National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# Little Bighorn Battlefield National Monument

*Geologic Resources Inventory Report*

Natural Resource Report NPS/NRSS/GRD/NRR—2011/407


**ON THE COVER**
The rolling topography of Last Stand Hill overlooks the floodplain of the Little Bighorn River. The topography of the area influenced the 1876 Battle of the Little Bighorn.

Photograph by Bob Reece (Friends of the Little Bighorn Battlefield), courtesy Melana Stichman (Little Bighorn Battlefield National Monument).

**THIS PAGE**
7th Cavalry Memorial and Indian Memorial. The 7th Cavalry Memorial (in the foreground) and the Indian Memorial (in the background) help interpret the Battle of the Little Bighorn from both the U.S. Cavalry and Indian perspectives.

National Park Service photograph by John Doerner (Little Bighorn Battlefield National Monument).

# Little Bighorn Battlefield National Monument

*Geologic Resources Inventory Report*

Natural Resource Report NPS/NRSS/GRD/NRR—2011/407

National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 80225

June 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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

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

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



Printed copies of this report are produced in a limited quantity and they are only available as long as the supply lasts. This report is available from the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as

KellerLynn, K. 2011. Little Bighorn Battlefield National Monument: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/407. National Park Service, Fort Collins, Colorado.

NPS 381/107967, June 2011

# Contents

# List of Figures

# Executive Summary

*This report accompanies the digital geologic map data for Little Bighorn Battlefield National Monument in Montana, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.*

Located in southeastern Montana, Little Bighorn Battlefield National Monument overlooks the valley of the Little Bighorn River. Here in 1876, the Battle of the Little Bighorn—also known as the Battle of the Greasy Grass—broke out between the U.S. Army and an allied group of Northern Plains Indians. The national monument memorializes a major victory of the Northern Plains Indians to preserve their ancestral way of life, and protects the site where Lieutenant Colonel George A. Custer and all the men under his immediate command met death on what is now "Last Stand Hill." The primary purpose of Little Bighorn Battlefield National Monument is to preserve and protect the historic and natural resources pertaining to the Battle of the Little Bighorn and to provide visitors with a greater understanding of the events that led up to the battle, the battle itself, and the resulting effects of the battle (National Park Service 1995).

The national monument is separated into two units—the 244-ha (603-ac) Custer Battlefield and the 66-ha (162-ac) Reno-Benteen Battlefield. A 6.6-km (4.1-mi) road connects the two units. The Custer Battlefield unit preserves Last Stand Hill, the Indian Memorial, and Custer National Cemetery. The Reno-Benteen Battlefield unit preserves the site where seven companies under the command of Major Marcus A. Reno and Captain Frederick W. Benteen held out against Indian attacks until the main army column arrived on June 27, 1876.

The bedrock that underlies Little Bighorn Battlefield National Monument is from the Upper Cretaceous Period (about 100 million to 65.5 million years ago) and represents sediments (mud and sand) originally deposited in a seaway that inundated west-central North America. Surficial units consist of alluvium (gravel, sand, silt, and clay) that streams deposited during the Quaternary Period (the past 2.6 million years). These rocks and unconsolidated deposits give rise to the landforms that influenced the actions taken during the Battle of the Little Bighorn.

This Geologic Resources Inventory (GRI) report is written for resource managers, to assist in resource management and science-based decision making, but it may also be useful for interpretation. The report discusses geologic issues facing resource managers at the national monument, distinctive geologic features and processes within the national monument, and the geologic history leading to the national monument's present-day landscape. An overview graphic illustrates the geologic data; a map unit properties table summarizes the main features, characteristics, and potential management issues for all the rocks and unconsolidated deposits on the digital geologic map for Little Bighorn Battlefield National Monument (see "Overview of Geologic Data" and Attachment 1). This report also provides a glossary, which contains explanations of technical, geologic terms, including terms on the map unit properties table. Additionally, a geologic timescale shows the chronologic arrangement of major geologic events, with the oldest events and time units at the bottom and the youngest at the top. The timescale is organized using formally accepted geologic-time subdivisions and ages (fig. 19).

Geologic issues of particular significance for resource management at Little Bighorn Battlefield National Monument include the following:

- Flooding, anthropogenic disturbances, and channel migration of the Little Bighorn River. Although channel migration is predominantly a natural phenomenon, this ongoing process of the Little Bighorn River has raised concern for the preservation of cultural resources within the national monument.
- Erosion. The main types of erosional processes occurring at Little Bighorn Battlefield National Monument are soil piping (formation of "pipes" through which soil material is removed) and sheet flow (movement of water across the landscape in thin sheets rather than in channels). Soil compaction and soil ruts also occur. Management of erosion includes the mitigation of informal, undesignated "social trails," and the potential treatment of headcuts (vertical cuts in an [intermittent] stream channel), for example in Deep Ravine.
- Energy development, specifically the impacts from coal-fired power plants. The National Parks Conservation Association identified emissions from coal-fired power plants as a primary concern for the protection of resources (soils, vegetation, and water) at Little Bighorn Battlefield National Monument. There are five power plants operating in Montana, all of which are relatively close to the national monument. The primary source of the coal used in these power plants is the Fort Union Formation, which crops out 24 km (15 mi) east of Little Bighorn Battlefield National Monument, but does not appear on the

digital geologic map of the national monument. Also known to host coal are the Parkman Member of the Judith River Formation (informally referred to as "Parkman Sandstone") (map unit symbol Kjp), Bearpaw Formation (Kb), and Lance Formation (Kl), which are shown on the digital geologic map for Little Bighorn Battlefield National Monument; however, these strata do not contain coal resources in the vicinity of the national monument.

- Impacts of development and land use on geologic features and processes, including increased erosion, runoff, and sedimentation into fluvial (river) systems; exacerbated eolian (wind) processes (e.g., dust storms); soil compaction; the formation of soil ruts; and potential erosion and theft of in situ paleontological resources. Additionally, past development impacted landforms that were both geologically and historically significant.

The historic and natural resources at the national monument include the following geologic features and processes:

- Landforms such as ridges, hills, coulees (small, intermittent streams or the channel of such a stream), ravines, riverbanks, floodplains, and terraces. All of these landforms played a role in the Battle of the Little Bighorn / Battle of the Greasy Grass.
- Paleontological resources from the Bearpaw Formation (Kb), in particular a rare plesiosaur (extinct marine reptile) specimen unearthed at Little Bighorn Battlefield National Monument, and fossils from the Judith River Formation (Kjr) such as bony fish, sharks, dinosaurs, soft-shelled turtles, and mammals.
- Building stone of the Superintendent's House (also referred to as The Stone House) as well as markers, monuments, and memorials. Building stones are a significant component of the setting of Little Bighorn Battlefield National Monument. These stones are both historic and geologic resources. If mined locally, building stones can help to interpret the geologic setting of a National Park System unit. If mined elsewhere, the stones can contribute to geologic education, and may help visitors make connections between the unit and their home states. The national monument has both local stones and ones from foreign lands. Furthermore, as both historic and geologic objects, building stones may contribute to an understanding of the technologies available to the stone industry and War Department around the time of the battle. Nonetheless, documentation of geologic information about these materials at the national monument is sparse.


# Acknowledgements

*The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The GRI is administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate.*

The Geologic Resources Division relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

GRI staff would like to thank John Doerner (Little Bighorn Battlefield National Monument) for the information he provided and questions he answered about the battle and building stones; David Lopez (geologist/consultant, formerly with the Montana Bureau of Mines and Geology) for reconnaissance he provided on the Parkman Sandstone; Melana Stichman (Little Bighorn Battlefield National Monument) and Ellen Porter (NPS Air Resources Division) for their input about the impacts of coal-fired power plants; Mike Martin (NPS Water Resources Division) for information about erosion, channel migration, and oxbows; Pete Biggam (NPS Geologic Resources Division) for imformation about soils and soil piping; Michael Timmons (Utah State University) for providing many photographs used in the report.

**Credits**

Author

Katie KellerLynn (Colorado State University)

Review

David Lopez (geologist/consultant, formerly with the Montana Bureau of Mines and Geology)
Melana Stichman (Little Bighorn Battlefield National Monument)
John Doerner (Little Bighorn Battlefield National Monument)

Editing

Steve Hoffman (Write Science Right)

Digital Geologic Data Production

Heather Stanton (Colorado State University)

Digital Geologic Data Overview Layout Design

Phil Reiker (NPS Geologic Resources Division)

# Introduction

*The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Little Bighorn Battlefield National Monument.*

### Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The GRI, administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate, is designed to provide and enhance baseline information available to park managers. The GRI team relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize these goals, the GRI team is systematically conducting a scoping meeting for each of the 270 identified natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps. The digital data sets provide geologic data for use in park GIS and facilitate the incorporation of geologic considerations into a wide range of resource management applications. The newest maps contain interactive help files. This geologic report assists park managers in the use of the map and provides an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information, please refer to the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/).

### Park Setting

Surrounded by the Crow Indian Reservation, Little Bighorn Battlefield National Monument is located in southeastern Montana on the western edge of the Great Plains (fig. 1). The national monument overlooks the lower Little Bighorn River valley (fig. 2). The headwaters of the Little Bighorn River (and its principal tributaries) are in the Wolf Mountains to the south. The confluence of this northward-flowing river with the Bighorn River is near Hardin, Montana, to the northeast. Much of the low-lying land adjacent to the river is irrigated land within the Crow Indian Reservation (Moulder et al. 1960).

The bedrock formations exposed in the area are primarily shale and sandstone of Upper Cretaceous (99.6 million to 65.5 million years ago) age and include the Bearpaw Formation (map unit symbol Kb) and Judith River Formation (Kjr). Pleistocene (2.6 million to 11,700 years ago) terrace deposits (Qat) and Holocene (the past 11,700 years) river alluvium (Qal), including some terraces, are the principal unconsolidated units within the national monument (see “Overview of Geologic Data”).

Various geomorphic landforms dominate the landscape of Little Bighorn Battlefield National Monument. The primary form consists of ridges dissected by ravines and coulees. “Coulee” is a French term applied in the western United States to a small stream (or the bed of such a stream) that is often intermittent. During the Battle of the Little Bighorn, ridges provided views across the broad valley and defensible high ground for soldiers of the 7th Cavalry. Ravines and coulees, which cut into the ridges, allowed for the secluded advance of Indian attackers. The steep banks on the east side of the Little Bighorn River form an abrupt edge, limiting access (and escape) from the floodplain. Some of the most conspicuous topographic features are the prominent stream terraces, which primarily line the west side of the Little Bighorn River valley. Unlike the ridges and coulees, these features did not figure significantly in the actions taken during the Battle of the Little Bighorn. However, the flat-topped terraces that sit above the Little Bighorn River served as suitable camping grounds for the warriors and their families at the time of the battle.

The national monument commemorates the Battle of the Little Bighorn (known as the Battle of the Greasy Grass by the Indians) where on June 25 and 26, 1876, allied Indian forces led by Tatanka-Iyotanka (Sitting Bull), a Hunkpapa Lakota, joined to defeat the U.S. 7th Cavalry on “Last Stand Hill.” Commonly referred to as “Custer’s

Last Stand," the battle also marks the last (and perhaps greatest) victory of Northern Plains Indians to preserve their ancestral way of life. Lieutenant Colonel George A. Custer commanded the cavalry and was among the soldiers and other personnel—including Arikara and Crow scouts—who were killed or mortally wounded during the battle. Also involved in the battle were seven companies under the command of Major Marcus A. Reno and Captain Frederick W. Benteen, who held out at their defense site on "Reno-Benteen Hill" until the main army column arrived on June 27, 1876. Total 7th Cavalry casualties numbered 263 killed and 5 mortally wounded. All 210 men under Custer's immediate command were killed, and 53 men under Reno and Benteen's command were killed. The number of Indian casualties is not known, but has been estimated at 60 or more men, women, and children with many dying from wounds after the battle (Michael Donahue, park ranger, Little Bighorn Battlefield National Monument, telephone communication, June 10, 2011). The total number of U.S. Army soldiers and attached personnel who participated in the battle was 647.

Between 1,500 and 2,000 Indians warriors participated in the battle from 17 different tribes: Northern Arapaho, Three Affiliated Tribes of the Fort Berthold Reservation (Mandan, Hidatsa, and Arikara Nation), Northern Cheyenne, Cheyenne and Arapaho Tribes of Oklahoma, Apsaalooke Nation (Crow Tribe), Assiniboine and Sioux tribes of the Fort Peck Indian Reservation, Cheyenne River Sioux Tribe of the Cheyenne River Reservation, Oglala Sioux Tribe, Crow Creek Sioux Tribe, Lower Brule Sioux Tribe, Rosebud Sioux Tribe, Santee Sioux Tribe of Nebraska, Yankton Sioux Tribe, Sprit Lake Sioux Tribe, Flandreau Santee Sioux Tribe of South Dakota, Sisseton-Wahpeton Oyate of the Lake Travers Reservation, and the Standing Rock Sioux Tribe. Two of these, the Arikara and Crow tribes, were scouts for the U.S. Army. An estimated 7,000 Indian men, women, and children, in more than 1,000 lodges, comprised the Indian encampment (John Doerner, chief historian, Little Bighorn Battlefield National Monument, telephone communication, March 10, 2011).

Almost overnight, the site of the Battle of the Little Bighorn became a national shrine and tourist attraction (Mangum 2000). Just three years after the battle, Congress designated the site "Custer Battlefield National Cemetery" under the administration of the War Department. Starting in 1881, the War Department began to erect stone memorials, monuments, and markers that told the Cavalry side of the story. The list of classified structures for Little Bighorn Battlefield National Monument contains 65 separate entries, including the Superintendent's House (referred to as The Stone House; fig. 15), 7th Cavalry Memorial (figs. 16 and 17), Reno-Benteen Monument (fig. 16), marble markers on the battlefield (fig. 17), and marble headstones in the national cemetery (fig. 2). There are approximately 5,000 individuals interred in the national cemetery, including soldiers from frontier posts and veterans from the Spanish American War, World War I and II, the Korean War, and the Vietnam War.

Gradually, the national monument has also come to include the Indian side of the story. In 1999 and 2001, the National Park Service installed red granite markers on sites where Indian warriors were known to have died (fig. 17), and in 2003 the Indian Memorial was dedicated (fig. 18). Significantly, this is the only national battlefield with markers that show where both Army soldiers and Indian warriors fell (National Parks Conservation Association 2003).

Connected by a 6.6-km (4.1-mi) stretch of paved road, Custer Battlefield and Reno-Benteen Battlefield comprise the 310 ha (765 ac) of Little Bighorn Battlefield National Monument (fig. 1). The Custer Battlefield unit covers 244 ha (603 ac) and includes Last Stand Hill, the Indian Memorial, a visitor center/museum, Custer National Cemetery, The Stone House (fig. 15), and other NPS buildings and housing. Located south of the Custer Battlefield, the Reno-Benteen Battlefield unit consists of 66 ha (162 ac), and includes a granite monument on the Reno-Benteen Defense Site (fig. 16). Little Bighorn Battlefield National Monument also houses one of the National Park Service's most impressive collections, with 119,000 artifacts and archives (Melana Stichman, resource manager, Little Bighorn Battlefield National Monument, written communication, June 24, 2011).

