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Natural Resource Stewardship and Science

Knife River Indian Villages National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2015/1016

ON THE COVER
Hidatsa Village on the Knife River. Painting by George Catlin, 1832. Image from the Smithsonian American Art Museum collection available at http://americanart.si.edu/collections/search/artwork/?id=4105 (accessed 24 March 2015).

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The "Four Bears Hide" within a reconstructed earthlodge at Knife River Indian Villages National Historic Site. National Park Service photograph available at https://www.flickr.com/photos/121365074@N05/ (accessed 24 March 2015).

Knife River Indian Villages National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2015/1016

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September 2015

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. These reports are 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.

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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.

This report is available from the Geologic Resources Inventory website (http://go.nps.gov/gripubs), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Graham, J. P. 2015. Knife River Indian Villages National Historic Site: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2015/1016. National Park Service, Fort Collins, Colorado.

NPS 468/129640, September 2015

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Executive Summary

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. This report synthesizes discussions from a scoping meeting for Knife River Indian Villages National Historic Site (North Dakota) on 16 August 2011 and a follow-up conference call on 9 July 2014, which were held by the Geologic Resources Division to determine geologic resources, the status of geologic mapping, and geologic resource management issues and needs. It is a companion document to previously completed GRI digital geologic map data.

Established in 1974 to preserve and protect some of the best surviving examples of earthlodge villages in the northern Great Plains, Knife River Indian Villages National Historic Site also preserves the geologic landscape that served as a foundation for this culture that thrived here for more than 500 years. Earthlodges were built on river terraces, which provided a commanding view of the Missouri and Knife rivers. The landscape surrounding Knife River Indian Villages National Historic Site contains eight river terraces, which began forming at the end of the last ice age and continue to form today.

The historic site is part of the Great Plains, a vast physiographic province that extends from Mexico into Canada and spreads east from the Rocky Mountains to the Missouri River. This province supported the grasslands and great herds of bison that played a critical role in the culture of the Plains Indians. Knife River Indian Villages National Historic Site is also located at the eastern margin of the Williston Basin, a subsurface basin with abundant quantities of oil and gas.

The terraces and their associated sediments offer the following geologic features and processes:

- Features that Connect Geology and Archeology. Geologic resources were integral to the lives of native people. Clay was molded into pottery, and crops were planted in the fertile soil of the Knife River floodplain, enabling communities to become established. Local coal was used to produce charcoal. Terraces along the river corridor not only provided expansive views of river traffic but also protected inhabitants from seasonal floods and allowed some respite from insects and summer heat. Knife River Flint was crafted into tools and projectile points and traded throughout North America.
- Terraces as Landscape Features. Three Pleistocene terraces and two Holocene terraces in Knife River Indian Villages National Historic Site are remnants of previous floodplains. The terraces record episodes of vertical incision by the Knife River and subsequent lateral erosion as the river established a new floodplain.
- Paleontological Resources. Although no fossils have been documented from the rocks and sediments within Knife River National Historic Site, fossils have been found in the same units outside of the historic site boundaries. In addition, fossils have been found associated with cultural artifacts.
- Glacial Features. Remnants of the Pleistocene ice ages include till, longitudinal ridges formed by subglacial shearing, glacial erratics, and outwash deposits of sand and gravel.
- Fluvial Features. Large-scale cross-bedding and moderately sorted heterogeneous mixtures of rock fragments characterize upper-flow regime, glaciofluvial deposition. In contrast, small-scale cross-bedding, ripple marks, and horizontal layers of silt and clay are some of the features that represent low-flow regimes common in overbank, marsh, and low-relief coastal plain environments.
- Lake (lacustrine) Features. Fine laminations, moderately well-sorted sediment, and flat bedding record deposition in meltwater-filled depressions that remained in till following the retreat of Pleistocene glaciers.
- Aeolian Features. Dunes, loess (windblown silt), and sand sheets reflect past aeolian processes that are the same processes that currently sweep across North Dakota. In some areas, the wind has removed all of the fine-grained sediment, leaving behind a depression known as a blowout.

- Fluvial Geomorphic Features. The Knife River has formed geomorphic features common to meandering rivers, such as cutbanks and point bars.

Processes responsible for the features in Knife River Indian Villages National Historical Site can also create geologic resource management issues. The primary issues in the historic site involve flooding and bank erosion caused by natural processes and anthropogenic activities, but other geologic issues are also present. Geologic issues discussed during the scoping meeting and conference call included:

- Impacts Resulting from the Garrison Dam. Construction of the Garrison Dam created downstream issues in the Missouri River that affected the Knife River in Knife River Indian Villages National Historic Site. Trapping all of the upstream sediment behind the dam has resulted in severe erosion immediately downstream from the dam. The channel of the Missouri River has deepened and narrowed. To compensate for a deeper Missouri River, the portion of the Knife River in the historic site has also deepened its channel. The regulated flow of the Missouri is not able to transport the high sediment load of the unregulated Knife River and so an island has formed at the confluence of the two rivers.
- Flooding of the Knife River. Flooding still regularly occurs on the unregulated Knife River. Overbank flooding can be caused by ice jams, rapid ice melt, and/or high spring runoff. The exceptionally wet spring of 2011 caused flooding on both the Missouri and Knife rivers. Global climate change models predict an increase in exceptionally wet springs for North Dakota.
- Bank Erosion on the Knife River. Bank erosion and failure along the Knife River is primarily caused by ice gouging, abundant precipitation, backflow of the Missouri River, and lateral channel migration.
- Impacts of Bank Erosion on Archeological Sites and Infrastructure. Bank erosion threatens archeological sites at Elbee Bluff and Taylor Bluff and a county road that crosses the historic site. Natural lateral migration of the channel may also intersect the historic site boundary.
- Recommendations to Monitor and Mitigate Bank Erosion. The potential loss of cultural resources prompted the need for a river management plan for the Knife River, and in 2013, work began on an environmental impact study (EIS) /archeological resources management plan. The plan, which is scheduled to be completed in 2016, will provide a better understanding of the impact of the river on archeological sites and infrastructure and provide a framework for making river-related decisions, especially with regard to bank stabilization.
- Slope Movement. Bank collapse is similar to larger-scale slope movements and may be monitored in a similar fashion. In addition, increased flooding due to global climate change may impact the bluffs below the Indian villages.
- External Energy Development. The boom of the Bakken Formation oil play in the Williston Basin is putting pressure on the natural resources of western North Dakota. Abundant water is required for the hydraulic fracturing process, and gravel is needed for drilling locations and roads. Increased pressure to develop these natural resources may impact the historic site. In addition, four lignite coal mines are active in the region, a new coal mine is scheduled to open in 2016, and two windfarms have been developed southeast and southwest of the historic site.
- Paleontological Resource Inventory and Monitoring. A paleontological inventory and monitoring program, combined with archeological projects, may help document the Pleistocene and Holocene fossil resources of the historic site. Detailed documentation of exposed fossils in the field, as well as identification of fossils in the museum collections, may significantly contribute to the understanding of fossils in a cultural context.
- Disturbed Lands. Although discussed in the scoping meeting and conference call, "disturbed lands" in the form of areas in need of restoration is not a significant issue at Knife River Indian Villages National Historic Site. However, before becoming part of the National Park System, much of the land of the historic site had been modified by agricultural practices, and the area was seeded with perennial grasses before it became a national historic site.
- Earthquakes. Although past earthquakes have shaken some windows and rattled some walls in western North Dakota, they do not pose a major hazard for Knife River Indian Villages National Historic Site. The probability that a moderate earthquake will impact the historic site in the next 100 years is between zero and 1.0%.

The units mapped within Knife River Indian Villages National Historic Site reflect processes active since the last phase of Pleistocene glaciation, but the geologic history of the Williston Basin extends back in time to the formative years of the southern margin of the North American craton, at least 550 million years ago. Although North Dakota is currently part of the Great Plains, it was covered by inland seas in the past. Fluctuations in sea level formed nearshore, open marine, and coastal environments in western North Dakota throughout the Paleozoic and Mesozoic eras.

During the Pleistocene ice ages, which began about 2.6 million years ago, advancing glaciers sculpted the landscape of North Dakota into a rolling topography and diverted many of the rivers to the south, including the Missouri River. When the last ice sheet melted about 11,000 years ago, meltwater carved channels into the landscape that were much larger than today's river channels. The Knife and Missouri rivers occupy only a portion of one of these meltwater channels.

Holocene river channels incised the easily eroded sediments of their floodplains, establishing new floodplains and leaving older floodplains as terraces. Weathering, erosion, lateral incision, freeze-and-thaw cycles, and flooding continue to modify the landscape and to expose, destroy, or bury the archeological resources in Knife River Indian Villages National Historic Site.

This Geologic Resources Inventory report was written for resource managers to support science-informed decision making, but it may also be useful for interpretation. The report was prepared using available geologic information and the NPS Geologic Resources Division did not conduct any new fieldwork in association with this report. Sections of the report discuss distinctive geologic features and processes within Knife River Indian Villages National Historic Site, highlight geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the GRI geologic map data. Posters (in pocket) illustrate these data. The Map Unit Properties Tables (in pocket) summarize report content for each geologic map unit.

Products and Acknowledgments

The NPS Geologic Resources Division partners with institutions such as Colorado State University, the US Geological Survey, state geological surveys, local museums, and universities to develop GRI products. This section describes those products and acknowledges contributors to this report.

GRI Products

The objective of the Geologic Resources Inventory is to provide geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. To realize this objective, the GRI team undertakes three tasks for each natural resource park: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report (this document). These products are designed and written for nongeoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to digital geologic map data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (section 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The "Additional References" section and Appendix B provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri. The current status and projected completion dates of products are available at http://go.nps.gov/gri_status.

Acknowledgments

Thanks to **Trista Thornberry-Ehrlich** (Colorado State University) and **Jason Kenworthy** (NPS Geologic Resources Division) for drafting some of the graphics used in this report. **Stephen Simon** and **Jeremiah Kimbell** (both from NPS Geologic Resources Division) provided comments and information for the oil and gas sections of this report. **Sarah Quinn** (NPS Geologic Resources Division) provided comments on the wind energy sections of this report.

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Geologic Setting and Significance

This chapter describes the regional geologic setting of Knife River Indian Villages National Historic Site, summarizes connections among geologic resources, other resources, and historic site stories.

Geologic Setting

When the Corps of Discovery, led by Meriwether Lewis and William Clark, traveled north from Bismarck in 1804, they encountered three Hidatsa villages on river terraces rising from the west bank of the Knife River (fig. 1). One of the villages contained 40 earthlodges and another had more than 130 earthlodges (Ambrose 1996). For more than 500 years, Hidatsa villages had overlooked the confluence of the Knife and Missouri rivers and carried on a brisk trade with other Indian tribes and travelers across the Northern Plains. The Hidatsa, Awatixa, and Awatixa Xi'e villages are now preserved in Knife River Indian Villages National Historic Site (fig. 2).

Knife River Indian Villages National Historic Site is part of the Great Plains physiographic province, a vast region that extends from Mexico into Canada and spreads east from the Rocky Mountains to the Missouri River. Before modern agriculture, the lush grassland prairies supported immense herds of bison. Trees were found only along narrow stream corridors. The Great Plains lie mostly between 610–1,800 m (2,000–6,000 ft) above sea level, and most of the semiarid region receives less than 61 cm (24 in) of precipitation a year (Trimble 1980).

The historic site also is on the eastern edge of the Williston Basin, an extensive area that includes western North Dakota, South Dakota, Montana, and Canada (fig. 3). The basin covers about 780,000 km^2 (300,000 mi^2), an area significantly larger than Texas. Hydrocarbons produced from the Williston Basin have made North Dakota the second largest, oil-producing state in the country.

During the Pleistocene, which began about 2.6 million years ago (fig. 4), North Dakota was both colder and wetter than it is today. Vast continental glaciers flowed into North Dakota from the north, smoothed the landscape into rolling hills, and diverted many of the rivers, including the Missouri River, to the south. When the climate warmed and the glaciers melted about 11,000 years ago, vast amounts of meltwater carved channels into the landscape that were much larger than today's river channels. The Knife and Missouri rivers occupy a portion of one of these meltwater channels.

Figure 1. Painting of Hidatsa village at Knife River. Hidatsa earthlodges were built upon terraces overlooking the Knife River. Original painting by George Catlin in 1832. The image is available at http://americanart.si.edu/collections/search/artwork/?id=4105 (accessed 8 September 2014).

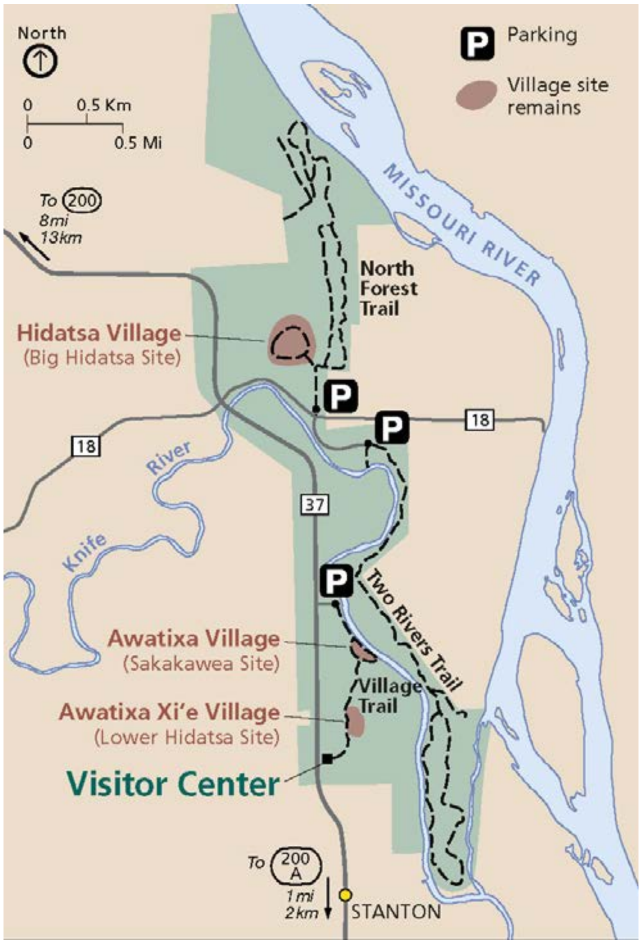

Figure 2. Map of Knife River Indian Villages National Historic Site. The villages are located on terraces above the modern floodplain. Note the meandering nature of the Knife River and the association of meander bends with County Road 18 and Two Rivers Trail. National Park Service map, available at http://www.nps.gov/hfc/cfm/carto.cfm (accessed 16 July 2014).

During the Holocene (fig. 4), river channels cut vertically into unconsolidated sediment until they hit harder, more erosion-resistant layers, and subsequent lateral erosion carved new floodplains. The abandoned floodplains became the terraces upon which the Hidatsa would eventually build their earthlodges. These terraces, along with uplands and slopes, form three distinct morphologic units found in the Knife River Indian Villages National Historic Site and surrounding region (table 1). The rolling hills that characterize the uplands (geologic map unit **Qup**) form the region above the Missouri River and Knife River valleys, north of the historic site (see posters in pocket). The surface lacks terraces and is primarily bedrock mantled with a thin layer of sediments deposited by glaciers, wind, rivers,

Figure 3. Map of the Williston Basin. Green star is the approximate location of Knife River Indian Villages National Historic Site. Graphic by Trista Thornberry Ehrlich (Colorado State University) using basemap by Tom Patterson (National Park Service), available at http://www.shadedrelief.com/physical/pages/download.html (accessed 4 November 2014).

and/or lakes (Reiten 1983).

The slopes (**Qsl**) separate the uplands from the highest terrace and the terraces from one another. In Knife River Indian Villages National Historic Site, slopes are generally less than 10°, but beyond the historic site boundaries, the unit (**Qsl**) also includes rugged badlands, which have 15°–90° slopes and cut into Paleocene sediments (Reiten 1983).

The landscape surrounding Knife River Indian Villages National Historic Site contains eight river terraces, which are identified and correlated by their surface expression, elevation above the Knife River, stratigraphy, and contact relationships (fig. 5; Reiten 1983). From the highest to lowest elevation above river level, five Pleistocene terraces include the Riverdale (**Qtr**), Sakakawea (**Qtsa**), McKenzie (**Qtm**), Hensler (**Qth**), and Stanton (**Qtst**) terraces (fig. 5).

