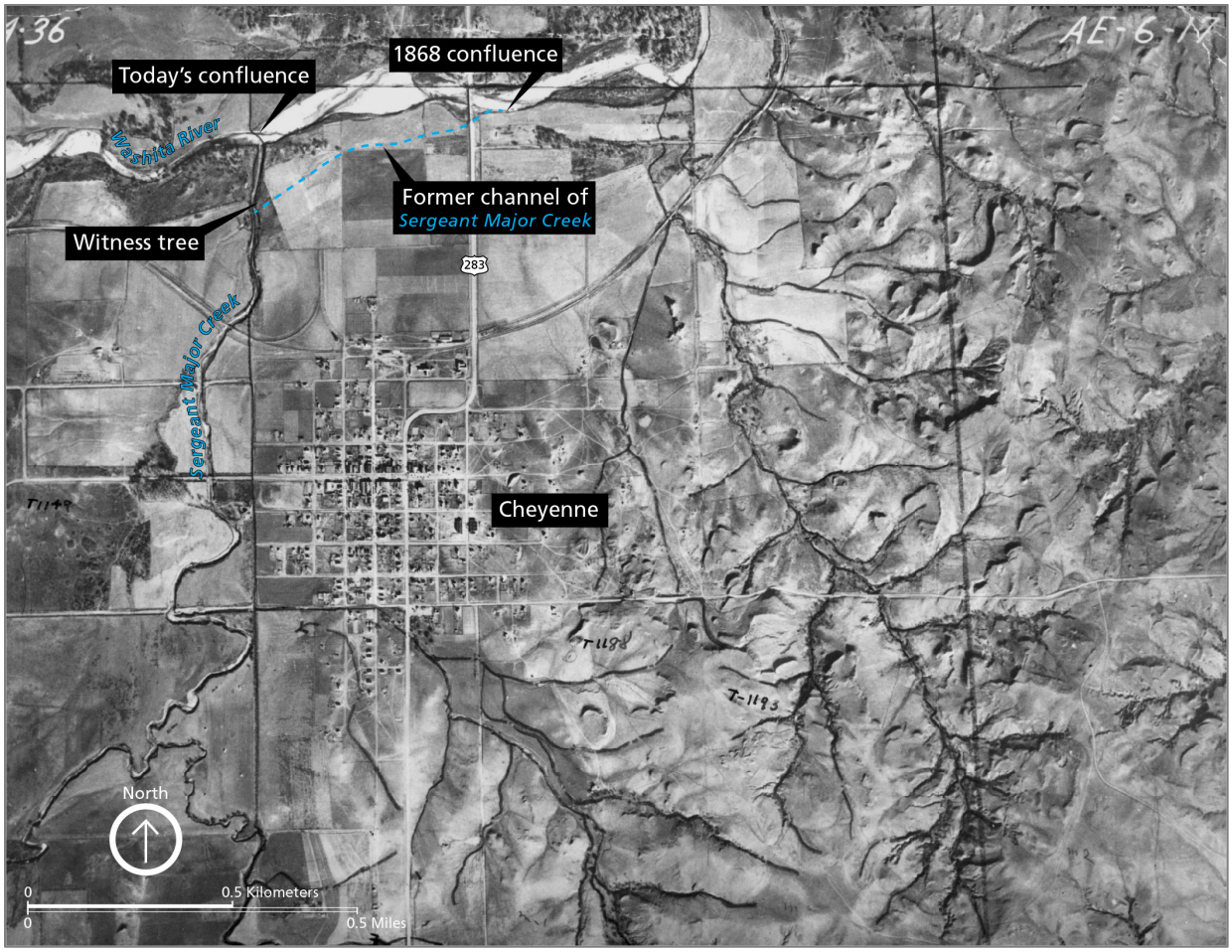


Figure 11. Aerial photograph (1936) illustrating the changing condition of Sergeant Major Creek. Today, the confluence of Sergeant Major Creek and the Washita River is a convenient description for explaining the location where Major Joel H. Elliott and other troops were overtaken, surrounded, and killed by Apache warriors who were camped upstream. Until 2023, a witness tree marked the location (see Figure 10). At the time of the attack, however, the confluence was located about 0.6 km (1 mi) farther east than it is today. Today, it is east of State Route 283. In the 1960s, the channel of Sergeant Major Creek was diverted directly north. The hashed line on the figure marks the former channel of Sergeant Major Creek. Annotations by Trista L. Thornberry-Ehrlich (Colorado State University). Aerial image courtesy of Richard Zahm (Washita Battlefield National Historic Site).

Building Stone

The stone markers/memorials at the historic site are an "other important resource and value" (National Park Service 2016). They are cultural resources that reflect the meaning of the historic site since the time when the first marker was placed in 1891. Notably, the meanings of these markers/memorials have changed over time as a variety of perspectives have been recognized and interpreted at the historic site.

Markers/memorials composed of building stones are geologic resources and possess geologic heritage values. To date, granite (a light-colored, coarse-grained igneous rock formed from magma that cooled beneath Earth's surface) is the most-used building stone for markers/memorials at the

historic site. Scoping participants assumed that the granite was mined in Oklahoma (see KellerLynn 2011a), but this assumption has not been verified by a geologist on-site. Oklahoma granites are light gray, pink, red, and brown (Johnson and Luza 2008).

Past geologic events (see "Geologic History") have resulted in two areas in the state ideal for quarrying: (1) the Wichita uplift (also known as the Wichita Mountains) and (2) the Arbuckle uplift (also known as the Arbuckle Mountains), south and southeast of the historic site, respectively (Figure 12). Quarries in the Wichita Mountains (Greer and Kiowa Counties), aptly called the "Granite Mountains Region," yield granite that formed from magma during the Cambrian Period, about 525 million years ago (Johnson and Luza 2008). These bodies of solidified molten material are nearly 6,100 m (20,000 ft) thick (Johnson and Luza 2008). Quarries in the Arbuckle Mountains (Johnson County) yield granite that formed during the Mesoproterozoic Era (1.6 billion–1.0 billion years ago). At 1.4 billion years old, these are the oldest rocks exposed at the surface in Oklahoma. In addition, Mesoproterozoic granite is exposed in the Ozark uplift (Mayes County) in the northeastern part of the state, though no quarries are known from there (Johnson and Luza 2008).



Figure 12. Map of uplifts, basins, and other geologic structures. The historic site (green star on map) is situated in the Anadarko basin. Building stones for the markers/memorials at the historic site were mined from the Wichita and Arbuckle uplifts. During the Pennsylvanian and Permian Periods, layers upon layers of sediment filled these basins, including sediments that would become the historic site's bedrock. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Dolliver (1984, Figure 4), Spearing (1991, p. 27), and Giles (2005). Base map by Tom Patterson (National Park Service).

Building stone can be significant for a site, particularly if it was collected or quarried locally. The park brochure, "Once Upon A Building…" mentions that the information desk at the visitor center is topped by Oklahoma speckled granite from a nearby quarry. In this case, however, "nearby" is likely 80 km (60 mi) away in the Wichita Mountains. Only one of the significant markers/memorials at the

historic site is composed of local stone, but it is not granite. The red sandstone of the first marker placed at the site was probably collected nearby (see "'Battle of the Washita' Stone" subsection).

A focused inventory of building stone has not taken place at the historic site, but it would be a fascinating project. A researcher could trace the stones' commercial origins (i.e., quarries) and, based on those locations, determine the geologic formations (fundamental rock-stratigraphic unit) of the extracted material. Geologic connections could then be made to other state, regional, national, and global stories as well as to NPS areas. For example, the gray granite panel at the overlook came from a quarry in the Wichita Mountains—the Pellow Brothers Quarry in Granite, Oklahoma, which is now run by Willis Granite Products (KellerLynn 2011a). That company also prepared the trailhead marker (Richard Zahm, Washita Battlefield National Historic Site, park ranger, GRI follow-up meeting, 28 March 2023; see "Etched Interpretive Panel" and "Trailhead Marker" subsections). Interestingly, the same granite from the same quarry composes the marker of the State of Oklahoma commemorative stone in the stairway of the Washington Monument in Washington, DC (Figure 13).



Figure 13. Photograph of the State of Oklahoma commemorative stone. Like the "The Battle of the Washita" marker at the historic site, this commemorative stone, which is in the Washington Monument in Washington, DC, is composed of granite quarried from the Wichita Mountains. Both the commemorative stone and the historic site's marker were prepared by Willis Granite Products in Granite, Oklahoma. The commemorative stone, which is located at the 290-foot level, is one of 193 displayed in the interior stairway of the Washington Monument. NPS photograph available at https://www.nps.gov/articles/state-of-oklahoma-290-level.htm (accessed 20 May 2024).

Receiving geologic expertise for an inventory of building stone may be possible through the Scientists in Parks (SIP) program (see "Guidance for Resource Management"). Such an inventory could be combined with and help address the need for an updated cultural landscape inventory and an updated list of classified structures, which were identified as needs in the historic site's foundation document (National Park Service 2016).

Other GRI products have revealed fossils in building stone at parks not previously known to host paleontological resources (e.g., see the scoping summary and GRI report about Fort Larned National Historic Site by KellerLynn 2008a and Barthelmes 2024, respectively). Moreover, culturally

significant fossils—such as in John Muir's fireplace (see the GRI report about John Muir National Historic Site by KellerLynn 2021) and the fireplace in the guest hogan at Hubbell Trading Post National Historic Site (see the GRI report by KellerLynn 2024)—occur as building stone.

The following stone markers/memorials are found within the historic site:

"Battle of the Washita" Stone

Initially placed 23 years after the attack (ca. 1891), the first marker to identify the "Battle of the Washita" is composed of red sandstone (Figure 14). Based on the description provided by Greene (2001), the marker is the only one at the historic site that is composed of local bedrock. Notably, neither unit of the historic site's bedrock—Cloud Chief Formation (**Pcc**) or Doxey Formation (**Pd**) (see "Permian Red Beds")—contains much sandstone. However, if the marker is one of these two, it will be the Cloud Chief Formation. A more probable explanation is that the sandstone came from the Rush Springs Formation, a unit stratigraphically just below the Cloud Chief Formation, or the Elk City Sandstone, a unit just above the Doxey Formation (Thomas Stanley, Oklahoma Geological Survey, geologist, written communication, 24 January 2024).



Figure 14. Photographs of the first marker. Initially placed in 1891, this memorial stone is composed of red sandstone. It is the only marker at the historic site identified as being "local bedrock." The stone is now on display at the visitor center. Top: Oklahoma Historical Society photograph WA037B, Czarina Conlan Collection, item number 4517, available at https://www.okhistory.org/publications/enc/entry?entry=WA037 (accessed 21 May 2024). Bottom: Oklahoma Historical Society photograph by Jim Argo, taken October 2000, available at https://gateway.okhistory.org/ark:/67531/metadc1642470/ (accessed 21 May 2024).

Concerned that the location of the engagement would likely be lost and forgotten as settlement increased in Roger Mills County, First Lieutenant Hugh L. Scott, who was a member of the 7th Cavalry during the attack, was determined to raise a marker to commemorate the action. "For three days in January 1891, [Scott] and his escort, aided by a military ambulance, searched the vicinity for large rocks suitable for a monument. [He] then commissioned one of his party, Sergeant Thomas Clancy, a former stone mason, to inscribe a large, flat, red sandstone slab with the inscription, '7th CAV,' followed by 'Nov. 27, 1868'" (Greene 2001, p. 274).

The carved memorial stone was placed on a pile of other stones on the south side of the Washita River at the site of Black Kettle's camp. Horse skulls collected from the pony kill site were placed around the foot of the marker (Greene 2001). Because of vandalism, the NPS removed the marker from its original location; it is now part of the historic site's museum collection (National Park Service 2016) and is exhibited at the visitor center (Figure 14).

"Custer's Battle" Stone

The memorial stone inscribed with the words "Custer's Battle, Nov. 27, 1868" (Figure 15) was placed by the Platonic Club of Cheyenne in 1933. This red granite memorial marks the reburial site of a Cheyenne teenage boy identified by Chief Magpie (who was wounded in the attack) as Hawk (Cheyenne spelling unknown). The remains had been uncovered during a railroad excavation project in 1914 (Greene 2001). The reburial took place in the 1930s, around the time of the memorial's dedication.



Figure 15. Photograph of "Custer's Battle" stone. Inscribed with the words "Custer's Battle, Nov. 27, 1868", the Platonic Club of Cheyenne placed the memorial stone in 1933. The red granite comes from Granite, Oklahoma, where it is exposed at the surface as part of the Wichita uplift. The quarry is about 80 km (50 mi) southeast of the historic site. Photograph by Katie KellerLynn (Colorado State University), taken May 2011.

In 2011, scoping participants suspected that the stone for the memorial was mined in Granite, Oklahoma, where Cambrian granite is exposed at the surface as part of the Wichita uplift (see

"Geologic History"). Based on a photograph that appeared in the scoping summary (Figure 10 in KellerLynn 2011a), Dr. David London (University of Oklahoma) confirmed this suspicion. He stated, "The red looks like ordinary Wichitas red granite to me. The small mafic enclaves are a familiar characteristic" (David London, University of Oklahoma, professor, email communication to Neil Suneson, Oklahoma Geological Survey, geologist, 18 July 2011).

The memorial stone remains in its original location but suffers from occasional vandalism. Vandals scratch out mentions of Custer and the word "battle" (National Park Service 2016).

Etched Interpretive Panel

Placed at the overlook, a gray granite marker serves as an interpretive panel that features etchings of Black Kettle and George A. Custer as well as text retelling the events of 27 November 1868 (Figure 16). According to the foundation document (National Park Service 2016), the accuracy of the text is questionable. Also, the identity of the sponsor is speculative, though the historic resource study (Greene 2001) states that the Oklahoma Industrial and Development Board placed the panel in 1962. In 1963, the State of Oklahoma acquired 1.2 ha (3 ac) accompanying this marker along State Route 47A and established an overlook and roadside park (Greene 2001).



Figure 16. Photograph of an etched interpretive panel. "The Battle of the Washita" marker was prepared by Willis Granite Products in Granite, Oklahoma. The stone is a piece of 525-million-year-old granite from the Wichita Mountains. The uplift itself took place about 300 million years ago. Photograph by Katie KellerLynn (Colorado State University), taken May 2011.

The panel was prepared by Willis Granite Products in Granite, Oklahoma (Richard Zahm, Washita Battlefield National Historic Site, park ranger, telephone communication, 28 June 2011). Although the gray color of the panel suggests that the granite was probably mined elsewhere (Neil Suneson, Oklahoma Geological Survey, geologist, telephone communication, 18 July 2011), Dr. David London confirmed that although it does not look like Oklahoma rock, some of the "autumn rose" building stone quarried in Troy, Oklahoma, is "pretty much gray" (David London, University of Oklahoma, professor, email communication to Neil Suneson, Oklahoma Geological Survey, geologist, 18 July 2011).

Commonly, visitors place small rocks as offerings for remembrance on the panel. Vandals remove these rocks and throw them onto the roof of the overlook pavilion and around the grounds. The panel suffers from occasional vandalism in the form of vandals scratching out mentions of Custer, the word "battle," and other problematic language (National Park Service 2016).

Plaque Fixed to Gray Granite

On 22 October 1965, Secretary of the Interior Stewart Udall unveiled a plaque designating the scene as a national historic landmark. The plaque is fixed to a granite slab. The geologic origin of this gray building stone is unknown but probably not from Oklahoma (KellerLynn 2011a).

Engraved Panel of Attack Routes

The overlook pavilion at the historic site also includes an engraved panel of gray granite that illustrates the maneuvers of the four military commands (Figure 17). Additionally, it depicts the relative locations of significant landscape features such as the Washita River and Sergeant Major Creek. Notably, it shows Sergeant Major Creek in its 1868 position. Installed in 1968, the geologic origin of this building stone is unknown.

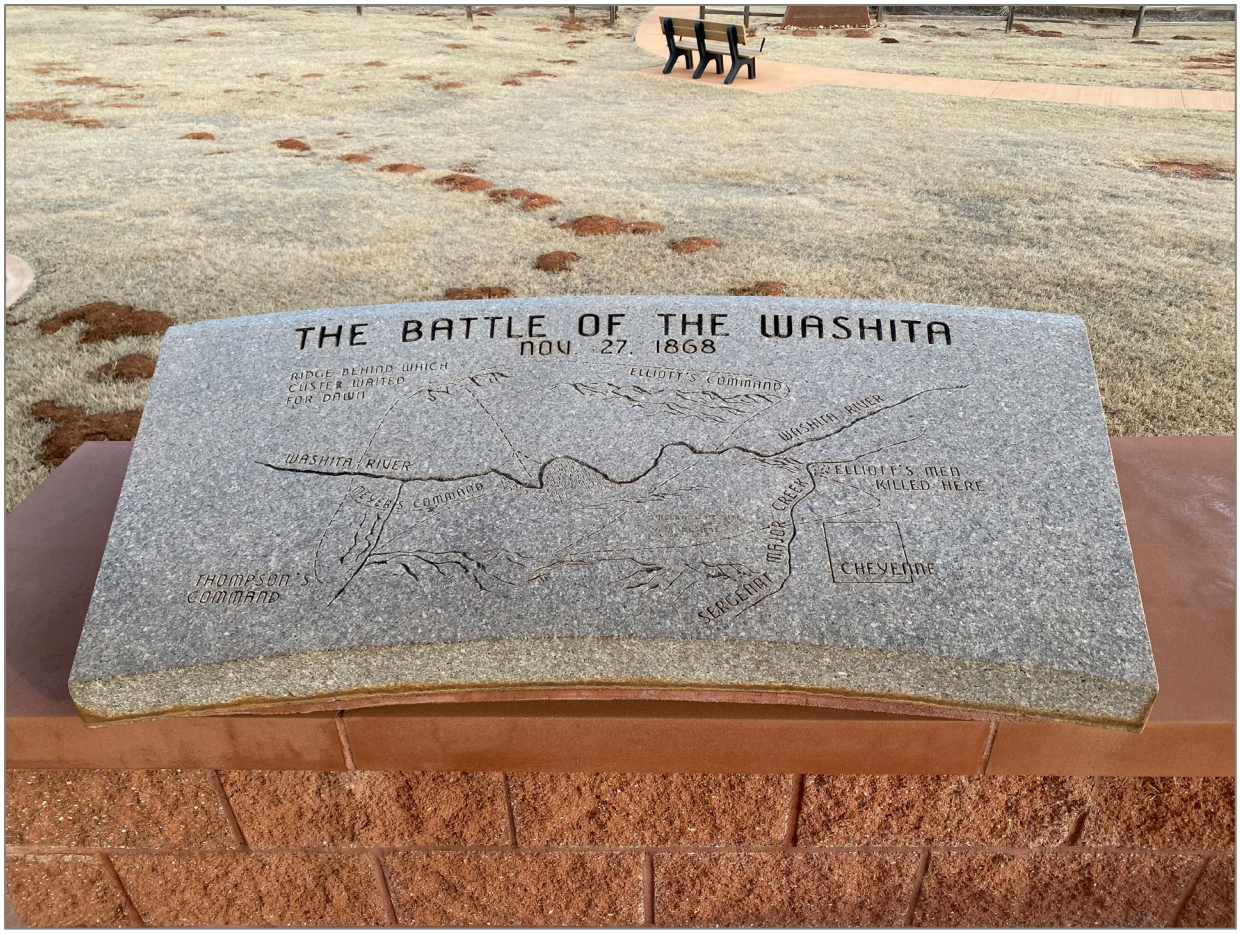


Figure 17. Photograph of the engraved panel of attack routes. Four routes etched in stone depict the military maneuvers that surrounded Black Kettle's camp on 27 November 1868. The panel depicts many important landscape features. Notably, it shows the channel of Sergeant Major Creek in its 1868 position. NPS photograph by Kenny Points (Washita Battlefield National Historic Site), taken January 2024.