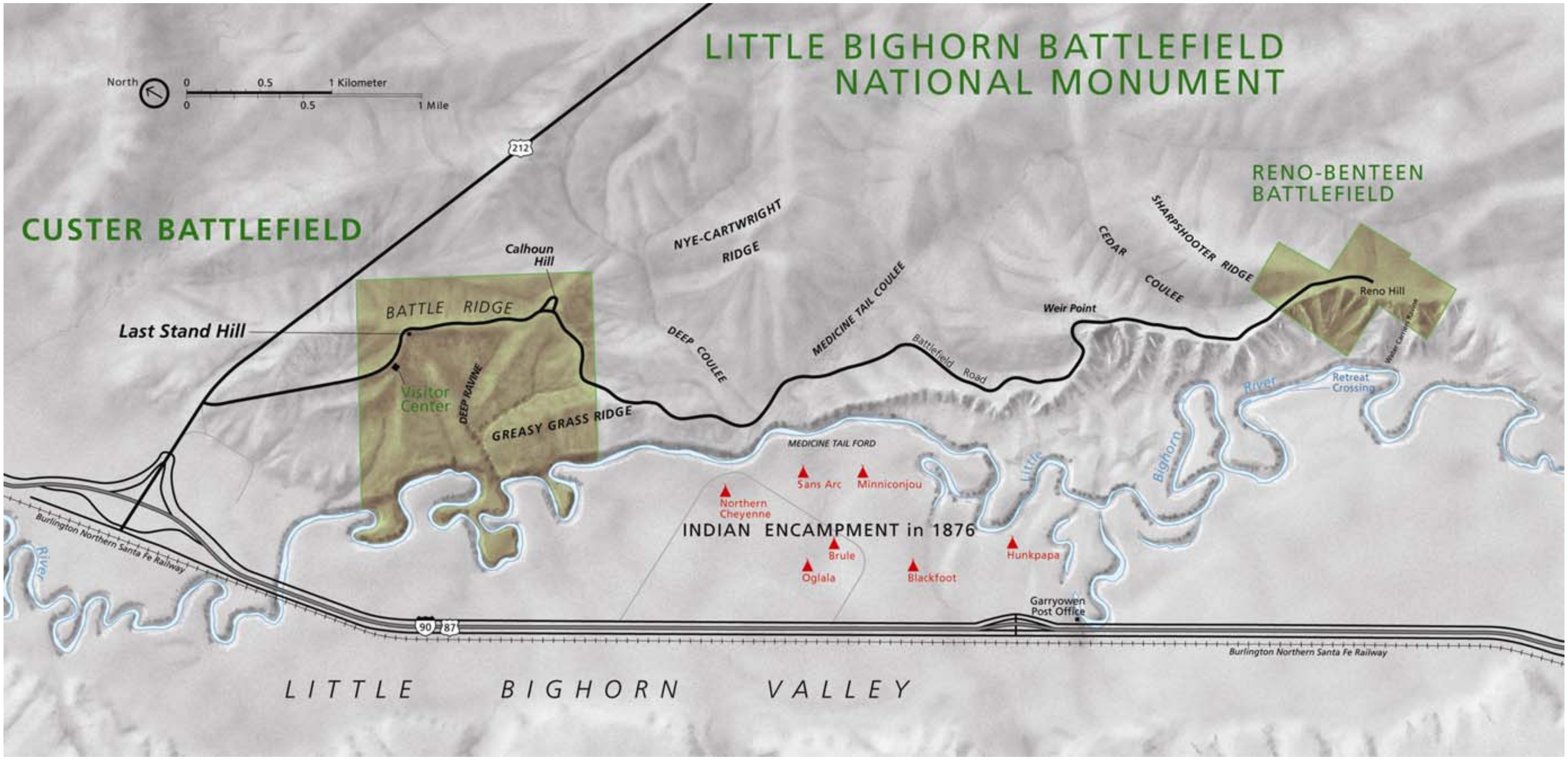



**Figure 1. Location map for Little Bighorn Battlefield National Monument. Little Bighorn Battlefield National Monument is in southeastern Montana in the valley of the Little Bighorn River. Note the meandering nature of the river and numerous landforms—ridges, hills, ravines, and coulees—depicted on the map. The national monument encompasses 310 ha (765 ac) of land split between the Custer Battlefield and Reno-Benteen Battlefield units. Battlefield Road connects the two units. National Park Service graphic.**

**Figure 2. Situated above the valley of the Little Bighorn River, the even spacing and straight rows of the marble headstones in Custer National Cemetery contrast with the surrounding, rolling topography and meandering river. Photo by John Doerner (Little Bighorn Battlefield National Monument).**

# Geologic Issues

*The Geologic Resources Division held a Geologic Resources Inventory scoping meeting for Little Bighorn Battlefield National Monument on May 18–19, 2005, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.*

### Little Bighorn River

The Little Bighorn River forms the southwestern boundary of the Custer Battlefield unit of Little Bighorn Battlefield National Monument (figs. 1 and 3). Although the Custer Battlefield unit is only 1.6 km (1 mi) wide from north to south, the boundary with the Little Bighorn River is three times this length because of stream meanders (Bramblett and Zale 2002). The river also runs near the western edge of the Reno-Benteen Battlefield unit but does not overlap it.

The Little Bighorn River drains an area of about 3,370 $km^2$ (1,300 $mi^2$), most of which—about 2,850 $km^2$ (1,100 $mi^2$)—is part of the Crow Indian Reservation. The headwaters of the Little Bighorn River are in the Wolf Mountains of Wyoming. From its headwaters, the Little Bighorn River flows swiftly and turbulently through a narrow, 610-m- (2,000-ft-) deep canyon at the Montana–Wyoming state line. From the canyon to its junction with the Bighorn River at Hardin, Montana, the Little Bighorn River is a meandering stream bounded by terraces (Moulder et al. 1960) (see "Landforms"). The increasing sinuosity of the channel as it meanders downstream is a reflection of the interaction between local gradient, sediment particle size of the floodplain deposits, and the conditions of riparian vegetation (Beschta 1998). A gravel/cobble substrate comprises most of the Little Bighorn River's streambed. The coarser sediments underlie finer textured soils associated with the riverbanks and floodplains (Beschta 1998).

#### Flooding

Overbank flows (flooding) represent an important floodplain function for low-gradient rivers such as the Little Bighorn River. During periods of overbank flow, significant detention storage of floodwaters can occur, moisture levels of floodplain soils and underlying aquifers are recharged, and fine sediments are deposited on floodplain surfaces. Overbank flows are crucial for the establishment and maintenance of riparian vegetation and aquatic habitats (Beschta 1998).

As an indicator of flooding potential in southeastern Montana, a record flood occurred on May 16–22, 1978. Runoff from abnormally high rainfall, combined with runoff from snowmelt, produced above-average stream flows. Peak flows exceeded the previous peak of record and also exceeded the computed 100-year-flood frequency (Parrett et al. 1978). On May 20, 1978, flows at the station on the Little Bighorn River near Hardin, Montana, were 447 $m^3$/s (15,800 $ft^3$/s) (U.S. Geological Survey 2011). The U.S. Geological Survey did not record gage height at this station until 2004, although Parrett et al. (1978) recorded a gage height of 3.41 m (11.19 ft) on May 19, 1978, for 637 $m^3$/s (22,500 $ft^3$/s) of flow. Flood stage is 2.4 m (8 ft). More recently, May 21–23, 2011, near record precipitation resulted in a major flood that inundated the Little Bighorn River valley. The floodwaters drew many comparisons to the 1978 floods (Thackeray 2011). The Little Bighorn River stream gage near Hardin measured 3.51 m (11.51 ft) on May 23, 2011. Discharge was 396 $m^3$/s (14,000 $ft^3$/s) (U.S. Geological Survey 2011). The flood forced the closure of Interstate 90 and the national monument, and likely exceeded the 500 year floodplain (Melana Stichman, resource manager, Little Bighorn Battlefield NM, written communication, June 27, 2011). Erosion from the heavy precipitation significantly damaged the Deep Ravine Trail within the national monument (Friends of the Little Bighorn Battlefield 2011).

Flooding can also occur as a result of ice jams during high spring runoff. Ice jams cause flooding of low-lying alluvial lands, which are chiefly pasture or woodland, along the Little Bighorn River (Moulder et al. 1960). Finally, during localized cloudbursts or thunderstorms, flash flooding is possible in narrow coulees (David Lopez, geologist/consultant, written communication, March 17, 2011).

The primary concern regarding flooding at the national monument is the potential loss of artifacts on the floodplain and riverbanks of the Little Bighorn River; this may require some type of stabilization to preserve potential collection sites (National Park Service 2007).

#### Anthropogenic Disturbances

Based on interpretation of aerial photographs taken in 1939, most sections of the Little Bighorn River had a sinuous, single-thread channel, with well-vegetated riverbanks and floodplains at that time (Beschta 1998). By the early 1960s, more than one-half (approximately 53%) of the 193 km (120 mi) of the main stem of the Little Bighorn River had been modified via channel relocation, riprap, channel clearing, and diking (Beschta 1998).

In the immediate vicinity of Little Bighorn Battlefield National Monument, a large portion of the meander belt has been prevented from continued fluvial processes by the construction of I-90 and the Burlington Northern Railroad grade (Martin 2010) (fig. 3). In addition, on the west side of the valley, the Little Bighorn River has been diverted from its natural channel to an artificial channel along the east side of the valley, about 3.2 km (2 mi) above its confluence with the Bighorn River at Hardin (Moulder et al. 1960).

According to Beschta (1998), the primary causes of substantive changes in the Little Bighorn River channel are (1) the widespread removal of streamside vegetation for agricultural and grazing purposes, (2) continued grazing of existing and reestablishing streamside vegetation, and (3) disturbance of the riverbanks and beds by bulldozer activity (in an attempt to increase channel stability by constructing berms, which actually increased the potential for long-term bank erosion, sediment transport, and channel instability).

Fortunately for the preservation of fluvial processes locally at Little Bighorn Battlefield National Monument, the battlefield is composed of a relatively undisturbed, mixed-grass, native prairie. The Custer Battlefield unit has been protected from grazing since the battle in 1876 (Britten et al. 2007). The Reno-Benteen Battlefield unit was partially fenced off in 1947, completely enclosed in 1954, and has subsequently self-restored to the pre-grazing plant community (Timmons and Wheeler 2010). Protection has resulted in particularly diverse riparian areas within the national monument (Bock and Bock 2006). However, Bock and Bock (2006)—a survey of vascular plants and birds of Little Bighorn Battlefield—suggested that riparian areas within the national monument could benefit from some active management, namely the removal of two nonnative woody species—honeysuckle (*Lonicera tatarica*) and Russian olive (*Eleagnus angustifolia*)—and the nurturing and judicious planting of native willow (*Salix amygdaloides* and *S. exigua*). Plantings could perhaps coincide with areas where significant channel adjustments have occurred. Indicators that a channel has undergone adjustments include (1) decreased width of the active channel; (2) decreased channel sinuosity, which results in increased local channel gradient; (3) sinuous, single-thread channels becoming braided; (4) frequent changes in channel form and location; (5) greatly accelerated riverbank and floodplain erosion; (6) channel downcutting; and (7) a general simplification of channel morphology, decreased connectivity with floodplains, and loss of instream habitat (Beschta 1998).

### Channel Migration

Decreasing sinuosity (river straightening) of the Little Bighorn River can increase stream power and, thereby, the potential for accelerated streambed and riverbank erosion (Beschta 1998). In the reach at Little Bighorn Battlefield National Monument, however, the river has been able to maintain a very sinuous and well-developed meander pattern, despite losing a portion of the valley's width to infrastructure (see "Anthropogenic Disturbances"). The primary meander belt of this segment of the Little Bighorn River has occupied the river-right side of the valley since the time of the Battle of the Little Bighorn (Martin 2010). The river continues to rework the older deposits in the river valley, abandoning established meanders and forming new ones. Evidence of this ongoing process is readily apparent in satellite imagery, aerial photos, and published maps, where numerous meanders and oxbows are visible (Martin 2010) (figs. 3–5).

Although channel migration is predominantly a natural phenomenon, this ongoing process has raised concern for the preservation of cultural resources within the national monument. On the length of the river that runs along the boundary of the Custer Battlefield unit, there is a well-developed meander that is very close to being abandoned through channel migration (fig. 4). This meander is the most upstream (farthest south) position of the three distinctive meander loops currently along the national monument's boundary (fig. 3). The alluvial deposit through which this meander is cutting likely contains cultural artifacts that would be lost as a result of channel migration (Martin 2010) and oxbow formation (fig. 5).

In August 2010, an interdisciplinary team of natural resource specialists, an archaeologist, and a hydrologist from Little Bighorn Battlefield, Bighorn Canyon National Recreation Area, and the NPS Water Resources Division evaluated ongoing channel migration, the presence of cultural material in the eroding alluvial deposit, and the feasibility of various stabilization treatments (Martin 2010). The team concluded that, overall, the river displays the elements of a properly functioning meandering stream. The observed erosion and channel migration is predominantly a natural process consistent with meandering river evolution. Furthermore, a cursory reconnaissance of the site failed to detect any cultural material on the surface or in the eroding bank. Consequently, investigators saw no compelling reason to undertake bank stabilization treatments (Martin 2010).

Ultimately, the meander of interest will form an oxbow. Oxbows are classic geomorphic features created as a river migrates across its floodplain in closely looping stream meanders. The piece of land left between the two endpoints of the meander is the "ox's neck" (figs. 4 and 5). Eventually, the stream will cut across the narrow neck, abandoning the meander and creating an oxbow lake. Over time, oxbow lakes (fig. 4) fill with sediment, but oxbow scars remain apparent on the landscape. A thorough inventory of oxbows in the vicinity of Little Bighorn Battlefield National Monument has not been conducted; however, comparison between the 1891 map depiction, which shows past oxbow lakes, and recent aerial photographs, which show oxbow scars, illustrates the continuation of this process over time (fig. 3).

The national monument may want to consider an inventory of oxbows and other channel migration features. Such an inventory could provide more information about how the river morphology has changed following the 1876 battle, and perhaps even over a longer timescale (Pleistocene or Holocene). Remapping of the river channel, or comparison of aerial photographs following the 2011 flooding could provide information regarding the record flood's impact on river morphology.

Lord et al. (2009) provided an overview of river and stream dynamics, described potential stressors that may lead to channel instability, and provided guidelines and methodologies for monitoring streams and rivers. Their "vital signs" and monitoring methods include (1) watershed landscape, (2) hydrology, (3) sediment transport, (4) channel cross section, (5) channel plan form, and (6) channel longitudinal profile. This information might assist national monument staff in their resource management efforts along the Little Bighorn River.

### Erosion

Upper Cretaceous (99.6 million to 65.5 million years ago) bedrock units, specifically the Judith River (Kjr) and Bearpaw (Kb) formations, underlie the broad alluvial valley of the Little Bighorn River and Little Bighorn Battlefield National Monument. These rocks are sandstone interbedded with shale (Kjr) and shale interbedded with sandstone (Kb). In general, shale gives rise to broad flats, while more resistant sandstone forms steep slopes (Thom et al. 1935). The resultant landscape is a series of dissected ridges that sit relatively high above the river valley (see "Landforms").

#### Piping and Sheet Flow

The composition of shale (i.e., clay, silt, or mud) and sandstone (i.e., sand in a matrix of silt or clay) results in a landscape that is highly erodible and especially susceptible to hydraulic piping (Martin 2010) (fig. 6). Piping causes the formation of narrow conduits, tunnels, or "pipes" through which soluble or granular soil material is removed (Neuendorf et al. 2005). Piping is a major management issue in anthropogenic areas such as earthen dams and raised roads (Pete Biggam, soil scientist, NPS Soils Program, e-mail communication, February 23, 2007). Piping can also occur in natural settings, typically when sheetwash erosion starts to concentrate into rill erosion, entering a soil through cracks, animal burrows, fence-post holes, or excavations, and eventually moving through the subsurface to an exit point (Pete Biggam, soil scientist, NPS Soils Program, e-mail communication, February 23, 2007). Following the precipitation of May 2011, one of the sediment pipes in the park created a sink hole approximately 20 m (66 ft) wide, 100 m (330 ft) long, and up to 15 m (49 ft) deep. (Chris Finley, archeologist, Bighorn Canyon National Recreation Area, email correspondence, May 28, 2011).

The primary agent of erosion across the Little Bighorn landscape is sheet flow. Sheet flow—the movement of water across a sloping surface—causes sheet erosion, which is also referred to as "sheetwash," "slope wash," or "surface wash." Sheet flow is the even removal of thin layers of surface material from an extensive area of gently sloping land. Broad continuous sheets of running water, rather than streams flowing in well-defined channels, are the agents of erosion (Neuendorf et al. 2005). However, sheet flow can grade into channelized flow as the water movement becomes progressively more concentrated into particular down-slope routes, such as coulees. For this reason, the distinction between "sheet flow" and "channelized flow" is sometimes indefinite (Summerfield 1991).

These two processes—sheet flow and piping—can dramatically degrade upland soils (Martin 2010). Once soil piping begins, it is very difficult to alleviate (Martin 2010). Consequently, during a geomorphic evaluation of channel migration at Little Bighorn Battlefield National Monument, investigators recommended "careful management of the uplands," especially those areas adjacent to the river valley (Martin 2010, p. 8). A soil resources inventory and database for the park was completed by National Park Service (2006).

#### Management of Erosion

Although active management at Little Bighorn Battlefield discourages activities that denude slopes of anchoring vegetation and compromise soil structure, staff members at Little Bighorn have noticed an increase in "social trails," primarily in areas where no maintained trails exist, such as on Last Stand Hill (National Park Service 2007). This impact is especially apparent surrounding the Indian Memorial, 7th Cavalry Memorial, 7th Cavalry Horse Cemetery, and the Crazy Horse/Keogh Trail (National Park Service 2007). Several social trails also have developed near small pull-offs along Battlefield Road. Even with the dense grass coverage, these trails form quite rapidly and begin to attract others to walk on them (National Park Service 2007).

Recent improvements to the trail system at Deep Ravine indicate that there is a correlation between improved trails and a decrease in the formation of social trails. Since the new trail system at Deep Ravine opened, the proliferation of social trails has "decreased dramatically" (National Park Service 2007). Short of improving all trail systems, however, park managers are addressing the problem by developing revegetation projects to reintroduce native "prickly" species such as yucca and cactus, in accordance with the national monument's resources management plan (National Park Service 2007). These methods will help to minimize both shortcutting and the continued use of unauthorized trails (National Park Service 2007). Bock and Bock (2006, p. 28) commended the National Park Service at Little Bighorn for "the re-working of visitor movement patterns and the excellent trail relocation, along with appropriate enforcement to keep visitors on the trails."

Another erosion-related issue at the national monument is the occurrence of headcuts in Deep Ravine (Martin 2010) (fig. 7). Deep Ravine is an important part of the historic landscape and likely contains cultural material (Staff, Little Bighorn Battlefield National Monument, personal communication in Martin 2010, p. 8). According to Martin (2010), the small headcuts—vertical faces or drops on the bed of a stream channel, in this case an intermittent stream, occurring at a knickpoint (break in the slope)—occurring in Deep Ravine could probably be stabilized fairly easily with hand labor, and are probably worthy of some form of treatment. Because this is a less dynamic environment than an active stream channel, there is a relatively high chance of success (Martin 2010). Deep Ravine Trail was significantly impacted by erosion associated with May 2011 precipitation (fig. 8) (Friends of Little Bighorn Battlefield 2011). As of June 2011, significant erosion continues at Deep Ravine. Additional landslides and erosion issues are also impacting steep slopes throughout the park, particularly within the Reno-Benteen unit and along the river bluffs of the Custer Battlefield unit (Melana Stichman, resource manager, Little Bighorn Battlefield National Monument, written communication, June 27, 2011).