The other three terraces are Holocene terraces and include (from highest to lowest) A terrace (**Qta**), B1 terrace, and B2 terrace. B1 and B2 terrace deposits are similar, so these have been combined into B terrace (**Qtb**) for mapping purposes (Reiten 1983). Holocene terraces consist primarily of fine-grained sediments ranging from clay to medium-grained sand. Ages from charcoal and wood collected from paleosols (ancient soils) in the lower terraces yielded radiocarbon ages

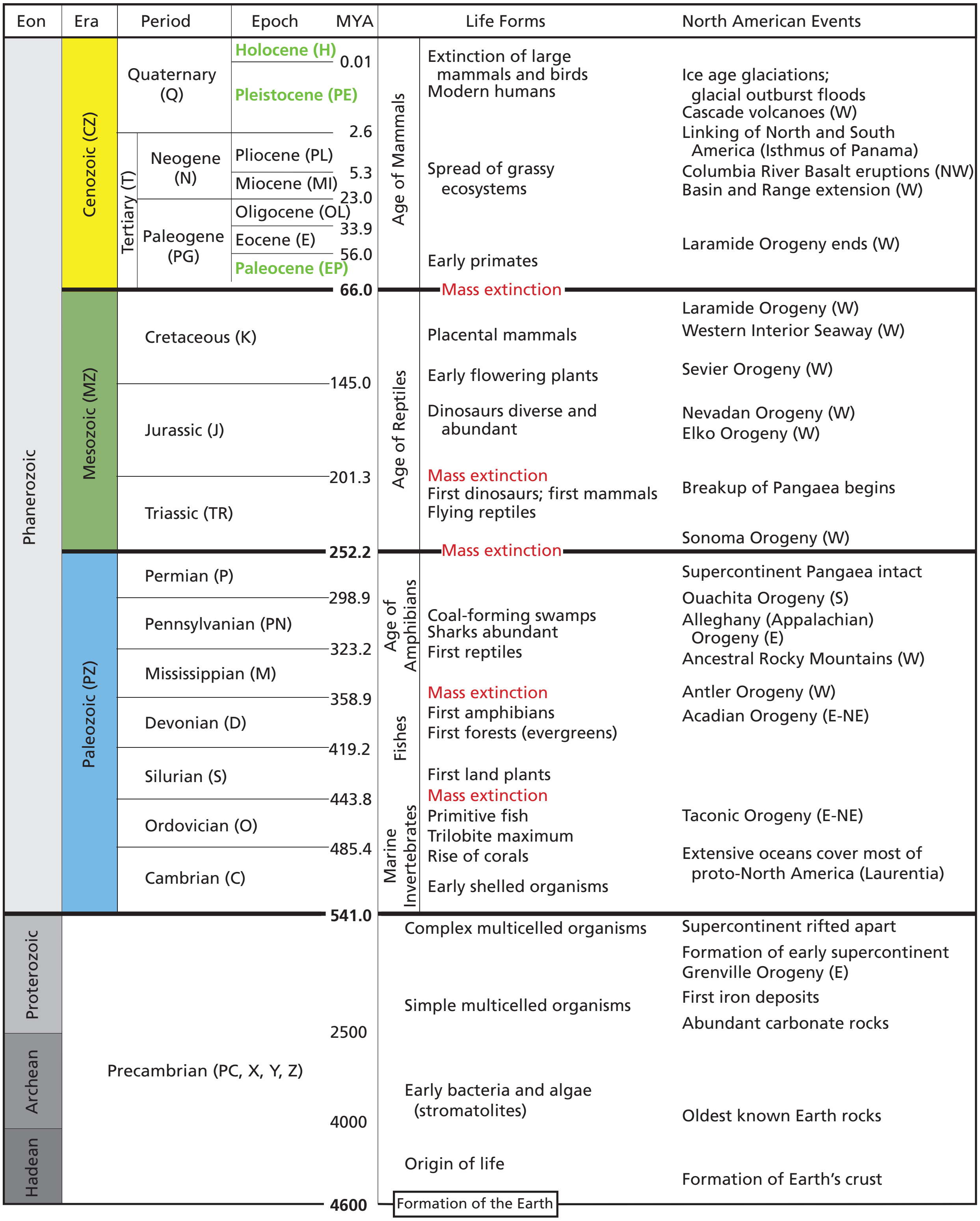

Figure 4. Geologic time scale. The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. Epochs of geologic time present in Knife River Indian Villages National Historic Site are indicated by green text. GRI map abbreviations for each time division are in parentheses. Compass directions in parentheses following items listed in the North American Events column indicate the regional locations of events. Boundary ages are millions of years ago (MYA). National Park Service graphic using dates from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale; accessed 7 May 2015).

Table 1. Morphological units in the Knife River Indian Villages National Historic Site area.

Age		Morphological Unit (map symbol)	Description
Quaternary	Holocene	Uplands (Qup)	Rolling hills, closed depressions, and sloughs. Bedrock is overlain by Paleocene sediments and Pleistocene till.
		Slopes (Qsl)	Breaks between terraces. Between the highest terrace and the uplands, and the slopes in the rugged badlands.
		Altered land and fill (Qaf)	Any area that has been altered by large-scale construction and coal mining, including unfilled pits, spoil piles, and reclaimed land.
		B terrace (Qtb)	Composite of two terraces (B1 and B2) located 0–6 m (0–20 ft) above the river level. Flat surface contains sand dunes, partially filled channels, and meander scars. Sediment consists of silt, clay, carbonate nodules, bones of large animals, organic matter, gastropods, charcoal, and fluvial sedimentary features.
		A terrace (Qta)	Terrace located 6–8 m (20–26 ft) above river level. Filled with fluvial sediment (silty sand and clay in a lower unit and silty clay in an upper unit). Contains charcoal, gastropods, carbonate nodules, bones of large mammals, and cultural artifacts. Capped by loess (windblown silt).
	Pleistocene	Sakakawea Terrace (Qtsa)	Former fluvial floodplain that is now 51–61 m (170–200 ft) above river level (same level as maximum elevation of Lake Sakakawea). Cut terrace with little remaining fluvial sediment. Modified by past glaciers.
		Riverdale Terrace (Qtr)	Cut terrace 67–90 m (220–295 ft) above river level. Cut terrace with little remaining fluvial sediment. Contains Paleocene fluvial sediment, till, fluvial gravel, aeolian sand, loess, lake sediment, and colluvium.
		Stanton Terrace (Qtst)	Flat, well-drained terrace 8–15 m (26–49 ft) above river level. Slopes are less than 5°. Filled with poorly sorted, flat-bedded to unbedded (massive) sand and gravel and capped by up to 5 m (16 ft) of loess or sand.
		Hensler Terrace (Qth)	Flat to undulating, well-drained terrace 17–31 m (56–100 ft) above river level. Slopes are less than 5°. Filled with up to 16 m (52 ft) of fluvial sand and gravel and capped by up to 10 m (30 ft) of aeolian sand or up to 5 m (16 ft) of loess.
		McKenzie Terrace (Qtm)	Parts of this gently sloping, well-drained terrace are 33–42 m (100–140 ft) above river level. Slopes are less than 5°. A previous shoreline of glacial Lake McKenzie, this terrace is either cut into Paleocene sediments or till, or is a fill terrace underlain by sand and gravel.

Rows shaded gray are not mapped on the surface in the historic site. Nomenclature and descriptions by Reiten (1983). Refer to the Morphologic Map Unit Properties Table (in pocket) for more information.

that confirm a Holocene age for A and B terraces and suggest time constraints for deposition of the layers within terraces (see table 4; Reiten 1983). For example, samples from Elbee Bluff suggest that the upper 3.3 m (11 ft) of A terrace have accumulated since about 2,900 years before present (BP), and sediment 4.2 m (14 ft) below the surface was deposited about 327 years ago at Madman Bluff (Reiten 1983).

Not only have the radiocarbon dates been used to support the chronology of the three Holocene terraces, but they have also been used to help determine Holocene climate change. For example, radiocarbon ages from the A terrace (sample SMU 708) at Elbee Bluff and B1 terrace (sample SMU 709) at Madman Bluff suggest that terrace incision, typically associated with moist climates, occurred between 2,974 and 1,132 years BP (Reiten 1983; Hartman and Kuehn, 1999). A global climatic transition to warmer drier conditions occurred about 2,500 years BP, which suggests that the erosional surface between A and B alluvial fills may have formed at this time (Wendland and Bryson 1974; Reiten 1983). Alluvial and aeolian deposition since the last glaciation has been significantly influenced by climatic variations (see “Geologic History” chapter).

In addition to the morphologic features that define the landscape, seven lithostratigraphic units are present in the area of Knife River Indian Villages National Historic Site (table 2). These units represent two intervals of geologic time: the late Paleocene Epoch (59–56 million years ago), and the Quaternary Period (the past 2.6 million years) (fig. 4; Thornberry-Ehrlich 2011). The oldest exposures mapped in the Knife River Indian Villages Historic Site consist of interlayered siltstone, claystone, sandstone, and lignite coal beds of the Paleocene Sentinel Butte/Bullion Creek formations, undivided (**Tsb**). The GRI report and GIS data follow the source map nomenclature of Reiten (1983), which refers to the undifferentiated Sentinel Butte/Bullion Creek formations (**Tsb**), but in North Dakota, the Sentinel Butte Formation is also known as the Sentinel Butte Member of the Fort Union Formation and the Bullion Creek Formation is also known as the Tongue River Member of the Fort Union Formation (table 2).

River and glacial sediments of Unit 3 of the Holocene-

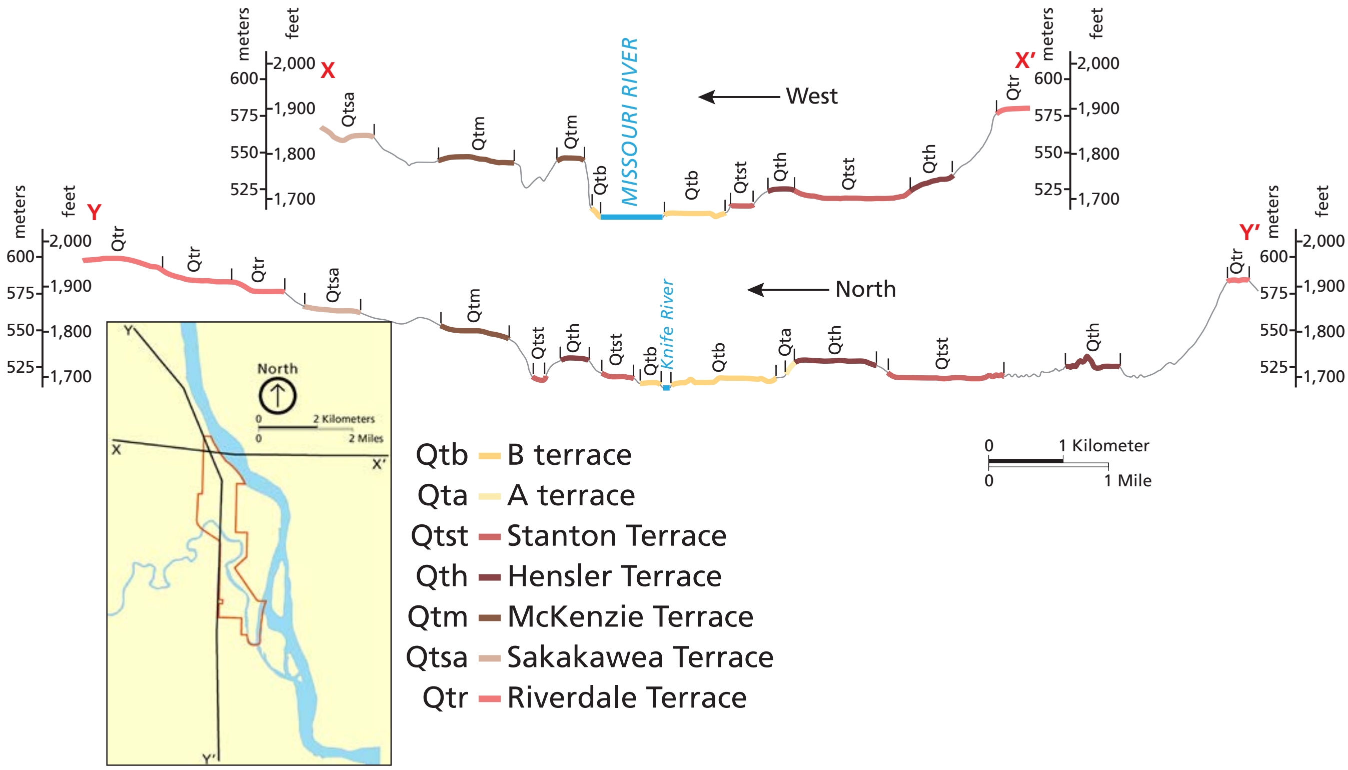

Figure 5. Surface profiles showing the terraces in the Knife River Indian Villages National Historic Site area. East–west profile x–x′ transects the historic site north of the Knife River. Profile y–y′ is a north-south transect that intersects the historic site (see inset map). Colors correspond to those on the morphologic units map poster (in pocket). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Reiten (1983).

Pleistocene Coleharbor Formation (**Qc3**) are mapped on terraces both north and south of the Knife River in the historic site. Aeolian sandy silt of Unit 5 of the younger Oahe Formation (**Qo5**) has been deposited on some of the terraces, and the clay, silt, and sand of Unit 7 of the Oahe Formation (**Qo7**) form the modern floodplain of the Knife River (see posters, in pocket; Reiten 1983). Some of the other units are not mapped on the surface of the historic site, but they occur in the subsurface and in geologic cross-sections of the terraces (fig. 6).

Geologic Significance and Connections

This region along the Missouri River contains archeological evidence documenting prehistoric hunter-gatherer groups, the growth of permanent agricultural communities, sophisticated trade economies, and the advent of European American exploration. Four major time periods and cultures are represented by the archeological remains discovered in more than 50 archeological sites in Knife River Indian Villages National Historic Site: (1) Paleo-Indian Period (11,500–8,000 years BP), (2) Archaic Period (8,000–2,000 BP), (3) Woodland Period (2,000–1,000 BP), and (4) Plains Village Period (1,000–100 BP) (Ahler 1978; Reiten 1983; Hoganson and Murphy 2003; Thornberry-Ehrlich 2011). The Plains Village Period has yielded the most abundant archeological artifacts.

Terraces, floodplains, and river systems provided native peoples with the resources needed to establish and sustain permanent communities. Hundreds of round structures, which outline previously constructed earthlodges, dot the river terraces along the Missouri and Knife rivers and represent several centuries of Plains Village Period communities of Hidatsa, Mandan, and Arikara tribes (fig. 7). Crops were cultivated in the river bottoms. Native peoples collected a distinctive dark brown rock known as ‘Knife River Flint’ in western North Dakota. The high quality flint was used for tools, and it was traded extensively throughout North America (see “Geologic Features and Processes” chapter).

Table 2. Lithostratigraphic units in the Knife River Indian Villages National Historic Site area.

Age		Lithostratigraphic Unit (map symbol)		Description
Quaternary	Holocene	Oahe Formation	Unit 7 (Qo7)	Silt, clay, sand, and gravel deposited in river channels and floodplains. Variable color, sorting, and thickness. Contains cultural artifacts, charcoal, wood, and fossils of terrestrial and aquatic gastropods, bison, elk, and other mammal bones. Underlies alluvial terraces and the modern floodplain of the Knife and Missouri rivers. At the base of some slopes, Unit 7 contains deposits of silty clay, pebble loam, or sandy silt.
			Unit 6 (Qo6)	Brown, well-sorted, fine- to medium-grained aeolian sand that forms either dune topography or a continuous sheet of sand. Contains 2 dark-colored paleosols.
			Unit 5 (Qo5)	Brown, well-sorted, very fine-grained sandy silt with a few pebbles and cobbles, which are commonly composed of Knife River Flint. Contains alternating layers of light-brown and dark-brown silt. Darker color corresponds with increased organic material. Fossils include terrestrial gastropods and bone fragments of large mammals. Unit 5 also contains rodent burrows and other burrows that may have been made by insects. Interpreted to be largely a loess deposit. Overlies Tsb, Qc2, Qc3, and Qc4 and may be interlayered with Qo6 and Qo7.
		Coleharbor Formation	Unit 4 (Qc4)	Brown, fine-grained sand, silt, and clay. Interpreted as offshore lake sediments. Found as a surficial deposit in depressions in till on uplands or gravels on terraces.
	Pleistocene		Unit 3 (Qc3)	Brown and gray, poorly to moderately well-sorted silty sand, sand, and gravel deposited in river beds, meltwater channels, and along shorelines. Contains a heterogeneous mixture of igneous, metamorphic, and sedimentary rock fragments. Overlies Tsb and is interlayered with lake sediments (Qc4) and till (Qc2).
			Unit 2 (Qc2)	Gray and brown, pebbly clay-loam containing some cobbles and boulders. This unit is a till deposit.
Paleogene	Paleocene	Sentinel Butte/ Bullion Creek Formations (Tsb)		Poorly lithified, brown, gray, and white sand, silt, silty clay, and clay with some carbonaceous shale and lignite. Primarily fluvial in origin and includes channel, overbank, and marsh deposits. Also, described as "Unit 1" in Reiten (1983).

Rows shaded gray are not mapped on the surface in the historic site. Nomenclature and descriptions by Reiten (1983). The Bullion Creek Formation is also known as the Tongue River Member of the Fort Union Formation, and the Sentinel Butte Formation is also known as the Sentinel Butte Member of the Fort Union Formation. Refer to the Lithologic Map Unit Properties Table (in pocket) for more information.

The 711.58 ha (1,758.4 ac) Knife River Indian Villages National Historic Site was established in 1974 to preserve and protect some of the best surviving examples of earthlodge villages in the northern Great Plains (National Park Service 2013a). The Hidatsa, Mandan, and Arikara lived in this region from about 1300 CE to 1845 CE, but cultural artifacts record about 3,500 years of human habitation that includes the transition from hunting and gathering of wild foods to primarily hunting with supplemental gardening (Ahler et al. 1991; Metcalf 1994).

European goods were traded in these settlements in the early 1600s, and fur traders first arrived in 1738. When Lewis and Clark arrived in 1804, they found an active, prosperous community. Crows, Assiniboines, Cheyennes, Kiowas, Arapahoes, whites from the North West and Hudson's Bay companies, and businessmen from St. Louis came to the villages to trade with the Hidatsa, Mandans, and Arikaras (Ambrose 1996).

The farthest north village in Knife River Indian Villages National Historic Site is Hidatsa Village, also known as Big Hidatsa Village (National Park Service 2014a). Established around 1600 CE, Hidatsa Village contained more than 100 earthlodges on roughly 6.3 ha (15.5 ac). An estimated 820–1,200 people lived in the village. In 1845, the Hidatsa abandoned the village and moved 64 km (40 mi) upriver to establish Like-a-Fishhook Village, which would be their last traditional earthlodge village.