Trailhead Marker

A red granite marker (Figure 18) welcomes visitors to take the path that leads down to the Washita River. Willis Granite Products prepared this trailhead marker (Richard Zahm, Washita Battlefield National Historic Site, park ranger, GRI follow-up meeting, 28 March 2023), which presumably came from their quarry in Granite. As such, the marker is 525 million years old.



Figure 18. Photograph of the trailhead marker. Composed of red granite mined in the Wichita Mountains in southwestern Oklahoma, the trailhead marker guides visitors on their way to the Washita River and across the battlefield landscape. NPS photograph by Kenny Points (Washita Battlefield National Historic Site), taken January 2024.

Sense of Place

Places are spatial localities given meaning by human experiences in them. The historic site's sense of place is a fundamental resource and value:

> *Sense of Place. The historic site possesses traditional and contemporary cultural, spiritual, and historic value for the Cheyenne and Arapaho Tribes, other Tribes, and park visitors. The atmosphere of the historic site retains much of its historic rangeland characteristics, which provide visitors the opportunity to experience the sacredness many Tribes associate with the site. The historic site is actively managed as a reverential place where all may remember those who lost their lives during the attack and reflect on the realities of war and its lasting impacts (National Park Service 2016, p. 6).*

As noted in the foundation document, part of the historic site's sense of place is its rangeland characteristics. Rangeland has historically surrounded the site and harkens back to the traditional land use of hunting buffalo. Rangeland characteristics speak to the enormity of the Plains and the

nomadic lifeways of the Plains Tribes (see “Park Setting”). The Cheyenne and other Plains Tribes went where there were buffalo to hunt and wild horses to capture in an area that stretches westward to the Rocky Mountains, eastward to the Mississippi River, and northward from the Rio Grande into Canada (Gardner 2002).

A search for the term “Cheyenne” in the GNIS serves as an indicator, albeit a perfunctory one, of the influence of the People on the landscape. Cheyenne is a populated place in Oklahoma, Kansas, Wyoming, and Texas. Nebraska and Colorado have counties with the name. Seven states—unexpectedly including Alaska, Oregon, and South Dakota, in addition to the more expected states of Oklahoma, Kansas, Texas, and Colorado—have creeks named Cheyenne.

Geologic History

This chapter describes the geologic events that led to the historic site's present-day landscape. Events are discussed more or less in order of geologic age (oldest to youngest). Paleogeographic maps help illustrate the geologic events. A geologic time scale shows the chronology of geologic events (bottom to top).

Significant Geologic Events

Assembling Pangea

The historic site's bedrock was deposited when Earth's continental crust was configured into the supercontinent Pangea. The Tethys Ocean was east of the colossal landmass. The remainder of Earth's surface was covered by the "super ocean" Panthalassa (Figure 19).

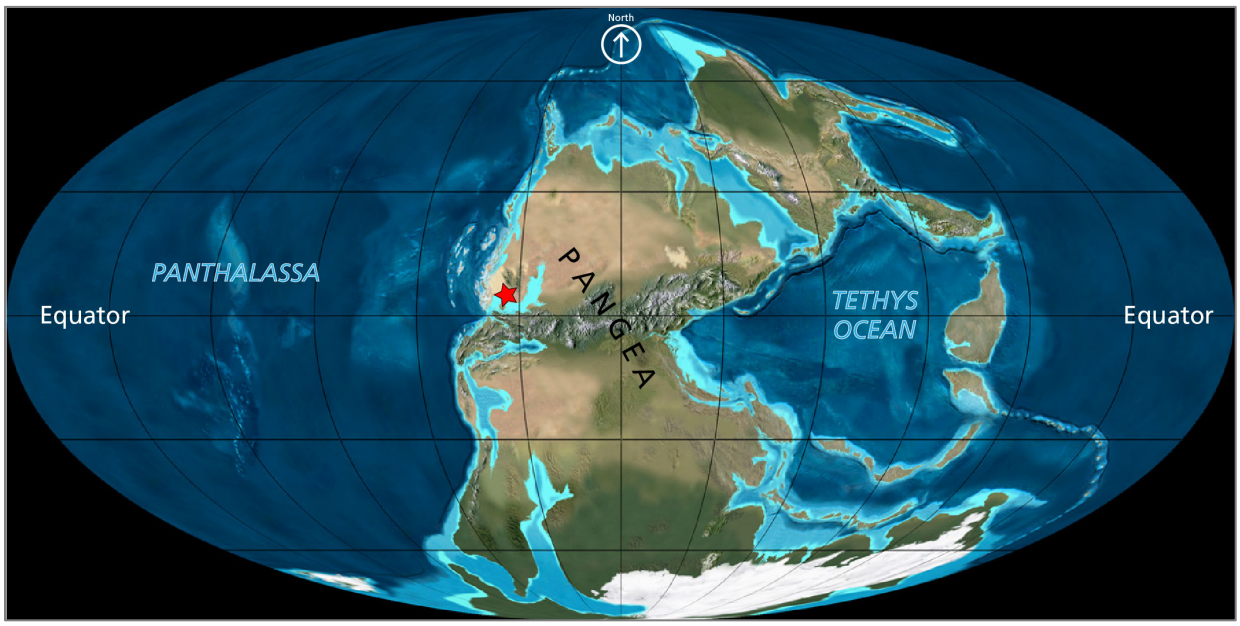


Figure 19. Paleogeographic map of Pangea during the Permian Period. About 260 million years ago, the supercontinent Pangea spread from pole to pole and was shaped like a huge letter "C." Oklahoma (red star) was on the western edge of Pangea near the equator. Note the uplifted swath of mountains spanning the midcontinent. Base paleogeographic map by Ron Blakey, "Paleogeography of Southwest North America," © 2012 Colorado Plateau Geosystems Inc., used under license; see https://deeptimemaps.com/ (accessed 21 May 2024). Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

The configuration of Pangea began about 335 million years ago (Middle Mississippian Period). The historic site's red beds were deposited about 259 million to 251 million years ago (middle–late Permian Period). The supercontinent reached its greatest extent about 250 million years ago (Early Triassic Period). Breakup began about 200 million years ago (Early Jurassic Period).

Pangea is commonly described as having two parts: Laurasia (representing northern Pangea and including continental crust that would compose North America, Europe, and Asia) and Gondwana (representing southern Pangea and including continental crust that would compose South America, Africa, Antarctica, Australia, and India). A mountain belt bifurcated the two parts. Of interest to the historic site's geologic story, part of this mountain chain was composed of the Wichita, Arbuckle, and Ouachita uplifts in Oklahoma and the Amarillo uplift in Texas (see Figure 12). In addition, the Ancestral Rocky Mountains, primarily in what are now Colorado and New Mexico, made up the western part of the Pangean mountain chain. Farther east, the Appalachian highlands dominated the scene (Figure 20).



Figure 20. Paleogeographic map of the Pennsylvanian Period. About 300 million years ago, mountains were forming while basins were subsiding in what is now Oklahoma. A red star marks the location of the historic site. Base paleogeographic map by Ron Blakey, “Paleogeography of Southwest North America,” © 2012 Colorado Plateau Geosystems Inc., used under license; see https://deeptimemaps.com/ (accessed 21 May 2024). Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

About 300 million years ago (during the Pennsylvanian Period), the principal mountain belts of Oklahoma—Wichita, Arbuckle, and Ouachita—were the sites of folding (bends in rock), faulting (breaks in rock), and uplifts (structurally high areas). Deeply buried Proterozoic–Mississippian rocks (approximately 1.4 billion to 323 million years old) were brought to the surface as part of mountain building. Of interest for the GRI, these uplifted rocks include Proterozoic and Cambrian granites of the Wichita and Arbuckle Mountains, which make up most of the markers/memorials that stand at the overlook and mark the trail at the historic site (see "Building Stone").

While Earth's crust fractured and was thrust upward into mountain ranges, adjacent areas warped, buckled, and subsided (sank), forming several large depositional basins. The mechanism for subsidence at that time is not well understood, but the evolving stress regime related to the event and/or events farther west (i.e., along the western continental margin) potentially contributed to coupled uplift and basin subsidence along high-angle (> 45°) faults (Soreghan et al. 2018).

Filling of the Anadarko Basin

Adjacent to the Wichita uplift, Earth's crust subsided into the Anadarko basin, which is one of the deepest in the continental United States (Hugman and Vidas 1987; Johnson 1989). The basin primarily underlies what is now western Oklahoma and the Texas Panhandle. The historic site is on the southern side of the basin. The basin is bounded on the east by the Nemaha uplift; on the southeast by the Arbuckle Mountains and Ardmore basin; and on the south by the Wichita Mountains and Amarillo uplift (see Figure 12). To the west and north, the basin shoals onto a broad shelf with subsurface depths of less than 1,500 m (5,000 ft) (Ball et al. 1991).

Now filled with as much as 12,000 m (40,000 ft) of sedimentary rock in the deepest part of the basin (Johnson 1989), subsidence provided room for sediments to accumulate. About 4,600 m (15,000 ft) of sediment accumulated during the Pennsylvanian Period (Sweet et al. 2013). The Permian sequence in Oklahoma is between 300 and 1,500 m (1,000 and 5,000 ft) thick (Johnson and Luza 2008).

Another factor that influenced sedimentation was that Pangea's continental crust extended over Earth's South Pole, which allowed for the growth of a continental ice sheet that covered the southern part of supercontinent (see Figure 19). Additionally, alpine glaciation occurred in higher elevation areas of the uplifts (Soreghan and Sweet 2013; Soreghan et al. 2018; Pfeifer et al. 2021). Consequently, copious amounts of glacially scoured silt (smaller than sand; see "Permian Red Beds") became available for transport, particularly as the climate became increasingly arid throughout the Permian Period.

By the late Permian Period, the Anadarko and other smaller basins were filled in (Figure 21), and the midcontinental region of Pangea was characterized by thick strata that were deposited during a change from "icehouse" to "greenhouse" conditions (Crowell 1999; Fielding et al. 2008). The influx of material was predominantly delivered via eolian (windblown) transport across a widespread arid landscape (Soreghan et al. 2018). Sediment accumulated in a "sink" (basin) that effectively captured this material, in part owing to ephemeral wetting across a broad sabkha (flat-lying area, typically between a desert and an ocean, which is subject to periodic flooding and evaporation), tidal mudflats

(sections of shoreline covered by silt or clay and submerged at high tide), and eolian landscapes. Bedrock—Cloud Chief Formation (**Pcc**), Doxey Formation (**Pd**), and Elk City Sandstone (**Pec**)—provides evidence of these depositional settings (see "Permian Red Beds").

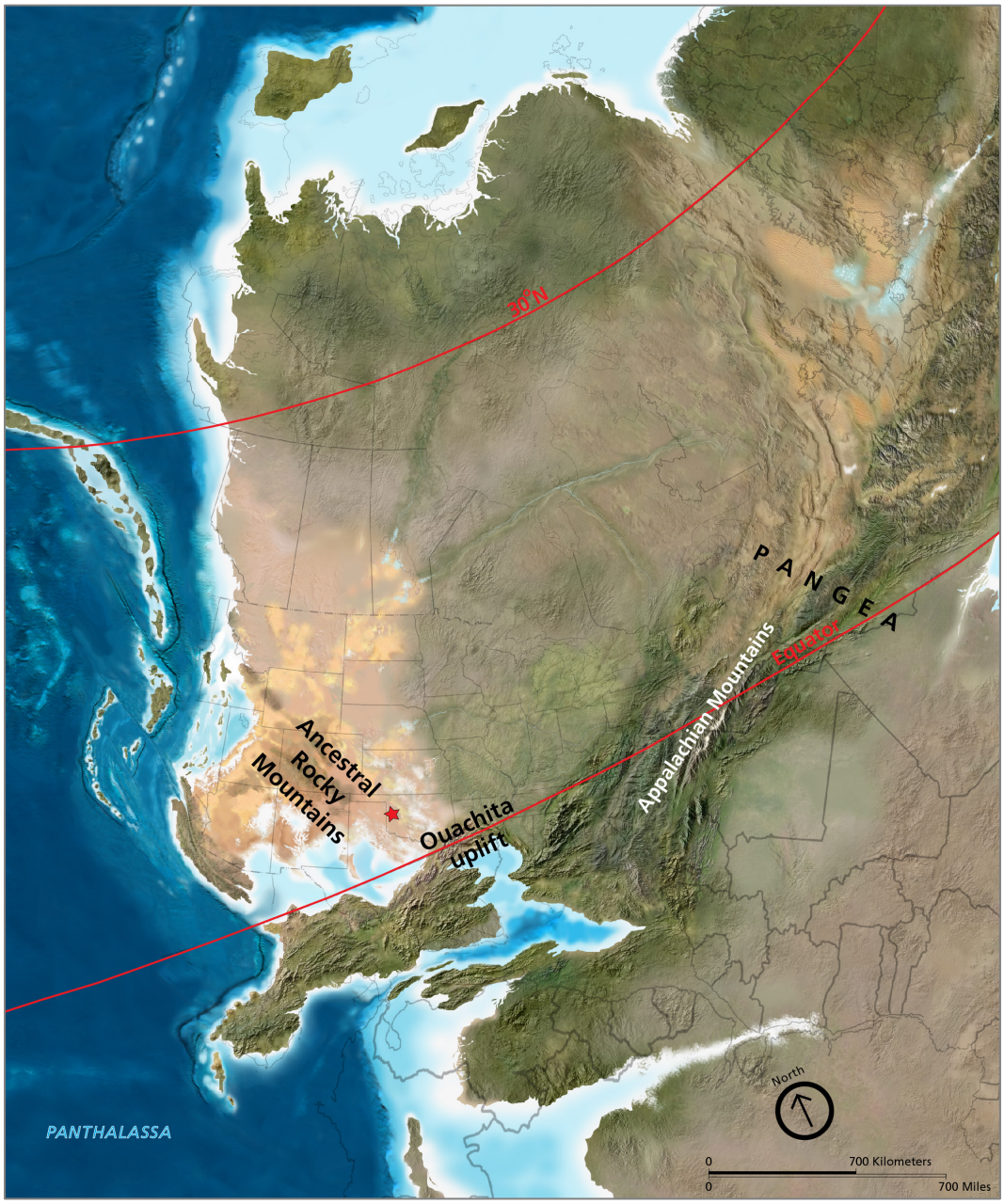


Figure 21. Paleogeographic map of the Permian Period. About 280 million years ago, erosion had beveled the Ancestral Rocky Mountains (though still a high area) and Wichita uplift, and the Anadarko basin was filling with sediment (compare to Figure 20). A red star marks the location of the historic site. Base paleogeographic map by Ron Blakey, "Paleogeography of Southwest North America," © 2012 Colorado Plateau Geosystems Inc., used under license; see https://deeptimemaps.com/ (accessed 21 May 2024). Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Unconformity

In geologic terminology, layers of rock that have been deposited essentially without interruption are referred to as "conformable." Although particular sites may have conformable beds representing significant spans of geologic time, no place on Earth has a full set of conformable strata. Comparatively, "unconformities" mark substantial breaks or gaps in the rock record when and where deposition ceased or erosion removed previously formed rocks.

Unconformities are important because they represent significant geologic events in Earth's history, and their identification helps geologists recognize what intervals of geologic time are not represented by the strata (Lutgens and Tarbuck 1992). Unconformities are intriguing because the infinitesimal surface (contact) between adjacent rock units covers thousands, millions, or even billions of years. Many major geologic events—mountain building, regional uplift, or development of river valleys—may be "collapsed" into a single horizontal surface. The layers of the Grand Canyon, which are full of "geologic gaps," illustrate the significance of unconformities. "In the Grand Canyon, much more time is absent than is represented. If a gap of five hundred million years were the right five hundred million years, it could erase the Grand Canyon" (McPhee 1999, p. 441).

Near the historic site, an unconformity encompassing 230 million years occurs between the Permian red beds and the Miocene–Pliocene Ogallala Formation (see "Geologic Time Scale"). Because the Ogallala Formation is not exposed within the historic site, an even greater gap in geologic time occurs there. Within the historic site, fluvial terraces or terrace deposits (see "Washita River") lie atop bedrock (see "Permian Red Beds"). The surface between the bottom of the Quaternary terraces and the top of the Permian red beds represents an unconformity of nearly 250 million years—from the end of the Permian Period, 251.9 million years ago, to the beginning of the Quaternary Period, 2.6 million years ago.

Laramide Orogeny and Deposition of the Ogallala Formation

The Laramide Orogeny (mountain-building event) was a seminal geologic event for North America. It commenced about 80 million years ago (Late Cretaceous Period) and ended about 50 million years ago (Paleogene Period) (Coney 1978; Humphreys et al. 2003; Liu and Gurnis 2010). Orogenesis involved "uplift, volcanism, intense compressive deformation, and plutonism [creation of plutons (igneous intrusions)]—in that order. This activity swept from southwest to northeast across the region" (Coney 1978, p. 287).