#### Energy Development

Montana is rich in fossil fuels, and coal-fired power plants dominate Montana's electricity market (Energy Information Administration 2010). There are five plants currently operating in Montana, all of which are relatively near Little Bighorn Battlefield National Monument. Approximately 21 km (13 mi) from the national monument, Hardin Generator Project is the closest plant and has a 116-meagwatt capacity. Approximately 108 km (67 mi) from Little Bighorn Battlefield National Monument, the Colstrip plant has the greatest capacity at 2,094 megawatts (PPL Corporation 2010a). The J. E. Corette plant near Billings, 97 km (60 mi) from the national monument, has a 154-megawatt capacity (PPL Corporation 2010b). Two stations for the Montana-Dakota Utilities also produce coal-generated energy within the state: Lewis and Clark (57 megawatts) in Colstrip, and Glendive Generating (84 megawatts) in Glendive, approximately 331 km (206 mi) from the national monument.

The primary concern with energy development for Little Bighorn Battlefield National Monument is the protection of resources (soils, vegetation, and water) (National Parks Conservation Association 2003). Emissions from coal-fired power plants are principally an issue for air quality. The National Park Service addresses the effect of pollutants on vegetation in the invasive plant management plan for Little Bighorn Battlefield National Monument (in draft form as of June 2011; Melana Stichman, resource manager, Little Bighorn Battlefield National Monument, written communication, June 27, 2011) . Moreover, the U.S. Geological Survey monitors air-quality conditions at Little Bighorn Battlefield National Monument as part of the National Atmospheric Deposition Program (NADP).

However, the use of coal for energy is also a geologic issue with respect to sources of coal and locations of mines. The primary source of the coal used in Montana's coal-fired power plants is the Paleocene (65.5 million to 55.8 million years ago) Fort Union Formation of the Powder River Basin. This formation crops out approximately 24 km (15 mi) east of Little Bighorn Battlefield National Monument. The beds of Parkman Sandstone (Kjp), Bearpaw Formation (Kb), and Lance Formation (Kl), shown on the digital geologic map and known to be coal-bearing formations elsewhere, do not host coal in the vicinity of the national monument.

#### Land Use and Development

The primary concern for development within and adjacent to Little Bighorn Battlefield National Monument is that contemporary structures and roadways threaten the battlefield's historic character and viewshed. Although many of the primary views retain near-historic authenticity, modern transportation development—road grading, parking lots, and vehicular movement across the site—disrupts the historic scene (Timmons and Wheeler 2010).

In addition, land-use changes and development can disrupt geologic features and processes. Construction and associated ground-disturbing activities can result in increased erosion, runoff, and sedimentation into fluvial systems; exacerbated eolian processes (e.g., dust storms); soil compaction; and the formation of ruts. Resistance to compaction in the soils at Little Bighorn Battlefield is low (i.e., the soils have one or more features that favor the formation of a compacted layer), and the susceptibility to rut formation is severe (i.e., ruts form readily) (National Park Service 2006; Natural Resources Conservation Service 2008). Soil compaction reduces vegetation and increases runoff, potentially changing species characterization. Soil ruts restrict the movement of water, robbing the surrounding areas of moisture they would otherwise receive. Additionally, construction in floodplains (e.g., buildings and bridges) can impact fluvial processes (see "Little Bighorn River"). Also, improved road access can increase the threat to (and loss of) resources such as fossils (see "Paleontological Resources") as a result of erosion and theft.

Notable development within Little Bighorn Battlefield National Monument includes road construction, which created a major cut slope near Weir Point in 1938–1940 (fig. 9), and leveling a portion of Reno Hill for a parking lot. According to Timmons and Wheeler (2010)—the national monument's cultural landscapes inventory—a rather heavy-handed approach to road building was seen frequently during an era not yet enlightened to sensitive treatment of historic landscapes. Development at this time degraded several primary landforms/landscape features, including the original contours of Last Stand Hill, the demolition of several smaller hillocks along Battle Ridge, the re-alignment of Medicine Tail Ford from its 1876 channel, a major road cut at Weir Point, and the flattening of significant landforms near the Reno-Benteen Memorial (Timmons and Wheeler 2010) (fig. 9).

Despite an increasing awareness and progress in protecting the historic authenticity and natural resources of the battlefield area, continued encroachment on the landscape remains a primary threat (National Park

Service 2001). Nearby residential and commercial construction has increased significantly in recent years (National Park Service 2001). Developments that have had impact include gravel mining, cell phone towers, private businesses, residential housing and ranches, and a future state rest area (at Exit 510) (Timmons and Wheeler 2010). The National Park Service is working with the Crow Tribe, Custer Battlefield Land Preservation Committee, and private landowners to preserve the viewshed within the entire corridor of the historic battle, reaching beyond the 310 ha (765 ac) of NPS lands (National Park Service 2001).

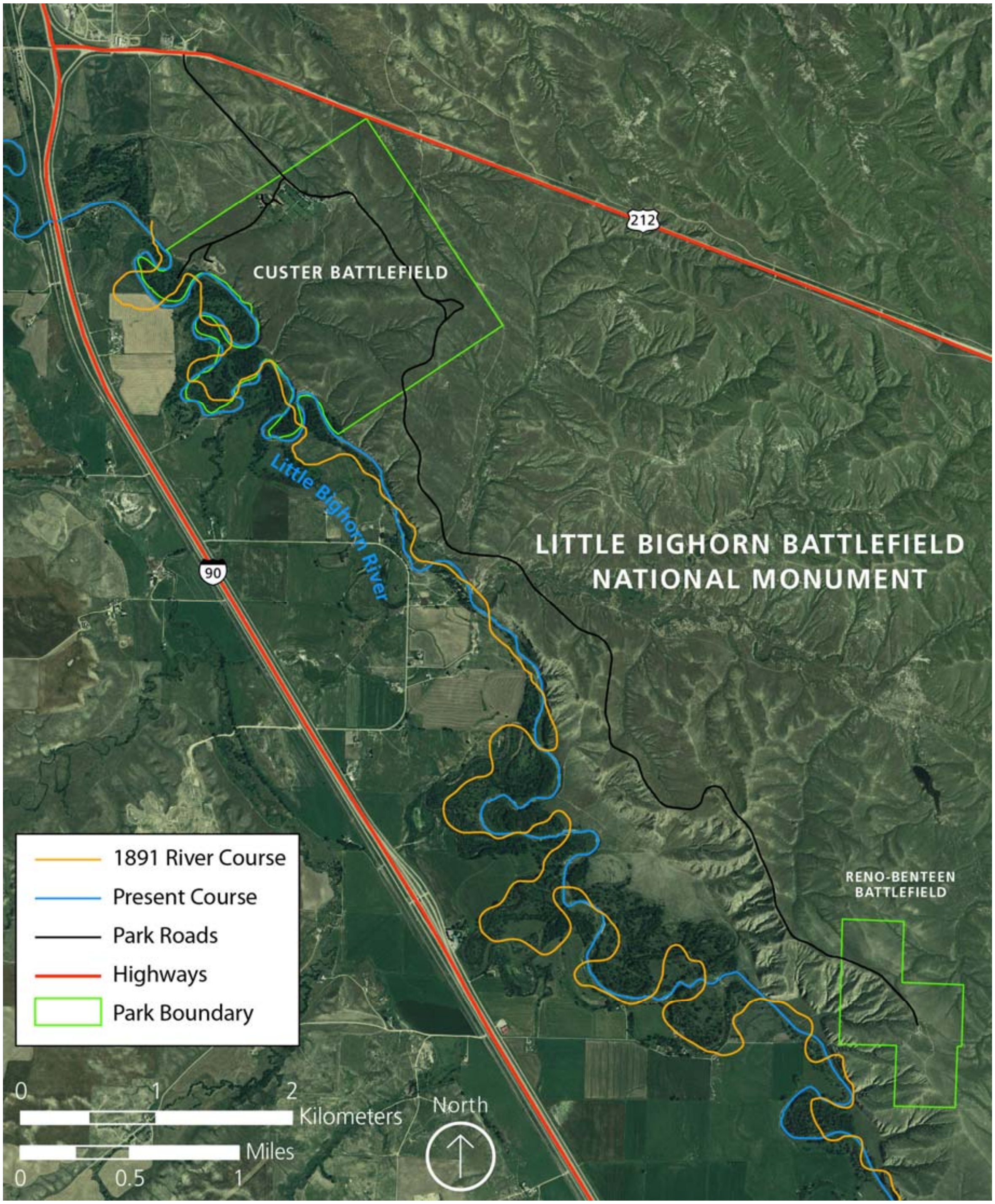



**Figure 3. Comparison of the Little Bighorn River channel between modern channel (blue) and an 1891 map depiction produced soon after the battle (orange). This comparison highlights that the meanders have shifted significantly. The river has maintained substantial sinuosity overall, even though the transportation corridor (I-90 and the Burlington Northern Railroad grade) has infringed upon the meander belt. Adapted from Martin (2010), by Phil Reiker (NPS Geologic Resources Division).**

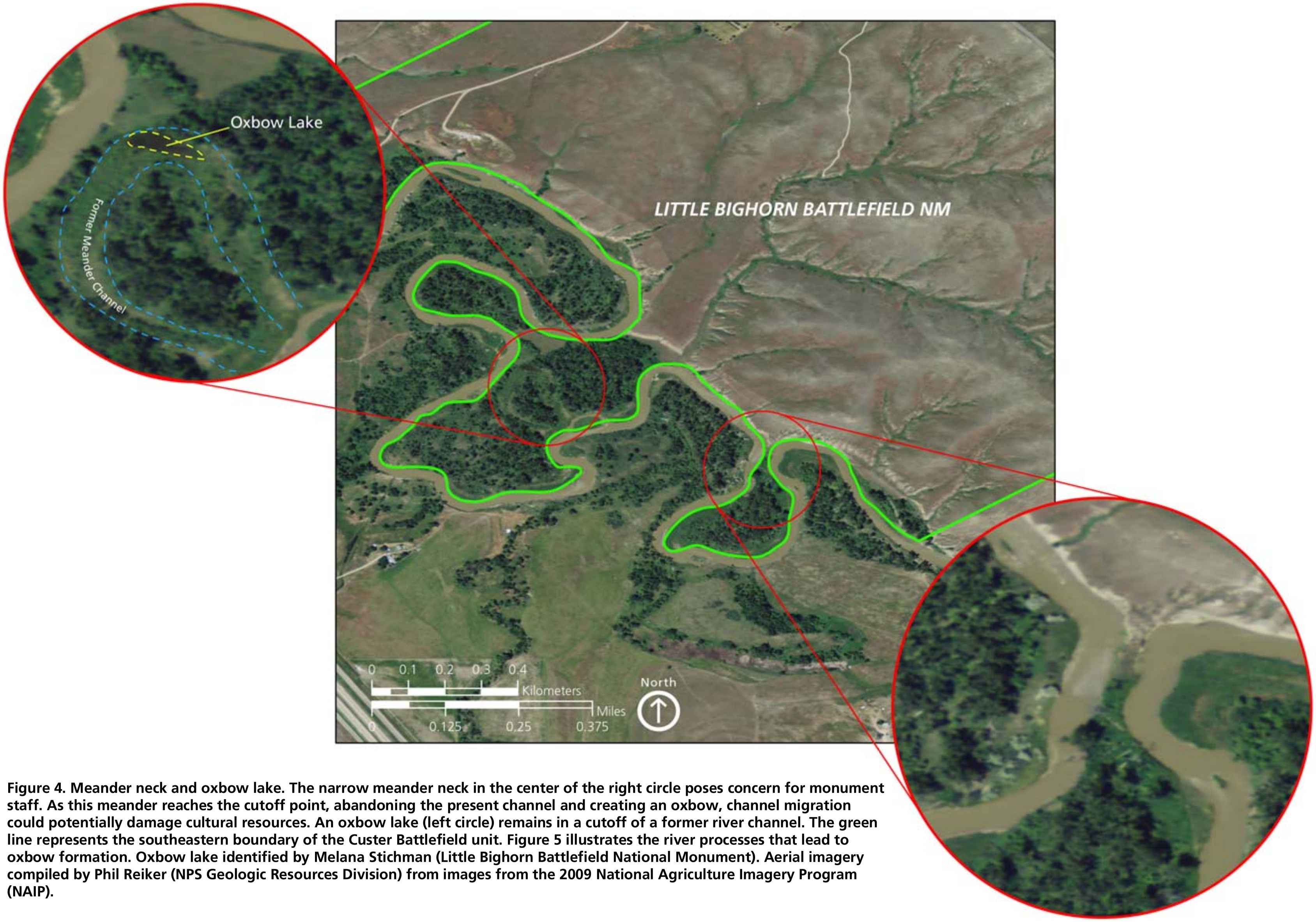



**Figure 4. Meander neck and oxbow lake. The narrow meander neck in the center of the right circle poses concern for monument staff. As this meander reaches the cutoff point, abandoning the present channel and creating an oxbow, channel migration could potentially damage cultural resources. An oxbow lake (left circle) remains in a cutoff of a former river channel. The green line represents the southeastern boundary of the Custer Battlefield unit. Figure 5 illustrates the river processes that lead to oxbow formation. Oxbow lake identified by Melana Stichman (Little Bighorn Battlefield National Monument). Aerial imagery compiled by Phil Reiker (NPS Geologic Resources Division) from images from the 2009 National Agriculture Imagery Program (NAIP).**

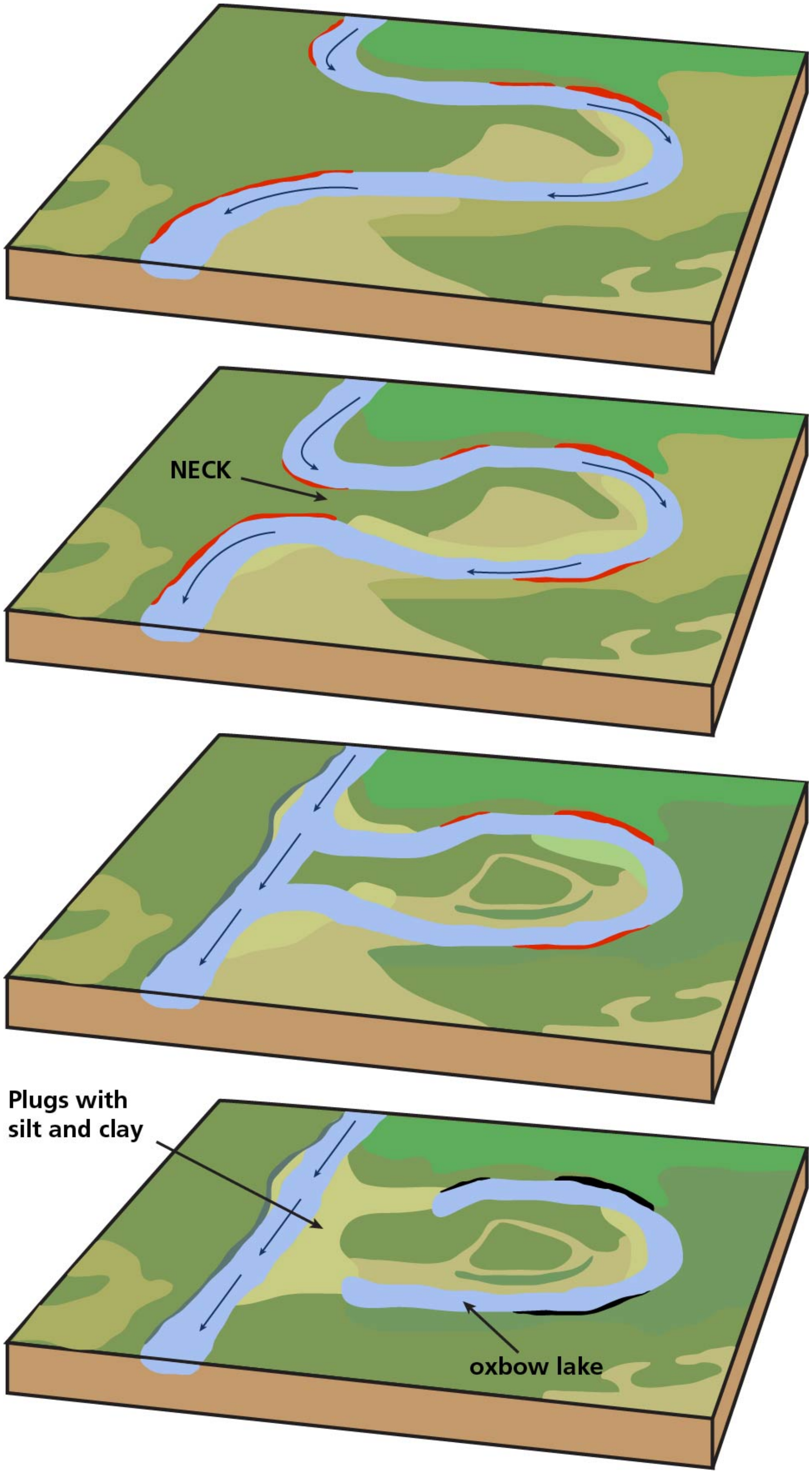



**Figure 5. Evolution of a meandering stream includes the following: (1) stream channel within meander belt; (2) development of an almost completely closed meander loop; (3) high water (during a flood) flowing across the neck of the loop, making a cutoff; and (4) deposition of sediment sealing the loop ends and creating an oxbow lake. Areas in red indicate active bank cutting or erosion. Graphic by Phil Reiker (NPS Geologic Resources Division).**

Figure 6. Piping in the soils at Little Bighorn Battlefield National Monument causes the formation of "pipes" (narrow conduits or tunnels) through which soluble or granular soil material is removed. Photo by Michael Timmons (Utah State University).