Established as early as 1525 CE and occupied until about 1780–1785, Awatixa Xi'e Village, also known as Lower Hidatsa Village, contained at least 50 earthlodges and covered about 4.0 ha (10 ac) (National Park Service 2014a). The village was home to an estimated 500–600 people. After a smallpox epidemic swept through the villages, the survivors abandoned Awatixa Xi'e Village and established Awatixa Village. The population of the Awatixa Village fluctuated widely, but it originally contained as many as 60 earthlodges. A Sioux raid burned the village to the ground in 1834, and the survivors are believed to have established Taylor Bluff

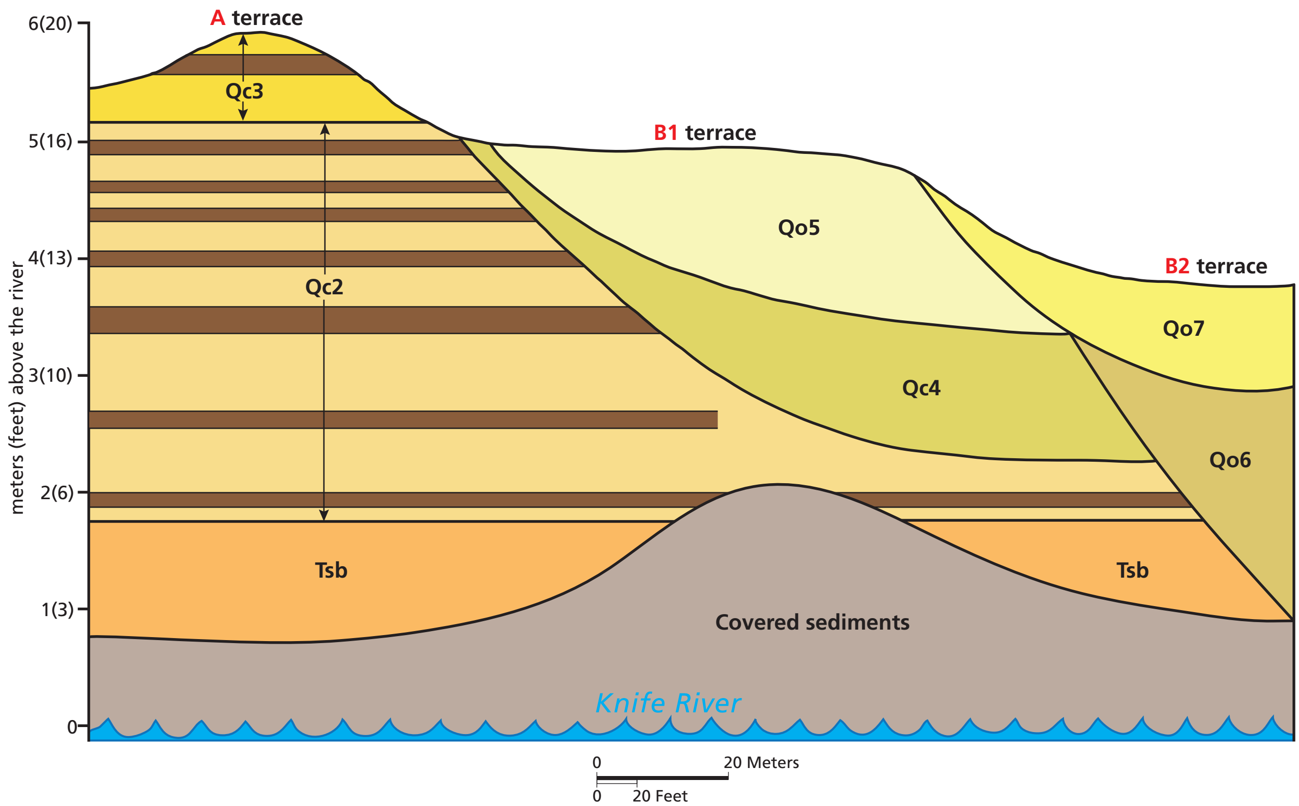

Figure 6. Sketch of Elbee Bluff showing the relationships among terraces. Elbee Bluff is north of the visitor center at Knife River National Historic Site. The figure shows the relationships among A, B1, and B2 terraces and the associated alluvial fill units (lithologic units Qo or Qc1–7). Brown layers in Qc2 represent paleosols. Thin sand layers are also present in Qc2. Thin clay layers are present in Qo5. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Reiten (1983; figure 30).

Village, a short lived village on the opposite bank of the Knife River (National Park Service 2014a).

Awatixa Village is also known as Sakakawea Village. Sacagawea was living in Awatixa Village when Lewis and Clark recruited her husband, Toussaint Charbonneau, to act as their interpreter. Sacagawea's knowledge of the people and land to the west became an indispensable resource for Lewis and Clark (National Park Service 2014a).

In addition to trade goods, Europeans also brought disease. The biggest smallpox outbreak occurred at the villages in 1837, and in the 1840s, after more than 50% of the population had died, residents abandoned the Knife River villages (Thornberry-Ehrlich 2011; National Park Service 2013a).

The landscape of the historic site continues to change. Surface processes such as weathering, erosion, lateral movement of the river channel, freeze-and-thaw cycles, and flooding modify the landscape and expose, destroy, or bury the archeological resources in Knife River Indian Villages National Historic Site.

Figure 7. Hidatsa villages in Knife River Indian Villages National Historic Site. Circular depressions mark the location of earthlodges. Note the travois (a type of sled) trails in the upper left (bottom photograph) that lead away from the Hidatsa Village. National Park Service photographs available at http://www.nps.gov/knri/historyculture/places.htm (accessed 17 July 2014).

Geologic Features and Processes

This section describes noteworthy geologic features and processes in Knife River Indian Villages National Historic Site

During the 2011 scoping meeting (Thornberry-Ehrlich 2011) and 2014 conference call, participants (see Appendix A) identified the following geologic features and processes:

- Features that Connect Geology and Archeology
- Terraces as Landscape Features
- Paleontological Resources
- Glacial Features
- Fluvial Features
- Lake (lacustrine) Features
- Aeolian Features
- Fluvial Geomorphic Features

Features that Connect Geology and Archeology

Geologic features in the area of Knife River Indian Villages National Historic Site became important resources for the Mandan and Hidatsa people. These resources, which are described in the following subsections, included the fertile floodplain for crops, Knife River flint for tools and projectile points, river terraces that protected the Indians from flooding and offered expansive views of river traffic, and clay for pottery and local coal (National Park Service 2013a).

Knife River Floodplain

Although flooding may cause management issues for the historic site (see the "Geologic Resource Management Issues" section), flooding in the 19th century provided nutrients and enriched the soil for the Hidatsa people. Flooding spread alluvial materials such as silt, clay, and organic matter over the floodplain. Weathered silt released minerals and nutrients for plants. Organic material decomposed to release plant nutrients, increase cation exchange capacity, and improve the soil's physical condition. The clay, silt, sand, and gravel of Unit 7 of the Oahe Formation (geologic map unit **Qo7**) forms the modern floodplain of the Knife River.

In addition to crops, the well-drained soils supported grasses, and cottonwood trees grew along the river banks. Grass was used to cover the earthlodges.

Figure 8. Photograph of a replica earthlodge at Knife River Indian Villages National Historical Site. The Hidatsa used natural resources from the surrounding area to build their earthlodges. Travois (a type of sled) poles are stacked against the entrance to the earthlodge. Photograph by Joseph Hartman (University of North Dakota).

Cottonwoods provided wooden supports for the earthlodges, abundant fuel for fires, and shelter from harsh winter winds (fig. 8).

Knife River Flint

Knife River Flint was mined from several quarries in the Knife River valley for at least the last 13,000 years (Clayton et al. 1970; Murphy 2014). Of the five major silica-rich (siliceous) beds in North Dakota (Rhame Bed, Rainy Butte Chert, Taylor Bed, HS Bed, and Knife River Flint), Paleo-Indians found Knife River Flint to be the easiest to fashion into tools and projectile points, such as arrowheads, knives, and scrapers (Murphy 2014).

The jet black to dark chocolate brown to gray Knife River Flint has a glassy to waxy texture and consists of silicified peat and fragments of fossil plants (Murphy 2014). The floral material suggests that it was originally deposited in ponds and swamps. In such an environment, silica-rich groundwater may have interacted with organic-rich peat to produce the Knife River Flint (Murphy 2014).

Details about the origin of Knife River Flint are sketchy because the flint has never been found in an outcrop.

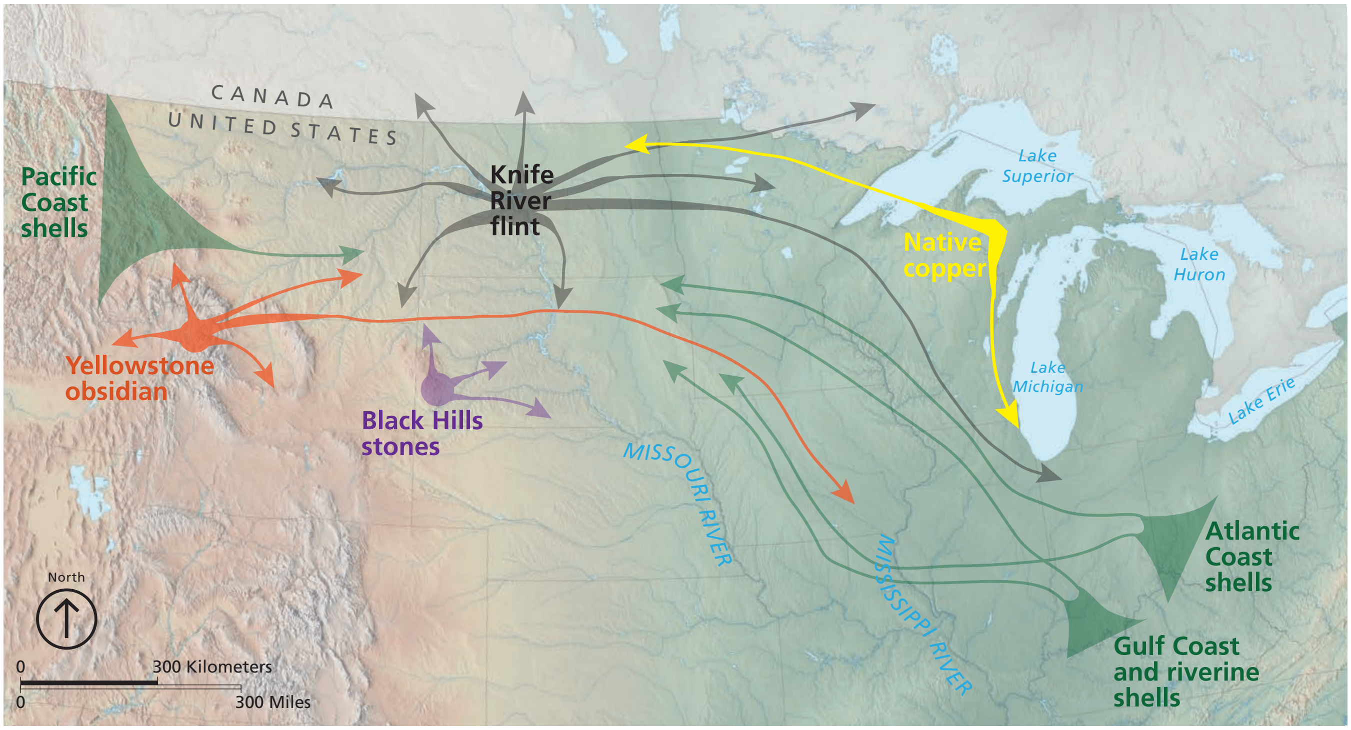

Figure 9. Map of Northern Plains prehistoric trading system. Paleo-Indians moved Knife River Flint and other goods such as stones, shells, and copper throughout the Great Plains. Graphic by Trista Thornberry-Ehrlich (Colorado State University), after Metcalf (1994, p. 6). Basemap by Tom Patterson (National Park Service), available at http://www.shadedrelief.com/physical/pages/download.html (accessed 4 November 2014).

It has only been found in eroded pre-glacial gravel deposits, glacial meltwater and till deposits, and modern river and coarse-grained deposits left behind after finer-grained material washed away (Clayton et al. 1970; Hoganson and Murphy 2003; Murphy 2014). Pieces of the flint are generally found along terraces of the Knife River and Spring Creek in Dunn, Mercer, and Oliver counties. Paleo-Indians dug shallow pits into these deposits to collect Knife River Flint (Murphy 2014).

Because it has not been found in place, the Knife River Flint age is uncertain. However, pieces of the Knife River Flint have been found lying on top of the Sentinel Butte Member, suggesting it is younger than 66 million–56 million years old (Paleocene Epoch; fig. 4). Pebbles of flint found in the late Eocene Chadron Formation further constrain the maximum age of the Knife River Flint to the early Eocene. The early Eocene Golden Valley Formation is currently considered to be the likely source of the Knife River Flint. In Stark County, the silica-rich HS Bed also occurs at this same stratigraphic level (Clayton et al. 1970; Murphy 2006, 2014).

Prized for its high quality, Knife River Flint was traded throughout North America. Artifacts made from Knife River Flint have been found in New York, New Mexico, and northern Canada (fig. 9; Clayton et al. 1970; Hoganson and Murphy 2003). Hidatsa and Mandan traded it for such items as copper, obsidian, shells, beads, cloth, and metal tools.

Quarrying ended about 300 years ago with the introduction of steel into North Dakota from the eastern United States. Today, the quarries are preserved in the Lynch Knife River Flint Quarry National Historic Landmark, which was dedicated in 2012, and is located approximately 100 km (65 mi) west of the historic site (Murphy 2006). Even after the introduction of steel, however, Knife River Flint continued to be a valuable resource. It was used in flintlock weapons until the mid-19th century (fig. 10). Knife River Flint is still used today by those that knap flint for a hobby, and is offered for sale on many websites (Murphy 2014).

Terraces and Indian Villages

The relatively flat surface of the Stanton Terrace (**Qtst**) proved ideal for the circular earthlodges of the

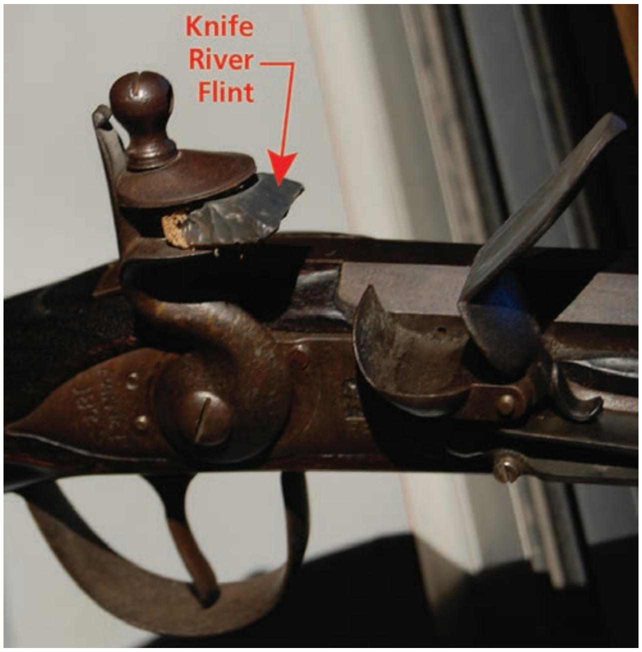

Figure 10. Photograph of Knife River Flint in a flintlock rifle. The flintlock mechanism was introduced in the 17th century. A spark from the flint ignited the powder, which fired the ball. Photograph by Joseph Hartman (University of North Dakota).

Hidatsa and Mandan. Villages often contained 40–50 earthlodges. Lewis and Clark noted one village with as many as 130 lodges (Ambrose 1996). The remains of earthlodge villages form clusters of circular depressions on the terraces (fig. 7). The depressions measure about 1 m (3 ft) deep and 7–12 m (23–39 ft) across (Reiten 1983). Big Hidatsa Village contained about 100 lodges; Sakakawea Village had about 30 lodges; and Lower Hidatsa Village had about 40 lodges (Reiten 1983).

Sedimentary Deposits and Cultural Materials

Because of its age and geographic extent, the Oahe Formation may contain cultural materials (Reiten 1983). Depositional environments in the Oahe Formation include windblown silt (loess) of Unit 5 (**Qo5**), windblown sand of Unit 6 (**Qo6**), and alluvium and colluvium of Unit 7 (**Qo7**). Vertical accretion deposits of Unit 7, such as overbank deposits, are more likely to preserve cultural resources than alluvial sediments deposited on point bars and other lateral accretion features where annual floods tend to erode and redistribute sediment (Reiten 1983).

Artifacts may also be preserved in loess deposits of Unit 5 because such deposits usually form on relatively flat topography that would apparently make good locations for permanent settlement. Paleosols in these loess deposits, as well as in overbank deposits, are the most likely stratigraphic horizons to contain artifacts (Reiten 1983).

Windblown sand deposits (**Qo6**) also contain artifacts, but preservation of the original stratigraphy is often poor. Cultural materials are commonly found in deflated areas (blowouts) scoured by wind erosion. As with the other depositional environments, paleosol horizons in windblown sand deposits contain the most artifacts.

Terraces as Landscape Features

Meltwater flowing from Pleistocene continental ice sheets distributed abundant quantities of sand and gravel in North Dakota. When rivers incised into these meltwater deposits, their old floodplains became terraces composed primarily of sand and gravel. When the Knife River channel cut vertically into the underlying sediment, it abandoned its former floodplain, and as it eroded laterally, it cut a new floodplain and produced the fluvial features discussed below. The Pleistocene Stanton (**Qtst**), Hensler (**Qth**), and McKenzie (**Qtm**) terraces and Holocene A (**Qta**) and B (**Qtb**) terraces are mapped in Knife River Indian Villages National Historic Site (table 1; see posters in pocket).

Pleistocene McKenzie Terrace (Qtm)

Remnants of the McKenzie Terrace are present in the northern part of the historic site, north of the Knife River. Rather than representing a former fluvial floodplain, the McKenzie Terrace represents the shoreline of glacial Lake McKenzie, from which it gets its name. About 14,000 years ago, ice blocked the river channel in south-central North Dakota, resulting in Lake McKenzie. Lake McKenzie occupied parts of the Missouri River valley from the border with present-day South Dakota to Riverdale (Hoganson and Murphy 2003).

The flat to gently sloping, well-drained surface of the McKenzie Terrace has been cut into Paleocene sediments or till or it has formed above deposits of sand and gravel. Up to 10 m (33 ft) of aeolian sand or up to 5 m (16 ft) of aeolian silt caps much of the McKenzie surface (Reiten 1983).

An abandoned gravel pit in the northern part of Knife River Indian Villages National Historic Site exposes 2 m (7 ft) of large-scale, high-angle, well-sorted, cross-bedded gravel in the McKenzie Terrace (Reiten 1983). The cross-bedded deposits represent back-beach deposits formed along the shoreline of Lake McKenzie. As with the other Pleistocene terraces, the McKenzie Terrace is differentiated by its flat surface within specific elevation limits (table 1).

Pleistocene Hensler Terrace (Qth)

The Hensler Terrace forms a flat to gently undulating, well-drained surface northwest of the Visitor Center. This Pleistocene terrace is filled with up to 16 m (52 ft) of fluvial sand and gravel and capped with up to 10 m (33 ft) of aeolian sand or up to 5 m (16 ft) of aeolian silt (Reiten 1983).