The Laramide Orogeny is commonly attributed to events off the west coast of North America, where the oceanic Farallon plate was subducting (extending beneath and disappearing) under the continental North American plate (Figure 22). A commonly cited plate tectonics mechanism for the Laramide Orogeny is shallow-slab or flat-slab (low-angle) subduction (Saleeby 2003).

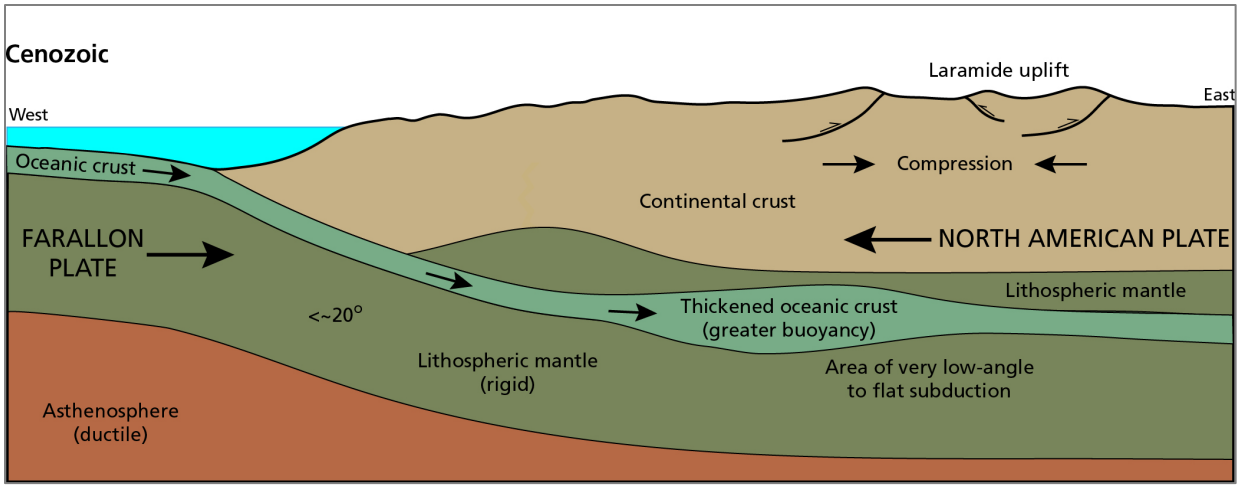


Figure 22. Schematic cross section of flat-slab subduction. A commonly cited plate tectonics mechanism for the Laramide Orogeny is flat-slab subduction, which is also called "shallow-slab" or "low-angle" subduction. About 80 million years ago (Cretaceous Period) as the subducting Farallon oceanic plate slid beneath the North American continental plate, a large oceanic plateau (thickened oceanic crust) that was riding on the Farallon plate subducted beneath the continent. The additional buoyancy provided to the Farallon plate caused the angle of the subducting plate to become less steep. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Lillie (2005, Figure 1.19b) and Blakey and Ranney (2018, Figure 8.13).

The Laramide Orogeny was first recognized and named for sediments shed into the Laramie Basin in southern Wyoming (Dana 1895; Tweto 1975). Over the years, however, uplifted mountain ranges have become the most recognizable Laramide feature (Blakey and Ranney 2018).

Erosion of uplands associated with the Laramide Orogeny produced thousands of meters of terrestrial sediments, which spread across the Interior Plains region. Erosion continued until about 18 million years ago when the Ogallala Formation began to be deposited by east-flowing rivers that drained the Rocky Mountains. The wave of sediment emanating from the mountain front overwhelmed the rivers of the High Plains, depositing silt, sand, and gravel, forming an apron of mega-alluvial fans that completely buried the preexisting topography (Willett et al. 2018). Wind also played a role in the deposition of the Ogallala Formation; eolian sand and silt blanketed older fluvial deposits. Ogallala sediments continued to accumulate until about 5 million years ago (Izett 1975).

Development of the Washita River Valley

When deposition of the Ogallala Formation ceased, rivers and tributaries began to carve the High Plains into today's river valleys. The Washita River is one of the rivers that breached the Ogallala surface; it also cut into the underlying Permian red beds (see "Permian Red Beds"), creating beautiful scenery in many locations (see "Washita River").

The Pleistocene (2.6 million to 11,700 years ago) ice ages are an often-cited factor in the development of today's river valleys. Although glaciers extended only as far south as northeastern Kansas, glacial meltwater fed major rivers. Also, increased precipitation is associated with glacial periods. Both these factors likely played a role in sculpting Oklahoma's land surface during that time

(Johnson and Luza 2008). Alluvial deposits in the form of fluvial terraces—in many cases, high above the present floodplain—record the river's shifting position during the Pleistocene Epoch (see "Washita River").

Work by Willett et al. (2018) provides a compelling model of landscape development since the deposition of the Ogallala Formation: The landscape of the High Plains is currently in a transient state; it is bifurcated into an older region—represented by the Ogallala Formation—that has an inefficient river network, and a younger, more efficient river network that is progressively cannibalizing the older region. The largest rivers have incised the older surface (i.e., Ogallala sediment fans), removed fan heads near the Rocky Mountains, and eroded the fan toes, but left portions of the central fan surface and the Ogallala sediments largely intact. These preserved fan surfaces have poor surface water drainage, and thus retain ephemeral water for wetlands and groundwater recharge (Willett et al. 2018).

Formation of Sand Dunes

In contrast to the Permian Period, eolian deposits in Oklahoma during the Late Pleistocene Epoch were composed primarily of sand, not loess (windblown silt; see "Permian Red Beds"). Sources of windblown sand were glacial floodplain deposits (Kitts 1959) as well as playas (ephemeral lakes) that formed on the Ogallala Formation (Thurmond and Wyckoff 1998). Distinctive lunettes (crescent-shaped dunes that line the perimeter of a playa) on the surface of the Ogallala Formation highlight playas as a sediment source (Holliday 1997).

A relative chronology for dunes in the area (i.e., eastern Major and southern Alfalfa counties, northeast of the historic site; Brady 1989) shows the consistency of the prevailing winds since the end of the Pleistocene Epoch. The distribution of the last glacial eolian sands relative to probable source sediments indicates that winds were likely northwesterly on the central Great Plains and westerly on the southern Great Plains at that time (Loope et al. 1995; Mason et al. 1997; Muhs et al. 1996; Holliday 1995, 1997). Present conditions are similar to those conditions (Muhs and Zárate 2001).

A formal study of the sand dunes at the historic site has not been conducted, but correlation to Late Quaternary eolian records of the midcontinental United States suggests that the paleodunes (**Qd**) at the historic site likely started forming during a period of extensive eolian activity that took place during the last glacial period, that is, 11,000–10,000 radiocarbon years before present (Holliday 1997; Muhs and Zárate 2001) or 12,920–11,490 years ago (converted from radiocarbon years using IntCal20; Reimer et al. 2020). Extensive eolian sand sheets in the region are confidently correlated to the last glacial period because of their association with well-dated Folsom, Midland, Clovis, and Hell Gap artifacts (Holliday 1997).

Using a combination of geomorphic methods, soil/stratigraphic descriptions, radiocarbon dating methods, and optically stimulated luminescence dating methods, a study by Lepper and Scott (2005) documents a late Holocene period of eolian activity in the Cimarron River valley, about 130 km (80 mi) northeast of the historic site. Eolian activity occurred between 1100 and 1250 CE (Lepper and

Scott 2005) or 924–774 calendar years ago (calculated from the year 2024). Thus, the paleodunes (**Pd**; see "Eolian Features and Processes") at the historic site are probably much younger than regional correlation suggests (Alex Simms, UC Santa Barbara, professor, written communication, 2 February 2024).

Interestingly, observations by 19th-century explorers (i.e., at the time of the attack) indicate that many parts of the Great Plains had active dune sand where it is now stable (Muhs and Holliday 1995; Muhs and Wolfe 1999). The evidence for multiple periods of eolian activity vs. dune stability in the past few thousand years indicates that Great Plains eolian sand is sensitive to small changes in overall moisture balance and degree of vegetation cover (Muhs and Zárate 2001; see "Climate Change and Geologic Resources"). Observations at the historic site attest to ongoing eolian activity; for example, an estimated 1 m (3 ft) of sand buries segments of the north fence line, which was rebuilt eight or nine years ago (ca. 2015) and unburied at that time (Richard Zahm, Washita Battlefield National Historic Site, park ranger, audio call, 10 April 2024).

Geologic Time Scale

The geologic time scale puts the divisions of geologic time and associated rocks or unconsolidated deposits in stratigraphic order, with the oldest divisions and rock units at the bottom and the youngest at the top. As represented here, the geologic time scale (Table 2) is divided into the following columns:

- Eon/Era, Period, and Epoch—These three columns show the divisions of geologic time. Items in parentheses include GRI map abbreviations for geologic time units. For example, "**P**" stands for the Permian Period (298.9 million to 251.9 million years ago) and "**Q**" stands for the Quaternary Period, which includes the Pleistocene Epoch (2.6 million to 11,700 years ago) and the Holocene Epoch (11,700 years ago to the present). Permian rocks and Quaternary deposits occur in the historic site.
- Boundary Age—The various boundary ages used in the table are from the International Chronostratigraphic Chart (International Commission on Stratigraphy 2023). Boundary ages separate segments of geologic time. When a more specific age for a rock unit or geologic event is known, that age and a reference citation are included in the table.
- Geologic Map Unit—This column highlights map units from the GRI GIS data. "n/a" indicates that no map unit in the GRI GIS data is representative of a geologic event. Geologic units mapped within the historic site are noted. In addition, the Elk City Sandstone (**Pec**) and Ogallala Formation (**PLMIo**), which do not occur within the historic site, are included in the table because of their significance to the geologic story. Items in parentheses are map unit symbols. Uppercase letters stand for a geologic period or epoch. Lowercase letters represent the name of a formation or deposit, such as "**cc**" for the Cloud Chief Formation in the map unit symbol **Pcc**.
- Geologic Event—By reading this column from bottom to top, a geologic history is provided. Descriptions of geologic events and associated geologic features are given in this chapter and

the “Geologic Features and Processes” chapter. In general, the timing of geologic events follows interpretations from the source maps (see “GRI Products”).

- Location—This column lists examples of where a geologic event is represented in the rocks within or near the historic site.

Table 2. Geologic time scale.

Eon/Era	Period	Epoch	Boundary Age (years ago)	Geologic Map Unit	Geologic Event	Location
Cenozoic Era (CZ)	Quaternary (Q)	Holocene (H)	Less than 11,700	Alluvium (**Qa**) of Fay (2010)	The Washita River and its tributaries deposit sediment during both flood and non-flood conditions.	The channel and floodplain of the Washita River and its tributaries
Cenozoic Era (CZ)	Quaternary (Q)	Holocene (H) and Pleistocene (PE)	Less than 2.6 million	Floodplain (**Qfp**) Tributary floodplain (**Qtf**)	The Washita River and its tributaries begin to carve today's drainages.	• Washita River • Sergeant Major Creek (west of the historic site)
Cenozoic Era (CZ)	Quaternary (Q)	Holocene (H) and Pleistocene (PE)	Less than 2.6 million	Fluvial terrace 1 (**Qt1**) Fluvial terrace 2 (**Qt2**) *Note*: Stahl (2012) divides terrace deposits.	Terraces form as the Washita River valley develops.	North and south (and higher than) the Washita River floodplain (**Qfp**)
Cenozoic Era (CZ)	Quaternary (Q)	Pleistocene (PE)	2.6 million–11,700	Terrace deposits (**Qt**) *Note*: Fay (2010) groups terrace deposits.	Enhanced streamflow due to wet ice-age conditions facilitates incision of river valleys.	South of and higher than the Washita River in the historic site
Cenozoic Era (CZ)	Quaternary (Q)	Holocene (H) and Pleistocene (PE)	Less than 2.6 million	Paleodunes (**Qd**) *Note*: For specific dates, see "Formation of Sand Dunes" subsection.	Drier conditions allow for the transport of windblown sediment from ice-age floodplains and playas. The dunes originally started to form in Late Pleistocene/early Holocene time but continued to be active (and deposit sand) into the Holocene Epoch.	• South of the Washita River, dunes form elongate strips parallel to the river valley. • North of the Washita River, dunes are more common and occur in dune fields.

Table 2 (continued). Geologic time scale.

Eon/Era	Period	Epoch	Boundary Age (years ago)	Geologic Map Unit	Geologic Event	Location
Cenozoic Era (CZ)	Neogene (N)	Pliocene (PL) Miocene (MI)	23.0 million–2.6 million	Ogallala Formation (**PLMIo**) *Note*: Deposited about 18 million to 5 million years ago (Izett 1975).	Layers of caliche (hard layers of calcium carbonate) represent the top of the Ogallala Formation. Eolian sand and silt blanket older fluvial deposits. Rivers and tributaries transport sediments shed from the Rocky Mountains; wind also distributes sediments.	• Uplands to the north and west of the historic site • None within the historic site
Cenozoic Era (CZ)	Paleogene (PG)	Oligocene (OL) Eocene (E) Paleocene (EP)	66.0 million–23.0 million	Unconformity	The Laramide Orogeny ends about 50 million years ago.	• Modern Rocky Mountains • A period of erosion and/or nondeposition at the historic site
Mesozoic Era (MZ)	Cretaceous (K) Jurassic (J) Triassic (TR)	All TR, J, and K epochs	251.9 million–66.0 million	Unconformity	The Laramide Orogeny begins about 80 million years ago. Pangea begins to break apart about 200 million years ago. Pangea attains its greatest extent about 250 million years ago.	• Modern Rocky Mountains • A period of erosion and/or nondeposition at the historic site
Paleozoic Era (PZ)	Permian (P)	Lopingian	259.1 million–251.9 million	Elk City Sandstone (**Pec**) Doxey Formation (**Pd**) *Note*: Called the “Doxey Shale” in Geolex (accessed 4 April 2024). Also, “Shale” has historical preference (Thomas Stanley, Oklahoma Geological Survey, geologist, written communication, 4 January 2024).	Terrestrial environments prevail on Pangea. Eolian transport of sediments predominates.	• Anadarko basin • Pec crops out south of the historic site. • Pd forms conical hills within and near the historic site.

Table 2 (continued). Geologic time scale.

Eon/Era	Period	Epoch	Boundary Age (years ago)	Geologic Map Unit	Geologic Event	Location
Paleozoic Era (PZ)	Permian (P)	Guadalupian	273.0 million–259.5 million	Cloud Chief Formation (**Pcc**) *Note*: See "Permian Red Beds" for a discussion about the age of the Cloud Chief Formation.	Increasing aridity Uplifts remain above sea level until the end of this epoch (about 260 million years ago).	• Anadarko basin • Pcc forms most of the underlying bedrock at the historic site.
Paleozoic Era (PZ)	Permian (P)	Cisuralian	298.9 million–273.0 million	n/a	Ocean water repeatedly inundates basins; sea level fluctuates.	Western Oklahoma, including the Anadarko basin
Paleozoic Era (PZ)	Pennsylvanian (PN)	Late/Upper Middle Early/Lower	323.2 million–298.9 million	n/a	Ancestral mountain building and development of basins continues. Alpine glaciers form at high elevations, and an ice sheet covers the southern tip of Pangea.	• Wichita, Amarillo (in Texas), Arbuckle, and Ouachita uplifts • Anadarko basin
Paleozoic Era (PZ)	Mississippian (M) Devonian (D) Silurian (S) Ordovician (O) Cambrian (C)	All C, O, S, D, and M epochs	538.8 million–323.2 million	n/a	Starting about 335 million years ago, Pangea starts assembling from existing continental crust.	• Ouachita Mountains (O, S, D, and M) • Wichita Mountains (C) • Arbuckle Mountains (C, O, and M)
Proterozoic Eon (X, Y, Z)	Neo-proterozoic Meso-proterozoic Paleo-proterozoic	n/a	2.5 billion–538.8 million	n/a	Earth's nascent crust assembles, and an early system of faults forms. Oklahoma's oldest rocks form about 1.4 billion years ago (Johnson and Luza 2008).	Arbuckle Mountains

Table 2 (continued). Geologic time scale.

Eon/Era	Period	Epoch	Boundary Age (years ago)	Geologic Map Unit	Geologic Event	Location
Archean Eon	n/a	n/a	4.031 billion–2.5 billion	n/a	Earth's basement (foundation) forms.	Earth's oldest rocks (4.4 billion years old) occur in the Hudson Bay area, northern Quebec, Canada. No Archean rocks occur in Oklahoma.
Hadean Eon	n/a	n/a	4.567 billion–4.031 billion	n/a	Earth forms about 4.6 billion years ago.	No representative Earth rocks

Geologic Features and Processes

This chapter highlights geologic features and processes of significance for the historic site's landscape and history. Selection of these features and processes was based on input from meeting participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. These features and processes are discussed more-or-less in order of geologic age (oldest to youngest).

Permian Red Beds

Map units: **Pcc**—Cloud Chief Formation of Stahl (2012) and Fay (2010). **Pd**—Doxey Formation of Stahl (2012) and Fay (2010). **Pec**—Elk City Sandstone of Fay (2010). *Note*: The Elk City Sandstone is not exposed at the surface of the historic site.

Red beds are a type of sedimentary rock referred to as "clastic," meaning they are composed of preexisting rock fragments called "clasts." Clasts range in size from less than 1/256 mm (0.00015 in) for clay to more than 256 mm (10 in) for boulders (Table 3). At the historic site, most red beds are composed of fine clasts, either clay or silt. Fissility (easily splitting along closely spaced planes) characterizes most of the red beds at the historic site. This characteristic classifies them as shale. Some red beds at the historic site contain layers of other sedimentary rocks, such as gypsum (an evaporite mineral), dolomite (a carbonate [$CaCO_3$] sedimentary rock), or centimeter-scale layers of sandstone (consisting of sand-size grains; Table 3). However, shale predominates (Figure 23).

Table 3. Grain sizes of sediments. Sand, silt, and clay may be subdivided into coarse, medium, fine, and very fine.

Sediment Name	Size Range in Millimeters	Size Range in Inches
Boulder	>256	10
Cobble	64–256	2.5–10
Pebble	4–64	0.16–2.5
Gravel	2–4	0.08–0.16
Sand	1/16–2	0.0025–0.08
Silt	1/256–1/16	0.00015–0.0025
Clay	<1/256	<0.00015



Figure 23. Photograph of the Cloud Chief Formation exposed at the historic site. As shown in the photograph, the Cloud Chief Formation crops out in an unnamed knoll along the trail to the Washita River. It is a Permian red bed composed primarily of shale. Note the fissility (splitting into thin layers), which characterizes shale. Photograph by Katie KellerLynn (Colorado State University), taken May 2011.