Figure 7. Deep Ravine is an important part of the historic landscape at Little Bighorn Battlefield National Monument. Headcuts (erosion-related features in the intermittent stream channel) are forming in the ravine at two knickpoints (breaks in the slope). This photo shows the larger of the two headcuts. Compare to figure 8. Photo by Mike Martin (NPS Water Resources Division).

Figure 8. During May 2011, erosion significantly altered the Deep Ravine headcut. Although not taken at the exact same location as figure 7, significant differences in the morphology of the headcut are apparent. Photo courtesy Melana Stichman (Little Bighorn Battlefield National Monument).

Figure 9. In 1938–1940, construction of Battlefield Road created a major cut slope near Weir Point. Past development of roads degraded significant landforms and altered the historic scene. Photo by Michael Timmons (Utah State University).

# Geologic Features and Processes

*This section describes the most prominent and distinctive geologic features and processes in Little Bighorn Battlefield National Monument.*

### Landforms

The natural landscape at Little Bighorn Battlefield National Monument played a significant role in the events of the Battle of the Little Bighorn. Many descriptions of the battle mention the landscape and its landforms, for example, the description noted in the official national park handbook (Utley 2000). These geologic features factored strongly in the strategy and outcome of the battle (fig. 10).

#### Ridges, Hills, Ravines, and Coulees

The topography of Little Bighorn Battlefield National Monument is dominated by ridges that rise above the floodplain of the Little Bighorn River. Ravines and coulees dissect these ridges (fig. 10). During storms and runoff events, water may flow in these incised channels. Only the main streams in the Little Bighorn area are perennial (i.e., the Little Bighorn River and its two tributaries, Lodge Grass Creek and Pass Creek). Numerous intermittent streams, which enter the valley from the east and west, carry large volumes of water during and immediately after storms (Thom et al. 1935). Although temporary, the volume of water carried during storm events provides enough erosive power to chisel coulees into the landscape (fig. 11).

During the Battle of the Little Bighorn, the ridges provided views across the broad valley and, also, provided defensible high ground for soldiers of the 7th Cavalry. Some of the most famous ridges in the vicinity of Little Bighorn Battlefield National Monument are Battle Ridge, Greasy Grass Ridge, Nye-Cartwright Ridge, and Sharpshooter Ridge (figs. 1 and 10). Associated with ridges are hills. For example, Last Stand Hill and Calhoun Hill anchor either end of Battle Ridge, which became a strategically important feature as the Battle of the Little Bighorn unfolded (Timmons and Wheeler 2010). Reno Hill dominates the Reno-Benteen Battlefield unit. Soldiers who survived the Battle of the Little Bighorn successfully defended this site of high ground (fig. 10).

Ravines and coulees, which cut into the ridges, allowed for the secluded advance of Indian attackers (Timmons and Wheeler 2010). The incised ravines and coulees also provided access routes to the higher ground for the retreating soldiers under Reno's command. During the siege of Reno's position, "water carriers" used the steep-banked terrain of Water Carriers Ravine to provide cover as they scrambled to the river below with canteens, thereby saving the lives of thirsting soldiers entrenched on Reno Hill (Timmons and Wheeler 2010) (fig. 10).

#### Riverbanks

The steep banks, which line the east side of the Little Bighorn River, form an abrupt edge, limiting access from the floodplain (fig. 12). The riverbanks are composed of alluvium (Qal)—gravel, sand, silt, and clay—and rise above the active channel as much as 10 m (35 ft) (Vuke et al. 2000a, 2000b). In early stages of the battle, Reno's men attacked the Indian village on the terraces, but were forced to retreat. After struggling to cross the river, about 40 soldiers were caught scrambling up the steep riverbanks and pulled or gunned down by Tasunke Witko (Crazy Horse) and his followers (Timmons and Wheeler 2010).

#### Terraces

Stream terraces are one of the most conspicuous geologic features in the Little Bighorn River valley. Vuke et al. (2000a, 2000b) mapped at least eight distinct levels of alluvial terrace deposits (Qat), ranging from 3 m (10 ft) to 170 m (560 ft) above the river. Holocene alluvial deposits (Qal) also include terrace deposits less than 2 m (6 ft) above the river. Terraces principally line the west side of the Little Bighorn River, although the terrace that is in the Custer Battlefield unit is on the east side of the river (see "Overview of Geologic Data").

These terraces represent past floodplain surfaces, which formed as a result of downcutting of the river in response to a drop in base level (David Lopez, geologist/consultant, written communication, March 17, 2011). The ages of the terraces are evidence that the river has flowed in this general location for more than a million years, situating itself long before the battle in 1876, and remaining there since. The lowest (youngest) terrace deposit is about 20,000 years old, and the highest (oldest) is about 1.4 million years old (Vuke et al. 2000b).

Unlike the ridges and coulees, terraces did not figure significantly into the actions taken during the Battle of the Little Bighorn. However, the warriors and their families from the various tribes selected these broad, flat surfaces as the location for their camps (figs. 1, 10, and 13). Today, terraces are used as agricultural lands irrigated by water from the Little Bighorn River (Tuck 2003). The national monument may want to consider supporting additional research into the fluvial, climatic, and tectonic history of the terraces.

### Paleontological Resources

The Bearpaw Formation (Kb) and Judith River Formation (Kjr), which underlie Little Bighorn Battlefield National Monument, both host fossils. The Bearpaw Formation (Kb) contains marine fauna such as bivalves, gastropods, scaphopods, and ammonites

(Reiskind 1975), as well as fossil lobster (Feldmann et al. 1977; Kammer and Raff 1978), crabs (Bishop 1983), and cephalopods (Cobban 1962). Horner (1979) reported four dinosaur specimens from the Bearpaw Formation in south-central Montana; these specimens represent the first dinosaur material to be reported from the Bearpaw Formation.

To date, the most notable fossil discovery at Little Bighorn Battlefield National Monument comes from the Bearpaw Formation. In 1977, an NPS employee found a short-necked plesiosaur (*Dolichorhynchops osborni* Williston) during a routine excavation of a grave in Custer National Cemetery. Tabrum (1978) summarized the discovery and concluded that this was probably the first short-necked plesiosaur collected in Montana, and the specimen may represent the first known occurrence of *Dolichorhynchops* in Campanian (Upper Cretaceous) time. Moreover, it was one of the most complete specimens known of *Dolichorhynchops osborni*; the specimen has complete pectoral and pelvic girdles, numerous ribs, and a nearly complete vertebral column. The find is significant because this extinct group of marine reptiles is poorly understood, and well-preserved specimens like this are rare. During winter 1977–1978, Tobe Wilkins (Dinosaur National Monument) prepared the specimen, which was then sent to the Smithsonian National Museum of Natural History in Washington, D.C., where it was displayed as part of the museum's "Ancient Seas" exhibit (Jennifer Young, paleontologist, Smithsonian National Museum of Natural History, personal communication in Koch et al. 2004, p. 35) (fig. 14).

The other rock unit at the national monument that has the potential to yield fossils is the Upper Cretaceous Judith River Formation (Kjr). The Judith River Formation hosts bony fish and shark remains (Case 1978; Wilson et al. 1992; Siverson 1995), dinosaur fossils (Ostrom 1964; Wall and Galton 1979; Galton and Sues 1983; Coombs 1988; Coombs and Galton 1988; Horner et al. 1992), soft-shelled turtles (Gardner et al. 1995; Blob 1997), and mammals (Montellano 1992). Rogers and Kidwell (2000) investigated terrestrial and shallow marine records of both the Judith River and Two Medicine formations in Montana, and reported the occurrence of carbonaceous plant debris, wood fragments, shell debris, freshwater clams, gastropods, shark teeth, fish bones, marine reptile bones, and dinosaur remains. Blob and Fiorillo (1996) analyzed the faunal abundance and fossil size and shape of microvertebrates of the Judith River Formation.

The 2009 Paleontological Resources Preservation Act directs the National Park Service to manage and protect paleontological resources using science-based principles and expertise. It also calls for inventory, monitoring, and scientific and educational use of fossil resources. Protection of associated location information is also required, as fossils are non-renewable resources. The National Park Service and other federal land management agencies are currently (June 2011) developing joint regulations associated with the Act. Santucci et al. (2009) outlined potential threats to in situ paleontological resources and suggested monitoring "vital signs" to qualitatively and quantitatively assess the potential impacts of these threats. Paleontological vital signs include (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use. Santucci et al. (2009) also presented detailed methodologies for monitoring each vital sign.

The national monument may want to consider field-based paleontological resource inventories to determine if additional fossil resources are present within exposed bedrock of the park.

#### Building Stone

According to the cultural landscapes inventory for the national monument, "the many monuments and headstones on the battlefield and in the national cemetery are integral to its meaning and sense of place" (Timmons and Wheeler 2010, p. 42). In addition to being significant cultural resources, these objects are also geologic resources; that is, building stone—any rock suitable for use in construction and chosen for its properties of durability, attractiveness, and economy (Neuendorf et al. 2005). However, geologic information about the building stones at Little Bighorn Battlefield National Monument is sparse: What are the stones? Where did the rocks originate? How old are they? How do these rocks relate to the surrounding geology?

Some information is available that could help track down specific geologic details. For instance, the locations of quarries are known for the building stones used in two distinctive monuments in Custer National Cemetery. First, limestone for the Fort C. F. Smith obelisk was quarried near the old fort at Fort Smith, Montana (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010). Second, red granite for the Fort Keogh Monument came from Montello and Red Granite Quarries in Montello, Wisconsin (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010). Knowing the locations of quarries could help identify the formation name on a geologic map, leading to a wealth of geologic information.

Identifying geologic information about the building stones at Little Bighorn would be an interesting geologic exercise that could promote an understanding of both natural and cultural resources. The Geologic Resources Division could assist park managers in organizing such a research effort through the Geoscientists-in-the-Parks Program (see "Additional References" for information). Another component of the research could identify late 1800s quarrying and transportation technology, providing additional interpretive material.

The following section highlights some of Little Bighorn's monuments, markers, memorials, and structures, and their building stones.

#### The Stone House

The Stone House was completed in 1894, as a residence for the first superintendent of the national cemetery, Andrew N. Grover, and his family (fig. 15). The National Register of Historic Places lists the structure as the "Superintendent's House," and states that it is constructed from "local red sandstone." The two-story stone lodge was the first permanent building at the national monument, and is also one of the first permanent dwellings in eastern Montana (National Park Service 2009). The Stone House remains the dominant structure in the Custer Battlefield unit and now houses the monument archives, library, and historian offices.

Assumed to have been mined locally, park staff has surmised that the building stone used in The Stone House is the Parkman Sandstone (John Doerner, chief historian, Little Bighorn National Monument, e-mail communication, November 16, 2010). However, reconnaissance of the geology in the area did not confirm this interpretation (David Lopez, geologist/consultant, telephone communication, March 23, 2011). In the vicinity of Little Bighorn Battlefield National Monument, the Judith River Formation (Kjr) (of which the Parkman Sandstone is a member) is quite shaley; the formation does not start to form cliffs (an indication of resilience and its potential use as a building stone) until closer to Lodge Grass, Montana (David Lopez, geologist/consultant, telephone communication, March 23, 2011). In the vicinity of Little Bighorn Battlefield National Monument, Vuke et al. (2000a, 2000b) mapped the Judith River Formation as having two members: an informal upper member (Kju) and the lower Parkman Member (Kjp). The lower member (Parkman Sandstone) is highly friable and does not make good building stone (David Lopez, geologist/consultant, written communication, March 17, 2011). The upper member is somewhat more resistant and crops out about 15 km (9.5 mi) south of the battlefield along Highway 87. East of the battlefield about 10 km (6 mi), the Lance Formation (Kl) crops out and is the closest "decent" sandstone to the battlefield (David Lopez, geologist/consultant, telephone communication, March 23, 2011). Hence, if mined locally, the best candidate for the building stone of The Stone House is most likely the Lance Formation (Kl).

Although the National Register of Historic Places states that the building stone is "local," the actual quarry site for the stone has not been confirmed. Hence, another possibility is that the building stone was not mined locally, but transported some distance via railway. In 1877, the Northern Pacific Railroad began to facilitate travel and commerce to the area. The Burlington-Quincy Railway line came into the Little Bighorn River Valley in 1894, the same year The Stone House was built. An inventory of local quarry sites would help answer this question.

Sandstone "flakes" are weathering off of the building's stones (fig. 15). This erosion is a concern for the park staff (Melana Stichman, resource manager, Little Bighorn Battlefield National Monument, written communication, June 27, 2011).

#### 7th Cavalry Memorial

A temporary monument of stacked logs from local cottonwood trees was erected on Last Stand Hill in 1879, near the site where Custer had fallen (John Doerner, chief historian, Little Bighorn Battlefield National Monument, telephone communication, November 16, 2010). Horse bones, which still littered the battleground, were gathered and placed inside the structure. In 1881, the remains of the soldiers were gathered and reburied around the base of a new permanent monument erected on Last Stand Hill. Built of granite in the form of a truncated pyramid, the 3.5-m- (11.5-ft-) high 7th Cavalry Memorial was inscribed with the names of all of the soldiers, Indian scouts, and attached personnel who fell on the battlefield (figs. 16 and 17). As a historic point of interest, this is the oldest known structure on the site; however, the geological age of the rock is not known. The Mount Auburn Marble and Granite Works of Cambridge, Massachusetts, created the monument, which was constructed in three pieces for the arduous journey to the site (Timmons and Wheeler 2010). An iron fence was constructed around the monument two years later, to prevent direct access to tourists who had been chipping away at the granite to collect a "souvenir" of their visit. The corners of the monument were beveled in 1890 to disguise the rough edges caused by this vandalism (Timmons and Wheeler 2010) (compare figs. 16 and 17). The fence was removed in 1963 (Timmons and Wheeler 2010).

#### Reno-Benteen Monument

On the 50th anniversary of the battle, in 1926, Congress authorized acquisition of the Reno-Benteen Defense Site; funds for acquisition were appropriated in 1928. In 1929, a granite monument was placed on the site (Rickey 2005). Livingston Marble and Granite Works in Livingston, Montana, supplied the granite (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010) (fig. 16).

#### Marble Markers and Cemetery Headstones

Sites where soldiers had fallen on the battlefield remained marked with wooden stakes until 1890, when they were replaced with 246 official War Department headstones of white marble (fig. 17). These marble markers conform to the official War Department standard for national cemetery headstones. The marble was supplied from Italy (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010). The overall placement of the markers helps visitors visually reconstruct the progress of the battle, creating a stark image of patterns of movement through the landscape (Timmons and Wheeler 2010). The largest concentration of markers occurs near the top of Last Stand Hill, clustered around the stone denoting the place of death of Custer himself.

In Custer National Cemetery, marble headstones mark the burial sites of approximately 5,000 individuals. Those interred include military soldiers and sailors killed in action or veterans (and their spouses) who served in the U.S. military during the Spanish American War, World War I, World War II, the Korean War, and Vietnam (Timmons and Wheeler 2010). In addition, when 23 forts throughout Montana, Wyoming, North Dakota, and South Dakota were decommissioned, the remains of those who had died at these isolated frontier posts were moved to the national cemetery (National Park Service 2009; Timmons and Wheeler 2010).

#### Granite Markers

Significantly, Little Bighorn is the only national battlefield with markers that show where both Army soldiers and Indian warriors died in battle (National Parks Conservation Association 2003). The markers for Indian warriors are of identical size and shape as the marble markers but are made of red granite—trade name "Radiant Red"—from a quarry in Cold Spring, Montana (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010). A white-paint treatment given to the engraved lettering on the markers highlights the inscription that recognizes where a particular warrior fell (fig. 17).

#### Indian Memorial

Construction of the Indian Memorial began in 1999 and was dedicated in 2003. The memorial, including the surrounding retention wall, uses sandstone quarried in Billings, Montana (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010) (fig. 18). Typically, sandstone from the Billings area used as building stone is the Eagle Sandstone (David Lopez, geologist/consultant, telephone communication, March 23, 2011). The interior walls of the memorial are black granite (John Doerner, chief historian, Little Bighorn Battlefield National Monument, e-mail communication, November 16, 2010). At least 60 Indian men, women, and children died during the battle. They fought in defense of their families, land, and traditional way of life. Inscribed on the surrounding walls of the memorial are the names of those who died during the battle.

#### Cairns

Most of the Indian dead were removed from the battlefield by the tribes immediately following the battle. However, in many instances, family members (either immediately or in ensuing years) placed small stone cairns to mark the place of death (Timmons and Wheeler 2010). These markers are made of local stone, probably collected from Battle Ridge shortly after the battle, and likely Parkman Sandstone (Kjp) (John Doerner, chief historian, Little Bighorn Battlefield National Monument, telephone communication, November 16, 2010). Although an oral history is often kept by family members, these cairns are significant because they are the only material record of where these warriors died during the battle (Timmons and Wheeler 2010).