About 5 km (3 mi) west of Stanton, the Hensler Terrace contains about 10 m (33 ft) of faulted and folded gravel. Deformation may have occurred following deposition of Hensler sand and gravel above a block of stagnant ice. When the stagnant ice melted, the overlying sediment would have collapsed, resulting in the deformation (Reiten 1983).

Pleistocene Stanton Terrace (Qtst)

The Hidatsa (Big Hidatsa Site), Awatixa (Sakakawea Site), and Awatixa Xi'e (Lower Hidatsa Site) villages were built on the Stanton terrace, the youngest of the five Pleistocene terraces (table 1; Reiten 1983). The terrace formed about 13,000 years ago during the Late Wisconsinan glacial event (most recent "ice age") (Hoganson and Murphy 2003). Poorly sorted, unbedded sand and gravel fill the terrace, and up to 5 m (16 ft) of aeolian silt or sand that grades upward into overbank silt and clay caps the terrace. Its flat surface and elevation limits are used to identify the Stanton Terrace, but if younger alluvial silt and clay cover its surface, the Stanton Terrace may be difficult to differentiate from A terrace (**Qta**) (Reiten 1983).

Holocene A Terrace (Qta)

Remnants of A terrace line the edges of the present Knife River valley in the historic site. The lithology of both A terrace and B terrace is mapped as Unit 7 of the Oahe Formation (**Qo7**). Two major units fill A terrace. The lower unit contains more than 5 m (16 ft) of light-colored silty sand and clay with sedimentary features that include high- and low-angle, small-scale cross-beds, climbing ripple cross-beds, and horizontal beds. The lithology and sedimentary features suggest that the fill is a product of lateral accretion, primarily as point bars (see "Fluvial Geomorphic Features" section) as the channel migrated across its floodplain. The grain size of the sediment becomes finer from the base of the unit to the top. This fining-upwards transition is also typical of fluvial deposition on point bars where coarser material initially settles out of the water column followed by finer-grained sediments as the velocity of the main channel shifts laterally away from the point bar.

The upper unit consists of darker-colored overbank flood deposits of clayey silt and silty clay. These vertical accretion deposits are capped by up to 1 m (3.3 ft) of grayish-brown loess (Reiten 1983). Discontinuous layers of charcoal, terrestrial gastropods, carbonate nodules, bones of large mammals, and cultural artifacts are found in A terrace. The charcoal layers, which are several meters long, were once thought to be remnants of hearths, but they do not contain any cultural artifacts. They are now thought to be the remains of floodplain forest fires (Reiten 1983). Dark bands containing disseminated organic matter have been interpreted as paleosols.

The color contrast between the lower and upper units, escarpments between the two units, the elevation limits of the terrace, paleosols, and the absence of meander scars (previous channels now filled with sediment) differentiate A terrace from the other terraces. The terrace is restricted to the Knife River valley. If A terrace also formed along the Missouri River, it has been destroyed by the meandering river. The larger drainage area of the Missouri River and increased flow from Rocky Mountain glaciers may have contributed enough water to prevent the accumulation of sediment (known as 'aggradation') to the A terrace surface (Reiten 1983).

Charcoal from the upper unit provided radiocarbon ages from 2,900 years BP to 3,900 years BP. The lower unit has not been age-dated, but it would be older than 3,900 years BP and younger than the Pleistocene Sakakawea terrace (Reiten 1983).

Holocene B Terrace (Qtb)

B terrace is the current terrace forming adjacent to the Knife and Missouri rivers. The terrace's flat surface contains meander scars, which are easily identifiable from the air, and floodplain sand dunes, which provide up to 6 m (20 ft) of relief on the terrace surface (Sturdevant et al. 2013). High-resolution airborne laser

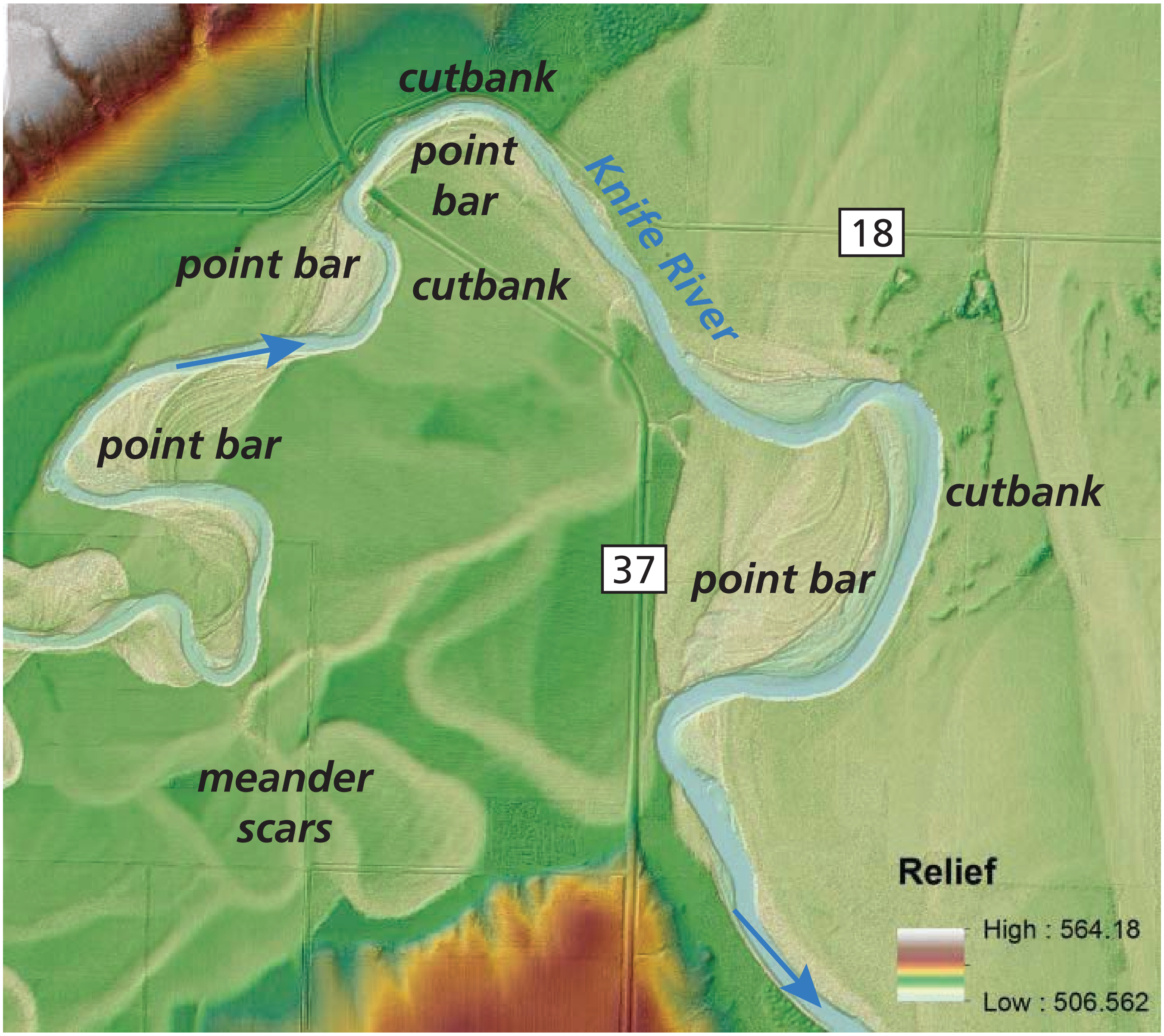

Figure 11. Illustration of meander scars of the Knife River. An airborne laser scan shows distinct meander scars that represent the old channel pattern. Digital terrain model from Sturdevant et al. (2013, fig. 2) available at http://www.nature.nps.gov/ParkScience/Archive/PDF/Article_PDFs/ParkScience30(2)Fall2013_22-25_Sturdevant_et_al_3662.pdf (accessed 08 October 2014).

scanning is an excellent tool to reveal meander scars in the present floodplain (fig. 11). These scars mark the previous position of river channels, which were abandoned and then filled with alluvium.

B terrace is a composite of two fill terraces (B1 and B2) that range from 0 m (0 ft) to 6 m (20 ft) above river level. A fill terrace forms in a two-step process. First, an existing valley fills with alluvial sediments, possibly from abundant sediments from a glacier or from a decrease in stream power. Then, a stream incises into these sediments that had filled the valley. The two B terraces can be differentiated by a geologic cross-section, but they are indistinguishable on the surface (Reiten 1983). The B1 surface is older and ranges from 4 m (13 ft) to 6 m (20 ft) above river level. The B2 surface is 0–5 m (0–16 ft) above river level and is the modern floodplain.

The lower 1–3 m (3.3–10 ft) of B1 terrace is primarily an overbank deposit of dark-gray silty clay that unconformably overlies A terrace. The fill contains carbonate nodules, bones of large mammals, organic matter, and terrestrial gastropods. The dark color is a result of soil development.

The upper 1–5 m (3.3–16 ft) of B1 terrace represents both lateral accretion (point bar) and vertical accretion (overbank) deposits. The fill is a light-brown to pale-brown silty clay with darker-colored layers of charcoal.

B2 terrace fill is similar to A terrace fill. Pale-brown to very light-brown silty sand in the lower part is overlain by dark-grayish-brown silty clay. Climbing ripple cross-beds, small-scale cross-beds, horizontal and convoluted beds, and fossils of terrestrial gastropods, aquatic gastropods, bivalves, large mammal bones, wood, and charcoal are found in the lower, light-colored part of the terrace. Similar to A terrace, these features suggest lateral accretion (point bar) deposits. The darker upper section of B2 terrace represents vertical accretion (overbank) deposits and paleosol development.

Wood and charcoal samples from B terrace have been radiocarbon dated from 1,100 years BP to modern day (Reiten 1983).

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are non-renewable. Body fossils are any remains of the actual organism, such as bones, teeth, shells, or leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, or coprolites (fossil dung). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts, such as building stones or archeological resources. As of August 2015, 260 parks, including Knife River Indian Villages National Historic Site had documented paleontological resources in at least one of these contexts. The NPS Geologic Resources Division Paleontology website provides more information (http://go.nps.gov/grd_paleo; accessed 10 February 2015).

Fossils are documented in the museum collections of Knife River Indian Villages National Historic Site as cultural resources, but no fossils have been documented from the rocks and sediments within the historic site (Tweet et al. 2011). However, fossils have been discovered in these units outside of the historic site, and future investigations may recover fossils from the units in the historic site. Pleistocene and Holocene fossils may be found that are hundreds to thousands of years older than specimens in the current collection (Tweet et al. 2011).

Knife River Indian Villages National Historic Site collections contain several invertebrate fossils, some of which were used for cultural purposes. The fossils include ammonites, crinoid stem segments, snail shells, and at least four unidentified fossil fragments (fig. 12; Tweet et al. 2011). Resource management issues associated with fossils are documented in that chapter of this report.

Fossils Used in a Cultural Context

Indian tribes, including the Crow, Hidatsa, Mandan, and Sioux, used invertebrate fossils for ornamental purposes (Hoganson and Murphy 2003; Mayor 2005). A drilled ammonite (sample KNRI 262) may have been a pendant, and the perforated snail shell (KNRI 1225) has been interpreted as jewelry (Hoganson and Murphy 2003). Snail shells may have come from local exposures of the Sentinel Butte/Bullion Creek Formations, undivided (**Tsb**), but ammonite fragments would have had to come from Cretaceous or older strata.

Fossiliferous rocks were also used in a cultural context. As mentioned above, Knife River Flint was used for tools, as was silicified peat of the Golden Valley Formation. An overview of how fossils were used in cultural resource contexts in some other National Park Service areas is presented by Kenworthy and Santucci (2006).

Potential Sources of Fossils

Fossils from the Paleocene Sentinel Butte Formation include pollen, plant macrofossils (roots, stumps, petrified wood fruits, leaves), fungal spores, freshwater bivalves and gastropods, ostracodes, fish, giant salamanders, turtles, champsosaurs (aquatic reptiles), crocodilians, mammals, and invertebrate trace fossils (Hartman et al. 1993; Kihm et al. 1993; Tweet et al. 2011). Fossil mammals and mollusks have been found at sites north and south of Garrison Dam, and a well-known fossil site 48 km (30 mi) south-southwest of Knife River Indian Villages Historic Site produced extremely well-preserved fossils of seeds, fruits, stems, leaves, and a few articulated fish (Crane et al. 1990; Newbrey and Bozek 2000, 2002; Tweet et al. 2011). The fossils suggest that the original environment consisted of a lake and nearshore depositional setting in which the average annual temperature was 19° C (66° F) and the average annual precipitation was 110 cm (43 in) or more (Evraets and Decker 2009).

Although scarce in North Dakota, Quaternary fossils

Crinoid stem (KNRI 1869)

Gastropod (snail; KNRI 1225)

Ammonite (KNRI 833)

Figure 12. Photographs of fossils from the Knife River Indian Villages National Historic Site collections. The gastropod is Paleocene in age and was identified as a narrow form of *Campeloma nebrascense nebrascense* (Meek and Hayden; Joseph Hartman, University of North Dakota, geologist, written communication, 16 April 2015. Scale is in centimeters (CM). National Park Service photographs.

fall into one of two general categories: (1) Pleistocene megafauna, such as ground sloths, extinct horses, mastodons and mammoths, and giant bison, and (2) Holocene paleoenvironmental fossils such as pollen, spores, and aquatic microfossils, which can be used to interpret past climates (Hoganson and Murphy 2003; Tweet et al. 2011). Pleistocene megafauna found in the vicinity include two approximately 5,000-year-old bison skulls from a site 44 km (28 mi) west of Knife River Indian Villages National Historic Site, and a skull from the giant ice age bison Bison latifrons from a site 106 km (66 mi) northwest of the historic site (Brophy 1966; Hoganson 2003; Hoganson and Murphy 2003).

Paleoenvironmental fossils have been found in Pleistocene and Holocene deposits. Terrestrial gastropods, bone fragments of large mammals, and rodent burrows are known from Unit 5 (Qo5) and Unit 7 (**Qo7**) of the Oahe Formation (Reiten 1983). Calcareous algae, bivalves, gastropods, ostracodes, and three types of fish were recovered in a Wisconsinan glacial lake in the Prophets Mountains, about 59 km (37 mi) northwest of Knife River Indian Villages National Historical Site (Sherrod 1963; Tweet et al. 2011). Abundant beetle fauna (more than 84 species), peat, spruce wood and cones, bivalves, and gastropods dating from 13,907 to 12,520 calendar years BP have been found at the Johns Lake Basin fossil site, 66 km (41 mi) east of the historical site (Ashworth and Schwert 1992). Fossils from Rice Lake—a well-studied paleoecological site 71 km (44 mi) north of Knife River Indian Villages National Historical Site—include 11,000–10,000-year-old charcoal, charophyte (a type of green algae) oospores, pollen, seeds, stems, wood, bivalves, and ostracodes (Yu and Ito 1999; Grimm 2001; Yu et al. 2002; Umbanhowar 2004).

Holocene paleoenvironmental fossils are relatively young. Phytoliths (plant cell minerals) from the 17th or 18th century to 1845 CE, charcoal, wood, bones, and human rubbish middens have been described from Big Hidatsa Village (Mulholland 1993). The fluvial/

floodplain environments along the Knife River in the historical site may contain relatively large resistant objects, such as logs, mammoth teeth, or bison bones (Clayton et al. 1976; Tweet et al. 2011).

Glacial Features

During the Wisconsinan glacial event (most recent "ice age"), which occurred between about 70,000 to 12,000 years ago, the continental ice sheet extended as far south as the Knife River Indian Villages National Historic Site area, although previous glaciers had advanced farther south (fig. 13; Hoganson and Murphy 2003). When the ice retreated from North Dakota about 11,000 years ago, sediment once trapped in the ice was deposited on the ground surface. This unsorted, heterogeneous mixture of clay, silt, sand, gravel, and boulders is referred to as till and is mapped as the unsorted pebbly clay-loam of Unit 2 of the Pleistocene Coleharbor Formation (**Qc2**; table 3; Dreimanis 1988).

The northeast–southwest-trending longitudinal ridges that are mapped northwest of the historic site may have been caused by subglacial shearing early in the Wisconsinan glaciation (Reiten 1983). Subglacial shearing is caused by dynamic and complex subglacial processes that mobilize, transport, and deposit sediment at the ice/bedrock interface (Evans et al. 2006).

The outwash deposits of sand and gravel and till in the terraces remain as evidence of glaciation, but Holocene erosion has removed most of the glacial deposits in the area surrounding Knife River Indian Villages National Historic Site, especially on the Uplands. In some areas, only glacial erratics (boulders left by the retreating glaciers that have no local source) remain as evidence that glaciers once covered the upland area (Hoganson and Murphy 2003).

Fluvial Features

When the climate warmed and the glaciers melted, following the most recent ice age, great volumes of meltwater flowed into the drainage systems. The velocity of the rivers cut extensive meltwater channels. The poorly to moderately sorted, heterogeneous mixture of igneous, metamorphic, and sedimentary rock fragments, high-angle large-scale cross-bedding, and large-scale trough cross-bedding in Unit 3 of the Coleharbor Formation (**Qc3**) are features characteristic of glaciofluvial deposition and an upper flow regime, which is characterized by high sediment transport rates (table 3). A lower flow regime is characterized by

Table 3. Stratigraphic features, processes, and depositional environments of map units of the Knife River Indian Villages National Historic Site area.