The red color of the rocks at the historic site is caused by the chemical bonding of iron and oxygen ions, creating an iron oxide molecule known as hematite (Fe_2O_3). Not all iron oxides are red; some are brown or yellow (e.g., in the minerals limonite and goethite) or black (e.g., in the mineral magnetite), but red is the most common (Chan and Parry 2002).

Red beds in Oklahoma and the Texas Panhandle have intrigued geologists for more than 100 years (e.g., Gould 1907, 1924). Historically, red beds were interpreted as originating in marginal marine (i.e., delta and tidal flat) and fluvial (river) settings based on the presence of gypsum and dolomite. Over the past decade, however, in-depth analysis—notably by investigators at the University of Oklahoma in Norman (e.g., Soreghan et al. 2016, 2018)—has revealed a predominance of previously overlooked loess (deposits of windblown dust) and reworked loess in these rocks. Loess is internally structureless (homogenous in texture or fabric) and consists of uniformly fine-grained sediments, predominantly silt but ranging in size to clay (Table 3). Loess deposits are commonly draped over preexisting landforms. Thick accumulations occur in protected, low-lying areas or on broad, flat,

stable upland divides (high ground) close to source areas. Thin accumulations occur on narrow, rounded hillcrests and/or locations distant from source areas (Muhs 2013).

The historic site's red beds, as well as those across much of the world, were deposited during the Permian Period (Table 4). This geologic period, which spans 47 million years, was named after the region of Perm, Russia, where rocks of this age were first studied (Neuendorf et al. 2005).

Table 4. Global and regional correlation of Permian red beds. Sources: US Geological Survey (1988); International Commission of Stratigraphy (2023); Geolex (accessed 17 April 2024).

Period	Years Ago	Global Epoch	Regional Age	Associated Formation by Fay (2010)	Associated Formation in Geolex
Permian (P)	259.5 million–251.9 million	Lopingian (late Permian)	Ochoan	Elk City Sandstone (**Pec**) Doxey Shale (**Pd**) Cloud Chief Formation (**Pcc**)	Elk City Sandstone (**Pec**) Doxey Shale (**Pd**)
	273.0 million–259.5 million	Guadalupian (middle Permian)	Guadalupian	n/a	Cloud Chief Formation (**Pcc**)
	289.9 million–273.0 million	Cisuralian (early Permian)	Leonardian	n/a	n/a

Globally, the Permian Period is divided into three epochs: Cisuralian, Guadalupian, and Lopingian (Table 4). The Guadalupian Epoch is particularly notable for the National Park System because that epoch takes its name from the stunning reef complex in Guadalupe Mountains National Park (see GRI report by KellerLynn 2008b). In 1991, the International Commission on Stratigraphy (ICS) proposed subdividing the Permian Period into three series/epochs—early/lower, middle, and late/upper. The Permian geology of the Guadalupe Mountains is so exceptional that the commission selected this section of rocks to be the exemplar of the middle Permian and named the series/epoch the Guadalupian (see Henderson et al. 2021). This chronostratigraphic scheme was adopted in 1996 (Glenister 1996).

Regionally, the Permian Period is divided into four epochs: Wolfcampian, Leonardian, Guadalupian, and Ochoan (Table 4). The rocks at the historic site are Guadalupian and/or Ochoan in age. The Doxey Formation is Ochoan, but some discrepancy exists as to the age of the Cloud Chief Formation. Geolex identifies it as Guadalupian. A numerical age range of 262 ± 3 million to 255 ± 3 million years old based on strontium isotopes supports a Guadalupian designation for the Cloud Chief Formation (Brillo 2015). However, the Oklahoma Geological Survey identifies the Cloud Chief Formation as Guadalupian–Ochoan. According to Thomas Stanley, the basal stratigraphy is, as best that can be determined, Guadalupian in age, but the upper part is definitely Ochoan (Thomas Stanley, Oklahoma Geological Survey, geologist, written communication, 24 January 2024). On the source map (Fay 2010), Robert O. Fay, now deceased, mapped the entire Cloud Chief Formation as Ochoan. Stanley is not sure why Fay included all of the formation in the Ochoan on the Foss Reservoir 30' ×

60' quadrangle, but the map was published after Fay died, and it did not go through a review process (Thomas Stanley, Oklahoma Geological Survey, geologist, written communication, 4 January 2024).

Colorful layers of Permian red beds dominate the scenery of the historic site. These strata underlie the Washita River valley, are exposed in knolls, and rise in distant hills. The following red beds are significant for the historic site's geologic story:

Cloud Chief Formation

Map unit: **Pcc**

The name "Cloud Chief" was proposed by Gould (1924) for exposures near the populated place of Cloud Chief in western Washita County, western Oklahoma. In the historic site, outcrops of the Cloud Chief Formation are rare (Figure 23), but the formation underlies most of the fluvial terraces (see "Washita River").

The Cloud Chief Formation is basically reddish-brown to orange-brown shale (Fay 2010; Neil Suneson, Oklahoma Geological Survey, geologist, personal communication during scoping, 13 May 2011). The middle part of the unit has siltstone and sandstone. The lower part has gypsum and dolomite (Fay 2010). In other parts of the state, the gypsum of the Cloud Chief Formation is massive, with thicknesses up to 30 m (100 ft). In such locations, the formation is mined. At the historic site, however, the gypsum is thin and interbedded with red shale (KellerLynn 2011a).

The Cloud Chief Formation was deposited in a sabkha (Figure 24), which formed under arid or semiarid conditions on a restricted coastal plain above normal high tide. Many modern coastlines, such as the Persian Gulf and the Gulf of California, are home to sabkhas (Neuendorf et al. 2005). Evaporite minerals (gypsum), tidal flood sediments (dolomite), and eolian deposits (shale) are characteristic of sabkhas. During deposition of the Cloud Chief Formation, an ancient fluvial system spread across the sabkha (Brillo 2015). As a result, features of the formation include deposits left by an anastomosing stream, meaning a stream consisting of multiple channels that divide and reconnect. The channels are separated by semi-permanent banks composed of cohesive material. The ancient fluvial system fed crevasse and terminal splays (small alluvial fans or other outspread deposits formed where a sediment-loaded stream breaks through a levee and deposits its material on the floodplain).

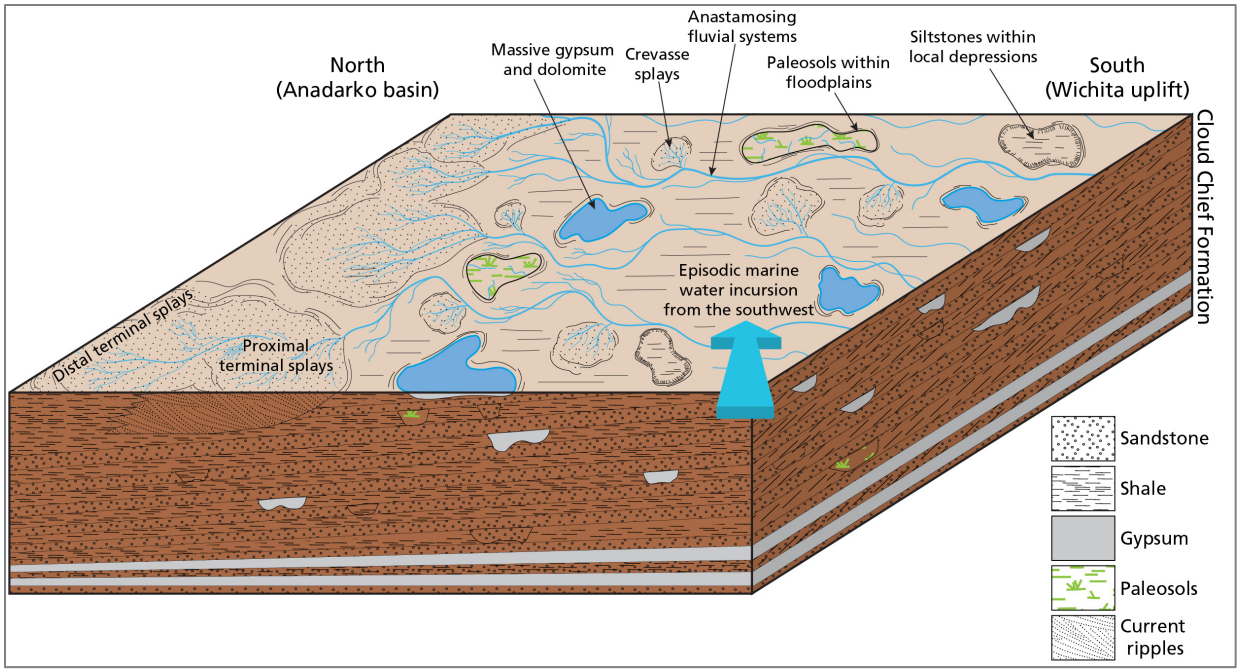


Figure 24. Block diagram of the Cloud Chief Formation. The Cloud Chief Formation, which is dominated by shale, formed in a sabkha setting. Wind was the primary agent of deposition, though beds and lenses of gypsum formed where shallow marine waters evaporated. Splays from fluvial systems deposited sandstone, whereas siltstone formed in local depressions. Dolomite formed during episodic incursions of marine water. Stratigraphy is from Brillo (2015). Color (Munsell 5YR 5/6) of sandstone and shale is from Stahl (2012). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Brillo (2015, Figures 11 and 12).

Toward the end of the deposition of the Cloud Chief Formation (and the beginning of the deposition of the overlying Doxey Formation), a local rise in sea level caused the development of a tidal mudflat (Figure 25). The absence of defining structures and the presence of fine-grained, silty claystone point to deposition in a relatively quiet and stable mudflat setting. In addition, the presence of thin greenish beds along the topmost portion of the Cloud Chief Formation suggests a reducing environment (Brillo 2015) in which water dissolved and removed hematite, thereby “bleaching” the red sediment.

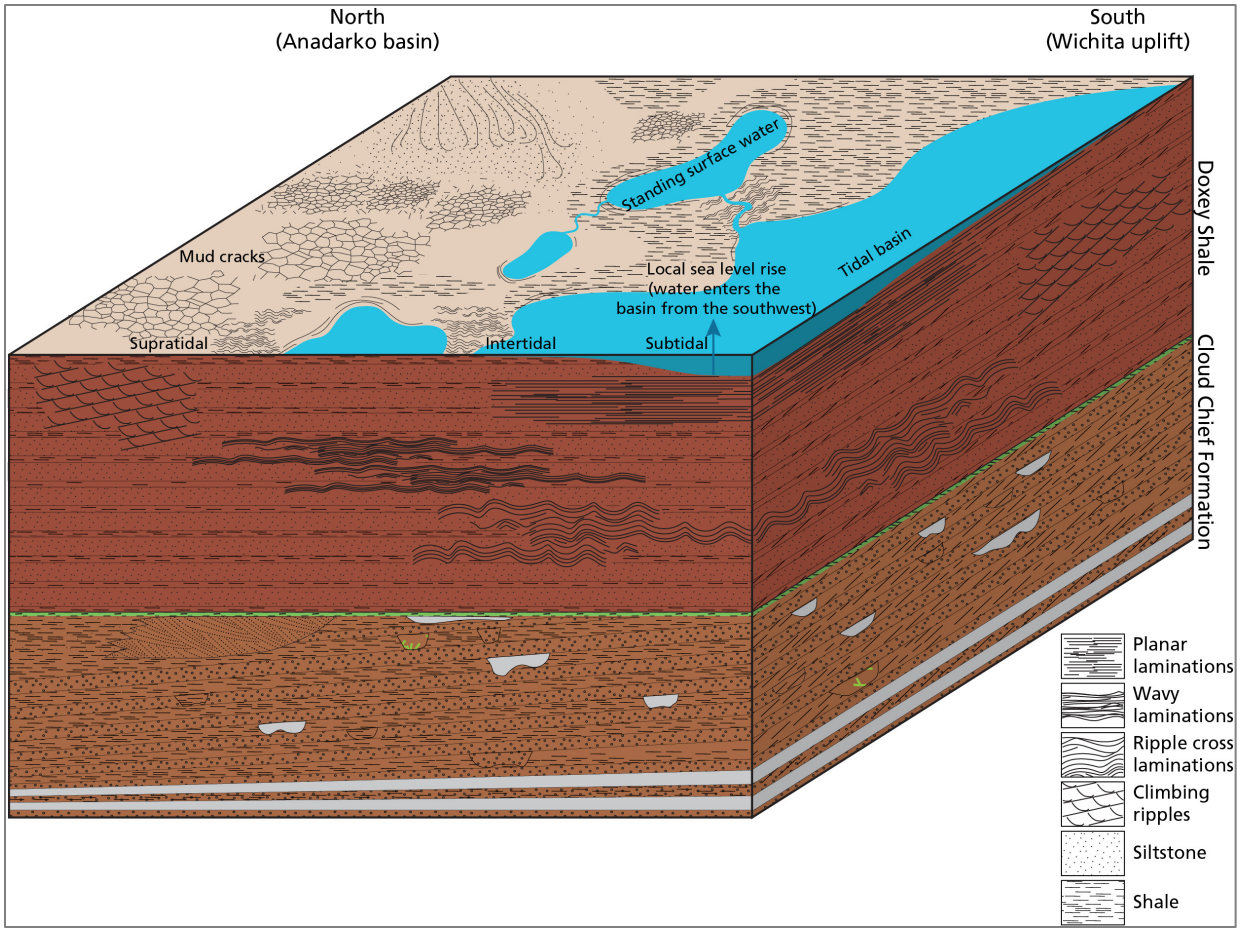


Figure 25. Block diagram of the Doxey Formation. The Doxey Formation was deposited in a tidal mudflat atop the Cloud Chief Formation (see Figure 24). Sedimentary structures within the shale include three types of laminations as well as climbing ripples, which are indicative of deposition of fine-grained sediments in shallow, calm waters. The color of the Doxey Formation (Munsell 10YR 5/6) is from Stahl (2012). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Doxey Formation

Map unit: **Pd**

The Doxey Formation, formally known as the Doxey "Shale" (Geolex, accessed 17 April 2024), overlies the Cloud Chief Formation (Figure 26). The contact between these two formations is marked by a color contrast between the lighter red Cloud Chief Formation and the darker red Doxey Formation, as well as by a thin layer of greenish-gray claystone that separates the two formations (Brillo 2015). The contact is "gradational," meaning it was deposited without interruption in a similar setting, in this case a mudflat (see Figure 25).

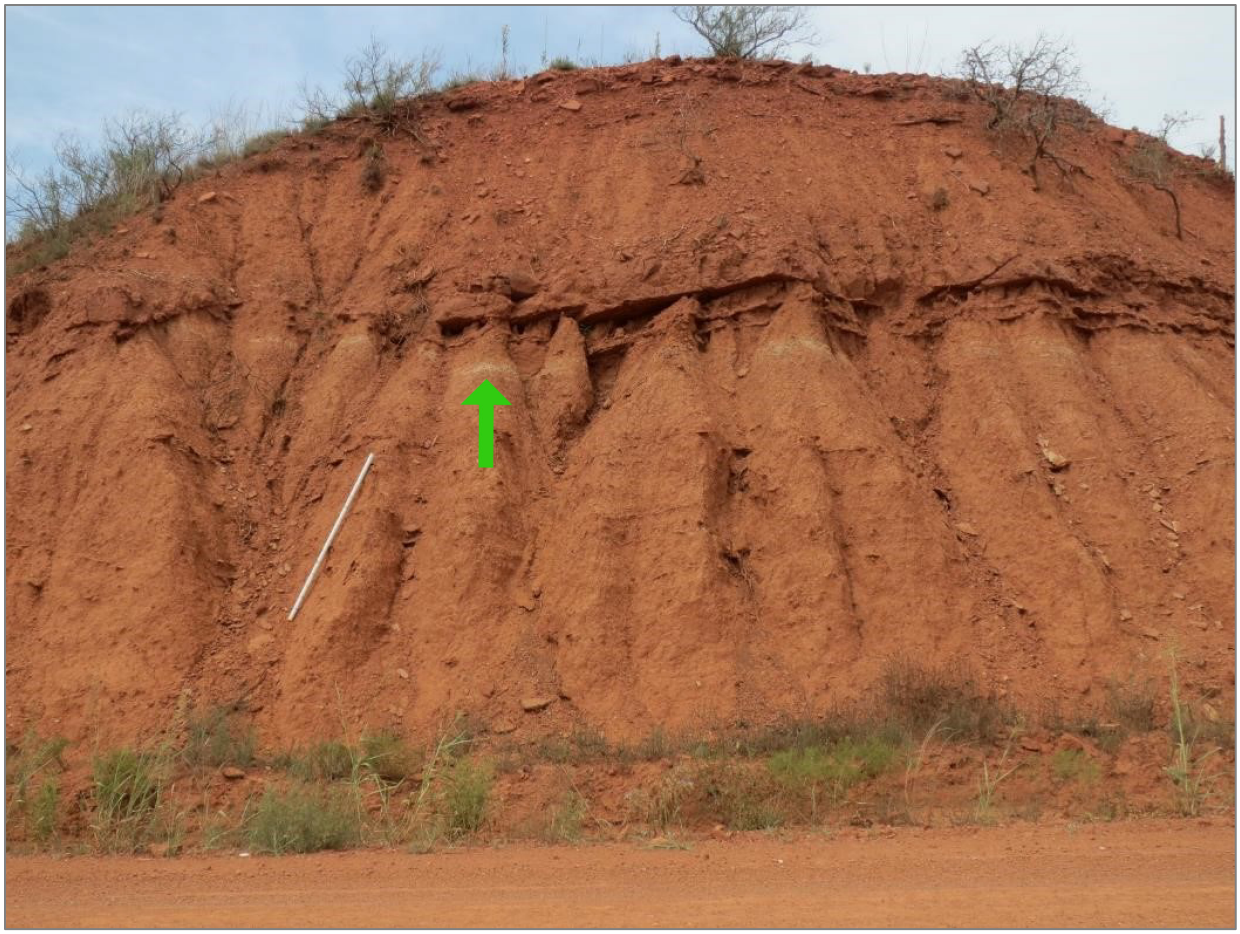


Figure 26. Photograph of the Cloud Chief Formation and Doxey Formation. The Cloud Chief Formation, which was deposited in a sabkha (see Figure 24), underlies the Doxey Shale (darker red), which was deposited in a tidal mudflat (see Figure 25). A color contrast marks the contact between the two formations. In addition, a layer of distinctive greenish claystone is approximately 20 cm (8 in) below the actual contact; a green arrow points to the claystone. The outcrop is along the N1780 road in Sayre, Oklahoma. Photograph by Vanessa May De Belen Brillo (UC Santa Barbara), taken 2015, used by permission.