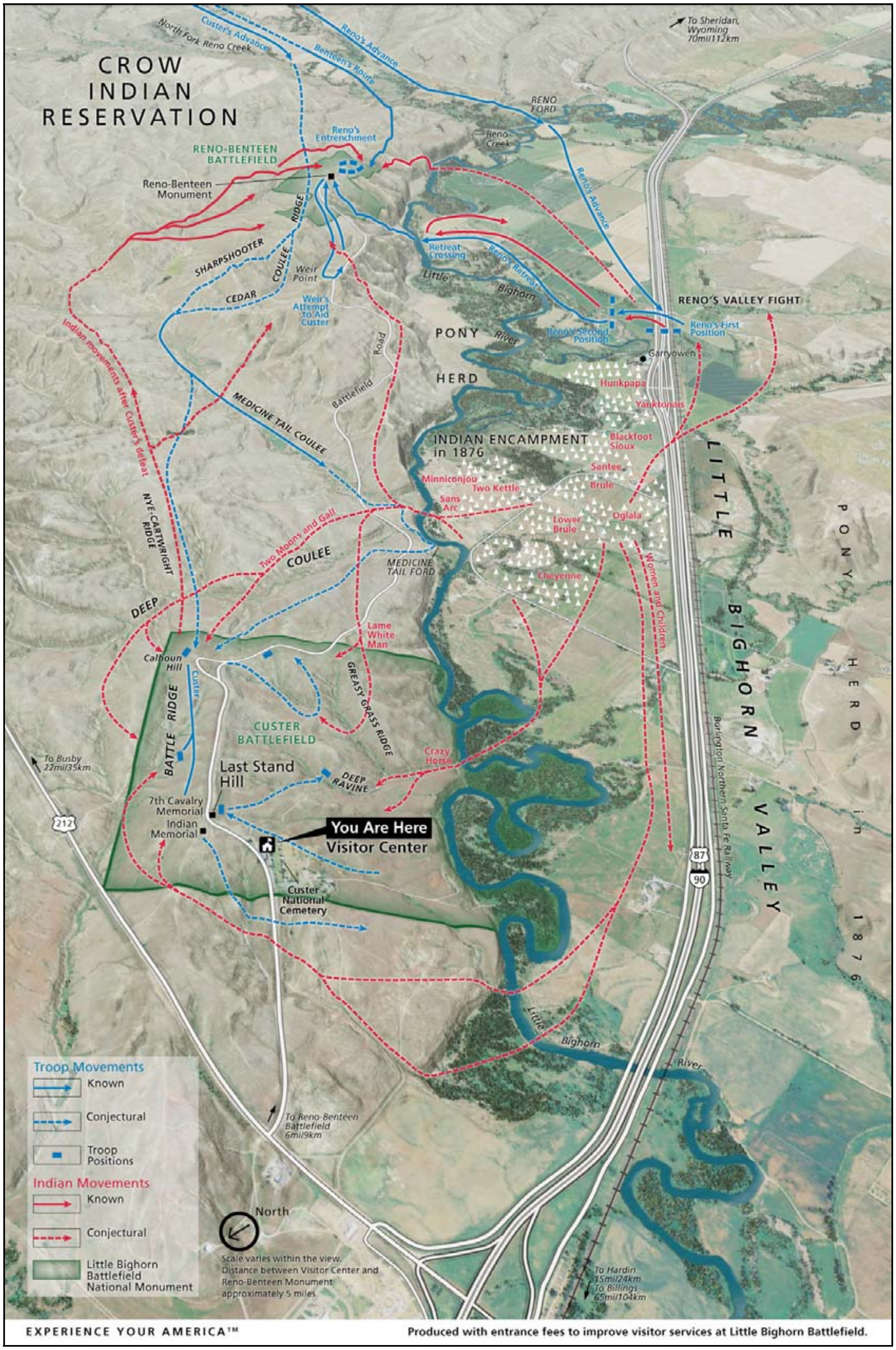



**Figure 10. This map shows U.S. Cavalry (troop) and Indian movements during the 1876 battle. Note the influence of the topography—particularly ridges, coulees, and river crossings—on military positions and movements. National Park Service graphic courtesy Melana Stichman (Little Bighorn Battlefield National Monument).**

**Figure 11. Ridges cut by ravines and coulees typify the topography at Little Bighorn Battlefield National Monument, for example at Reno's Retreat Crossing shown rising above the Little Bighorn River in the photo. Photo by Michael Timmons (Utah State University).**

**Figure 12. Steep banks line the eastern side of the Little Bighorn River. The banks form an abrupt edge, which limited access from the floodplain during the Battle of the Little Bighorn. Photo by Michael Timmons (Utah State University).**

**Figure 13. The tribes of Northern Plains Indians set up their camps on terrace deposits (Qat) above the floodplain of the Little Bighorn River. This view of the Reno-Benteen Defense Site from the valley near Garryowen shows the perspective from the southern end of the Indian encampment. The arrow points to the defense site, now marked by the Reno-Benteen Monument (fig. 16). Photo by Michael Timmons (Utah State University).**

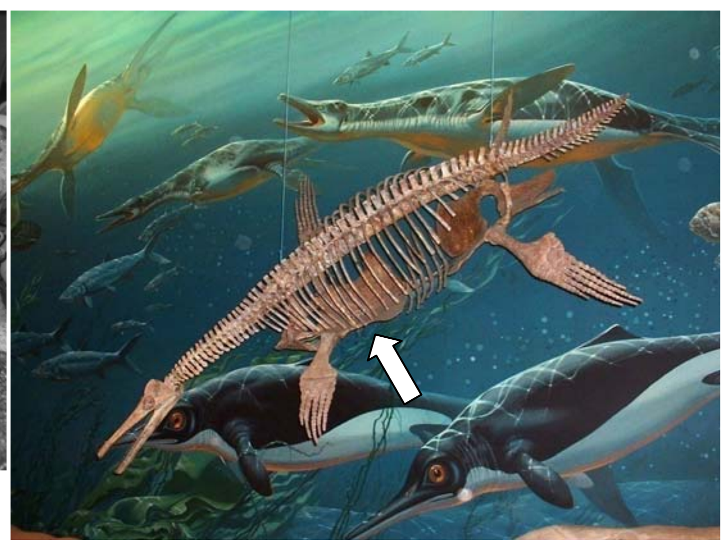


**Figure 14. Tobe Wilkins (Dinosaur National Monument) prepared the rare plesiosaur specimen (*Dolichorhynchops osborni* Williston) found in Little Bighorn Battlefield National Monument in 1977 (left). The short-necked plesiosaur discovered at Little Bighorn Battlefield National Monument was displayed as part of the "Ancient Seas" exhibit at the Smithsonian National Museum of Natural History in Washington, D.C. (right). The white arrow points to the area being prepared in the photo to the left. Plesiosaurs are group of extinct marine reptiles from the Cretaceous Period (145.5 million to 65.5 million years ago) when a vast seaway covered west-central North America. NPS photo of preparation by Jim Adams, courtesy Ann Elder (Dinosaur National Monument). Photo of exhibit by Jason Kenworthy (NPS Geologic Resources Division).**

Figure 15. The historic Stone House at the entrance of Custer National Cemetery is made of sandstone, which may have been mined locally. Flakes of sandstone "spall" off of the sandstone blocks and litter the ground surrounding the house (inset photos). Stone House photo by John Doerner (Little Bighorn Battlefield National Monument). Inset photos courtesy of Melana Stichman (Little Bighorn Battlefield National Monument).


Figure 16. Both made of granite, the 7th Cavalry Memorial (left) and Reno-Benteen Monument (right) are distinctive reminders of the Battle of the Little Bighorn in the two units of the national monument. The 7th Cavalry Memorial was erected in 1879 on Last Stand Hill in what is now the Custer Battlefield unit. The Reno-Benteen Monument was placed on the defense site in 1929, in what is now the Reno-Benteen Battlefield unit. 7th Cavalry Memorial photo (left) by National Park Service/Little Bighorn Battlefield National Monument archives. Reno-Benteen Monument photo (right) by Michael Timmons (Utah State University).


**Figure 17. Constructed of white Italian marble, the markers that represent the deaths of U.S. soldiers conform to the official War Department standard for national cemetery headstones (left). The red granite markers that represent the deaths of Indian warriors are of identical size and shape as the marble markers of U.S. soldiers but are made of "Radiant Red" granite (right). Photos by Michael Timmons (Utah State University).**

**Figure 18. The Indian Memorial incorporates sandstone from a quarry in Billings, Montana. Construction of the memorial began in 1999 and was dedicated in 2003. National Park Service photo/Little Bighorn Battlefield National Monument archives.**

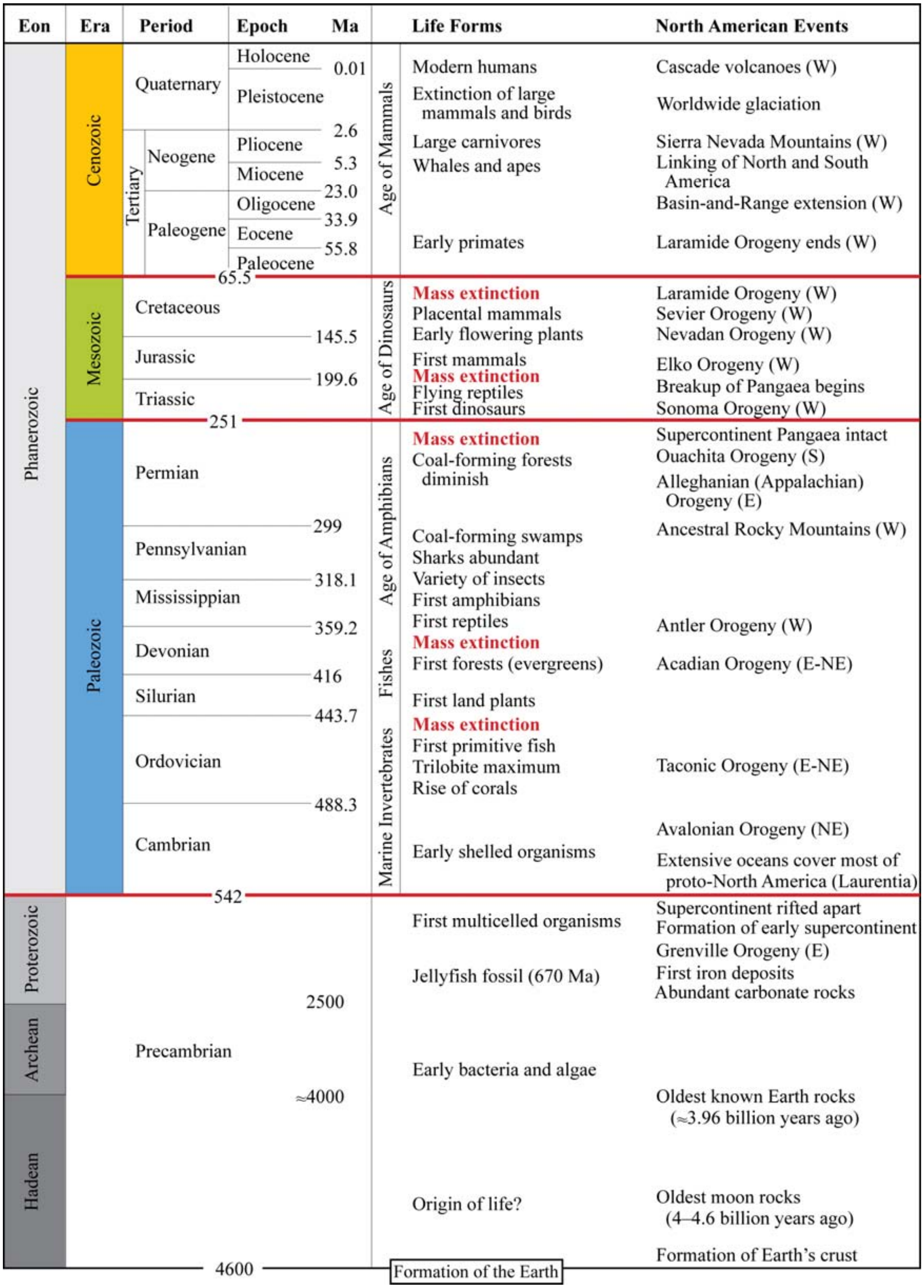



**Figure 19. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. "Orogeny" refers to a period of mountain-building activity. Geologic map unit symbols in the "LIBI Map Unit" column correspond to the digital geologic map data for the national monument (see Geologic Map Data section). Units with an * are mapped within Little Bighorn Battlefield National Monument. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, http://pubs.usgs.gov/fs/2007/3015/ with additional information from the International Commission on Stratigraphy, http://www.stratigraphy.org/view.php?id=25.**

# Geologic History

*This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Little Bighorn Battlefield National Monument, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.*

The bedrock that underlies Little Bighorn Battlefield National Monument is from the Upper Cretaceous Period (about 100 million to 65.5 million years ago), and represents sediments originally deposited in a seaway that inundated North America from the Arctic to the Tropics (figs. 19–20).

Vuke et al. (2000a, 200b) mapped six Upper Cretaceous formations in the vicinity of Little Bighorn Battlefield National Monument: Lance (Kl), Fox Hills (Kfh), Bearpaw (Kb), Judith River (Kjr), Claggett (Kcl), and Gammon (Kga). Of the six Upper Cretaceous units, only the Bearpaw and Judith River formations are exposed in the national monument. Additionally, Vuke et al. (2000a, 200b) mapped the Tertiary Tullock Member of the Fort Union Formation (Tft), although this unit does not crop out within the national monument. The term "Tertiary" is now used informally. The Paleogene (65.5 million to 23 million years ago) and Neogene (23 million to 2.6 million years ago) periods are the formally designated terms to cover this segment of geologic time (fig. 19). More recent units deposited during the Quaternary Period (the past 2.6 million years) are terrace (Qat) and landslide (Qls) deposits and alluvium (Qal); however, no landslide deposits occur within the national monument (see "Geologic Map Data").

#### Cretaceous Period (145.5 million to 65.5 million years ago)

During the Cretaceous Period, an extensive seaway—the "Cretaceous Interior Seaway"—advanced, retreated, and re-advanced many times across the entire west-central part of North America, including Montana and what is now Little Bighorn Battlefield National Monument (fig. 20). The basin of the seaway covered 4,800 km (3,000 mi). During periods of maximum transgression (ocean advance/shoreline retreat), the width of the basin reached 1,600 km (1,000 miles), stretching across Utah and into Iowa. The Cretaceous Interior Seaway left thick layers of shale and sandstone, such as the Judith River Formation (Kjr) and the Bearpaw Formation (Kb). These sediments accumulated in marine, nearshore, and coastal-plain settings (Tuck 2003). Teeming with life, these environments were home to the national monument's notable plesiosaur, as well as bivalves, gastropods, cephalopods, scaphopods, ammonites, lobster, crab, bony fish and shark, and soft-shelled turtles (see "Paleontological Resources").

Near the end of the Cretaceous Period, western North America emerged from the sea as marine waters drained away; Rocky Mountain uplift ultimately displaced the Cretaceous Interior Seaway. In the vicinity of Little Bighorn Battlefield National Monument, mountain building and uplift created the Bighorn and Pryor mountains. During this mountain-building event—known as the Laramide Orogeny—repeated uplifts, periods of volcanism, and episodes of erosion occurred. As mountains rose (uplifted), bordering basins fell (subsided); the basins filled with sediment shed from the adjoining mountains. The Laramide Orogeny continued into the Paleogene Period.

#### Paleogene and Neogene Periods (65.5 million to 2.6 million years ago)

The Tullock Member of the Fort Union Formation (Tft)—the only rock unit in the vicinity of Little Bighorn Battlefield National Monument from this time period—was deposited in a large structural basin that formed as a result of intermittent faulting and seismic activity. During the Paleogene and Neogene, the area was a depositional center for locally derived sediments in lakes and rivers (Flores and Ethridge 1985). By late Miocene and early Pliocene time (approximately 10 million to 5 million years ago), renewed faulting uplifted the area and facilitated fluvial erosion (via rivers and streams) of preexisting Tertiary deposits (Tuck 2003). The Rosebud and Wolf mountains—east of the national monument and topographically higher—are erosional remnants where Tertiary rocks are preserved.

#### Quaternary Period (the past 2.6 million years)

By Pleistocene time (2.6 million to 11,700 years ago), the mountains in the Little Bighorn region had been eroded to their present-day configurations (Glaze and Keller 1965). Pleistocene streams deposited gravel, sand, silt, and clay on the valley floors and valley margins. Extensive alluvial terrace deposits (Qat) formed along the western side of the present Little Bighorn River valley. Major tectonic activity had ended by late Tertiary time, but the area was probably seismically active, at least periodically, during the Quaternary Period (Agard 1989).