Unit (map symbol)		Stratigraphic Features	Processes Associated with Features	Depositional Environments
Oahe Formation	Unit 7 (Qo7)	Layers of gravel, sand, silt, and clay. Climbing ripple cross-beds, flat beds, large- and small-scale cross-beds, terrestrial and aquatic gastropods, and the bones of large mammals (bison and elk).	Fluctuating flow conditions from low-flow regime (small-scale cross-beds) to flood events (large mammal bones).	Channels to floodplains of a river system.
	Unit 6 (Qo6)	Well-sorted sand in low-angle cross-beds and flat beds.	Deposition and erosion (blowout) from wind currents.	Dunes, sand sheets, and blowouts.
	Unit 5 (Qo5)	Well-sorted, homogeneous deposits of silt.	Rock fragments pulverized to silt by glaciers and then picked up wind currents.	Windblown silt (loess).
Coleharbor Formation	Unit 4 (Qc4)	Fine laminations, moderately well-sorted sediment, and flat bedding.	Settling of sediment out of currents with decreasing velocity.	Lakes and water-filled depressions on till.
	Unit 3 (Qc3)	Poor to moderate sorting; high-angle large-scale and trough cross-bedding.	Upper-flow regime of a river system.	Meltwater flowing from the margins of melting glaciers.
	Unit 2 (Qc2)	Unsorted, heterogeneous mixture of clay, silt, sand, gravel, and boulders.	Material left behind when glaciers melted.	Till deposited beneath a glacier.
Sentinel Butte/ Bullion Creek Formations (Tsb)		Fining-upward sequences of grain sizes in layers of sand, silt, silty clay, and clay.	Upper- and lower-flow regimes (sand-to-clay) of a river system.	Channel, overbank, marsh environments on a low-relief coastal plain.

Figure 13. Extent of Pleistocene glaciation in North America. The Wisconsinan glaciation is the youngest glacial episode, occurring approximately 35,000–11,150 years ago. Knife River Indian Villages National Historic Site (green star) was near the margin of the late Wisconsinan ice sheet (solid white line in detail map) and also covered by older Pleistocene continental glaciers (dashed white line in detail map). Graphic by Jason Kenworthy (NPS Geologic Resources Division) using paleogeographic map by Ron Blakey (Colorado Plateau Geosystems, Inc; available online: http://cpgeosystems.com/nam.html, accessed 10 March 2015) and glacial extent data from Garrity and Soller (2009).

relatively low sediment transport rates. Unit 3 underlies the Hidatsa Village.

Features representing upper and lower flow regimes in river systems, as well as stagnant water, are present in the much older Paleocene Sentinel Butte/Bullion Creek Formations (**Tsb**) and the Holocene Unit 7 of the Oahe Formation (**Qo7**). The sand, silt, silty clay, and clay of the undivided Sentinel Butte/Bullion Creek Formations represent channel, overbank, and marsh depositional environments on a low-relief coastal plain (table 3; Jacob 1973; Reiten 1983; Hoganson and Murphy 2003). In contrast to present-day North Dakota climate, the Paleocene climate about 60 million years ago was warm temperate to subtropical, similar to today's Carolinas (Newbrey and Bozek 2003; Evraets and Decker 2009) The Sentinel Butte/Bullion Creek Formations have limited exposure in the historic site and are mapped primarily north of the Knife River.

Unit 7 contains features common to river processes and fluctuating flow conditions such as climbing ripple cross-beds, flat beds, and large- and small-scale cross-beds (table 3). Unit 7 also contains terrestrial gastropods, aquatic gastropods, and the bones of large mammals (bison and elk) that were transported downstream during flood events. This unit underlies the Awatixa Village.

Lake (Lacustrine) Features

Meltwater from the ice age glaciers also filled depressions in the till. Features such as fine laminations, moderately well-sorted sediment, and flat bedding in Unit 4 of the Coleharbor Formation (**Qc4**) suggest offshore deposition by currents flowing into a lake (table 3; Reiten 1983). Density currents that flowed along the lake bottoms were also responsible for the convolute beds found in Unit 4. Unit 4 is found in depressions in till on the uplands and terraces.

The McKenzie Terrace (described previously) formed as part of the shoreline of glacial Lake McKenzie.

Aeolian Features

Aeolian processes refer to windblown erosion, transportation, and deposition of sediments (Lancaster 2009). Features created by aeolian processes include dunes, loess, sand sheets, desert pavement, yardangs, and alcoves.

Glaciers pulverized rock fragments into fine silt and dust particles. With the retreat of the glaciers and before vegetation stabilized the surface, wind transported this fine silt across the landscape. Windblown silt is referred to as "loess," and is generally less than 1 m (3 ft) thick in North Dakota (Thornberry-Ehrlich 2011). The silt in Unit 5 of the Oahe Formation (**Qo5**) has been interpreted as loess, some of which has been reworked by slope wash and floodwaters (table 3; Reiten 1983). Unit 5 has a maximum thickness of 5 m (15 ft), and it was only mapped where its thickness was at least 1 m (3 ft), which was on flat-lying areas such as terraces with slopes of less than 5° (Reiten 1983). The Knife River Indian Villages National Historic Site visitor center and Awatixa Xi'e Village rest on a terrace surface covered by Unit 5.

Aeolian features associated with the area of Knife River Indian Villages National Historic Site include dunes, sand sheets, and blowouts. Unit 6 of the Oahe Formation (**Qo6**), which is mapped southwest of the Visitor Center and east of the Missouri River, includes these features (table 3; Reiten 1983).

A blowout results when wind removes all of the fine-grained sediment and leaves behind a depression in coarse-grained material. They often occur on hilltops or next to large glacial erratics. Bison would rub against these large boulders, subsequently removing the vegetation from the base of the erratic and exposing the fine sediment to the wind. Because they are heavier than the finer-grained sediment that gets blown away, fossils and resistant material such as flint are commonly associated with blowouts (Thornberry-Ehrlich 2011).

Fluvial Geomorphic Features

In addition to terraces, fluvial geomorphic features such as cutbanks and point bars formed along the Knife and Missouri rivers. Meandering rivers erode laterally, rather than vertically, as their main currents migrate from bank to bank. A cutbank forms on the outside of a meander loop where the current cuts into and erodes the unconsolidated sediments in the bank (fig. 14). Cutbanks are the only place where alluvial sediments are exposed. Cutbanks along the Knife and Missouri rivers include Big Hidatsa, Madman, Elbee, Sakakawea, and the Stanton Ferry bluffs (Reiten 1983). Charcoal samples collected from these cutbanks were used for carbon-14 analysis (table 4).

Eroded sediment from cutbanks is deposited downstream to form a point bar on the inside of a meander loop where the channel's energy decreases (fig. 14). In Knife River Indian Villages National Historic Site, these lateral accretion deposits form ridges or scrolls that are oriented almost parallel to the river channel. The point bars along the Knife River are mostly sand. Climbing-ripple cross-beds are the most common sedimentary feature in these point bars. Other features include large-scale and small-scale cross-bedding, flat-bedding, and distorted bedding. Fossils are also deposited on point bars and include aquatic and terrestrial gastropods, bivalves, and large mammal bones (Reiten 1983).

Table 4. Radiocarbon ages from Knife River Indian Villages National Historic Site.

Sample No.	Location		Material Dated	Morphological Unit (map symbol)	Radiocarbon years before present
SMU 791	Madman Bluff	4.2 m (14 ft) below B2 terrace	Wood	B2 terrace (Qtb)	327
SMU 709		2.2 m (7.2 ft) below B1 terrace	Charcoal	B1 terrace (Qtb)	1,132
SMU 708	Elbee Bluff	2.6 m (8.5 ft) below A terrace	Charcoal	A terrace (Qta)	2,974
SMU 710	Big Hidatsa Bluff (Taylor Bluff)	1.8 m (5.9 ft) below A Terrace	Charcoal		3,431
SMU 787	Elbee Bluff	3.3 m (11 ft) below A terrace	Charcoal		3,870
SMU 786		3.3 m (11 ft) below A terrace	Charcoal		3,942

Data are from Reiten (1983, Table 2). Samples were collected from paleosols and are arranged in chronological order, beginning with the youngest sample.

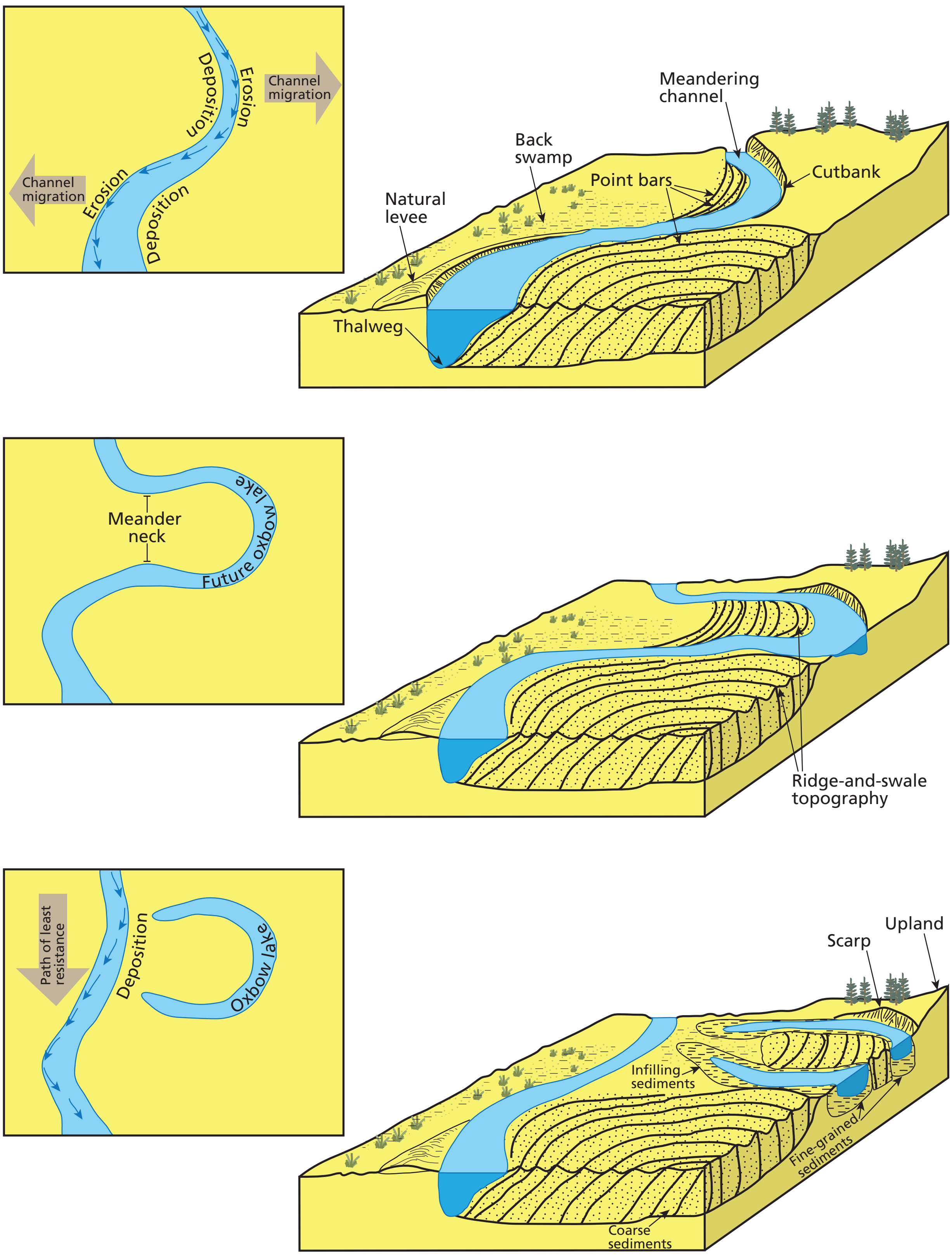

Figure 14. Schematic illustration of various meandering-stream features. Point bars are areas of deposition. Lateral erosion takes place at cutbanks. The thalweg is the path of maximum velocity and deepest part of the channel. It is represented by the arrows within the stream. When a meander neck is cut off, an oxbow lake forms. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Geologic Resource Management Issues

This section describes geologic features, processes, or human activities that may require management for visitor safety, protection of infrastructure, and preservation of natural and cultural resources in Knife River Indian Villages National Historic Site. The NPS Geologic Resources Division provides technical and policy assistance for these issues.

During the 2011 scoping meeting (see Thornberry-Ehrlich 2011) and 2014 conference call, participants (see Appendix A) identified the flooding and bank erosion as the primary and interrelated geologic resource management issues. These issues may be subdivided as follows:

- Impacts Resulting from the Garrison Dam
- Flooding of the Knife River
- Bank Erosion on the Knife River
- Impacts of Bank Erosion on Archeological Sites and Infrastructure.
- Recommendations to Monitor and Mitigate Bank Erosion

Flood events, bank erosion on the Knife River, and the impact on archeological sites and infrastructure are intimately connected. The landscape in Knife River Indian Villages National Historic Site is modified primarily by fluvial processes associated with the Missouri and Knife rivers. Channel migration, lateral erosion, and deposition continue to modify the Knife River floodplain. Cutbanks erode A terrace (geologic map unit **Qta**), B terrace (**Qtb**), lithologic Units 7 and 5 of the Oahe Formation (**Qo7**, **Qo5**), and lithologic Unit 3 of the Coleharbor Formation (**Qc3**), and a linear point bar has formed below the Stanton Terrace (**Qtst**), northeast of the Visitor Center.

Other geologic resource management issues discussed included:

- Slope Movement
- External Energy Issues
- Paleontological Resource Inventory and Monitoring
- Disturbed Lands
- Earthquakes

Resource managers should consult the Foundation Document (National Park Service 2013) and Natural Resource Condition Assessment (Nadeau et al. 2014) for the historic site. The foundation document lists the following as fundamental resources or values: archeological resources, cultural landscape, museum collection, traditional and contemporary cultural significance, and interdisciplinary scholarly research and traditional ecological knowledge. Other important resources include replica earthlodge, viewshed, natural soundscape, dark night sky, native prairie, Missouri and Knife rivers, and the visitor center. The natural resource condition assessment framework includes the following components: landcover, riparian forest community, terrace prairie communities, raptors, land birds, air quality, water quality, soundscape, dark night skies, and Knife River geomorphology/watershed. Geologic features and processes and some of the resource management features listed below affect those values and resources.

Resource managers may also find the chapters on fluvial geomorphology, seismic monitoring, monitoring in situ paleontological resources, and monitoring slope movements in *Geological Monitoring* (Young and Norby 2009) useful for addressing some of these geologic resource management issues. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers and suggested methods of monitoring.

Impacts Resulting from the Garrison Dam

Flooding on the Missouri River is controlled by the Garrison Dam, built in 1955 about 16 km (10 mi) upstream from the confluence of the Knife and Missouri rivers. Both rivers are considered important resources to the park (National Park Service 2013). The dam is the fifth largest earthen dam in the world, measuring 64 m (210 ft) high, 3,444 m (11,300 ft) long, 18 m (60 ft) wide at its crest, and 1 km (0.5 mi) wide at its base. Behind the dam is the 286-km-long (178 mi-long) Lake Sakakawea.

The Garrison Dam has had significant impacts on the active channel system of both rivers. Prior to the dam, the Missouri River meandered across a wide floodplain contained within high sandstone bluffs consisting of Coleharbor (**Qc**) and Oahe (**Qo**) formations. Since the dam construction, the Missouri River is contained within a much narrower active channel defined by river banks eroded into Unit 7 of the Oahe Formation (**Qo7**). The variability of daily average discharges has decreased, as has the magnitude and duration of flooding. The dam has also changed seasonal discharge patterns. The largest flows on the pre-dam river occurred in June and July and between March and May. Regulation now maintains a more consistent discharge rate throughout the year.

In addition to impounding water in Lake Sakakawea, the dam has also impounded the naturally high sediment load that once provided nutrients to floodplains as well as the Missouri's nickname "Big Muddy." Without the sediment load carried by the Missouri River, erosion immediately downstream from the dam has increased, leading to severe degradation (Ellis 2005; Nadeau et al. 2014).

The confluence of the two rivers lies within this zone of degradation, and as a result, the channel in the lower section of the Knife River that flows through Knife River National Historic Site has become deeper and narrower in order to adjust to a lower base level. Base level is the lowest level to which a stream channel can erode, and for the Knife River, base level is the Missouri River bottom. As the Missouri River channel has deepened, therefore, so has the channel of the Knife River. Channel velocity has increased with depth in this lower section, and less deposition occurs than in the upstream sections of the river (Ellis 2005; Nadeau et al. 2014). The size of the sediment has also increased. Fine-grained sediment is no longer available downstream of the dam, so coarser-grained sediment is being transported by the river (Ellis 2005).

Prior to the Garrison Dam, the Missouri River was a braided stream with channels flowing around many mid-channel bars. Since the dam was constructed, the river has transformed into primarily a single-channel flow system with semi-permanent, vegetated islands. One such island has developed at the confluence of the Missouri and Knife rivers, possibly due to the high sediment load of the Knife River (Ellis 2005). With a reduced transport capacity due to dam regulation, the Missouri River is no longer able to carry the high sediment load of the Knife River downstream. As a result, only a narrow channel now connects the Knife with the Missouri River.

The loss of sedimentation and floodwaters has negatively impacted the health of the riparian zone. Several agencies, including Knife River Indian Villages National Historic Site and the US Army Corps of Engineers, currently monitor shoreline changes along the Missouri River. Historic site staff members are photo monitoring stream banks where many large cottonwoods have collapsed, and are analyzing impacts to the riparian zone using US Army Corps of Engineers' aerial surveys (Thornberry-Ehrlich 2011). Because the riparian forest communities in Knife River Indian Villages National Historic Site are closely tied to historic fluctuations of the two rivers, Nadeau et al. (2014) recommended that current and sustained monitoring of the riparian forest community continue and an investigative study of the age class structures of the riparian forests be completed.

Flooding on the Knife River

Flooding is still relatively frequent along the unregulated Knife River, depositing overbank sediments onto Unit 7 of the Oahe Formation (**Qo7**) (see "Fluvial Features" section). Flooding generally occurs during the winter months when ice dams form on the Knife River (fig. 15; Thornberry-Ehrlich 2011). Ice jams, which may precede rapid ice melt, restrict flow and may result in overbank flooding and bank erosion (see "Bank Erosion on the Knife River" section). For example, rapid ice melt caused a major flood in the historic site in 1997. High river levels were sustained for several weeks and overbank flooding occurred for a period of 3–4 hours (Ellis 2005; Nadeau et al. 2014).

The only time the Garrison Dam spillway has been used to reduce pressure on the rapidly filling reservoir was in the exceptionally wet spring of 2011. In that year, high snowpack/snowmelt and high spring rainfall caused flooding on both rivers (fig. 16). High flow on the Missouri River is normally about 1,800 cubic meters per second (64,000 cubic feet per second [cfs]), but in 2011, peak flow in June and July was approximately 4,200 cubic meters per second (150,000 cfs; Thornberry-Ehrlich 2011), or more than twice as great. The Missouri River was flooded most of the summer, and

Figure 15. Ice jam on the Knife River. Ice jams can cause overbank flooding and contribute to bank erosion. Note how the ice is piled onto and impacting the river bank. National Park Service photograph from March 2014, available online: https://www.flickr.com/photos/121365074@N05/ (accessed 10 March 2015).