The Doxey Formation is exposed in knolls within the historic site and throughout the Washita River valley (see poster). In addition, it crops out at higher elevations to the north and south of the historic site on the flanks of the Washita River valley (Fay 2010).

Unlike the dissertation by Brillo (2015) about the Cloud Chief Formation, no formation-specific study is known to have provided an updated paleogeographic interpretation of the Doxey Formation. During scoping, however, the unit was interpreted as deposited on a coastal mudflat, tens of feet above sea level (Neil Suneson, Oklahoma Geological Survey, geologist, personal communication during scoping, 13 May 2011).

Taking the name from the populated place of Doxey in central Beckham County, Griley (1933) was the first to propose the name “Doxey” for these rocks. Typically, the type section is also where the

formation was first described, but this is not the case for the Doxey Formation. Later, Fay and Hart (1978) designated the type section in Custer County, where the formation is most clearly observable. Stratigraphic information about the Doxey Shale is provided by Green (1936), Ham and Jordan (1961), and Fay and Hart (1978).

The base of the Doxey Shale can be traced to the Texas Panhandle where it is correlated with the colorful Alibates Dolomite (Fay and Hart 1978), a marine sedimentary rock. This is an example of two National Park System units connected by their geology. At Alibates Flint Quarries National Monument, the upper dolomite member forms massive layers, as much as 0.6 m (2 ft) thick. These layers extend laterally for more than 1,000 m (3,300 ft) along a ridge that is the source of the Alibates flint, in which silica replaced dolomite in a process called "chertification" and created the multi-hued, mottled, or banded rock. For thousands of years, people came to the red bluffs above the Canadian River to dig for flint used in making projectile points, knives, and other tools. Alibates Flint Quarries National Monument preserves more than 700 quarries (see GRI report about Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument by KellerLynn 2015b).

Elk City Sandstone

Map unit: **Pec**

The contact between the red-brown Doxey Formation and the orange-brown Elk City Sandstone is sharp. The contact zone between the two formations weathers from white to light greenish gray, allowing mappers to easily trace the contact on the ground and on aerial photographs. The Elk City Sandstone erodes into rounded hills, whereas the underlying Doxey Formation erodes into slopes below the hills. As a result, an escarpment (continuous cliff or relatively steep slope) has formed at the contact. Mappers placed the Doxey–Elk City contact slightly below the escarpment (Fay and Hart 1978).

Detailed analysis of the Elk City Sandstone describes the unit as friable (easily crumbled), fine-grained, orange-brown sandstone in beds 1–4 m (3–13 ft) thick, with local siltstone interbeds. Internally, the beds have thin horizontal stratification (layering or bedding of sediments in a rock) or trough cross-stratification (sediment beds inclined at an angle) with possible vertical lungfish burrows (Soreghan et al. 2018). Although earlier investigators proposed that the lungfish burrows and possible "submarine cross bedding" indicated a marine origin (Fay and Hart 1978), the fine-grained, large-amplitude cross-stratification are more consistent with eolian deposition (Figure 27). The lungfish burrows signal ephemeral wetting (Soreghan et al. 2018), perhaps in an interdune area flooded during heavy monsoon rains. Investigators hypothesize that these animals lived and died in an environment characterized by seasonal rainfall (Parrish 1989).

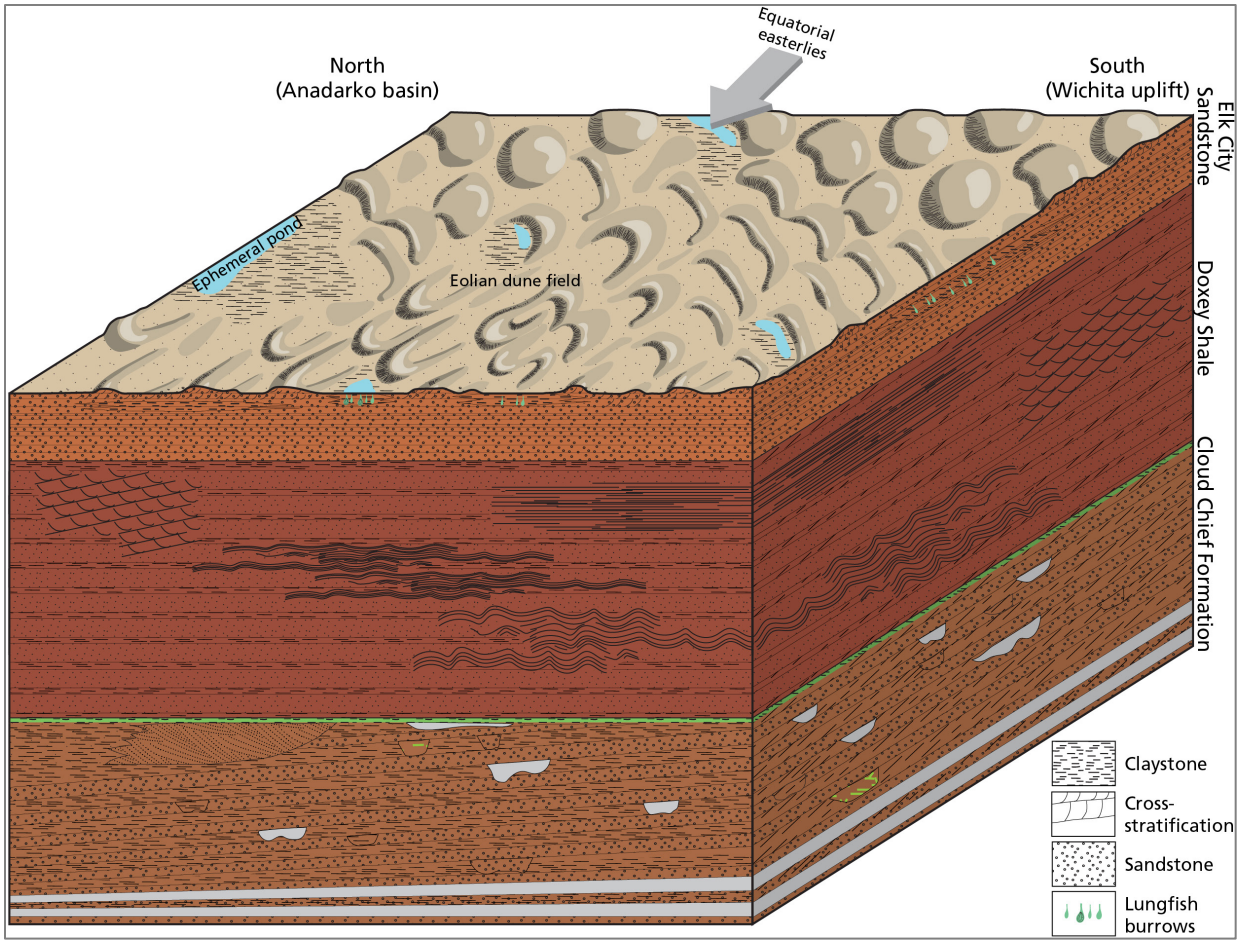


Figure 27. Block diagram of the Elk City Sandstone. The orange-brown Elk City Sandstone was deposited in an eolian landscape atop the Doxey Formation (see Figure 25) which, in turn, was deposited on the Cloud Chief Formation (see Figure 24). The presence of the various dune types on the figure is hypothetical because details of such sedimentary structures in the Elk City Sandstone have not been identified to date. The present-day dune field in White Sands National Monument in New Mexico served as a model (see GRI report by KellerLynn 2012), though that dune field does not contain lungfish burrows. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

The name Elk City Sandstone was proposed by Griley (1933) for strata above the Doxey Formation and spanning to the top of the Permian section of rocks. As such, the Elk City Sandstone is the highest and youngest red bed in the area and marks the end of the Permian Period here. The sandstone was named for Elk City in Beckham County, southeast of the historic site. Stratigraphic information is provided by Green (1936), Ham and Jordan (1961), and Fay and Hart (1978). The unit is exposed on the southern flank of the Washita River valley, about 7 km (4 mi) south of the historic site.

Origin of Conical Hills

Map unit: **Pd**—Doxey Formation of Stahl (2012). *Note*: Mapped at a scale of 1:100,000, Fay (2010) did not distinguish these features from the Cloud Chief Formation (**Pcc**).

Conical hills are a distinctive—or "peculiar" (Stahl and Simms 2013, p. 372)—feature of the Washita River valley and the historic site's landscape (Figure 28). Examples include Sugar Loaf and Custer's Knoll (see poster and Figures 6 and 8, respectively). The hills are a positive relief structure with moderate to steep (45°–80°) slopes, composed of blocks of the Doxey Formation. The peculiar thing is that these blocks occur at the stratigraphic position of the geologically older and typically underlying Cloud Chief Formation.



Figure 28. Photographs of a conical hill. Distinctive—sometimes called "peculiar"—conical hills rise above the landscape of the Washita Valley. This one is near the entrance to the historic site. Others such as Custer's Knoll, Twin Knolls, and Sugar Loaf are significant for the historic site's geologic heritage. Photographs by Katie KellerLynn (Colorado State University), taken May 2011.

In order to characterize these features and examine their origin, Stahl and Simms (2013) conducted a field investigation in and around the historic site, which revealed collapsed beds, slump blocks, and isolated boulders. The presence of collapsed strata also results in unusual strikes and dips (trends and angles of bedrock at the landscape scale) of what otherwise should be flat-lying strata in the area (Neil Suneson, Oklahoma Geological Survey, geologist, written communication, 27 July 2011).

This evidence points to an origin of collapse. Gypsum dissolution in the Cloud Chief Formation resulted in the collapse of the overlying Doxey Formation into voids. Fluvial erosion followed collapse. The greater carbonate content—as both crystals and cement—may have preferentially preserved the hills of Doxey Shale during fluvial erosion of the surrounding friable Cloud Chief Formation (Stahl and Simms 2013).

Ogallala Formation

Map unit: **PLMIo** of Fay (2010). *Note*: The unit is beyond the map extent of Stahl (2012).

The Ogallala Formation was named for exposures along the South Platte River near Ogallala, Nebraska (Darton 1899). The type section is 0.8 km (0.5 mi) north of the town (Hesse 1935). In western Oklahoma, the formation ranges between 60 and 180 m (200 and 600 ft) thick (Johnson and

Luza 2008) and consists of gray to light-brown, fine- to medium-grained sand with some clay, silt, gravel, volcanic ash, and caliche beds (Fay 2010).

A source of volcanic ash deposited within the Ogallala Formation was the Yellowstone hot-spot track, where various volcanic fields erupted as the North American plate moved southwestward over the stationary hot spot that now underlies Yellowstone (Figure 29; see the GRI report about Craters of the Moon National Monument and Preserve by KellerLynn 2018). Another source of volcanic ash was the Jemez Mountains volcanic field in New Mexico (Ludvigson et al. 2009; see the GRI report about Bandelier National Monument by KellerLynn 2015a).

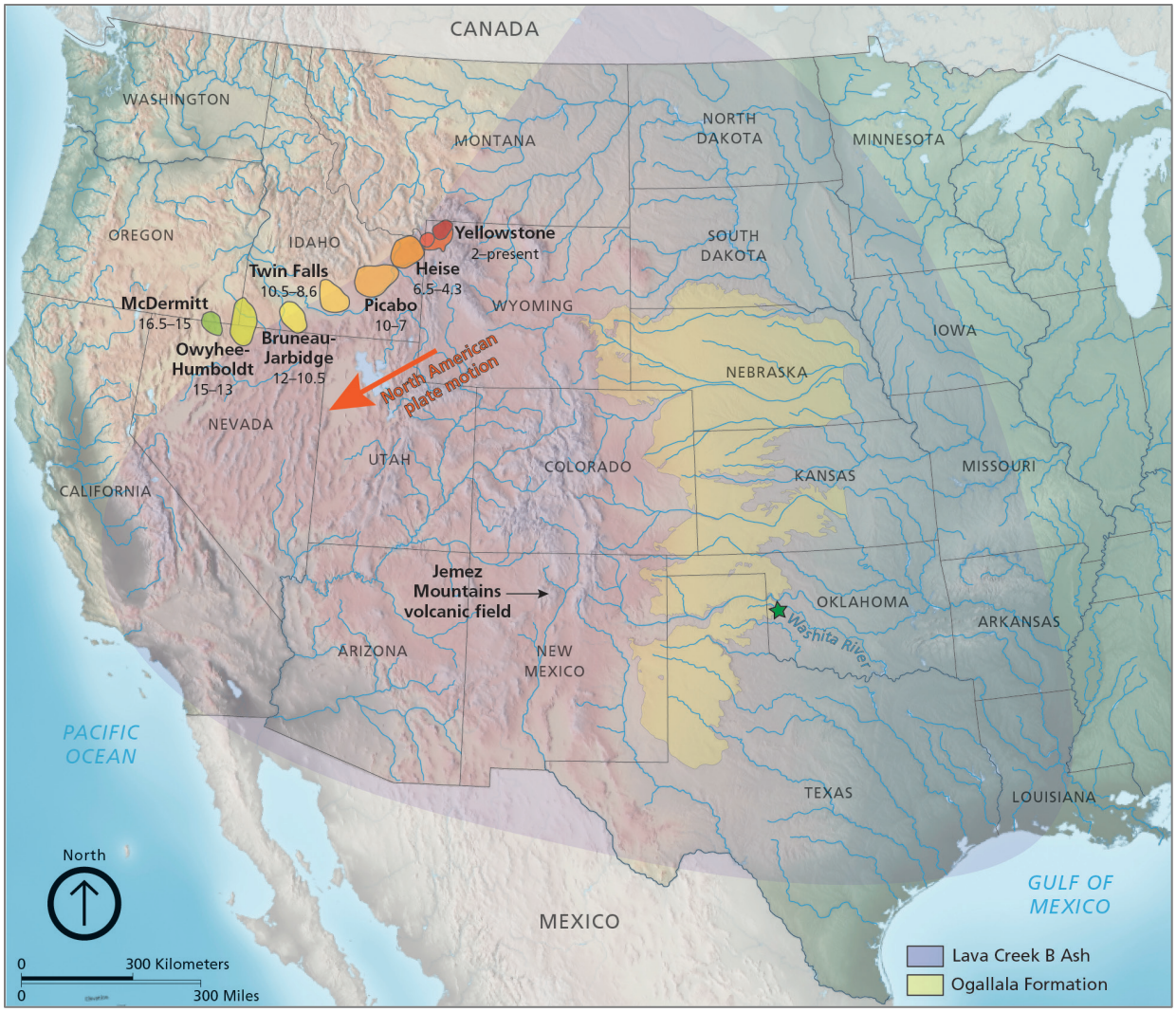


Figure 29. Regional map with some geologic features of interest. The map shows the Yellowstone hot-spot track (multicolored polygons), the extent of the Lava Creek B ash (purple shading), and the present extent of the Ogallala Formation (yellow shading). The Yellowstone hot spot remained stationary as the North American plate moved to the southwest (arrow). Starting with the McDermitt volcanic field to the present location under Yellowstone, the ages of the various volcanic fields (in millions of years ago; Smith and Siegel 2000) indicate this progression. The purple shading on the figure shows the estimated area covered by the Lava Creek B ash, which was the last major eruption from the Yellowstone volcanic center, approximately 639,000 years ago (Izett and Wilcox 1982). Ashes from other eruptions along the hot-spot track would have been distributed across a similar geographic area. Ash in the Ogallala Formation also originated from the Jemez Mountains volcanic field in New Mexico (Ludvigson et al. 2009). The green star represents the location of the historic site. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University). Base map by Tom Patterson (National Park Service).

Ogallala sediments once covered the entirety of the High Plains (Figure 29). Between 18 million and 5 million years ago, Ogallala sediments accumulated in a braided river environment, with coarse sands and gravels as channel deposits, and finer sand and silt as overbank flood deposits. The sand, clay, silt, and gravel were derived mostly from the erosion of the Southern Rocky Mountains to the

west. Caliche, which forms the resistant caprock of the Ogallala Formation, accumulated in soils following deposition of the fluvial sediments (Scholle et al. 2020). Fine-grained eolian sediments, which compose the caliche, blanketed valleys and ridges. This extensive and resistant material underlies the broad, flat expanse of the High Plains and serves as the foundation for agricultural activity (Willett et al. 2018). Analysis of mammalian fossils and dated volcanic ashes established the timing of deposition of the Ogallala Formation (Izett 1975).

Incision by rivers and tributaries adjacent to the caprock created a rough, broken, and scenic landscape composed of a widespread erosion scarp (line of cliffs), referred to as the "Caprock Escarpment." The escarpment forms the edge of the Llano Estacado in Texas and New Mexico. In the Canadian River valley (north of the historic site; see the GRI report about Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument by KellerLynn 2015b), the Ogallala caprock forms the upper edge of the scenic "Canadian Breaks"; the caprock also composes the adjacent, relatively flat plain.

Ogallala sediments form a major aquifer in the region (Scholle et al. 2020) known as both the "Ogallala aquifer" and the "High Plains aquifer." The aquifer feeds groundwater-based farming. It has also long been the source of water for many natural springs (Boyd 1987). At the historic site, however, the source of groundwater is the alluvial aquifer along the Washita River (Reber et al. 1999). This water is extremely hard (Becker and Varonka 2021). Before the wells were capped in the 1990s, groundwater was used to irrigate agricultural fields of alfalfa and hay. At present, water used at the historic site for domestic and administrative uses is "city water" derived from a surface water pond (GRI follow-up meeting, 28 March 2023).

Washita River

Map units: **Qt2**—fluvial terrace 2, **Qt1**—fluvial terrace 1, **Qfp**—floodplain, and **Qtf**—tributary floodplain of Stahl (2012). **Qt**—terrace deposits and **Qa**—alluvium of Fay (2010).