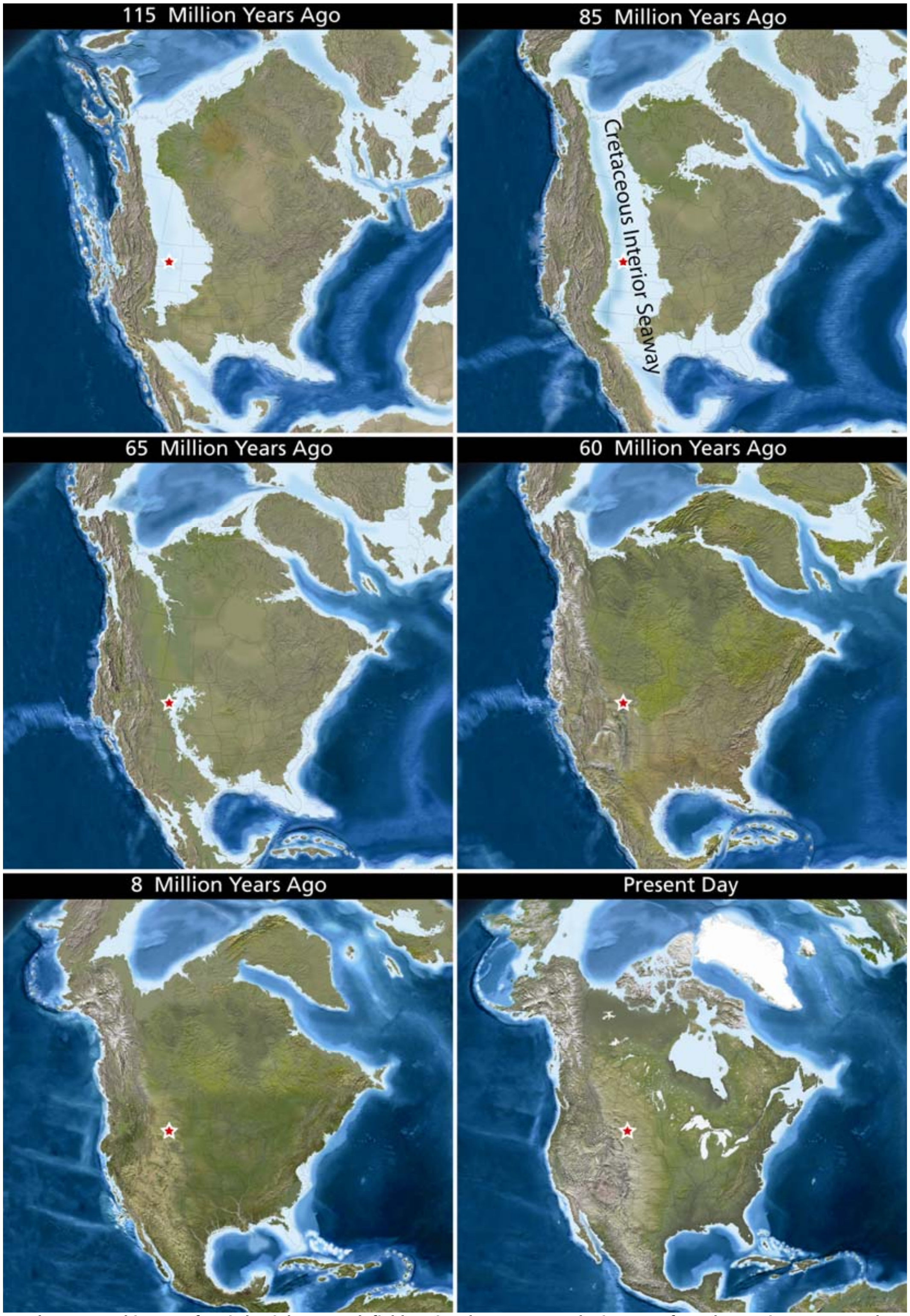



**Figure 20. Paleogeographic maps for Little Bighorn Battlefield National Monument. The images of North America represent the past 115 million years. During the Cretaceous Period, a major seaway filled a basin that spanned from the Arctic to the Tropics, culminating about 85 million years ago. The bedrock within the national monument was deposited in this seaway. The plesiosaur fossil discovered within the national monument is evidence of the national monument's marine history. During the Cenozoic Era (the past 65.5 million years), the Rocky Mountains rose and the seaway drained away. The "stars" on the figure represent the approximate locations of Little Bighorn Battlefield National Monument during various points of geologic time. Graphic complied by Phil Reiker (NPS Geologic Resources Division). Base paleogeographic maps created by Ron Blakey (Northern Arizona University), which are available at http://jan.ucc.nau.edu/~rcb7/index.html (accessed February 24, 2011).**

# Geologic Map Data

*This section summarizes the digital geologic data available for Little Bighorn Battlefield National Monument. It includes an overview graphic of the GIS data and a summary table that lists each map unit displayed on the digital geologic map for the park. Complete GIS data are included on the accompanying CD and are also available at the Geologic Resources Inventory (GRI) publications website: (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).*

### Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, geologic maps portray the spatial distribution and relationships of rocks and unconsolidated deposits. Geologic maps also may show geomorphic features, structural interpretations, and locations of past geologic hazards that may be prone to future activity. Additionally, anthropogenic features such as mines and quarries may be indicated on geologic maps.

### Source Maps

The Geologic Resources Inventory (GRI) team converts digital and/or paper source maps into the GIS formats that conform to the GRI GIS data model. The GRI digital geologic map product also includes essential elements of the source maps such as unit descriptions, map legend, map notes, references, and figures. The GRI team used the following source maps to create the digital geologic data for Little Bighorn Battlefield National Monument:

Vuke, S. M., E. M. Wilde, and R. N. Bergantino. 2000a. Geologic map of the Hardin 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-57. Montana Bureau of Mines and Geology, Butte, Montana, USA.

Vuke, S. M., E. M. Wilde, D. A. Lopez, and R. N. Bergantino. 2000b. Geologic map of the Lodge Grass 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-56. Montana Bureau of Mines and Geology, Butte, Montana, USA.

These source maps provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report.

### Geologic GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available online (http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm). This data model dictates GIS data structure including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Little Bighorn Battlefield National Monument using data model version 1.4.

GRI digital geologic data for Little Bighorn Battlefield National Monument are included on the attached CD and are available through the NPS Natural Resource Information Portal (https://nrinfo.nps.gov/Reference.mvc/Search). Enter "GRI" as the search text and select Little Bighorn Battlefield National Monument from the unit list. The following components and geology data layers are part of the data set:

- Data in ESRI geodatabase and shapefile GIS formats
- Layer files with feature symbology
- Federal Geographic Data Committee (FGDC)–compliant metadata
- A help file (.hlp) document that contains all of the ancillary map information and graphics, including geologic unit correlation tables and map unit descriptions, legends, and other information captured from source maps.
- An ESRI map document file (.mxd) that displays the digital geologic data

**Geology data layers in the Little Bighorn Battlefield National Monument GIS data**

| Data Layer | Code | On Overview? |
|---|---|---|
| Geologic Attitude and Observation Points | ATD | No |
| Geologic Contacts | GLGA | Yes |
| Geologic Units | GLG | Yes |

***Note**: All data layers may not be visible on the overview graphic.*

### Overview Graphic of Digital Geologic Data

The overview graphic displays the GRI digital geologic data draped over a shaded relief image of Little Bighorn Battlefield National Monument and includes basic geographic information. For graphic clarity and legibility, not all GIS feature classes are visible on the overview graphic. The digital elevation data and geographic information are not included with the GRI digital geologic GIS data for Little Bighorn Battlefield National Monument, but are available online from a variety of sources.

### Map Unit Properties Table

The geologic units listed in the map unit properties table correspond to the accompanying digital geologic data. Following overall structure of the report, the table highlights the geologic issues, features, and processes associated with each map unit. The units, their relationships, and the series of events the created them are highlighted in the "Geologic History" section. Please refer to the geologic timescale (fig. 19) for the geologic period and age associated with each unit.

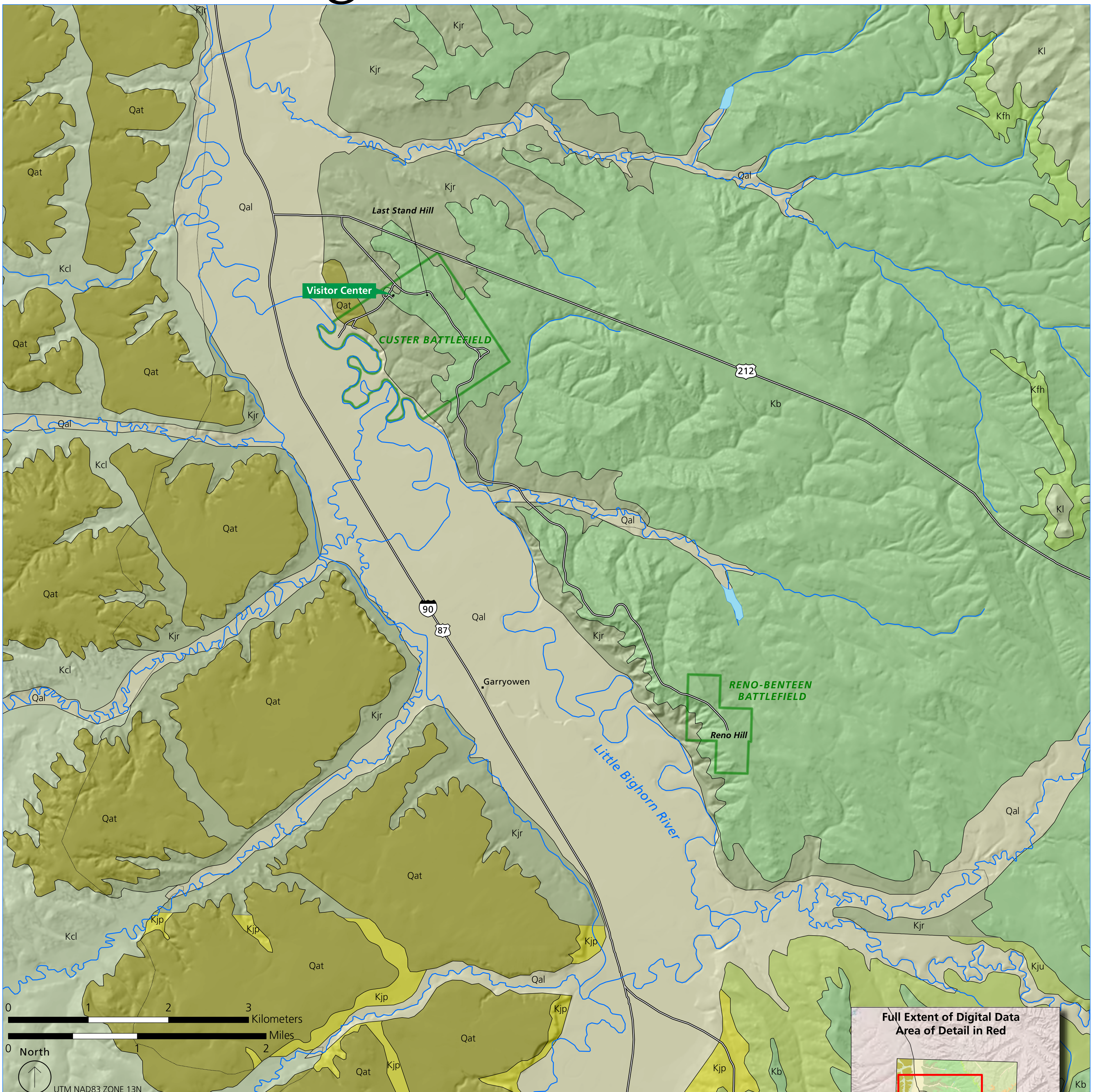
### Use Constraints

Graphic and written information provided in this section is not a substitute for site-specific investigations, and ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the overview graphic. Based on the source map scale (1:100,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 51 m (167 ft) (horizontally) of their true location.

Please contact GRI with any questions.

National Park Service
U.S. Department of the Interior

# Overview of Digital Geologic Data for Little Bighorn Battlefield NM




This figure is an overview of compiled digital geologic data. It is not a substitute for site-specific investigations.

Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the figure. Based on the source map scale (1:100,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 51 meters /167 feet (horizontally) of their true location.

This figure was prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. The source maps used in creation of the digital geologic data product were:

Vuke, S. M., E. M. Wilde, and R. N. Bergantino. 2000a. Geologic map of the Hardin 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-57. Montana Bureau of Mines and Geology, Butte, Montana, USA.

Vuke, S. M., E. M. Wilde, D. A. Lopez, and R. N. Bergantino. 2000b. Geologic map of the Lodge Grass 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-56. Montana Bureau of Mines and Geology, Butte, Montana, USA.

Digital geologic data and cross sections for Little Bighorn Battlefield National Monument, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Natural Resource Information Portal: https://nrinfo.nps.gov/Reference.mvc/Search. (Enter "GRI" as the search text and select Little Bighorn Battlefield National Monument from the unit list.)

**NPS Boundary**

**Geologic Contacts**

- known or certain
- concealed
- quadrangle boundary
- water or shoreline

**Geologic Units**

- Qal - Alluvium
- Qat - Alluvial terrace deposit
- Kl - Lance Formation
- Kfh - Fox Hillls Formation
- Kb - Bearpaw Formation
- Kjr - Judith River Formation
- Kju - Upper member of Judith River Formation (informal)
- Kjp - Parkman Member of Judith River Formation
- Kcl - Claggett Formation
- Water

Produced by the Geologic Resources Inventory

June 2011

# Map Unit Properties Table: Little Bighorn Battlefield National Monument

*Colored rows indicate units mapped within Little Bighorn Battlefield National Monument. Colors in Map Unit column correspond to colors on the overview graphic.*

| Age | Map Unit (Symbol) | Geologic Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| QUATERNARY (Holocene) | **Alluvium (Qal)** | Well to poorly stratified, dominantly clast supported, and moderately well sorted gravel, sand, silt, and clay along active channels of rivers, streams, and tributaries. Includes alluvial terrace deposits less than 1.8 m (6 ft) above river or stream. Thickness as much as 10 m (35 ft). | Channel migration and erosion.<br><br>Flooding potential.<br><br>Anthropogenic disturbances—Channel relocation, riprap, channel clearing, diking, bridge abutments, and diversion. | Makes up steep riverbanks.<br><br>Mineral resources—Sand, gravel, clay, and placer gold. | Impaired troop movements during the battle. |
| QUATERNARY (Holocene and Pleistocene) | **Landslide deposits (Qls)** | Rock and soil that moved down slope in discrete units through mass-wasting processes that resulted in irregular or hummocky surfaces. Thickness 30 m (100 ft) to 46 m (150 ft). | Potential impacts to infrastructure and human safety. | Potentially unstable deposit prone to future gravity-driven movement. | Mass wasting indicates slope instability sometime during the Holocene (the past 11,700 years). |
| QUATERNARY (Pleistocene) | **Alluvial terrace deposits (Qat)** | Gravel, sand, silt, and clay underlying alluvial terrace surfaces adjacent to and higher in elevation than modern streams and rivers. Poorly to moderately well stratified and sorted with planar and trough cross bedding. At least eight, distinct terrace levels occur along Little Big Horn River, ranging from 3 m (10 ft) to 170 m (560 ft) above the river. Gravel composed of rounded to subrounded clasts of limestone and dolomite, andesite and other mafic volcanic rocks, as well as quartzite, granitic rocks, sandstone, and chert. Thickness 5 m (16 ft) to 15 m (49 ft). | Flooding potential.<br><br>Erosion potential. | Principal aquifer along the Little Bighorn River.<br><br>Fossils—Known to contain Pleistocene fossils regionally (e.g., musk ox; see Reheis 1987).<br><br>Mineral resources—Sand, gravel, and placer gold. | Location of Indian encampment during the battle.<br><br>Records past floodplain surfaces.<br><br>Formed during the Pleistocene. Lowest terrace deposit is approximately 20,000 years old; highest is 1.4 million years old (Agard 1989). The wide variety of clasts within the gravels attest to the wide variety of geologic units eroded by the ancient Little Bighorn River. |
| TERTIARY (Paleocene) | **Tullock Member of Fort Union Formation (Tft)** | Yellowish-gray, fine- to medium-grained trough cross-bedded, plane-bedded, or massive sandstone. Interbedded with brownish-gray or dark-gray carbonaceous shale (much less abundant than the sandstone). Sandstone beds thinner, more tabular, and persistent than those in underlying Lance Formation. Thickness 70 m (230 ft) to 120 m (395 ft). | Shale may cause slippage. Usually forms steep escarpments.<br><br>Energy development (unit is source of coal). | Fossils—Freshwater shells, ceratopsian supraorbital bone fragment, and plant fossils (Rogers and Lee 1923).<br><br>Mineral resources—Coal.<br><br>Water resources—Aquifer. | Originally deposited in lakes and rivers in a large basin formed during the rise of the Rocky Mountains. The major coal beds of the Fort Union Formation, particularly in Wyoming, are deposits of organic material buried in forests within the basin. |
| UPPER CRETACEOUS | **Lance Formation (Kl)** | Light brownish-gray, fine-grained, cross-bedded, lenticular-bedded, or massive sandstone. Interbedded with light olive-gray to greenish-gray shale, less abundant than the sandstone. Contains calcite-cemented concretionary sandstone lenses. Sandstone beds thicker and more lenticular than those in overlying Tullock Member. In many areas contains very light-gray, fine- to medium-grained sandstone interbedded with coal in the lower part, with some associated clinker. Thickness 140 m (460 ft) to 160 m (525 ft). | Shale may cause slippage.<br><br>Energy development (unit is source of coal). | Fossils—Abundant marine fauna (Thom and Dobbin 1924). Shells and leaves (Stone and Calvert 1910). Ceratopsian fossils (Calvert 1912). Marine fossils, plants, and bones of reptiles (turtles and dinosaurs), brackish-water oysters (Lloyd and Hares 1915). Freshwater snails (Rogers and Lee 1923). Extensive vertebrate fauna (amphibians, reptiles, mammals, and fish), gastropods, and pelecypods (Breithaupt 1982).<br><br>Mineral resources—Coal and gypsum.<br><br>Water resources—Fairly good source of water (Thom et al. 1935). | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean.<br><br>Brackish-water fossils suggest shallower marine environments, likely near a shoreline.<br><br>Potential source of local building stone. |
| UPPER CRETACEOUS | **Fox Hills Formation (Kfh)** | Brownish-gray siltstone and fine-grained cross-bedded or hummocky-bedded poorly resistant sandstone interbedded with dark gray shale. Thickness 30 m (100 ft). | Shale may cause slippage.<br><br>Forms ledges and cliffs (Shroba and Carrara 1996).<br><br>Bentonite may cause shrink-swell. | Fossils—Rounded concretions with fossils (Brown 1917). Brackish-water pelecypods (Scott 1963). Foraminifera (Van Horn 1957). Flora and burrows, usually *Ophiomorpha* (Rigby and Rigby 1990). Oyster shells and trace fossils (Roehler 1993).<br><br>Mineral resources—Bentonite (Obradovich and Cobban 1975). | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |

*Colored rows indicate units mapped within Little Bighorn Battlefield National Monument. Colors in Map Unit column correspond to colors on the overview graphic.*

| Age | Map Unit (Symbol) | Geologic Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| UPPER CRETACEOUS | **Bearpaw Formation (Kb)** | Dark-gray fissile shale interbedded with thin, brownish-gray siltstone and fine-grained sandstone beds. Contains numerous brown-weathering calcareous concretions throughout, and numerous bentonite beds in the middle, one of which is 6 m (20 ft) thick. Thickness as much as 262 m (860 ft). | Shale may cause slippage.<br><br>Bentonite may cause shrink-swell. | Fossils—Nearly complete plesiosaur (marine reptile) *Dolichorhynchops osborni* collected within the national monument, now on display at the Smithsonian Institution. Calcareous concretions with marine fauna, including fossil lobsters, crabs, and mollusks. Dinosaur fossils elsewhere.<br><br>Mineral resources—Bentonite and coal. | One of two Cretaceous formations within the national monument; underlies broad flats.<br><br>Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |
| | **Judith River Formation (Kjr)** | Yellowish-gray to brownish-gray and olive-green, fine- to medium-grained cross-bedded sandstone interbedded with lesser amounts of yellowish-gray silty shale. Thickness 70 m (230 ft) to 79 m (260 ft). | Shale may cause slippage. | Fossils—Bony fish and shark remains. Marine reptile bones. Dinosaur, soft-shelled turtle, and mammalian fossils. Plant debris and wood fragments. Freshwater clams, gastropods, and shell debris. Invertebrate fossils.<br><br>Mineral resources—Coal, which is part of the "great lignite group" (Hayden 1869).<br><br>Water resources—Important aquifer. | One of two Cretaceous formations within the national monument; underlies ridges.<br><br>Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |
| | **Upper Member of Judith River Formation (Kju)** | Greenish-gray to brownish-gray sandy shale and shale interbedded with some thin, brown sandstone beds. Thickness 60 m (200 ft) to 136 m (445 ft). | Shale may cause slippage. | See Judith River Formation (Kjr). | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |
| | **Parkman Member of Judith River Formation (Kjp)** | Yellowish-gray to brownish-gray and olive-green, fine- to medium-grained cross-bedded sandstone interbedded with yellowish-gray silty shale, less abundant than the sandstone. Thickness 78 m (255 ft). | Shale may cause slippage.<br><br>Energy development (unit is source of coal). | Fossils—Marine organisms (Darton 1906). Fossiliferous (turtles, crocodiles, and ammonites) (Wegemann 1911). Fossil pollen (Nichols 1994).<br><br>Mineral resources—Thin coal seams. Oil and gas potential.<br><br>Water resources–Fairly good source of water (Thom et al. 1935). | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |
| | **Claggett Formation (Kcl)** | Brownish-gray and dark-gray fissile or bentonitic shale. Contains distinctive yellowish-tan or orange septarian concretions, many of which contain fossils. Thickness 120 m (395 ft). | Shale may cause slippage.<br><br>Bentonite may cause shrink-swell. | Fossils—Fossiliferous septarian concretions.<br><br>Mineral resources—Bentonite. | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |
| | **Gammon Formation (Kga)** | Yellowish-brown calcareous siltstone interbedded with yellowish-brown weathering, brownish-gray, calcareous silty shale. Contains several yellowish-brown fine-grained sandstone beds. Contains a zone of reddish-orange ferruginous concretions in sandy shale. Thickness 99 m (325 ft) to 261 m (855 ft). | Shale may cause slippage.<br><br>Bentonite is nonswelling (Gill et al. 1966). | Fossils—Fossiliferous (Robinson et al. 1959). Mollusks (Merewether 1996).<br><br>Mineral resources—Ferruginous concretions (Rubey 1931). Bentonite (Knechtel and Patterson 1955). | Originally deposited in Cretaceous Interior Seaway, a shallow sea connecting ancient Gulf of Mexico to ancient Arctic Ocean. |

# Glossary

*This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here, please visit http://geomaps.wr.usgs.gov/parks/misc/glossarya.html. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).*

**alluvium.** Stream-deposited sediment.

**ammonite.** Any ammonoid belonging to the suborder Ammonitina, characterized by a thick, strongly ornamental shell with sutures having finely divided lobes and saddles. Range—Jurassic to Cretaceous.

**aquifer.** A rock or sedimentary unit that is sufficiently porous that it has a capacity to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.

**base level.** The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

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

**bed.** The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two, and distinguishable from beds above and below.

**bedding.** Depositional layering or stratification of sediments.

**bedrock.** A general term for the rock that underlies soil or other unconsolidated, surficial material.

**bentonite.** A soft clay or greasy claystone composed largely of smectite. Formed by the chemical alteration of glassy volcanic ash in contact with water.

**bivalve.** Having a shell composed of two distinct and usually movable valves, equal or subequal, that open and shut.

**calcareous.** Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

**cephalopod.** A marine mollusk of the class Cephalopoda, characterized by a head surrounded by tentacles and, in most fossil forms, by a straight, curved, or coiled calcareous shell divided into chambers by transverse septa. Range—Cambrian to the present.

**ceratopsian.** Any of a suborder (Ceratopsia) of ornithischian dinosaurs of the late Cretaceous having horns, a sharp horny beak, and a bony frill projecting backward from the skull.

**chert.** An extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz.

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

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

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

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

**clinker.** Coal that has been altered by igneous intrusion.

**concretion.** A hard, compact aggregate of mineral matter, subspherical to irregular in shape; formed by precipitation from water solution around a nucleus such as shell or bone in a sedimentary or pyroclastic rock. Concretions are generally different in composition from the rocks in which they occur.

**coulee.** A term applied in the western United States to a small stream, often intermittent. Also, the bed of such a stream when dry.

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

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

**crystalline**. Describes a regular, orderly, repeating geometric structural arrangement of atoms.

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

**detention.** The amount of water from precipitation existing as overland flow. Sheet flow of water is overland flow before channel is reached.

**differential erosion.** Erosion that occurs at irregular or varying rates, caused by the differences in the resistance and hardness of surface materials: softer and weaker rocks are rapidly worn away, whereas harder and more resistant rocks remain to form ridges, hills, or mountains.

**dolomite.** A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).

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

**eolian.** Formed, eroded, or deposited by or related to the action of the wind. Also spelled "Aeolian."

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

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

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

**fluvial.** Of or pertaining to a river or rivers.

**foraminifer.** Any protozoan belonging to the subclass Sarcodina, order Foraminiferida, characterized by the presence of a test ("shell") of one to many chambers composed of secreted calcite (rarely silica or aragonite) or of agglutinated particles. Most foraminifers are marine, but freshwater forms are known. Range—Cambrian to Holocene.

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

**gastropod.** Any mollusk belonging to the class Gastropoda, characterized by a distinct head with eyes and tentacles and, in most, by a single calcareous shell that is closed at the apex, sometimes spiraled, not chambered, and generally asymmetrical (e.g., a snail). Range—Upper Cambrian to the present.

**geology.** The study of Earth including its origin, history, physical processes, components, and morphology.

**granite.** An intrusive igneous (plutonic) rock composed primarily of quartz and feldspar. Mica and amphibole minerals are also common. Intrusive equivalent of rhyolite.

**igneous.** Refers to a rock or mineral that originated from molten material; one of the three main classes of rocks—igneous, metamorphic, and sedimentary.

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

**knickpoint.** Any interruption or break in a slope, especially a point of abrupt change or inflection in the longitudinal profile of a stream or of its valley, resulting from rejuvenation, glacial erosion, or the outcropping of a resistant bed.

**landslide.** Any process or landform resulting from rapid, gravity-driven mass movement.

**lignite.** A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

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

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

**marble.** A metamorphic rock consisting predominately of fine- to coarse-grained recrystallized calcite and/or dolomite. In commerce, any crystalline carbonate rock, including true marble and certain types of limestone (orthomarble), that will take a polish and can be used as architectural or ornamental stone.

**mass wasting.** A general term for the down-slope movement of soil and rock material under the direct influence of gravity.

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

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

**mineral.** A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

**orogeny.** A mountain-building event.

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

**paleontology.** The study of the life and chronology of Earth's geologic past based on the fossil record.

**parent material.** Geologic material from which soils form.

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

**pelecypod.** Any benthic aquatic mollusk belonging to the class Pelecypoda, characterized by a bilaterally symmetrical bivalve shell, a hatchet-shaped foot, and sheetlike gills. Range—Ordovician to present.

**piping.** Erosion or solution by percolating water in a layer of subsoil, resulting in caving and in the formation of narrow conduits, tunnels, or "pipes" through which soluble or granular soil material is removed

**ravine.** A small, narrow, deep depression, smaller than a gorge or canyon but larger than a gully, usually carved by running water, especially the narrow, excavated channel of a mountain stream.

**rill erosion.** The development of numerous minute, closely spaced channels, resulting from the uneven removal of surface soil by running water that is concentrated in streamlets of sufficient discharge and velocity to generate cutting power. It is an intermediate process between sheet erosion and gully erosion.

**rock.** A solid, cohesive aggregate of one or more minerals.

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

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

**scaphopod**. Any benthic marine univalve mollusk belonging to the class Scaphopoda.

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

**septarian.** Describes the irregular polygonal pattern of internal cracks developed in a spheroidal limestone or ironstone concretion, closely resembling the desiccation structure of mud cracks; also describes the mineral deposits that may occur as fillings of these cracks.

**shale.** A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

**sheetwash/sheet erosion.** The removal of thin layers of surface material more or less evenly from an extensive area of gently sloping land by broad continuous sheets of running water rather than by streams flowing in well-defined channels.

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

**siltstone.** A variably lithified sedimentary rock composed of silt-sized grains.
**slope.** The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."
**soil.** Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.
**stage (hydrology).** The height of a water surface above an arbitrarily established datum plane.
**strata.** Tabular or sheet-like masses or distinct layers of rock.
**stream.** Any body of water moving under gravity flow in a clearly confined channel.
**stream channel.** A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.
**stream terrace.** Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).
**substrate.** The substance or nutrient on or in which an organism lives and grows, or the surface to which a fixed organism is attached (e.g., soil, rock, or leaf tissue).
**supraorbital.** Situated or occurring above the orbit of the eye.
**strata.** Tabular or sheet-like masses or distinct layers of rock.
**stratification.** The accumulation, or layering, of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.
**tectonic.** Relating to large-scale movement and deformation of Earth's crust.
**terrace.** A relatively level bench or step-like surface breaking the continuity of a slope (see "marine terrace" and "stream terrace").
**topography.** The general morphology of Earth's surface, including relief and locations of natural and anthropogenic features.
**transgression.** Landward migration of the sea as a result of a relative rise in sea level.
**uplift.** A structurally high area in the crust, produced by movement that raises the rocks.

# Literature Cited

*This section lists references cited in this report, including the Map Unit Properties Table. A more complete geologic bibliography is available from the National Park Service Geologic Resources Division.*


Agard, S. S. 1989. Map showing Quaternary and late Tertiary terraces of the lower Bighorn River, Montana (scale 1:100,000). Miscellaneous Field Studies Map MF-2094. U.S. Geological Survey, Washington, D.C., USA.

Beschta, R. L. 1998. Long-term changes in channel morphology of gravel-bed rivers: Three case studies. Pages 229–256 (Chapter 11) *in* P. C. Klingeman, R. L. Beschta, P. D. Komar, and J. B. Bradley, editors. Gravel-Bed Rivers in the Environment. Volume 4. Fourth International Gravel-Bed Rivers Workshop on Gravel-Bed Rivers in the Environment, Gold Bar, Washington, USA. Water Resources Publications, LLC., Highlands Ranch, Colorado, USA.

Bishop, G. A. 1983. Two new species of crabs, *Notopocorystes* (*Eucorystes*) *eichhorni* and *Zygastrocarcinus griesi* (Decapoda; Brachyura) from the Bearpaw Shale (Campanian) of north-central Montana. Journal of Paleontology 57(5):900–910.

Blob, R. W. 1997. Relative hydrodynamic dispersal potentials of soft-shelled turtle elements: Implications for interpreting skeletal sorting in assemblages of non-mammalian terrestrial vertebrates. Palaios 12(2):151–164.

Blob, R. W., and A. R. Fiorillo. 1996. The significance of vertebrate microfossil size and shape distributions for faunal abundance reconstructions: A Late Cretaceous example. Paleobiology 2293:422–435.

Bock, J. H., and C. E. Bock. 2006. A survey of the vascular plants and birds of Little Bighorn Battlefield. Final report. Cooperative Ecosystem Studies Unit (CESU) task agreement CA-1200-99-007. University of Colorado, Department of Ecology and Evolutionary Biology, Boulder, Colorado, USA.

Bramblett, R. G., and A. V. Zale. 2002. Fish inventories in four park units in the Rocky Mountain Network (December 15, 2002). U.S. Geological Survey, Montana Cooperative Fishery Research Unit, and Montana State University, Department of Ecology, Bozeman, Montana, USA. http://science.nature.nps.gov/im/units/romn/inventory/LIBI/Bramblett_2002_FishInventories.pdf (accessed December 7, 2010).

Brown, B. 1907. The Hell Creek beds of the Upper Cretaceous of Montana. American Museum of Natural History Bulletin 23(article 33):823–845.

Breithaupt, B. H. 1982. Paleontology and ecology of the Lance Formation (Maastrichtian), east flank of Rock Springs uplift, Sweetwater County, Wyoming. University of Wyoming Contributions to Geology 21(2):123–151.

Britten, M., E. W. Schweiger, B. Frakes, D. Manier, and D. Pillmore. 2007. Rocky Mountain Network vital signs monitoring plan. Natural Resource Report NPS/ROMN/NRR-2007/010. National Park Service, Natural Resource Program Center, Fort Collins, Colorado, USA. http://science.nature.nps.gov/im/units/romn/docs/ROMN_VSPlanWeb_FINAL.pdf (accessed December 7, 2010).

Calvert, W. R. 1912. Geology of certain lignite fields in eastern Montana. Pages D187–D201 *in* Contributions to Economic Geology, 1910, Part 2—Mineral Fuels. Bulletin 471-D. U.S. Geological Survey, Washington, D.C., USA.

Case, G. R. 1978. A new selachian fauna from the Judith River Formation (Campanian) of Montana: Palaeontolographica, Abteilung A. Palaeozoologie-Stratigraphie 160(1–6):176–205.

Cobban, W. A. 1962. New Baculites from the Bearpaw Shale and equivalent rocks of the Western Interior. Journal of Paleontology 36(1):126–135.

Coombs, W. P. Jr. 1988. The status of the dinosaurian genus *Diclonius* and the taxonomic utility of hadrosaurian teeth. Journal of Paleontology 62(5):812–817.

Coombs, W. P. Jr., and P. M. Galton. 1988. *Dysganus*, an indeterminate ceratopsian dinosaur. Journal of Paleontology 62(5):818–821.

Darton, N. H., and R. D. Salisbury. 1906. Bald Mountain–Dayton. Geological Atlas of the United States. Folio 141. U.S. Geological Survey, Washington, D.C., USA. http://repository.tamu.edu/handle/1969.1/3522 (accessed December 7, 2010).

Energy Information Administration. 2010. Independent statistics and analysis, state energy profiles: Montana. Online information (December 2, 2010 update). Energy Information Administration, Washington, D.C., USA. http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=MT# (accessed December 7, 2010).

Feldmann, R. M., G. A. Bishop, and T. W. Kammer. 1977. Macrurous decapods from the Bearpaw Shale (Cretaceous; Campanian) of northeastern Montana. Journal of Paleontology 51(6):1161–1180.

Flores, R. M., and F. G. Ethridge. 1985. Evolution of intermontane fluvial systems of Tertiary Powder River Basin, Montana and Wyoming. Pages 107–126 *in* R. M. Flores and S. S. Kaplan, editors. Cenozoic Paleogeography of the West-Central United States. Rocky Mountain Paleogeography Symposium 3. Society of Economic Paleontologists and Mineralogists (SEPM), Rocky Mountain Section, Denver, Colorado, USA.

Friends of the Little Bighorn Battlefield. 2011. May 21-22, 2011. Photos of floods. Webpage. Friends of the Little Bighorn Battlefield, Crow Agency, Montana, USA. http://www.friendslittlebighorn.com/littlebighornriverfloodmay2011.htm (accessed June 24, 2011).

Galton, P. M., and H. Sues. 1983. New data on pachycephalosaurid dinosaurs (reptilian; Ornithischia) from North America. Canadian Journal of Earth Sciences 20(3):462–472.

Gardner, J. D., A. P. Russell, and D. B. Brinkman. 1995. Systematics and taxonomy of soft-shelled turtles (Family Trionychidae) from the Judith River Group (mid-Campanian) of North America. Canadian Journal of Earth Sciences 32(5):631–643.

Gill, J. R., W. A. Cobban, and P. M. Kier. 1966. The Red Bird section of the upper Cretaceous Pierre Shale in Wyoming, with a section on a new echinoid from the Cretaceous Pierre Shale of eastern Wyoming. Professional Paper 393-A. U.S. Geological Survey, Washington, D.C., USA. http://pubs.er.usgs.gov/publication/pp393A (accessed December 7, 2010).