Figure 16. Flooding on the Knife River at Elbee Bluff during 2011.The photograph on the left was taken in June 2010; the one on the right was taken in July 2011. Note higher water level in right photograph. The people in the right photograph are standing on a tension crack that has formed parallel to the bank. View is looking downstream. National Park Service photograph by J. Cummings reproduced from Nadeau et al. (2014, figure. 21).

fine silt filled the Missouri River channel that flanked the eastern boundary of the historic site.

Global climate change is expected to increase the frequency of exceptionally wet springs and increase flooding in the northern Great Plains (Intergovernmental Panel on Climate Change [IPCC] 2014; Melillo et al. 2014). Precipitation in the region is projected to increase between 10% to more than 40% by the end of the century, and snowmelt is expected to begin earlier in the spring (Karl et al. 2009; IPCC 2014). Currently, average yearly precipitation for the Knife River Indian Villages National Historic Site region is 42.7 cm (16.8 in) with June typically being the wettest month. With global climate change, the annual precipitation may range between 47.0 cm (18.5 in) to 59.8 cm (23.5 in). Refer to Monahan and Fisichelli (2014) for a climate change resource brief of Knife River Indian Villages National Historic Site.

Bank Erosion on the Knife River

Many of the factors that facilitate flooding also increase bank erosion in Knife River Indian Villages National Historic Site. In 1997, for example, ice jams, overbank flooding, and rapid ice melt resulted in significant soil and sediment loss along several bends of the Knife River. A portion of a trail in Knife River Indian Villages National Historic Site was lost and 26 m (86 ft) of shoreline downstream of Elbee Bluff was eroded (Ellis 2005; Nadeau et al. 2014). The geomorphology of the Knife River is a monitorable natural resource as outlined in the Natural Resource Condition Assessment (Nadeau et al. 2014).

Most of the high priority erosion sites in Knife River Indian Villages National Historic Site occur at steep cutbanks in Unit 7 of the Oahe Formation (**Qo7**). Many of the bluffs in the historic site, such as Elbee Bluff and Taylor Bluff, are named after prominent cutbanks. Typically, sediments in the cutbanks are layered so that the bank becomes finer-grained from the base of the cutbank to the floodplain surface. Coarse- to fine-grained channel sand, silt, and mud is overlain by medium-grained channel and overbank sands, which are then covered by overbank muds (Thornberry-Ehrlich 2011). When a cutbank is undercut beyond a critical point, gravitational forces exceed the strength of the sediment and bank failure occurs (Ellis 2005). Stability of these cutbanks depends on the strength of the material in the bank, the amount of bank saturation, tension cracking, presence of failed material, and the influence of vegetation, which may be the most important factor in stabilizing river banks (Ellis 2005).

Prior to the Garrison Dam, mass bank failure would frequently occur due to a rapid fall in river stage following a high-magnitude flood. Now that the Missouri River is regulated, these high-magnitude

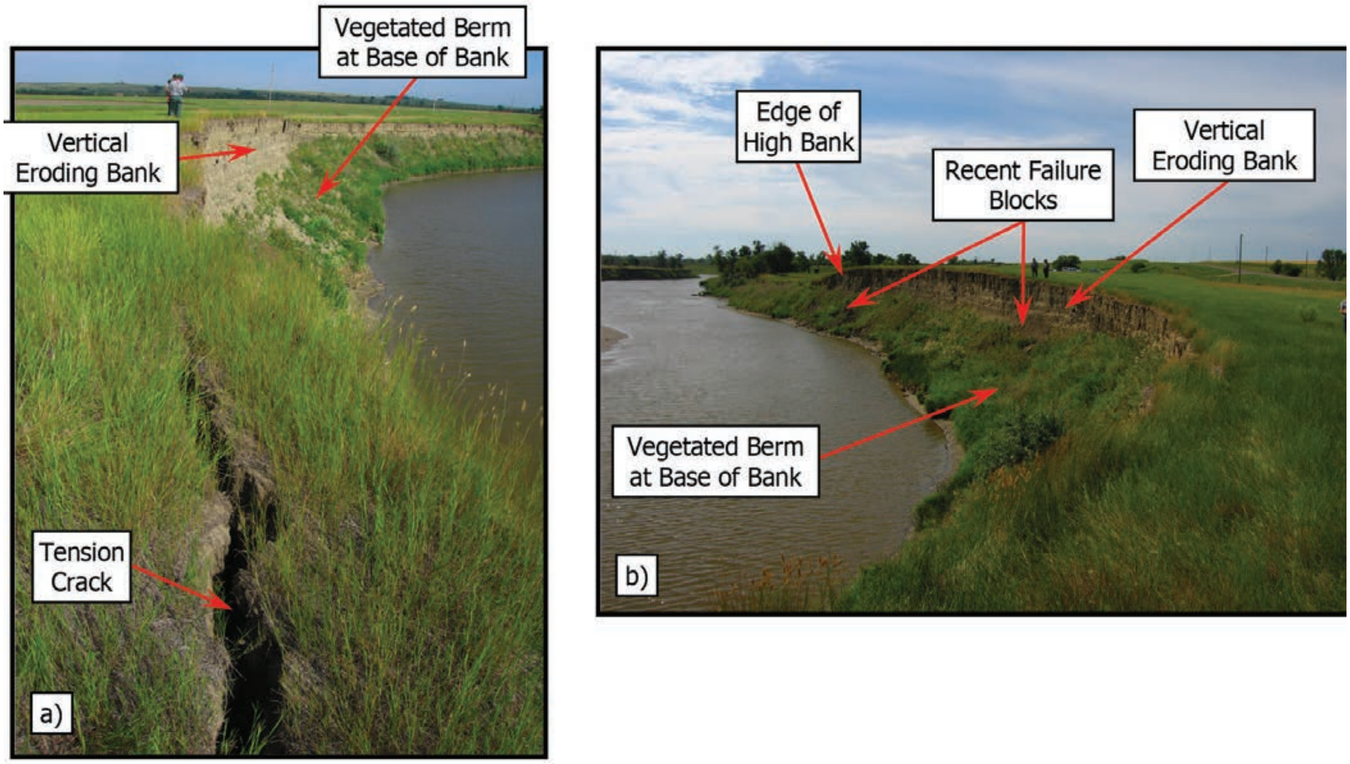

Figure 17. Tension cracks and bank failure in the Elbee Bluff area. Tension cracks opened as a result of bank saturation caused by prolonged precipitation. The left photograph is looking upstream, and the right photograph is a downstream view. National Park Service photograph by Lucy Ellis reproduced from Ellis (2005, figure. 4.5).

floods are less frequent in the lower reaches of the Knife River (Ellis 2005). Currently, the leading causes for bank erosion and failure in Knife River Indian Villages National Historic Site include: (1) ice gouging and abrasion of saturated river banks during spring thaw, (2) prolonged periods of precipitation, (3) backflow of the Missouri River, and (4) lateral erosion that results from natural river flow on the Knife River (Ellis 2005; Nadeau et al. 2014).

Ice Gouging and Ice Jams

River ice typically forms on the Knife River in December and breaks up by late March (fig. 15; Ellis 2005). Huge ice dams, which typically form just before the tight meander loops in the Knife River, can cause the river to rise more than 3 m (10 ft) in an hour and last for 3–38 hours (Ellis 2005; Thornberry-Ehrlich 2011). The ice jams may cause overbank flooding as the Knife River backs up behind the jam, as previously mentioned, and when the ice melts, the bank becomes saturated and the extra weight of any remaining ice sheet may trigger bank failure.

Precipitation

Severe precipitation events can saturate river banks, which increases pore-water pressure and decreases the overall strength of bank sediment. Tension cracks develop, which may be followed by bank failure. Prolonged rainfall in June 2005, for example, produced tension cracks and extensive bank failures on the Knife River (fig. 17; Ellis 2005; Nadeau et al. 2014). In that month, total precipitation exceeded the 30-year average by more than 10 cm (4 in) (Nadeau et al. 2014; NOAA National Climate Data Center 2014). Bank failure resulted from increased precipitation, rather than from natural flow and undercutting of the Knife River.

In the wet spring of 2011, total precipitation in the historic site area from January through May was 8.15 cm (3.21 in) above normal (NOAA National Climate Data Center 2014). As with flood events, global climate change is expected to increase precipitation in North Dakota, possibly including an increase in intensity and duration of rainfall events (Karl et al. 2009; IPCC 2014).

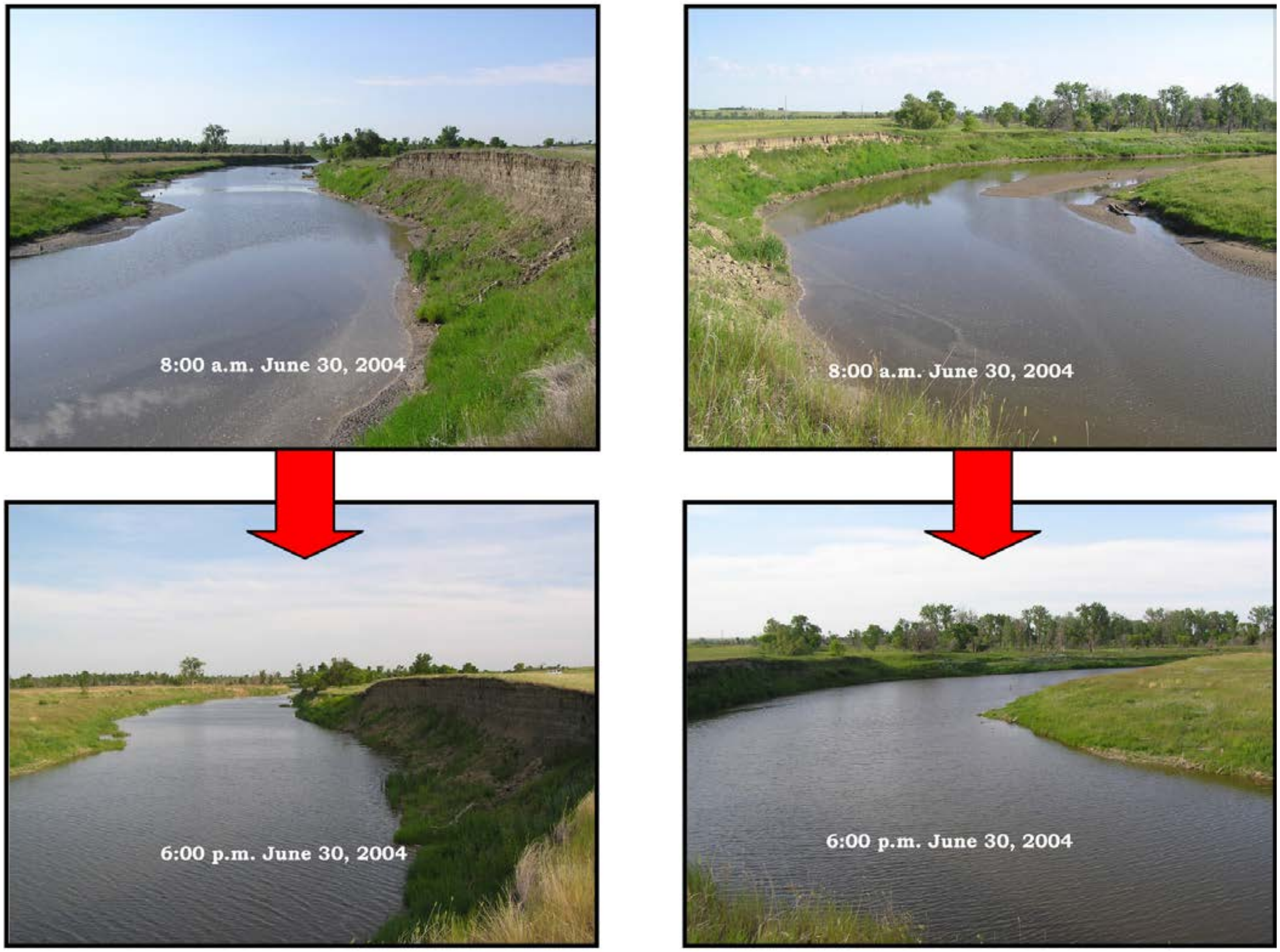

Figure 18. Backflow from the Missouri River floods the lower section of the Knife River and erodes the banks. This backwater effect is caused by releases from Garrison Dam. In both sets of photographs, backwater flooding has inundated the sandy point bar and risen on the cutbank in the ten hours from 8:00 a.m. to 6:00 p.m. on June 30, 2004. National Park Service photographs by Lucy Ellis reproduced from Ellis (2005, figure. 4.7).

Backflow of the Missouri River

Regulation of the Missouri River may cause a "backflow" of river water at the confluence with the Knife River, making it appear that water in the Knife River is flowing upstream (fig. 18; Ellis 2005). This phenomenon occurs primarily during the summer months when the Knife River is flowing at a lower stage than the Missouri River. Garrison Dam functions as a hydroelectric dam, releasing a greater amount of water during high consumer demand, which occurs primarily during the hotter summer months. The Knife River is not regulated and is not subject to anthropogenic fluctuations, so its stage lowers during the summer. When the Missouri River is flowing at a higher stage then the Knife River, water from the Missouri flows up the Knife, much like a tidal river during high tide (Ellis 2005).

Natural Erosion and Deposition from Knife River

Natural channel shifting has also caused bank erosion along the Knife River. An estimated 1–40 m (3–130 ft) of river bank has been lost due to lateral erosion in the last several years (Ellis 2005). Currently, lateral migration dominates the geomorphic evolution of the Knife River with the outer banks typically eroding and deposition occurring on downstream point bars and mid-channel bars (fig. 19). The meander bend upstream from Elbee Bluff has eroded in this manner although the bend at Elbee Bluff has not been significantly eroded since 1995 (Ellis 2005).

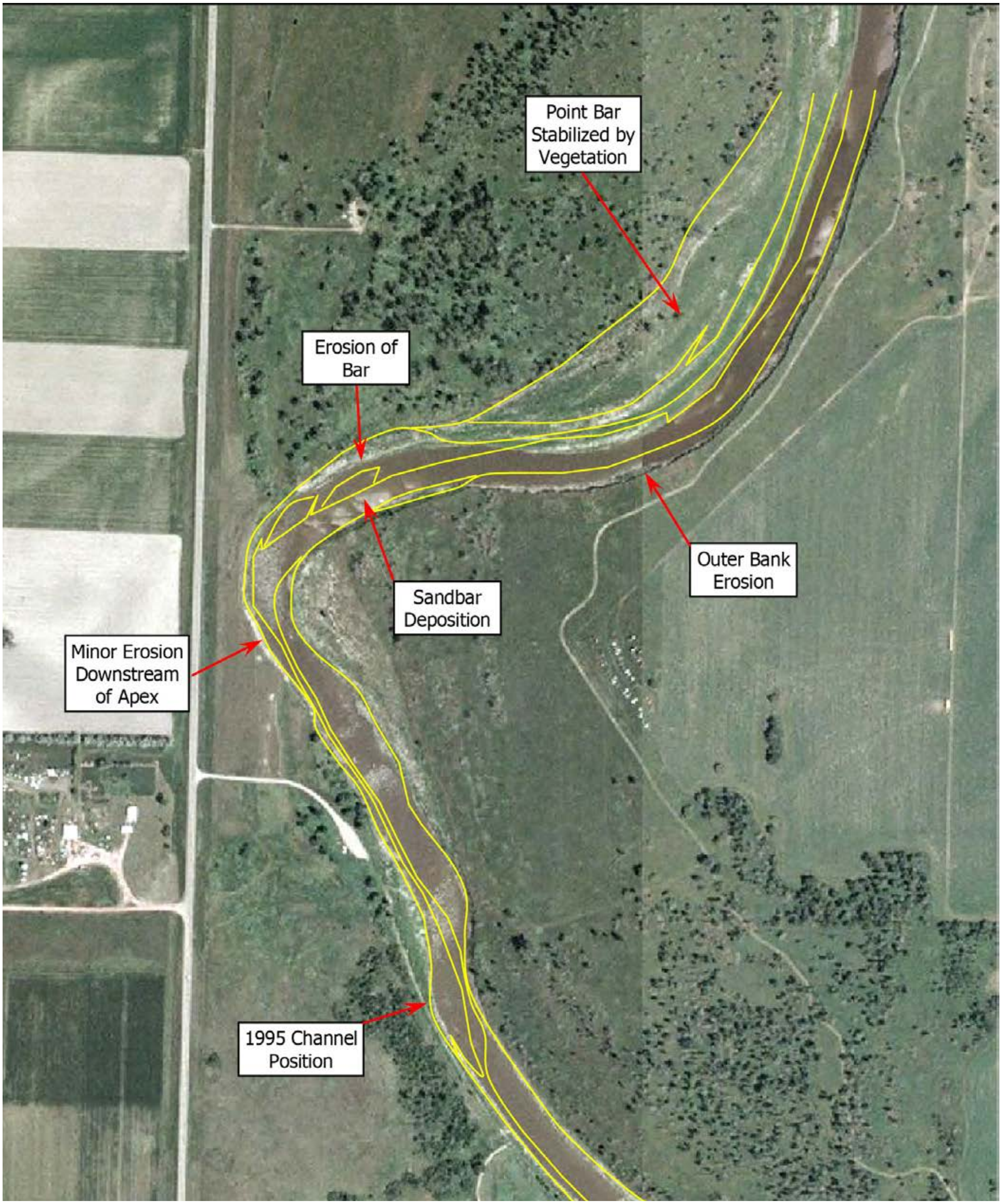

Figure 19. Lateral migration of the Knife River between 1995 and 2004. The yellow outline on the photograph (taken in 2004) represents the position of the Knife River channel in 1995. Upstream bank erosion has resulted in downstream deposition. Flow is from the top of the aerial photograph to the bottom. National Park Service photographs by Lucy Ellis reproduced from Ellis (2005, figure. 4.3).