Starting at its headwaters in the Texas Panhandle, about 80 km (50 mi) upstream, the Washita River flows from west to east across the historic site. It enters the historic site about halfway along the western border, where it then meanders northeastward (see poster). The river is a tributary of the Red River, which is a major drainage in Oklahoma (see Figure 1). Water in the Red River ultimately flows through Arkansas and Louisiana to the Atchafalaya River near the Mississippi River (Johnson and Luza 2008).

The "Washita Headwaters watershed," which encompasses approximately 1,940 km^2 (750 mi^2), is rural in character, consisting primarily of rangeland and irrigated agriculture. It is subject to long-term and short-term droughts (National Park Service 2021a). The historic site is located within the Sergeant Major Creek subdrainage of the Washita Headwaters watershed.

The morphology of the Washita River, both in 1868 and at present, is that of a single-thread, low-gradient sinuous channel with a sandy bottom. In bed load–dominated channels like the Washita River, most of the bed material is entrained (picked up and transported) during even the most

moderate-magnitude flow events, which can result in impressive changes in channel characteristics when observed from one year to another (Buchanan 1994).

The Washita River is, by nature, a meandering stream. However, flood control structures (see "Flood Control Projects and Flooding") have inhibited the river. Compared to the former landscape before flood control structures, the river now appears "dead" (Richard Zahm, Washita Battlefield National Historic Site, park ranger, audio call, 18 August 2023), meaning it no longer meanders across the floodplain. Moreover, the riparian habitat is impaired, including the observed lack of native fish, salamanders, and mammals (Richard Zahm, Washita Battlefield National Historic Site, park ranger, audio call, 13 February 2024).

In the past, the meandering river created a series of horseshoe bends within and around the historic site. A notable horseshoe bend occurs upstream from Black Kettle's winter camp (see poster), where an oxbow (cutoff meander, separate from the main river) was in the process of forming (Figure 30). As an outcome of channel straightening and flood control structures, however, oxbow formation has stagnated. Nevertheless, during heavy rain events, which locally increase the flow of water, the stream does flow across the neck of the meander loop, bypassing the meander bend. Also, flooding as a result of dam breaks (malfunction) in the past has caused streamflow to bypass the meander bend (Richard Zahm, Washita Battlefield National Historic Site, audio call, 13 February 2024).

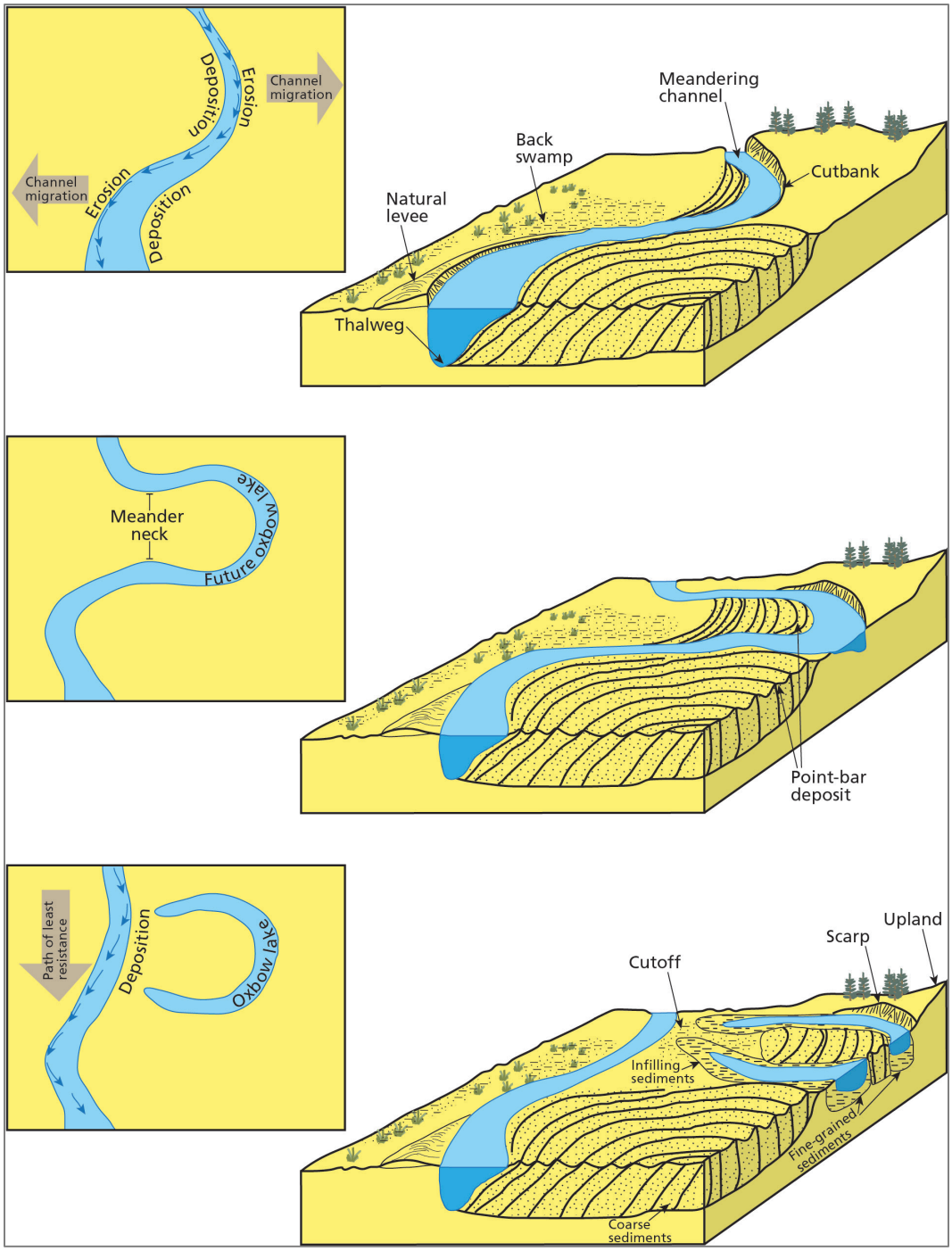


Figure 30. Schematic illustration of oxbow formation. Meanders—also called “horseshoe bends”—originate from the enlargement of bends in the flow path of a stream. On the inside of the bend, a series of sand and gravel bars accumulate to produce a point-bar deposit. A meander may become constricted, creating a narrow meander neck. The neck may be cut through by bank caving or by overflow during a flood, permitting the stream to bypass the bend and create a cutoff, whose meander bend is sealed off from the main channel by silt deposits (infilling sediments) thus becoming an oxbow. When it contains water, the oxbow is known as an oxbow lake. Gradual filling of the lake results in an oxbow swamp. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

As mapped by Stahl (2012), fluvial landforms associated with the Washita River cover most of the surface of the historic site (see poster). Fluvial deposits include the sediments on the Washita River floodplain (**Qfp**), which are mostly fine-grained. On the modern floodplain, as well as in stream and river channels, Fay (2010) mapped alluvium (**Qa**), which consists of unconsolidated sand, silt, clay, and gravel (see Table 3).

Older fluvial landforms include fluvial terraces (former floodplains) that consist of sediments ranging in size from silt to fine sand (see Table 3). Stahl (2012) mapped two terrace levels in the historic site (**Qt2** and **Qt1**; see poster). Other investigators have interpreted more levels; for example, the archeological report (Lees et al. 2001) documented three terrace levels. Within the greater Washita River drainage, as many as six terrace levels occur on the south side of the river, whereas five terrace levels occur on the north side of the river (Carter et al. 1990). Multiple terrace levels indicate that the incision of a valley was not steady (Connell et al. 2005). The number of terraces on the south side of the Washita River, as well as the greater width and volume of sediment, indicate that the river has migrated southward over time (Carter et al. 1990).

Fluvial terrace 2 (**Qt2**)—the older of the two terrace levels of Stahl (2012)—is 2.84 m (9.32 ft) above the floodplain (**Qfp**), whereas fluvial terrace 1 (**Qt1**) is 1.62 m (5.31 ft) above the floodplain (**Qfp**). Due to extensive erosion, the older terrace forms elongate, discontinuous mounds perpendicular to the Washita River (see poster). Well-rounded quartzite (origin unknown) pebbles and cobbles are scattered on the surface of the older terrace. The younger terrace displays broad, gently sloping surfaces that transition into the steeper slopes of the older terrace. Fluvial terrace 1 contains gravel sourced from the underlying Cloud Chief Formation. In addition to unconsolidated sand, silt, clay, and gravel, Fay (2010) noted the presence of volcanic ash in the terrace deposits (**Qt**).

Eolian Features and Processes

Map unit: **Qd**—paleodunes of Stahl (2012).

The map by Stahl (2012) shows paleodunes (**Qd**) within the historic site. These features overprint the former activity of the Washita River. Paleodunes are composed of light gray to salmon-colored, quartz-rich, medium- to coarse-grained sand. They rise between 3 and 8 m (10 and 25 ft) above the surrounding surface and are easily distinguished in LiDAR by their geomorphology (i.e., convex, crescent shape; Stahl 2012).

A particularly dense accumulation of paleodunes occurs northeast of the major river bend at the historic site. At this location, dunes overlie terraces (**Qt2** and **Qt1**; see "Washita River") as well as the Cloud Chief and Doxey Formations. South of the Washita River, at the historic site, the paleodunes form elongated strips parallel to the river valley. North of the river, the dunes are more common and occur in larger dune fields (Stahl 2012). Vegetation has stabilized many of the dunes (KellerLynn 2011a).

Unfortunately, Stahl (2012) does not specify the meaning of "paleodunes" or clarify the use of that term with respect to the timing of eolian activity at the historic site. Commonly, the term "paleo" describes a geologic feature that is no longer active. However, future reactivation of the sand dunes is

possible, primarily as a result of the reduction of plant cover (Muhs and Holliday 1995). Mobilization of sand may take place during periods of drought (see "Dust Bowl Dunes" subsection).

Older eolian landforms may be more resistant to activation because of the presence of finer soil particles, which accumulate as the soil forms over time. These finer particles retain moisture that sustains vegetation, anchoring the deposit even during more arid times. Younger deposits lack these fine particles and are more easily reactivated (Werner et al. 2011).

"Sand Hills" of the Battlefield Landscape

The location of the Washita River channel in 1868 compared to its present-day location has garnered much interest and inquiry. By contrast, the presence of sand dunes has not evoked a similar enthusiasm, regardless of their likely presence on the landscape during the attack. In general, eolian features go unrecognized in the presence of other geologic and geomorphic features (Soreghan et al. 2018), and they are commonly ignored in geologic mapping, even though they may blanket extensive areas (Madole 1995).

The following quote made in 1930 during an interview with Chief Magpie, who was a boy at the time of the attack, suggests that "sand hills" (ridges of sand; Neuendorf et al. 2005) were indeed a significant feature on the battlefield landscape:

> *Black Kettle's village stood on the south side of the big bend in the creek. There were sand hills and scattered timber north of the stream. There was a fringe of larger trees along the creek which gave partial shelter from the cold north winds. There was snow on the ground, but in the village the snow had been beaten down by many feet. Our pony herds grazed in the valley and up on the sides of the hills to the south when snow did not hide the grass. Some few horses, however, were kept always in the village for emergencies or to be ridden after the herds. That night some of them were across the creek in the sand hills... (Crowley 1999, p. 105).*

Recognizing sand dunes as significant landscape features has the potential to improve overall understanding of the battlefield landscape. A study that incorporates a survey of historic accounts as well as a review of previous studies, early topographic or other maps, and aerial photographs may yield a reinterpretation of the 1868 landscape, including features of significance for geologic heritage. Such a project could be conducted by a Scientists in Parks (SIP) participant (see "Guidance for Resource Management").

"Dust Bowl Dunes"

In 2011, scoping participants suspected that nearby areas of sand sheets may be relicts of the Dust Bowl (KellerLynn 2011a), but this suspicion requires clarification. The dunes likely formed at the end of the Pleistocene Epoch (12,920–11,490 years ago) and probably experienced widespread activity between 1100 and 1250 CE (see "Formation of Sand Dunes"). As such, the historic site's dunes formed long before the Dust Bowl. However, the formation of blowouts (small saucer-, cup-, or trough-shaped hollows or depressions formed by wind erosion on a preexisting dune or other sand deposit) was common during the prolonged drought periods of the 1930s and 1950s. Minor blowout

activity still occurs in areas where digging has fostered deflation (removal of fine-grained particles by the wind) (Cordova et al. 2004).

Geologic Resource Management Issues

This chapter highlights issues (geologic features, geologic processes, and human activities affecting or affected by geology) that may require management for human safety, protection of infrastructure, or preservation of natural and cultural resources. The GRD provides technical and policy assistance for these issues (see "Guidance for Resource Management"). The issues are ordered alphabetically, not with respect to management priority.

Climate Change and Geologic Resources

Although climate change planning is beyond the scope of the GRI, a discussion is included in this report because of the potential disruption it may cause to geologic resources. Historic site managers are directed to the NPS Climate Change Response Program (see "Additional References, Resources, and Websites") to address climate change planning.

According to the 2022 state climate summary for Oklahoma (Frankson et al. 2022), historically unprecedented warming is projected during this century. Also, extreme precipitation events and drought intensity are projected to increase. Extreme precipitation events will increase the risk of flooding and associated soil erosion. Increased temperature and drought intensity will decrease soil moisture, which adversely affects vegetation, thereby increasing erosion potential, including windblown erosion.

Direct impacts from climate change will principally arise through changes in geomorphic processes and in vegetation cover. Landforms may be lost to greater erosion or become obscured by sediment deposition. Geomorphic processes may become either more or less dynamic, change entirely, or cease to operate. Some landforms, such as sand dunes and meandering streams, may shift location, including migrating outside NPS boundaries (Gordon et al. 2022).

Studies of sand dunes and eolian records (Muhs and Holliday 1995; Muhs and Wolfe 1999; Scott 1999; Muhs and Zárate 2001; Fine et al. 2010, 2012) illustrate how wind erosion and transport affect the landscape. Eolian sand is quite sensitive to small changes in overall moisture balance and degree of vegetation cover (Muhs and Zárate 2001), so prolonged drought could induce eolian activity on the floodplain (**Qfp**), with potential sand burial of the channel, as well as promote the formation of blowouts in paleodunes (**Qd**). Evidence of active eolian sand in the 19th century indicates that the potential for reactivation of dunes in the future is high, with or without a "greenhouse climate" (Muhs and Holliday 1995, p. 206).

Although not a direct outcome of climate change, the type of vegetation cover may influence dune activity. For example, in other parts of the country (particularly coastal regions), dunes were active until nonnative grasses were introduced (Alex Simms, UC Santa Barbara, professor, written communication, 2 February 2024). A study would need to be conducted at the historic site to determine whether native or nonnative vegetation covers the paleodunes and its connection to dune activity. Notably, all the dunes at the historic site, except those at the northwest corner, have been

impacted by agriculture—either crops or grazing (Richard Zahm, Washita Battlefield National Historic Site, park ranger, audio call, 10 April 2024).

Drought conditions may increase the number and magnitude of sand/dust storms, which cause lower visibility and safety hazards for drivers (see "Geologic Hazards"). Additionally, "sand blasting" of cultural and natural resources such as memorials/markers (see "Building Stone"), signs, wayside exhibits, building facades, tree bark, and new plant growth may ensue. Increased eolian transport of silt could result in greater dust accumulation within and surrounding buildings, such as in doorways and windowsills, as well as onto fluvial terraces and the present-day floodplain.

Energy Development

When addressing external energy development, the NPS carries out its protection mandate by working with the lead federal or state permitting agency to identify alternative locations and solutions for the proposal that would avoid park resources, identify mitigation measures to protect park resources, and apply applicable laws and regulations to protect park resources and values.

Oil and Gas Development

The historic site is situated in the Anadarko basin, which is one of the most prolific producers of hydrocarbons (oil and natural gas) in the continental United States (Ball et al. 1991). The Anadarko basin is a major oil and gas province because of its large size (approximately 130,000 km^2 [50,000 mi^2]), thick section of sedimentary deposits (12,000 m [40,000 ft] thick in the deepest part of the basin), and significant accumulations of hydrocarbons (an estimated 16 billion barrels of oil and more than 200 trillion cubic feet of natural gas; Mitchell 2012; American Oil & Gas Reporter 2019).

The sources of oil and gas are shales in the Pennsylvanian Atoka Formation and Morrow Group (Neil Suneson, Oklahoma Geological Survey, geologist, written communication, 27 July 2011). These rocks are older than the historic site's bedrock (see "Permian Red Beds") and are neither exposed in the historic site nor included on either source map (i.e., Fay 2010 or Stahl 2012).

The Anadarko basin is also a significant helium reserve because some of the natural gas has an unusually high helium content (greater than 0.3%). Helium is recovered from natural gas as a byproduct (Krukowski 2009). Iodine is another important byproduct of natural gas production in the Anadarko basin. Iodine occurs in the brine (saline water) produced during the extraction of natural gas from the Pennsylvanian Morrow Group (Krukowski 2009).

Multiple well pads are found east of the historic site near the Washita River and along Highway 47 west of Cheyenne, including two on the north side of the highway 0.8 km (0.5 mi) south of the historic site's border. These two active wells extend into and reach their maximum depth beneath the historic site (Forrest Smith, GRD, lead petroleum and environmental engineer, email communication, 17 August 2023).

A key issue for the historic site is encroachment (National Park Service 2016). The historic site's foundation document notes that "[w]hile the majority of the area is still used for agricultural purposes, there has been significant industrial development related to the oil industry around

Cheyenne, Oklahoma. Oil-related construction and other modern development such as wind farms have the potential to significantly affect the park's landscape setting and sense of place, two of its fundamental resources and values" (National Park Service 2016, p. 27). In addition, preserving natural sounds and night skies is a concern (KellerLynn 2011a). Baseline data in the form of soundscape, night sky, and visual resource inventories, as well as Historic American Landscapes Survey (HALS) documentation, are needed to capture current conditions in preparation for future development and additional intrusions (National Park Service 2016).

Preservation of the historic site's viewshed is related to the key issue of encroachment. An example of encroachment is a pumping station within the north viewshed of the visitor overlook. The station is bright white, which makes it highly visible on the "red carpet country" landscape (GRI follow-up meeting, 28 March 2023). This pumping station is also visible from the visitor center (National Park Service 2016).