Glaze, R. E., and E. R. Keller. 1965. Geologic history of the Powder River Basin. American Association of Petroleum Geologists Bulletin 49 (part 2, number 11):1893–1907.

Hayden, F. V. 1869. Preliminary field report of the United States Geological Survey of Colorado and New Mexico. Third Annual Report. U.S. Geological and Geographical Survey of the Territories, Washington, D.C., USA.

Horner, J. R. 1979. Upper Cretaceous dinosaurs from the Bearpaw Shale (marine) of south-central Montana with a checklist of Upper Cretaceous dinosaur remains from marine sediments in North America. Journal of Paleontology 53(3):566–577.

Horner, J. R., D. J. Varricchio, and M. B. Goodwin. 1992. Marine transgressions and the evolution of Cretaceous dinosaurs. Nature (London) 358(6381):59–61.

Kammer, T. W., and R. A. Raff. 1978. Additional information on *Hoploparia bearpawensis* Feldman (Crustacea; Decapoda) from the Bearpaw Shale (Cretaceous; Campanian) of northeastern Montana. Journal of Paleontology 52(6):1388–1389.

Knechtel, M. M., and S. H. Patterson. 1955. Bentonite deposits of the northern Black Hills district, Montana, Wyoming, and South Dakota (scale 1:48,000). Miscellaneous Field Studies Map MF-36 [also published as Bulletin 1082-M]. U.S. Geological Survey, Washington, D.C., USA.

Koch, A. L., J. P. Kenworthy, and V. L. Santucci. 2004. Paleontological resource inventory and monitoring, Rocky Mountain Network. Technical Information Center (TIC) number D-436. National Park Service, Denver, Colorado, USA.

Lloyd, E. R., and C. J. Hares. 1915. The Cannonball Marine Member of the Lance Formation of North and South Dakota and its bearing on the Lance-Laramie problem. Journal of Geology 23(6):523–547.

Lord, M. L., D. Germanoski, N. E. Allmendinger. 2009. Fluvial geomorphology: Monitoring stream systems in response to a changing environment. Pages 69–103 *in* R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA. http://nature.nps.gov/geology/monitoring/fluvial.cfm (accessed June 6, 2011).

Mangum, N. C. 2000. Little Bighorn Battlefield today. Pages 90–109 (Part 3) in R. M. Utley, author. Little Bighorn Battlefield: A History and Guide to the Battle of the Little Bighorn, Little Bighorn Battlefield National Monument, Montana. Official National Park Handbook 132. National Park Service, Division of Publications, Washington, D.C., USA.

Martin, M. 2010. Geomorphic evaluation of on-going channel migration in a portion of the Little Bighorn River. Memorandum to Superintendent, Little Bighorn Battlefield National Monument, from Mike Martin, Hydrologist, WRD (August 26, 2010). National Park Service, Water Resources Division, Fort Collins, Colorado, USA.

Merewether, E. A. 1996. Stratigraphy and tectonic implications of Upper Cretaceous rocks in the Powder River basin, northeastern Wyoming and southeastern Montana. Pages T1–T92 in Evolution of Sedimentary Basins—Powder River Basin. Bulletin 1917-T. U.S. Geological Survey, Washington, D.C., USA. http://pubs.er.usgs.gov/publication/b1917T (accessed December 7, 2010).

Montellano, M. 1992. Mammalian fauna of the Judith River Formation (Late Cretaceous; Judithian) north central Montana. University of California Publications in Geological Sciences 136:115.

Moulder, E. A., M. F. Klug, D. A. Morris, and F. A. Swenson. 1960. Geology and ground-water resources of the lower Little Bighorn River valley, Big Horn County, Montana, with special reference to the drainage of waterlogged lands. Water-Supply Paper 1487. U.S. Geological Survey, Washington, D.C., USA. http://pubs.er.usgs.gov/publication/wsp1487 (accessed December 7, 2010).

National Parks Conservation Association. 2003. Little Bighorn Battlefield National Monument: A resource assessment (June 2003). National Parks Conservation Association, Washington, D.C., USA. http://www.npca.org/stateoftheparks/little_bighorn/littlebighorn.pdf (accessed December 7, 2010).

National Park Service. 1995. Final general management plan and development concept plan, Little Bighorn Battlefield National Monument, August 1986 (updated May 1995). Little Bighorn Battlefield National Monument, Crow Agency, Montana, USA. http://www.nps.gov/libi/parkmgmt/planning.htm (accessed December 7, 2010).

National Park Service. 2001. Strategic plan, Little Bighorn Battlefield National Monument, October 1, 2001–September 30, 2005. Little Bighorn Battlefield National Monument, Crow Agency, Montana, USA. http://www.nps.gov/libi/parkmgmt/planning.htm (accessed December 7, 2010).

National Park Service. 2006. Soil resources inventory (SRI) soil survey geographic (SSURGO) for Little Bighorn National Monument, Montana, 2005–2006. Project 1048921. National Park Service, Inventory & Monitoring Program, Fort Collins, Colorado, USA. https://nrinfo.nps.gov/Reference.mvc/Profile?Code=1048921 (accessed December 7, 2010; use Internet Explorer browser only).

National Park Service. 2007. Little Bighorn Battlefield National Monument resources management plan (July 9, 2007). Little Bighorn Battlefield National Monument, Crow Agency, Montana, USA. http://www.nps.gov/libi/parkmgmt/planning.htm (accessed December 7, 2010).

National Park Service. 2009. Custer National Cemetery, Little Bighorn Battlefield National Monument, Montana. Custer National Cemetery Guide. Western National Parks Association, Tucson, Arizona, USA.

Natural Resources Conservation Service. 2008. Web soil survey. U.S. Department of Agriculture, National Resources Conservation Service, Washington, D.C., USA.http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx (accessed December 8, 2010).

Neuendorf, K. K. E., J. P. Mehl Jr., and J. A. Jackson. 2005. Glossary of geology. Fifth edition. American Geological Institute, Alexandria, Virginia, USA.

Nichols, D. J. 1994. A revised palynostratigraphic zonation of the nonmarine Upper Cretaceous, Rocky Mountain region, United States. Pages 503–522 in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, editors. Mesozoic systems of the Rocky Mountain Region, USA. Society of Economic Paleontologists and Mineralogists (SEPM), Rocky Mountain Section, Denver, Colorado, USA.

Obradovich, J. D., and W. A. Cobban. 1975. A time-scale for the Late Cretaceous of the Western Interior of North America. Pages 31–54 in W. G. Caldwell, editor. The Cretaceous System in the Western Interior of North America. Special Paper 13. Geological Association of Canada, St. John's, Newfoundland, Canada.

Ostrom, J. H. 1964. The systematic position of *Hadrosaurus* (*Ceratops*) *paucidens* Marsh. Journal of Paleontology 38(1):130–134.

Parrett, C., D. D. Carlson, G. S. Craig, Jr., and J. A. Hull. 1978. Data for floods of May 1978 in northeastern Wyoming and southeastern Montana. Open-File Report 78-985. U.S. Geological Survey, Helena, Montana, USA. http://pubs.er.usgs.gov/publication/ofr78985 (accessed December 7, 2010).

PPL Corporation. 2010a. PPL Montana: Producing power—Colstrip. Online information. PPL Corporation, Billings, Montana, USA. http://www.pplmontana.com/producing+power/power+plants/Colstrip.htm (accessed December 7, 2010).

PPL Corporation. 2010b. PPL Montana: Producing power—J. E. Corette. Online information. PPL Corporation, Billings, Montana, USA. http://www.pplmontana.com/producing+power/power+plants/J.E.+Corette.htm (accessed December 7, 2010).

Reheis, M. C. 1987. Gypsic soils on the Kane alluvial fans, Big Horn County, Wyoming. Bulletin 1590-C. U.S. Geological Survey, Washington, D.C., USA. http://pubs.er.usgs.gov/publication/b1590C (accessed December 7, 2010).

Reiskind, J. 1975. Marine concretionary faunas of the uppermost Bearpaw Shale (Maestrichtian) in eastern Montana and southwestern Saskatchewan. Pages 235–252 *in* Cretaceous System in the Western Interior of North America. Special Paper 13. Geological Association of Canada, Toronto, Ontario, Canada.

Rickey, D. Jr. 2005. History of Custer Battlefield. Second printing, reprint edition. Old Army Press, Inc., Johnstown, Colorado, USA.

Rigby, J. K., and J. K. Rigby Jr. 1990. Geology of the Sand Arroyo and Bug Creek quadrangles, McCone County, Montana. Brigham Young University Geology Studies 36:69–134.

Robinson, C. S., W. J. Mapel, and W. A. Cobban. 1959. Pierre shale along western and northern flanks of Black Hills, Wyoming and Montana. American Association of Petroleum Geologists Bulletin 43(1):101–123.

Roehler, H. W. 1993. Stratigraphy of the Upper Cretaceous Fox Hills Sandstone and adjacent parts of the Lewis Shale and Lance Formation, east flank of the Rock Springs uplift, southwest Wyoming. Professional Paper 1532. U.S. Geological Survey, Washington, D.C., USA. http://pubs.er.usgs.gov/publication/pp1532 (accessed December 7, 2010).

Rogers, G. S., and W. Lee. 1923. Geology of the Tullock Creek coal field, Rosebud and Big Horn counties, Montana. Bulletin 749. U.S. Geological Survey, Washington, D.C., USA.

Rogers, R. R., and S. M. Kidwell. 2000. Associations of vertebrate skeletal concentrations and discontinuity surfaces in terrestrial and shallow marine records: A test in the Cretaceous of Montana. Journal of Geology 108(2):131–154.

Rubey, W. W. 1931. Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region. Pages A1–A54 in Shorter Contributions to General Geology, 1930. Professional Paper 165-A. U.S. Geological Survey, Washington, D.C., USA.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado, USA. http://nature.nps.gov/geology/monitoring/paleo.cfm (accessed June 6, 2011).

Scott, G. R. 1963. Bedrock geology of the Kassler quadrangle, Colorado. Pages B71–B125 *in* Geology of the Kassler Quadrangle, Jefferson and Douglas counties, Colorado. Professional Paper 421-B. U.S. Geological Survey, Washington, D.C., USA.

Shroba, R. R., and P. E. Carrara. 1996. Surficial geologic map of the Rocky Flats environmental technology site and vicinity, Jefferson and Boulder counties, Colorado (scale 1:12,000). Miscellaneous Investigations Series Map I-2526. U.S. Geological Survey, Washington, D.C., USA.

Siverson, M. 1995. Revision of *Cretorectolobus* (Neoselachii) and description of *Cederstroemia* n. gen., a Cretaceous carpet shark (Orectolobiformes) with a cutting dentition. Journal of Paleontology 69(5):974–979.

Stone, R. W., and W. R. Calvert. 1910. Stratigraphic relations of the Livingston Formation of Montana, Part III. Economic Geology 5(8):741–764.

Summerfield, M. A. 1991. Global geomorphology: An introduction to the study of landforms. Longman Scientific & Technical, copublished in the United States with John Wiley & Sons, Inc., New York, New York, USA.

Tabrum, A. R. 1978. Report on the plesiosaur collected at Custer Battlefield National Monument. Report submitted to National Park Service, Rocky Mountain Regional Office, Denver, Colorado. Custer Battlefield National Monument, Crow Agency, Montana, USA.

Thackeray. L. 2011. Old-timers make comparisons with the epic 1978 flood. Billings Gazette, June 4, 2011. http://billingsgazette.com/ (accessed June 24, 2011).

Thom, W. T. Jr., G. M. Hall, C. H. Wegemann, and G. F. Moulton. 1935. Geology of the Big Horn County and the Crow Indian Reservation, Montana, with special reference to the water, coal, oil, and gas resources. Bulletin 856. U.S. Geological Survey, Washington, D.C., USA.

Thom, W. T. Jr., and C. E. Dobbin. 1924. Stratigraphy of Cretaceous–Eocene transition beds in eastern Montana and the Dakotas. Geological Society of America Bulletin 35(9):481–505.

Timmons, M., and E. Wheeler. 2010. National Park Service, cultural landscapes inventory, Little Bighorn Battlefield National Monument (November 2010). Completed in fulfillment of Rocky Mountain Cooperative Ecosystem Studies Unit (CESU) cooperative agreement H12000400. Utah State University, Department of Landscape Architecture and Environmental Planning, Logan, Utah, USA.

Tuck, L. K. 2003. Ground-water resources along the Little Bighorn River, Crow Indian Reservation, Montana. Water-Resources Investigations Report 03-4052. U.S. Geological Survey in cooperation with the Bureau of Indian Affairs, Helena, Montana, USA.

U.S. Geological Survey. 2011. USGS 06294000 Little Bighorn River near Hardin MT. National Water Information System: Web interface. U.S. Geological Survey, Water Resources, Reston, Virginia, USA. http://waterdata.usgs.gov/mt/nwis/dv?cb_00060=on&cb_00065=on&format=html&begin_date=2011-05-21&end_date=2011-05-24&site_no=06294000&referred_module=sw (accessed June 27, 2011).

Utley, R. M. 2000. Little Bighorn Battlefield: A history and guide to the Battle of the Little Bighorn. Official National Park Handbook 132. National Park Service, Division of Publications, Washington, D.C., USA.

Van Horn, R. 1957. Bedrock geology of the Golden quadrangle, Colorado (scale 1:24,000). Geologic Quadrangle Map GQ-103. U.S. Geological Survey, Washington, D.C., USA.

Vuke, S. M., E. M. Wilde, and R. N. Bergantino. 2000a. Geologic map of the Hardin 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-57. Montana Bureau of Mines and Geology, Butte, Montana, USA.

Vuke, S. M., E. M. Wilde, D. A. Lopez, and R. N. Bergantino. 2000b. Geologic map of the Lodge Grass 30' × 60' quadrangle, Montana (scale 1:100,000). Geologic Map GM-56. Montana Bureau of Mines and Geology, Butte, Montana, USA.

Wall, W. P., and P. M. Galton. 1979. Notes on pachycephalosaurid dinosaurs (Reptilia; ornithischia) from North America, with comments on their status as ornithopods. Canadian Journal of Earth Sciences 16(6):1176–1186.

Wegemann, C. H. 1911. The Salt Creek oil field, Natrona County, Wyoming. Pages 37–83 *in* E. G. Woodruff and C. H. Wegemann, editors. The Lander and Salt Creek Oil Fields, Wyoming. Bulletin 452. U.S. Geological Survey, Washington, D.C., USA.

Wilson, M. V. H., D. B. Brinkman, and A. G. Neuman. 1992. Cretaceous Esocoidei (Teleostei): Early radiation of the pikes in North American fresh waters. Journal of Paleontology 66(5):839–846.

# Additional References

*This section lists additional references, resources, and websites that may be of use to resource managers.*


#### Geology of National Park Service Areas

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

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

Harris, A. G., E. Tuttle, and S. D. Tuttle. 2003. Geology of National Parks. Sixth Edition. Kendall/Hunt Publishing Co., Dubuque, Iowa, USA.

Kiver, E. P. and D. V. Harris. 1999. Geology of U.S. parklands. John Wiley and Sons, Inc., New York, New York, USA.

Lillie, R. J. 2005. Parks and Plates: The geology of our national parks, monuments, and seashores. W.W. Norton and Co., New York, New York, USA. [Geared for interpreters].

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

#### Resource Management/Legislation Documents

NPS 2006 Management Policies (Chapter 4; Natural Resource Management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

NPS-75: Natural Resource Inventory and Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf.

NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/

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

NPS Technical Information Center (Denver, repository for technical (TIC) documents): http://etic.nps.gov/

#### Geological Survey Websites

Montana Bureau of Mines and Geology: http://www.mbmg.mtech.edu/

U.S. Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geological Institute: http://www.agiweb.org/

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

#### Other Geology/Resource Management Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

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

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

# Appendix: Scoping Meeting Participants

*The following is a list of participants from the GRI scoping meeting for Little Bighorn Battlefield National Monument, held on May 18 and 19, 2005. The contact information and e-mail addresses in this appendix may be outdated; please contact the Geologic Resources Division for current information. The scoping meeting summary was used as the foundation for this GRI report. The original scoping summary document is available on the GRI website http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).*

| Name | Affiliation | Title | Phone | E-mail |
|---|---|---|---|---|
| Cassity Bromley | Bighorn Canyon National Recreation Area | Biological Science Technician | 307-548-5416 | cassity_bromley@nps.gov |
| Tim Connors | NPS Geologic Resources Division | Geologist | 303-969-2093 | tim_connors@nps.gov |
| Elizabeth Crowe | Greater Yellowstone Network | Vegetation Ecologist | 406-994-7202 | elizabeth_a_crowe@ contractor.nps.gov |
| Bruce Heise | NPS Geologic Resources Division | Geologist/GRI Program Coordinator | 303-969-2017 | bruce_heise@nps.gov |
| Katie KellerLynn | Colorado State University | Geologist/Research Associate | 801-608-7114 | katiekellerlynn@msn.com |
| David Lopez | Montana Bureau of Mines and Geology (at the time of scoping) | Geologist | | |
| Carol McCoy | NPS Geologic Resources Division | Branch Chief | 303-969-2096 | carol_mccoy@nps.gov |
| Tom Oesleby | Northwest College | Geology Professor | 307-754-6054 307-527-6844 | tom.oesleby@ northwestcollege.edu |
| Jim Staebler | Bighorn Canyon National Recreation Area | Park Ranger | 307-548-5403 | james_staebler@nps.gov |

NPS 381/107967, June 2011

National Park Service
U.S. Department of the Interior

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

www.nature.nps.gov