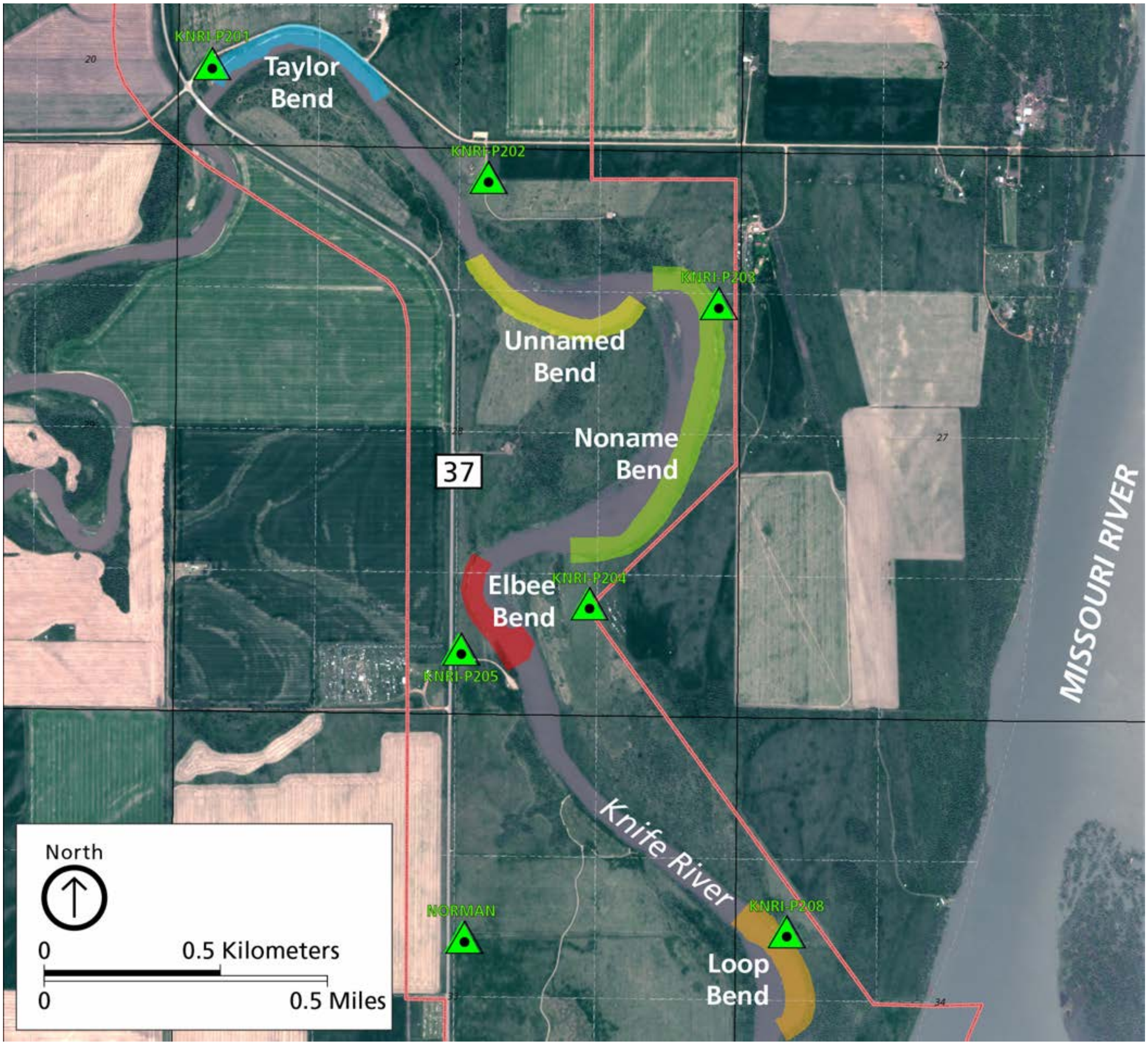

Figure 20. Map of the five river bends in Knife River Indian Villages National Historic Site that were studied by Sexton (2012). Green triangles are mapping control points. Peach colored outline is the boundary of the historic site. National Park Service map by Chad Sexton (Theodore Roosevelt National Park). Cropped and annotated by Jason Kenworthy (NPS Geologic Resources Division).

The Knife River contains a high sediment load. Because of the Garrison Dam, the Missouri River does not have the ability to transport this incoming high sediment load from the Knife River so the sediment is deposited at their confluence. Deposition has resulted in the formation of a semi-permanent island at the confluence that now separates the two rivers (Ellis 2005; Nadeau et al. 2014). The rivers are connected by a narrow channel that flows around the island.

Impacts of Bank Erosion on Archeological Sites and Infrastructure

Erosion of the historic site's subtle topography occurs on many scales. The depressions that mark the location of the Indian earthlodges are eroding slowly by natural processes. Burrowing animals contribute to erosion and also unearth archeological resources. However, the amount of bank erosion due to lateral channel migration has made river bank erosion the most significant threat to the archeological resources and

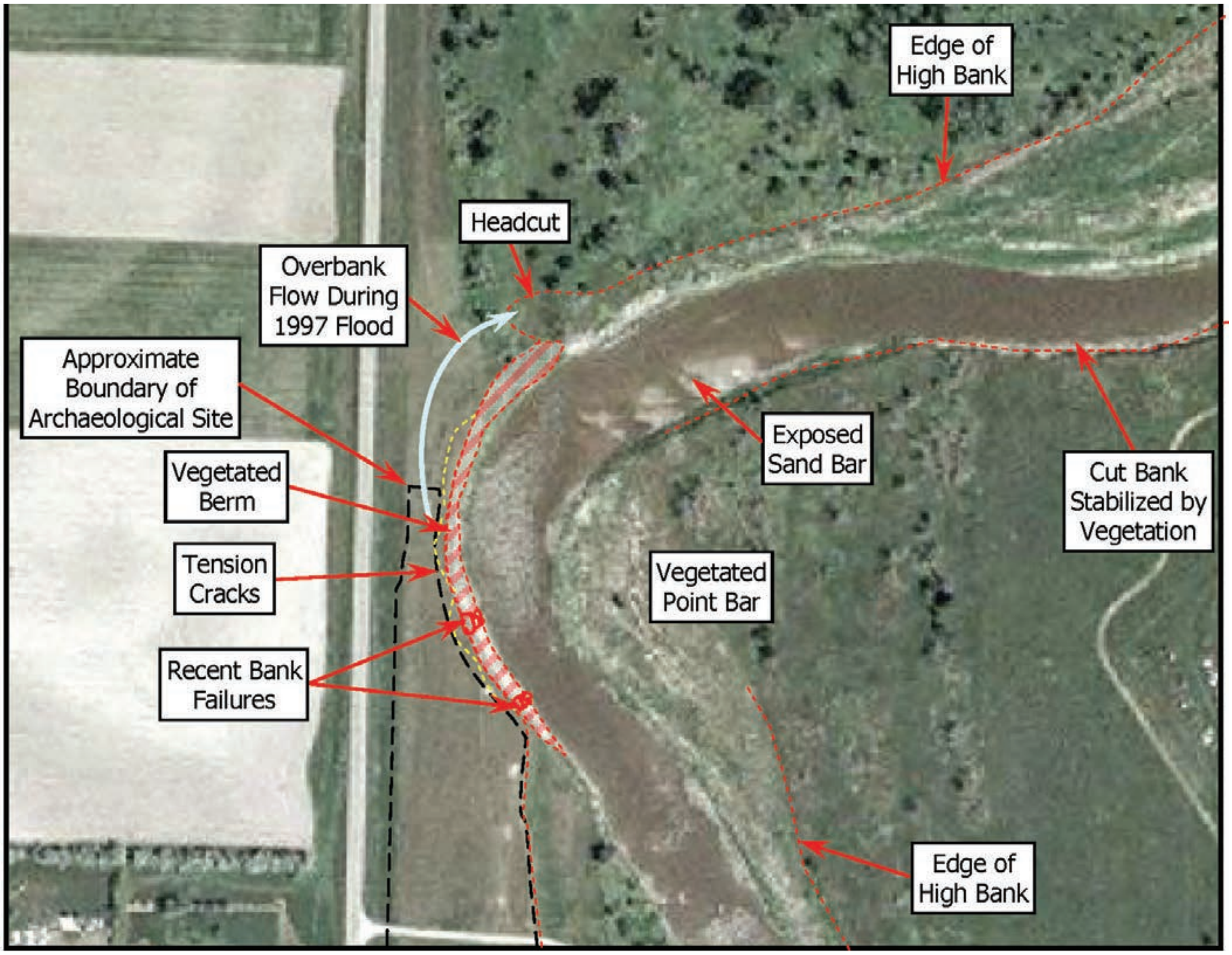

Figure 21. Annotated aerial photograph of the geomorphology of the Elbee Bluff on Knife River. Tension cracks and bank failures occur on the outside bend of the river and may impact the archeological features. National Park Service photograph by Lucy Ellis reproduced from Ellis (2005, figure 4.6).

infrastructure in Knife River Indian Villages National Historic Site (Sturdevant 2009; Nadeau et al. 2014).

In 2011, Chad Sexton, GIS analyst at Theodore Roosevelt National Park, mapped the extent of contemporary cutbank edges on five priority river bends in Knife River Indian Villages National Historic Site: Elbee Bend, Taylor Bend, Unnamed Bend, Noname Bend, and Loop Bend (fig. 20). These meanders are primarily cut into Unit 7 of the Oahe Formation (**Qo7**) and B terrace (**Qtb**). The impact of bank erosion on archeological sites and infrastructure from this study is presented in this GRI report. The methodology and detailed analysis of this project can be found in Sexton (2012).

Erosion of Elbee Bluff significantly impacts archeological sites (Ellis 2005; Nadeau et al. 2014). In 2005, 50 m (160 ft) of shoreline separated the archeological features at the Elbee Bluff site from the Knife River (fig. 21; Ellis 2005). However, strong storms in 2009 resulted in significant erosion so that archeological features at the Elbee Bluff site are either exposed in the bluff or less than 1 m (3.3 ft) from the river bank (Cummings 2011; Nadeau et al. 2014). Cultural sites and archeological artifacts can also be lost or exposed to theft when ice dams erode the banks during spring thaw (National Park Service 2014b). From 1965 to 2010, bank erosion at Elbee Bluff averaged 0.7 m/year (2.2 ft/year), and the bank has moved an average of 42.0 m (137.8 ft) to the west (Sexton 2012; Nadeau et al. 2014).

Paleosols occur in cutbank exposures, especially in cutbanks opposite the Awatixa Village (Sakakawea site). Layered volcanic ash deposits from Yellowstone and Cascade eruptions are also exposed. Preservation of these deposits is important as they may provide important isotopic ages and environmental indicators useful for archeological correlations.

Erosion at Taylor Bend impacts the Taylor Bluff archeological site as well as Mercer County Road 18 (Thornberry-Ehrlich 2011; Nadeau et al. 2014). Re-contouring and rip-rap have been used to try and stabilize the bank (Sexton 2012; Nadeau et al. 2014). However, erosion has accelerated in areas adjacent to the rip-rap. In addition, the steep cutbank near the road is prone to sloughing (fig. 22). Because of cutbank erosion, the county road adjacent to Big Hidatsa Bluff has been rebuilt several times in the last 50 years, making it difficult to identify terrace surfaces (Reiten 1983). At Taylor Bend, bank erosion occurs at an average rate of 0.3 m/year (0.9 ft/yr) (Sexton 2012; Nadeau et al. 2014).

Unnamed Bend, located downstream from Taylor Bend (fig. 20), does not impact the historic site's infrastructure to the extent of the other bends. Between 1965 and 2010, the bank moved an average of 72.1 m (236.4 ft) at an average rate of 1.2 m/year (3.9 ft/yr) (Sexton 2012; Nadeau et al. 2014).

Bank erosion at Noname Bend is causing the channel to migrate eastward towards the historic site's boundary (fig. 20). Movement from 1965 to 2010 averaged 77.1 m (253.1 ft) at a rate of 1.5 m/year (4.9 ft/year) (Sexton 2012; Nadeau et al. 2014). Continued erosion may eliminate access to the peninsula-like portion of the historic site.

Erosion at Loop Bend, which is downstream from Elbee Bend and Awatixa Village (Sakakawea Site), has required rerouting of the Two Rivers hiking trail (fig. 20; Sexton 2012; Nadeau et al. 2014). From 1965 to 2010, the bank moved an average of 56.8 m (184.4 ft) at an average rate of 1.3 m/year (4.2 ft/year).

Recommendations to Monitor and Mitigate Bank Erosion

With regards to Elbee Bluff, Ellis (2005) recommended monitoring the geometry of the bend immediately upstream because it affected the geometry and morphology of the Elbee Bend. Changes to the upstream bend may shift the locus of maximum erosion at Elbee Bluff, which could impact the archeological site (Ellis 2005). Sturdevant (2009) and Cummings (2011) recommended that managers at Knife River Indian Villages National Historic Site develop a plan that would utilize bank stabilization techniques to control bank erosion at Elbee Bluff (Nadeau et al. 2014). They also recommended excavation of the archeological sites at Elbee Bluff to document artifacts before they are lost to erosion. Considering the rate of bank erosion near archeological features, they suggested that immediate action may be necessary (Nadeau et al. 2014).

Ellis (2005) summarized from Mellema (1997) the different types of bank stabilization methods and the effectiveness of each type. The primary focus of each method, except bendway weirs, is on stabilizing the river bank. Bendway weirs, on the other hand, are designed to divert the thalweg away from the cutbank, thus eliminating the intersection of the major flow line with the river bank and reducing erosion potential. Ellis (2005) cautioned that any bank stabilization scheme must be carefully evaluated for potential negative impacts to the river system in the future.

Ellis (2005) recommended monitoring the rate and location of erosion at Elbee Bend, but considered any bank stabilization project unnecessary and not cost effective. If a project was necessary, Ellis (2005) recommended the use of hay bale/willow revetments or trilock revetments as the most suitable stabilization types. Hay bale/willow revetments consist of mesh-covered hay bales cabled together to form an inverted "T" and anchored on the lower bank. Willows are planted on the upper bank. Hay bale/willow revetments require stone toe protection. Trilock revetments consist of interlocking concrete placed on the top of a filter membrane on the berm at the base of the river bank. These allow revegetation, but may also cause downstream erosion (Ellis 2005).

Both Ellis (2005) and Nadeau et al. (2014) recommended that Knife River Indian Villages National Historic Site develop a river management plan for the Knife River. Although erosion is a natural process, the potential loss of cultural resources has prompted a higher level of concern (Nadeau et al. 2014). In 2013, work began on an environmental impact statement (EIS)/archeological resources management plan. The plan, which is scheduled to be completed in 2016,

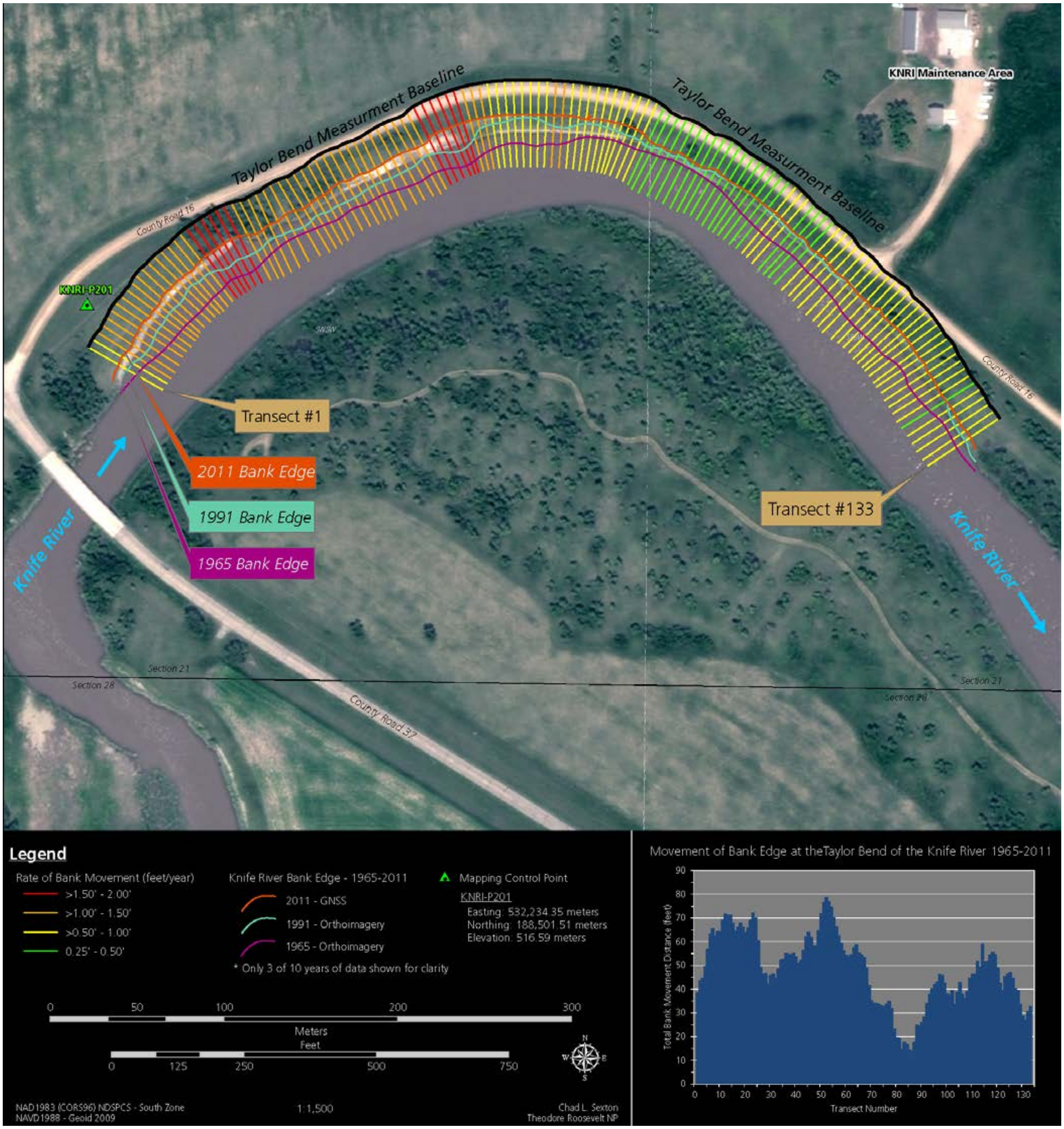

Figure 22. Annotated aerial photograph showing erosion rates at Taylor Bend and its impact on Mercer County Road 18. Sexton (2012) analyzed the movements of the Knife River and concluded that since 1965, the average distance of bank movement was 14.7 m (48.3 ft). National Park Service map by Chad Sexton (Theodore Roosevelt National Park).

will provide a better understanding of the impact of the river on archeological sites and infrastructure and provide a framework for making river-related decisions, especially with regard to bank stabilization.