Natural Gas Pipeline

A small (unsure of exact diameter; Forrest Smith, GRD, lead petroleum and environmental engineer, email communication, 13 July 2023) underground gas pipeline—called a "flowline" in the oil and gas industry—crosses the historic site. A flowline transports small amounts of natural gas from a wellhead to a "trunk line," where it is shipped "downstream" in larger pipelines. The pipeline intersects the historic site near the southwest corner, then heads more-or-less diagonally to midway along the northern boundary (see poster). The pipeline runs under the Washita River.

The gas transported through the pipeline is pumped to King Fisher, a town 160 km (100 mi) east of the historic site (GRI follow-up meeting, 28 March 2023). The present owner/operator of the pipeline is El Paso Natural Gas (EPNG) Company, LLC, which is a Kinder Morgan company (Richard Zahm, Washita Battlefield National Historic Site, park ranger, email communication, 20 July 2023).

The biggest concern related to the pipeline at the historic site is the potential for hydrocarbon leaks in the form of natural gas or light liquid condensates, both of which pose little hazard to groundwater and surface water given their volatile nature. Another concern would be the point at which the flowline passes under the river in the historic site. Natural erosion could undermine the pipe and expose it to external threats. If historic site staff notices that the pipeline is visible above the ground or on the stream bottom, or if they identify areas of dead vegetation with an unknown origin, they should contract the regional office or GRD for further guidance (Forrest Smith, GRD, lead petroleum and environmental engineer, email communication, 13 July 2023).

The historic site and Roger Mills County have an emergency operations plan for handling hazardous spills (Richard Zahm, Washita Battlefield National Historic Site, park ranger, telephone communication, 28 June 2011). The plan has not been utilized to date because no spills are known to have occurred at the historic site (GRI follow-up meeting, 28 March 2023).

During scoping in 2011, an abandoned pipeline was thought to possibly occur within the historic site, but communication with the manager of the NPS Abandoned Mineral Lands (AML) Program revealed no abandoned pipeline, or any other AML feature, listed in the servicewide AML database

(Nida Holliday, NPS Regional Office serving Interior Regions 6, 7, and 8, regional energy specialist & AML Program manager, email communication, 22 June 2023). The only known pipeline is the previously discussed, active flowline. If this is an error, historic site managers are encouraged to contact the GRD or regional AML Program.

Wind Development

Since 2008, 257 wind turbines at four major wind farms—Elk City (43 turbines), Big Smile Wind Farm at Dempsey Ridge (66 turbines), Elk City II (66 turbines), and Red Hills (82 turbines)—have come online near the historic site (Hoen et al. 2018). These projects are 19 km (12 mi) southwest, 9 km (5.6 mi) southwest, 10 km (6.2 mi) south, and 24 km (15 mi) southeast of the historic site (Figure 31).

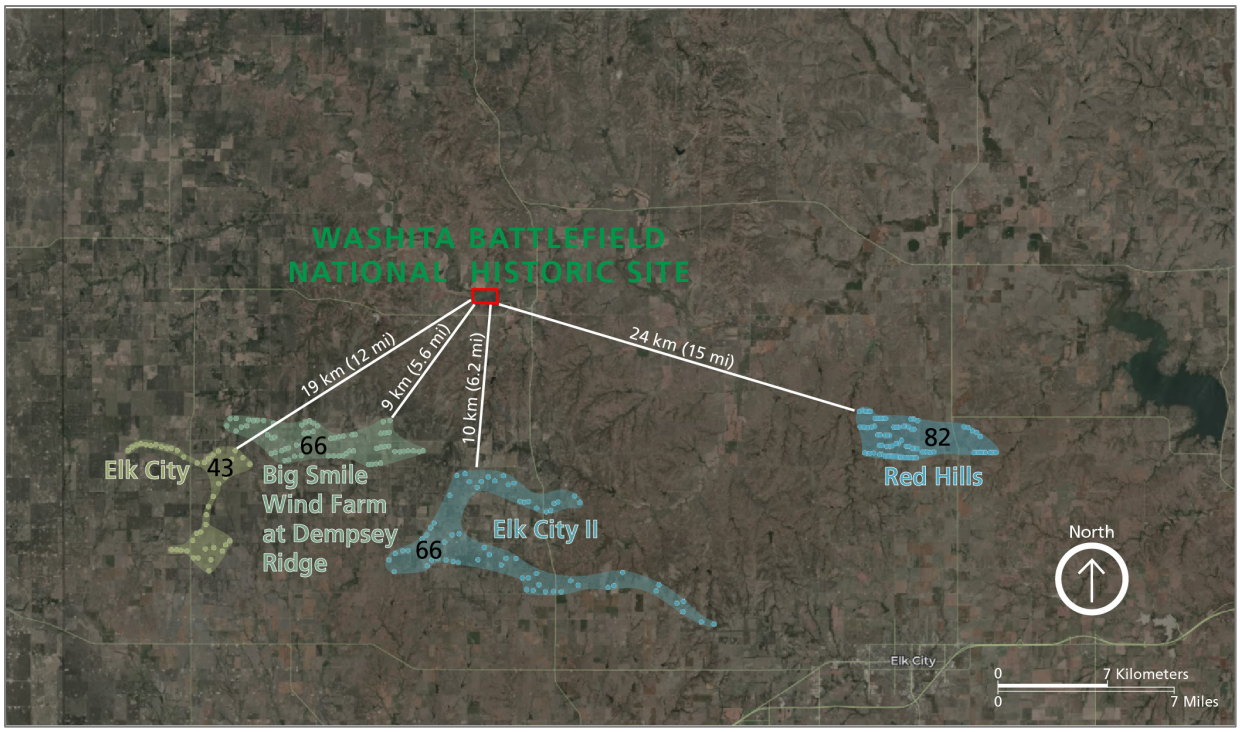


Figure 31. Map of wind turbines near the historic site. Four major wind farms with a total of 257 turbines (marked by dots on the figure) are south of the historic site. The projects are, from west to east, Elk City, Big Smile Wind Farm at Dempsey Ridge, Elk City II, and Red Hills. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using US Wind Turbine Database provided by the US Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory at https://eerscmap.usgs.gov/uswtdb (accessed 3 October 2023).

The primary concern with the development of wind energy near the historic site is preserving viewsheds associated with the attack (KellerLynn 2011a). Preserving the viewshed is important because the historic site is a significant place of contemplation where unobstructed views aid visitors in acknowledging and understanding the past. Preserving the viewshed is related to the key issue of encroachment, which is noted in the historic site's foundation document (National Park Service 2016).

The viewshed south of the historic site has diminished with the introduction of wind farms (National Park Service 2016; see Figure 9). The viewshed to the north is of greater significance for contemplating and interpreting the attack, and, at present, no plans are in place for turbines immediately north of the park (GRI follow-up meeting, 28 March 2023).

If needed in the future, managers at the historic site may obtain direct support from the GRD Renewable Energy Team by submitting a technical assistance request or phone-in request to the regional energy specialist. If in-house assistance cannot be provided, the Renewable Energy Team will find outside assistance and funding possibilities.

Erosion

The Doxey Formation is more resistant than the Cloud Chief Formation, but it too erodes into "badlands" topography (KellerLynn 2011a). Erosion of landforms associated with the Battle of the Washita—from off-trail use, military-staff rides, and natural weathering—can affect the historic views and interpretation of the site (National Park Service 2016).

On the interpretive trail down to the river, areas of erosion periodically need fixing. Possible causes of erosion are inadequate drainage and trail users attempting to avoid standing water and/or areas of mud (Figure 32). Youth Corps, whose participants assist with exotic weed mitigation on the railroad grade, may be able to assist with erosion-related projects along the trail (GRI follow-up meeting, 28 March 2023).



Figure 32. Photographs of trail segments at the historic site. Heavy rain events can cause ponding and muddy conditions on the trail leading to the Washita River. Erosion on a portion of the trail has been addressed using a concrete pathway. Left and right: NPS photographs by Richard Zahm (Washita Battlefield National Historic Site), taken 2011 and 2021, respectively.

Flood Control Projects and Flooding

The Flood Control Act of 1944 (PL 78-534) started a plethora of dam building, and Oklahoma was at the forefront. It was the first state to develop a watershed flood control dam (on a tributary of the Washita River—Cloud Creek), have an entire watershed project completed (the Sandstone Creek

Watershed Project in 1952), and develop a multipurpose flood control structure (Lake Humphrey). Moreover, it was the first state to complete 1,500 flood control dams and 1,776 watershed structures (Mundende, n.d.).

By 1977, the Washita River watershed and its 64 subwatersheds had more than 1,200 dams (Mundende, n.d.). The dam at Foss Reservoir (downstream from the historic site) was constructed in 1961. The purpose of that dam was to impound the Washita River for use as drinking water for the city of Clinton, Oklahoma (National Park Service 2021a).

The nearest NOAA stream gage is at Cheyenne, Oklahoma. Flood stage is 4.11 m (13.5 ft). The highest recorded historic crest was 6.17 m (20.24 ft) on 29 April 1954. Recent crests include 4.43 m (14.55 ft) on 17 April 2015 (National Weather Service 2020).

Long-term flow records, starting in 1937, indicate that flood-control structures have greatly reduced flooding as well as significantly modified natural flow patterns on the Washita River since at least the early 1960s (National Park Service 2021a). Under present conditions, the river channel within the historic site is sometimes dry (KellerLynn 2011a).

Before dam construction, flooding across the entire floodplain was a natural and regular process of the Washita River (Marston and Halihan 2007). Occasionally, flooding still occurs at the historic site, but generally only when check dams upriver fail (GRI follow-up meeting, 28 March 2023). Flooding is not a serious issue for infrastructure at the historic site, but flood waters could make visitor-experience areas and parts of the trail down to the river inaccessible. Also, flood waters could impact landforms and vegetation (National Park Service 2016).

In 2011, scoping participants mentioned how the lack of flooding has generally resulted in the loss of seed banks for replenishing native vegetation such as cottonwood trees (*Populus deltoides*). In a rare event, in the unusually wet spring of 2007, however, flood waters, 0.3 m (1 ft) deep, covered the floodplain at the historic site, which was much to the delight of park biologists who were hoping for the replenishment of seed banks (KellerLynn 2011a).

The NPS Water Resources Division (WRD) is the lead office for riverine hydrology and flooding assistance. Historic site staff can contact the WRD Floodplains and Hydrology Program for assistance.

Geologic Hazards

The dynamic landscapes preserved at many National Park System units present a variety of natural hazards that threaten facilities, staff, and visitors. Many of these natural hazards are geologic (e.g., earthquakes, landslides, and volcanic eruptions). NPS Policy Memorandum 15-01 (Jarvis 2015) directs NPS managers and their teams to proactively identify and document facilities vulnerable to climate change and other natural hazards.

Table 5 summarizes the geologic hazards at the historic site. The table is modeled after the Natural Hazard Checklist (see Jarvis 2015 and National Park Service 2015). It is meant to provide general

information to identify the full range of natural hazard-based risks at the historic site. The table is appropriate for use in park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis and compliance. Ground-disturbing activities should neither be approved nor denied based on the information in the table.

Note that the table provides a coarse filter evaluation; local knowledge of a hazard or hazards should be used when available. A geologic understanding of the historic site and the "sources of geohazard information" listed in Table 5 were used to determine the "best professional judgment." Best professional judgment is divided into the following three categories:

- Known hazard: Conditions that cause the hazard are well documented in the area where the park occurs. If applicable to the project site, these hazards should always be addressed in the project plan.
- Potential hazard: Conditions that cause or underlie the hazard are known to occur nearby or are likely to occur based on studies with conditions similar to those in the park. If applicable to the project site, these hazards should be considered for inclusion in the project plan.
- Not applicable: No evidence was identified showing that the hazard is relevant to the park.

Table 5. Geologic hazards checklist.

Potential Hazard	Best Professional Judgment	Risk or Secondary Hazard	Sources of Geohazard Information
Earthquakes	Known hazard	• <1% chance of potentially minor-damage (i.e., Modified Mercalli Scale Intensity IV) ground shaking at the historic site (US Geological Survey 2017, 2019) • Induced earthquakes: Much ground shaking in Oklahoma (primarily east of the historic site) is due to the underground injection of wastewater from oil and gas production (e.g., Ellsworth 2013). • Natural earthquakes: Paleoseismic studies found evidence of Holocene movement on the Meers fault (between the Wichita Mountains and Anadarko basin) (Crone 1994).	• USGS US Quaternary faults database and map viewer (US Geological Survey, n.d.) • Oklahoma area seismicity (US Geological Survey 2017) • Short-term induced seismicity models (US Geological Survey 2019) • DOI SHIRA (Strategic Hazard Identification and Risk Assessment) risk mapper (Department of the Interior 2023)
Slope movements (landslide/avalanche)	Potential hazard	• DOI SHIRA risk mapper found the historic site “susceptible to landslides,” though no landslide deposits were mapped within the boundary by Fay (2010) or Stahl (2012). • A minor landslide seems possible where the trail hops onto the higher terrace (Qt1; Denny Capps, GRD, geomorphologist, email communication, 23 January 2024).	DOI SHIRA risk mapper (Department of the Interior 2023)
Permafrost	Not applicable; permafrost is not present in Oklahoma	Not applicable	Not applicable
Cave/karst and sinkholes	Potential hazard	• Where water-soluble rocks (e.g., gypsum) are at or near the surface, dissolution features are prone to develop by the dissolving action of circulating groundwater. • DOI SHIRA risk mapper found current and future karst-related sinkhole susceptibility as very low.	• Johnson and Luza (2008) • GRI scoping summary (KellerLynn 2011a) • Weary and Doctor (2014) • DOI SHIRA risk mapper (Department of the Interior 2023)

Table 5 (continued). Geologic hazards checklist.

Potential Hazard	Best Professional Judgment	Risk or Secondary Hazard	Sources of Geohazard Information
Shrink/swell soils	Potential hazard	• Shrink/swell soils have the potential to damage structures, cause heaving of ground beneath structures, and increase landslide susceptibility. • Most soils in the historic site are rated “low” (<3% linear extensibility) except for about 10 ha (25 ac) south of the railroad grade and west of the overlook that are rated moderate (3.8%–4.0% linear extensibility). Limited historic site infrastructure in this area reduces risk.	NRCS Web Soil Survey, “linear extensibility” interpretation
Coastal storm surge/sea or lake level change/shoreline erosion	Not applicable; no shoreline in the historic site	Not applicable	Not applicable
Tsunami	Not applicable; no shoreline in the historic site	Not applicable	Not applicable

Table 5 (continued). Geologic hazards checklist.

Potential Hazard	Best Professional Judgment	Risk or Secondary Hazard	Sources of Geohazard Information
Riverine flood	Known hazard	• Federal Emergency Management Agency (FEMA) classifies the north part of the historic site along the Washita River as either a “regulatory floodway” (i.e., development within this zone is regulated) or “Zone AE” (i.e., a special flood hazard area that will be inundated by a flood event having a 1% chance of being equaled or exceeded in any given year. The 1% annual chance flood is also referred to as the base flood or 100-year flood). • DOI SHIRA risk mapper found riverine flooding with respect to 100-year and 500-year storm events as “extreme” in the historic site. With respect to the national flood hazard layer, that hazard level is “susceptible to flooding.” • The visitor center and south part of the historic site are in an area of minimal flood hazard. • Although not verified in the field, the Washita River could have the potential to “bite into the trail” (Denny Capps, GRD, geomorphologist, email communication, 23 January 2024).	• GRI GIS data: areas mapped as alluvium (Qa) by Fay (2010) and areas mapped as floodplain (Qfp) and tributary floodplain (Qtf) by Stahl (2012) represent the floodplain. • FEMA Map Service Center (FEMA, n.d.) and glossary (FEMA 2020) • DOI SHIRA risk mapper (Department of the Interior 2023)
Flash flood	Potential hazard	Flash floods may be caused by dam failures.	• Definition of flash flood in Neuendorf et al. (2005) • DOI SHIRA risk mapper (Department of the Interior 2023)
Volcanic eruption	Potential hazard	Ash fall could cover the historic site in the event of an eruption at Yellowstone or the Jemez volcanic field (see Figure 29).	• Izett and Wilcox (1982) • Ludvigson et al. (2009)
Hydrothermal activity	Not applicable	Not applicable	Not applicable

Table 5 (continued). Geologic hazards checklist.

Potential Hazard	Best Professional Judgment	Risk or Secondary Hazard	Sources of Geohazard Information
Radon	Potential hazard	Roger Mills County has an EPA assigned Radon Zone of 3, which predicts an average indoor radon screening level <2 pCi/L, which is below the 4pCi/L level suggested by EPA for mitigation. The only way to know for sure what levels are in a structure, regardless of Radon Zone, is to test. Oklahoma Department of Environmental Quality offers free radon testing kits to Oklahoma residents.	• EPA map of radon zones (EPA 2022) • Oklahoma Department of Environmental Quality (2023)
Dust storms (visibility <1 km [0.6 mi]; World Meteorological Organization 2019)	Known hazard	• Loss of visibility and reduced traction on roadways may cause accidents and traffic delays. • Fugitive dust reduces air quality and sight distance. • Dust buildup degrades natural and cultural resources.	• GRI GIS data—areas mapped as paleodunes (Pd) by Stahl (2012) • Sweeney et al. (2018) • Discussion during GRI follow-up meeting on 28 March 2023 • Tong et al. (2023)

Paleontological Resource Inventory, Monitoring, and Protection

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 coprolites [fossil feces]). All fossils are nonrenewable. Fossils in NPS areas may be found in rocks or unconsolidated deposits, in museum collections, and in cultural contexts such as building stones or archeological resources.

No fossils have been found within the historic site to date, but the historic site has the same bedrock units and surficial deposits that are known to preserve fossils elsewhere. Thus, future field investigations within the historic site may result in the discovery of fossils in one or more of these units (Tweet et al. 2015). Table 6 summarizes the potential.

Table 6. Fossil potential for map units within the historic site. Source: Tweet et al. (2015). Map units are from Fay (2010) and Stahl (2012). Lungfish burrows of the Elk City Sandstone (Pec) are not included because this map unit does not occur within the historic site.

Map Unit	Period	Fossils within the Historic Site?
Alluvium (**Qa**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Floodplain (**Qfp**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Tributary floodplain (**Qtf**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Paleodunes (**Qd**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Fluvial terrace 1 (**Qt1**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Fluvial terrace 2 (**Qt2**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Terrace deposits (**Qt**)	Quaternary	None to date; mollusks and isolated vertebrate remains are most likely
Doxey Shale (**Pd**)	Permian	None to date; fossils are rare
Cloud Chief Formation (**Pcc**)	Permian	None to date; corals, cephalopods, and invertebrate trace fossils have been reported from just outside the historic site

The following documents provide paleontological information specific to the historic site:

- Brown (2001) summarizes findings from Janet Brown, a GeoScientists-in-the-Parks (GIP) participant, who discovered fossils from the Cloud Chief Formation just east of the historic site (see Table 6). *Note*: The GIP Program was the forerunner of today's SIP Program.
- Koch and Santucci (2003) and Tweet et al. (2015) are paleontological resource inventory and monitoring reports for the Southern Plains Network; both include information about the historic site.

- Scoping participants suggested that Pleistocene mammal fossils may occur in the alluvial deposits within the historic site, although this has not yet been confirmed (see KellerLynn 2011a).

Future study, including the fossil location documented by Brown (2001), is warranted for the Cloud Chief Formation. Tweet et al. (2015) notes that the find by Brown (2001) is remarkable because of its rarity, and it may represent an isolated fossiliferous bed like the one reported from the Doxey Shale in Texas by Roth et al. (1941).

In addition, surveying the historic site's museum collection and archives, which are an "other important resource and value," for paleontological resources is warranted. Most of the collection consists of archeological objects related to the 1868 attack on Black Kettle's winter camp and objects left by the US military at that time, though the collection also includes objects related to the Cheyenne and Arapaho Tribes' connection to the site (National Park Service 2016). Surveying the collection specifically for paleontological resources is likely to reveal petrified wood from the Upper Triassic Chinle Formation. Petrified wood was commonly used for making tools, and the majority of parks in the neighboring Southern Colorado Plateau Network have examples (see Tweet et al. 2009). Other types of fossiliferous rocks also served as tool-making materials. The report by Kenworthy and Santucci (2006) presents an overview and cites selected examples of fossils found in NPS cultural resource contexts. Such a survey at the historic site could be conducted in conjunction with an archival survey, which is a medium-priority management need (National Park Service 2016).

Restoration of the Railroad Grade

Constructed in 1928–1929 as part of the Panhandle and Santa Fe Railroad, the railroad grade is "the greatest impact to the cultural landscape" at the historic site (National Park Service 2001, p. 74). The now-abandoned railroad grade bisects the historic site (see poster), dividing it into north and south sections in a way uncharacteristic of 1868 conditions (Cowley 1999). The railroad tracks have been removed, but the grade and related culverts remain (Figure 33).



Figure 33. Photographs of the railroad grade. The railroad grade is constructed of fill that varies in height throughout its length. During construction of the railroad grade, several small drainages were diverted and/or rerouted. A wooden drainage structure under the railroad grade diverts one of these drainages, as shown in the lower right image. The upper left photograph shows where Custer's Knoll was cut through during construction. NPS photographs by Deanna Greco (NPS Geologic Resources Division), taken 2001.

The railroad grade traverses 1.67 km (1.04 mi). The disturbed area encompasses approximately 6.9 ha (16.9 ac) (Greco 2002). Depending on location, the railroad grade rises 0.6–3 m (2–10 ft) above the ground surface (GRI follow-up meeting, 28 March 2023). The fill used to construct the grade is composed of excavated soil from local fields, as well as cinders and gravel, so the soil quality is poor. No major erosional problems are known to be associated with the railroad grade, however.

The primary geologic issue related to the railroad grade is that it interrupts drainage patterns; several small drainages were diverted or rerouted during construction. The railroad grade acts as a dam or constriction to local drainage, altering the natural hydrology of the site (Greco 2002). In addition, the railroad grade disrupts landforms as well as scenic views related to the time of the attack. In particular, the railroad grade cuts through Custer's Knoll (GRI follow-up meeting, 28 March 2023; see Figure 8).

The railroad grade also disrupts vegetation (National Park Service 2016). Many nonnative plant species have taken advantage of the disturbance, and trees have established in areas that would normally be composed of native prairie grasses (Greco 2002). Historic site managers work with the

Exotic Plant Management Team of the Intermountain Region to control the spread of exotic and invasive plants (GRI follow-up meeting, 28 March 2023).

In 2001, staff at the historic site contacted the GRD for technical assistance in removing the railroad grade. As a result of the request for technical assistance, the site conditions were analyzed and a report (Greco 2002) was completed, which includes suggestions for how to restore the area, what kind of restoration might be best, what factors might enhance or limit the restoration activities, and how much the suggested materials and equipment will cost. That report identifies the ultimate goal as restoring "the cultural integrity of the battlefield and to transform the disturbed area into a landscape that appears and functions as 'naturally' as possible" (Greco 2002, p. 1). With the goal of restoring topography, Custer's Knoll would be returned to its 1868 form (GRI follow-up meeting, 28 March 2023).

Many legacy documents discuss restoration of the railroad grade. The historic site's enabling legislation specifically calls for the preservation of the natural resources of the site and the visual scene to be maintained "as closely as possible as it was at the time of battle," which would require the removal of the railroad grade and associated culverts. The historic site's general management plan (National Park Service 2001) proposes to remove the railroad grade or restore a portion of the original grade and use other sections as part of the trail system. The foundation document reiterates this plan "to remove part of the grade and convert a segment into a new visitor use trail" (National Park Service 2016, p. 11). Moreover, the foundation document notes that removal of the railroad grade would greatly improve the hydrology of the site, restore important viewsheds, and potentially lead to archeology projects, increased archeology museum collections, and improved native species and ecosystem health. Nevertheless, the railroad grade remains in place (GRI follow-up meeting, 28 March 2023).

Guidance for Resource Management

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

Access to GRI Products

- GRI products (scoping summaries, GIS data, posters, and reports): https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm
- GRI products are also available on the NPS DataStore through the Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.
- GRI GIS data model: https://www.nps.gov/articles/gri-geodatabase-model.htm

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.
- Formally request assistance at the Solution for Technical Assistance Requests (STAR) webpage: https://irma.nps.gov/Star/ (only available while connected to the Department of the Interior [DOI] network). NPS employees (from a park, region, or any other office outside of the NRSS Directorate) can submit a request for technical assistance from NRSS divisions and programs.
- Submit a proposal to receive geologic expertise through the SIP program: https://www.nps.gov/subjects/science/scientists-in-parks.htm. Formerly the Geoscientists-in-the-Parks (GIP) program, the SIP program places scientists (typically undergraduate students) in parks to complete science-related projects that can address the geologic resource management issues discussed in this report as well as other resource management issues. Proposals may also be for assistance with research, interpretation, outreach, inventory, and monitoring. The GRD can provide guidance and assistance with submitting a proposal: https://doimspp.sharepoint.com/sites/nps-scientistsinparks (only available while connected to the DOI network). The Geological Society of America and Environmental Stewards are partners of the SIP program.
- Refer to *Geological Monitoring* (Young and Norby 2009). Chapters are available at https://www.nps.gov/subjects/geology/geological-monitoring.htm. *Geological Monitoring* 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.

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
- Natural Resources Inventory and Monitoring guideline (NPS-75): https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Natural Resource Management Reference Manual #77 (NPS-77): https://irma.nps.gov/DataStore/Reference/Profile/572379
- Resist-Accept-Direct (RAD)—A Framework for the 21st-Century Natural Resource Manager: https://doi.org/10.36967/nrr-2283597

Geologic Resource Laws, Regulations, and Policies

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

Geoheritage Resource Laws, Regulations, and Policies

Caves and Karst Systems

Resource-specific laws:

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

Resource-specific regulations:

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

NPS Management Policies 2006:

- **Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts.
- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact 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.

<u>Geothermal</u>

Resource-specific laws:

- **Geothermal Steam Act of 1970, 30 USC. § 1001** et seq. as amended in 1988, states:
    - No geothermal leasing is allowed in parks.
    - "Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead).
    - NPS is required to monitor those features.
    - Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects.
- **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.

Resource-specific regulations:

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

NPS Management Policies 2006:

- **Section 4.8.2.3** requires NPS to:

- Preserve/maintain integrity of all thermal resources in parks.
- Work closely with outside agencies.
- Monitor significant thermal features.

Paleontological Resources

Resource-specific laws:

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

Resource-specific regulations:

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

NPS Management Policies 2006:

- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.

Energy and Minerals Laws, Regulations, and Policies

Abandoned Mineral Lands and Orphaned Oil and Gas Wells

Resource-specific laws:

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

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Coal

Resource-specific laws:

- **Surface Mining Control and Reclamation Act (SMCRA) of 1977, 30 USC § 1201** et. seq. prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.

Resource-specific regulations:

- **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.

NPS Management Policies 2006:

- None applicable.

Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)

Resource-specific laws:

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

use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and:
    - Only for park administrative uses;
    - After compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment;
    - After finding the use is the park's most reasonable alternative based on environment and economics;
    - Parks should use existing pits and create new pits only in accordance with park-wide borrow management plan;
    - Spoil areas must comply with Part 6 standards; and
    - NPS must evaluate use of external quarries.
- Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

<u>Federal Mineral Leasing (Oil, Gas, and Solid Minerals)</u>

Resource-specific laws:

- **The Mineral Leasing Act, 30 USC § 181** et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq. do not authorize the BLM to lease federally owned minerals in NPS units.
- **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in 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.

Resource-specific regulations:

- **36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law.
- **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing.
- Regulations re: Native American Lands within NPS Units:
    - **25 CFR Part 211** governs leasing of tribal lands for mineral development.
    - **25 CFR Part 212** governs leasing of allotted lands for mineral development.
    - **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development.
    - **25 CFR Part 224** governs tribal energy resource agreements.
    - **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC §§ 2101-2108).
    - **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases.
    - **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases.
    - **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases.
    - **30 CFR § 1206.450** governs the valuation of coal from Indian Tribal and Allotted leases.
- **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.

NPS Management Policies 2006:

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

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

Resource-specific laws:

- **Mining in the Parks Act of 1976, 54 USC § 100731** et seq. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas.

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

Resource-specific regulations:

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

NPS Management Policies 2006:

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

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

Resource-specific laws:

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

Resource-specific regulations:

- **NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a § 5.3 business operation, and § 5.7 – Construction of buildings or other facilities, and to comply with the solid waste regulations at Part 6.

NPS Management Policies 2006:

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

Nonfederal Oil and Gas

Resource-specific laws:

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

Resource-specific regulations:

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

NPS Management Policies 2006:

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

Recreational Collection of Rocks and Minerals

Resource-specific laws:

- **NPS Organic Act, 54 USC. § 100101** et seq. directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law.

- **Exception: 16 USC. § 445c (c)** – Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).

Resource-specific regulations:

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

NPS Management Policies 2006:

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

<u>Transpark Petroleum Product Pipelines</u>

Resource-specific laws:

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

Resource-specific regulations:

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

NPS Management Policies 2006:

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

Uranium

Resource-specific laws:

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

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Active Processes and Geohazards Laws, Regulations, and Policies

Coastal Features and Processes

Resource-specific laws:

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

Resource-specific regulations:

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

NPS Management Policies 2006:

- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/park facilities/historic properties.
- **Section 4.8.1.1** requires NPS to:
    - Allow natural processes to continue without interference,
    - Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions,
    - Study impacts of cultural resource protection proposals on natural resources,
    - Use the most effective and natural-looking erosion control methods available, and
    - Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.

<u>Geologic Hazards</u>

Resource-specific laws:

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

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

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

Soils

Resource-specific laws:

- **Soil and Water Resources Conservation Act, 16 USC §§ 2001–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources.
- **Farmland Protection Policy Act, 7 USC § 4201** et. seq. requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and 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).

Resource-specific regulations:

- **7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. Part 610 governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. Part 611 governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.

NPS Management Policies 2006:

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

Upland and Fluvial Processes

Resource-specific laws:

- **Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE.
- **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]).
- **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**).
- **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1**).

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems.
- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding.
- **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams.
- **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes.
- **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Additional References, Resources, and Websites

The online and other publications listed in this chapter may be considered "further reading," but they were selected because of their applicability to the geologic features, processes, and resource management issues discussed in this report.

Building Stone

- Willis Granite in Granite, Oklahoma: https://www.willisgranite.com/
- Washington Monument in Washington, DC: https://www.nps.gov/wamo/learn/photosmultimedia/photogallery.htm

Climate Change

- Fourth National Climate Assessment (Reidmiller et al. 2018): https://nca2018.globalchange.gov/. *Note*: Chapter 23 (Kloesel et al. 2018) provides information about the Southern Great Plains: https://nca2018.globalchange.gov/chapter/23/.
- Intergovernmental Panel on Climate Change (IPCC): https://www.ipcc.ch/
- National Weather Service: https://www.weather.gov/
- NPS Climate Change, Useful Resources: https://www.nps.gov/subjects/climatechange/resources.htm
- NPS Climate Friendly Parks Program: https://www.nps.gov/subjects/climatechange/cfpprogram.htm
- NPS Policy Memorandum 15-01—Addressing Climate Change and Natural Hazards for Facilities: https://www.nps.gov/subjects/policy/index.htm
- Secretarial Order No. 3289—Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources: https://www.usgs.gov/media/files/secretarial-order-no-3289
- Southern Plains Inventory & Monitoring Network, Weather & Climate: https://www.nps.gov/subjects/swscience/weather-climate.htm
- US Global Change Research Program: https://www.globalchange.gov/

Earthquakes

- Oklahoma Geological Survey, Seismic Monitoring Program: https://www.ou.edu/ogs/research/earthquakes/seismicstations
- "Seismic Monitoring" (Braile 2009) in *Geological Monitoring* (Young and Norby 2009): https://www.nps.gov/articles/seismic-monitoring.htm
- USGS Earthquake Hazards Program, Unified Hazard Tool: https://earthquake.usgs.gov/hazards/interactive/

- USGS Earthquakes Hazard Program, Information by Region: https://www.usgs.gov/programs/earthquake-hazards/information-region

Geologic Heritage

- America's Geoheritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- *America's Geologic Heritage: An Invitation to Leadership (National Park Service and American Geosciences Institute 2015):* https://www.americangeosciences.org/geotimes/americas-geologic-heritage-invitation-leadership-recognized-design-excellence
- International Union of Geological Sciences (IUGS), International Commission on Geoheritage: https://iugs-geoheritage.org/
- National Register of Historic Places: https://www.nps.gov/subjects/nationalregister/index.htm
- NPS Museum Collections (online database): https://museum.nps.gov/ParkPList.aspx
- NPS Unofficial National Register of Geoheritage Sites: https://www.nps.gov/subjects/geology/unofficial-register.htm

Geologic Maps

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

Geological Surveys and Societies

- American Geophysical Union (AGU): https://www.agu.org/
- American Geosciences Institute (AGI): https://www.americangeosciences.org/
- Association of American State Geologists (AASG): http://www.stategeologists.org/
- Geological Society of America (GSA): https://www.geosociety.org/
- Oklahoma Geological Survey: https://www.ou.edu/ogs
- USGS: https://www.usgs.gov/

History of Washita

- Cheyenne and Arapaho Tribes, Language and Culture: https://www.cheyenneandarapaho-nsn.gov/language-culture
- *Cultural Landscape Inventory, Washita Battlefield National Historic Site* (Cowley 1999): http://npshistory.com/publications/waba/index.htm#documents
- *Historic Resource Study, Washita Battlefield National Historic Site, Oklahoma* (Greene 2001): http://npshistory.com/publications/waba/index.htm#documents

- National Register of Historic Places Inventory, Washita Battlefield nomination form (Mendinghall 1976): https://catalog.archives.gov/id/86510637
- NPS History eLibrary (many park-specific documents are available electronically): http://www.npshistory.com/
- Oklahoma Historical Society, The Encyclopedia of Oklahoma History and Culture: https://www.okhistory.org/publications/encyclopediaonline
- *Special Report on Washita Battlefield, Oklahoma* (Brown 1964): http://npshistory.com/publications/waba/index.htm#documents
- *Washita* (Warde 2005): http://npshistory.com/publications/waba/index.htm#documents
- *Washita Battlefield National Historic Site, Cultural Landscape Report, Part Two* (John Milner Associates, Inc., and Susan Maxman Architects 2003): http://npshistory.com/publications/waba/index.htm#documents

NPS Geology

- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm
- NPS Geologic Resources Division: https://www.nps.gov/orgs/1088/index.htm
- NPS Geologic Resources Inventory: https://www.nps.gov/subjects/geology/gri.htm
- NPS Geology, Geoscience Concepts: https://www.nps.gov/subjects/geology/geology-concepts.htm
- NPS Geology, Physiographic Provinces: https://www.nps.gov/subjects/geology/physiographic-provinces.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 (geologic citation database). The GRI team collaborates with TIC to maintain an NPS subscription to GeoRef via the Denver Service Center Library interagency agreement with the Library of Congress. Multiple portals are available for NPS staff to access these records. Historic site staff can contact the GRI team or GRD for access.
- NPS Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/Portal/. *Note*: The GRI team uploads scoping summaries, maps, and reports to the NPS DataStore on IRMA.

Oklahoma Geology

- Oklahoma Geological Survey: https://www.ou.edu/ogs
- Oklahoma Geological Survey, Educational Publications: https://www.ou.edu/ogs/publications/educationalpublications
- Oklahoma Geological Survey, Maps: https://www.ou.edu/ogs/maps

Soil Survey

- Web Soil Survey (WSS): https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. WSS provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS).
- *Soil Survey of Washita Battlefield National Historic Site, Oklahoma* (Natural Resources Conservation Service and National Park Service 2015): http://npshistory.com/publications/waba/index.htm#documents

USGS Reference Tools

- The Geographic Names Information System (GNIS): https://www.usgs.gov/tools/geographic-names-information-system-gnis
- The National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- US Board on Geographic Names: https://www.usgs.gov/us-board-on-geographic-names
- US Geologic Names Lexicon (Geolex): https://ngmdb.usgs.gov/Geolex/search
- USGS Publications Warehouse: https://pubs.usgs.gov/
- USGS Store, Map Locator: https://store.usgs.gov/map-locator
- Tapestry of Time and Terrain (descriptions of physiographic provinces; Vigil et al. 2000): https://pubs.usgs.gov/imap/i2720/

Wind Energy

- Map of Oklahoma showing wind speeds at 100 m above the land surface: https://windexchange.energy.gov/maps-data/375
- US Wind Turbine Database (USGS): https://eerscmap.usgs.gov/uswtdb/
- WINDExchange, Wind Energy in Oklahoma: https://windexchange.energy.gov/states/ok

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