Monitoring is necessary along the Knife River in order to identify and prioritize archeological sites. Resource managers may find the fluvial geomorphology chapter by Lord et al. (2009) in *Geological Monitoring* (Young and Norby 2009) to be useful. Lord et al. (2009)

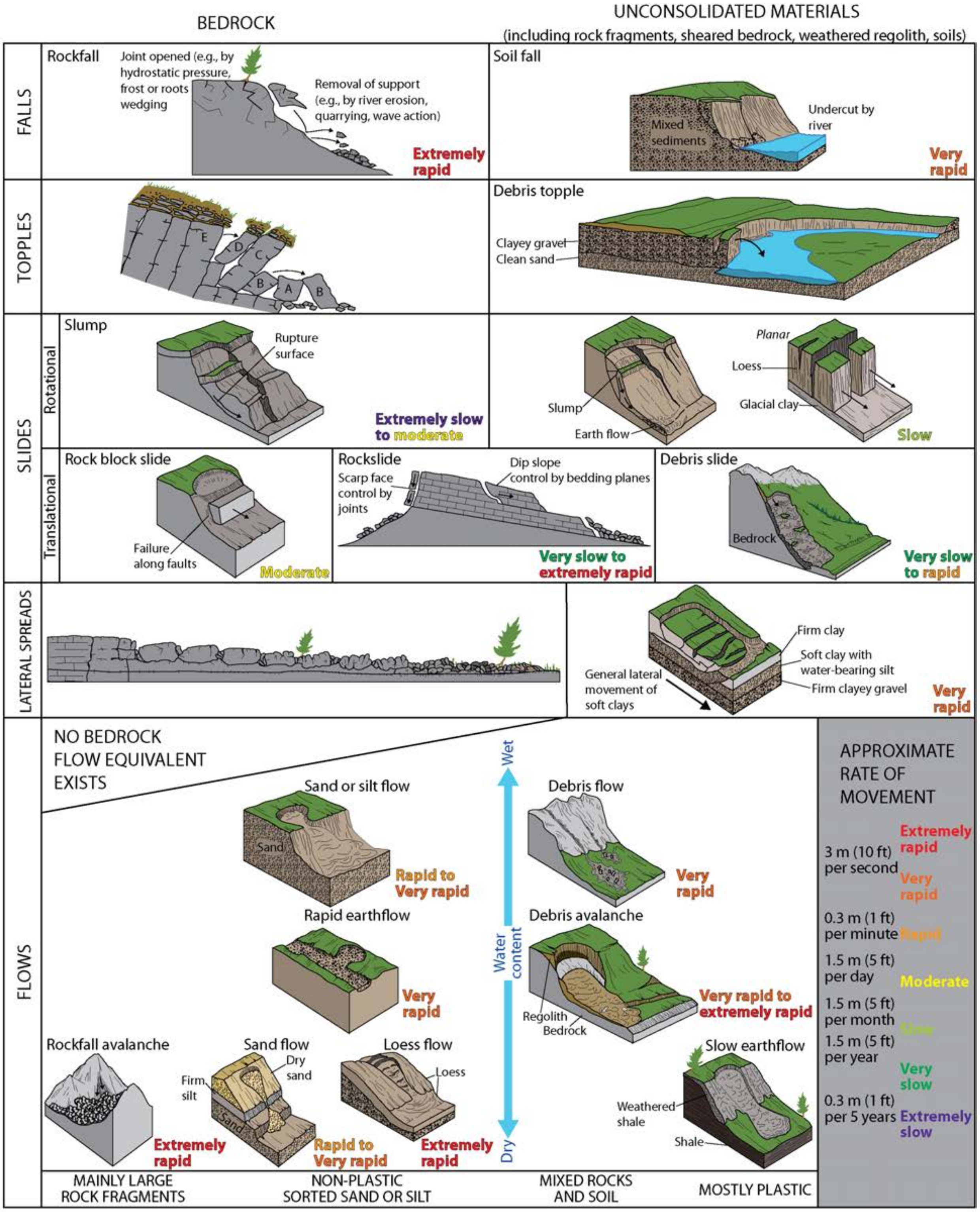

Figure 23. Schematic illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. At the historic site, bank and terrace erosion may occur by soil fall, debris topple, or slumps. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978).

described methods for inventorying and monitoring geomorphology-related vital signs, including: (1) watershed landscape (vegetation, land use, surficial geology, slopes, and hydrology), (2) hydrology (frequency, magnitude, and duration of stream flow rates), (3) sediment transport (rates, modes, sources, and types of sediment), (4) channel cross section, (5) channel planform, and (6) channel longitudinal profile.

Slope Movement

Ellis (2005) noted that the unconsolidated bank material of Unit 7 of the Oahe Formation (**Qo7**) and B terrace (**Qtb**) along the Knife River failed "in much the same way as a landslide" (Ellis 2005, p. 32). A "landslide" is a general term for many different types of slope movement (fig. 23). Types of slope movement than may affect bank and terrace slope erosion at Knife River Indian Villages National Historic Site include soil fall, debris topple, and slumping. Wieczorek and Snyder (2009) described the various types of slope movement and monitoring methods, which may assist resource managers in monitoring bank failure along the Knife River.

In the northern part of the historic site, slope wash has reworked some of the silt in Unit 5 of the Oahe Formation (**Qo5**) (Reiten 1983). Slope wash has also eroded some of the sediment from A terrace and the Sakakawea and Riverdale terraces. Potential slope failure may impact the steeper slopes.

The earthlodge villages in Knife River Indian Villages National Historical Site were constructed on high terraces (**Qth**, **Qtm**) that are not affected by flooding. However, exceptionally wet springs, such as the 2011 spring, are expected to bring increased flooding in North Dakota and these floods may erode the bluffs composed of the Coleharbor (**Qc3**) and Oahe (**Qo5**) formations upon which the villages rest (IPCC 2014; Melillo et al. 2014). Precipitation in the region of the historic site is projected to increase between 10% to more than 40% by the end of the century, compared with a 1960-1979 baseline (Karl et al. 2009). The effect that increased precipitation and flooding will have on sedimentation rates, cutbank erosion, and subsequent impact to archeological sites is not known.

External Energy Issues

Hydraulic fracturing (fracking) of the Bakken Formation in the Williston Basin has made North Dakota the second largest oil-producing state in the country. In addition, four surface coal-mining operations, six coal-fired electric generation plants, a coal gasification plant, a Missouri River hydropower facility, several windfarms, and high voltage power lines are within a 50 km (30 mi) radius of Knife River Indian Villages National Historic Site. Infrastructure and housing issues caused by oil and gas development, coal development, and wind power have begun to impact the historic site in ways that were perhaps unimaginable just a few years ago and are discussed below (National Park Service 2013a).

The National Park Service works with adjacent land managers and other permitting entities to help ensure that National Park System resources and values are not adversely impacted by external mineral exploration and development. Potential impacts include groundwater and surface water contamination, erosion and siltation, introduction of exotic plant species, reduction of wildlife habitat, impairment of viewsheds and night skies, excessive noise, and diminished air quality. Visitor safety and overall degradation of the visitor experience are particular concerns. The NPS Geologic Resources Division Energy and Minerals program provides additional information (National Park Service 2013b).

The NPS Geologic Resources Division is available to provide managers at Knife River Indian Villages National Historic Site with policy and technical assistance regarding minerals and energy issues. Recommendations include remaining aware of public and private mineral ownership and speculation, exploration, or drilling activity on lands in the vicinity of the historic site. Regulations and permit procedures vary among states.

Recommendations for mitigation and management strategies, including legal options, are summarized for Fort Union Trading Post National Historic Site (on the western border of North Dakota and in an area where oil and gas resources are being rapidly developed) in *Potential for the Development of Oil and Gas Resources in and Adjacent to Fort Union Trading Post NHS, and Strategies for Addressing Such Development* (Geologic Resources Division 2006; see also GRI report by Graham 2015). That document may provide useful context to resource managers at Knife River Indian Villages National Historic Site. An online GIS tool on the North Dakota Oil and Gas Division website (http://

www.dmr.nd.gov/oilgas/; accessed 15 June 2015) shows the locations and horizontal extents of oil and gas wells. The NPS Geologic Resources Division Energy and Minerals website (http://go.nps.gov/grd_energyminerals; accessed 15 June 2015) provides additional information.

Oil and Gas Development: Bakken Formation

The Upper Devonian–Lower Mississippian Bakken Formation is widespread in the central and deeper parts of the Williston Basin and consists of three informal members: (1) lower shale member, (2) middle sandstone member, and (3) upper shale member (table 5). The shale members contain abundant organic matter (as much as 35% by weight), and although the formation is only as much as 50 m (160 ft) thick, it contains a tremendous amount of recoverable hydrocarbons (Pollastro et al. 2008, 2011). The Bakken shale units are the principal source rocks in the continuous hydrocarbon reservoir known as the Bakken-Lodgepole Total Petroleum System (Bakken-Lodgepole TPS).

Table 5. Table showing the age, geologic formations, and members that comprise the Bakken-Lodgepole Total Petroleum System (TPS), shown in red.

Age	Formation	Member
Mississippian	Mission Canyon Limestone	
Mississippian	Lodgepole Limestone	
Mississippian	Lodgepole Limestone	
Mississippian	Bakken Formation	Upper Shale
Devonian	Bakken Formation	Middle Sandstone
Devonian	Bakken Formation	Lower Shale
Devonian	Three Forks Sand	Sanish Sand
Devonian	Three Forks Sand	

This continuous reservoir includes a porous sandstone unit in the underlying Upper Devonian Three Forks Formation (Sanish Sand) and porous strata in the overlying Lower Mississippian Lodgepole Limestone (fig. 24). In 2008, the US Geological Survey estimated that the Bakken-Lodgepole TPS contained undiscovered, technically recoverable resources of 3.65 billion barrels of oil (Pollastro et al. 2008).

Improved technology in the field of hydraulic fracturing ("fracking") has led to an energy boom in the Williston

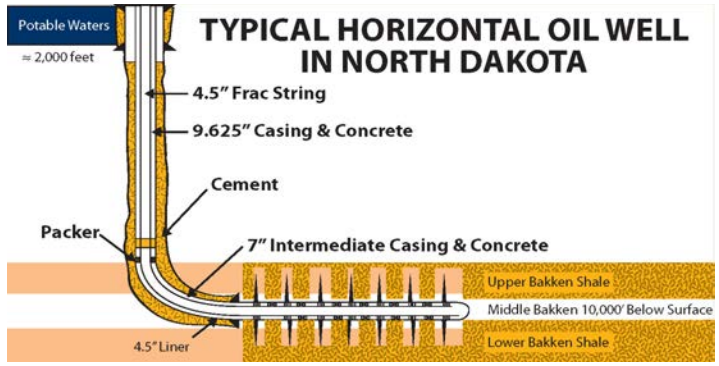

Figure 24. Schematic illustration of hydraulic fracturing. Although fracking processes occur thousands of feet below potable water sources, many safety measures are used to protect groundwater from contamination. North Dakota State Water Commission diagram available online: http://www.swc.nd.gov/4dlink9/4dcgi/getcontentpdf/pb-2419/fact%20sheet.pdf (accessed 17 November 2014).

Basin. Fracking involves the injection of water, sand, and chemicals at high pressure into horizontally drilled wells as far as 3,000 m (10,000 ft) below the surface (fig. 25). The pressurized mixture causes the shale in the Bakken Formation to crack. These cracks are held open by the sand particles, known as proppant, so that natural gas or oil from the shale can flow into the wellbore. Recovered water is stored and then transported to a treatment plant.

Steel casing lines a hydrocarbon well and is cemented in place to prevent any communication between fluids in the wellbore and fluids, such as groundwater, in adjacent strata. Thousands of feet of impermeable rock also separate shallow formations holding fresh water that may be useful for farming or public consumption from the fractured shale.

Although the eastern extent of the Bakken-Lodgepole TPS includes Knife River Indian Villages National Historic Site, the geographic extent of thermally mature Bakken shale does not include the historic site (fig. 25; Pollastro et al. 2008, 2011; Pat O'Dell, DNR National Wildlife Refuge System, petroleum engineer, written communication, 5 June 2014). The potential for drilling on the 505.22 ha (1,248.43 ac) of non-federal land in the historic site is slim for the following reasons: most of the production is in the western counties of North Dakota and Montana, the Bakken Formation is relatively thin beneath the historic site, and the shale is not thermally mature (Pat O'Dell, DNR National Wildlife Refuge System, petroleum engineer, written communication,

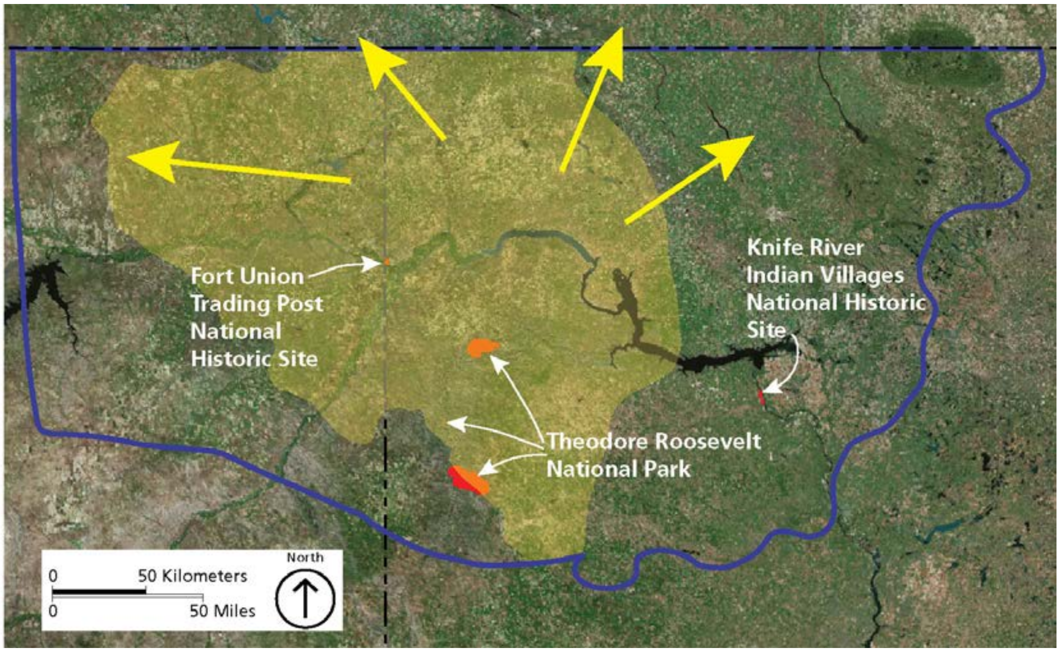

Figure 25. Geographic extent of the thermally mature shale member of the Bakken Formation (yellow). The blue line indicates the boundary of the Bakken-Lodgepole Total Petroleum System (TPS). Three NPS areas in North Dakota are labelled. Yellow arrows mark the probable oil migration pathways in the Williston Basin. Features on this map extend into Canada; however, the source graphic only covers area in the United States. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Pollastro et al. (2011, figure 15).

5 June 2014; Eric Brevik, Dickinson State University, geologist, conference call, 9 July 2014; Joseph Hartman, University of North Dakota, geologist, conference call, 9 July 2014).

Conference call participants expressed concern that certain activities, such as mining sand needed for hydraulic fracturing and mining gravel for well sites and roads, may impact the historic site's viewshed. Glacial deposits of sand and gravel cover about 75% of North Dakota, and sand and gravel mining is the third largest mineral industry after hydrocarbons and lignite (North Dakota Geological Survey 2014a). However, sand sampled from North Dakota deposits is not suitable as proppant for hydraulic fracturing. Frac sand for use as proppant currently comes primarily from west-central Wisconsin (Lindquist 2012). Gravel, on the other hand, is plentiful, but transporting gravel is expensive (North Dakota Geological Survey 2014a). As a result, gravel is typically mined near where it will be used. Consequently, few gravel mines could be dedicated to the oil industry in the vicinity of Knife River Indian Villages National Historic Site.

The limiting factors to producing oil in North Dakota by hydraulic fracturing might be water and the price of oil. According to North Dakota Department of Natural Resources Director Lynn Helms, the expected 2,000 new wells per year require 42–45 million liters (11–12 million gallons) of fresh water per day, and 40,000–45,000 new wells will require 64–106 million liters (17–28 million gallons) of water per day of maintenance water (Helms 2013). The primary use of water for maintenance activities is to keep salt from building up in the wellbore and restricting the flow of oil. Over the life of one well, which is typically 30–40 years, maintenance water can be 25–33 million liters (6.6–8.8 million gallons) (Kiger 2013). In its driest years, North Dakota receives less than 33 cm (13 in) of rainfall. Salt buildup and subsequently the need for maintenance water appear to be unique to North Dakota, and its impact on the Knife River and the historic site are not known (Kiger 2013).

The oil and gas boom in the Bakken Formation has contributed to the unprecedented hydrocarbon production in the United States and has significantly increased worldwide energy supplies (The Economist 2014). This increase has led to a dramatic plummet in oil prices (Krauss 2015; InfoMine 2015; Said et al. 2014). Analysts do not believe the drop in price will lead to a major bust in drilling, at least not in the near term (Gunderson 2014). Some producing fields with high-quality reservoir rock can turn a profit at an average break-even price of $36/barrel (Zawadski 2013; Gunderson 2014; The Economist 2014). If a well has already been drilled, average operating costs range from only $10/barrel to $20/barrel (The Economist 2014). Although drilling permits have declined in North Dakota and service companies, like Schlumberger, have

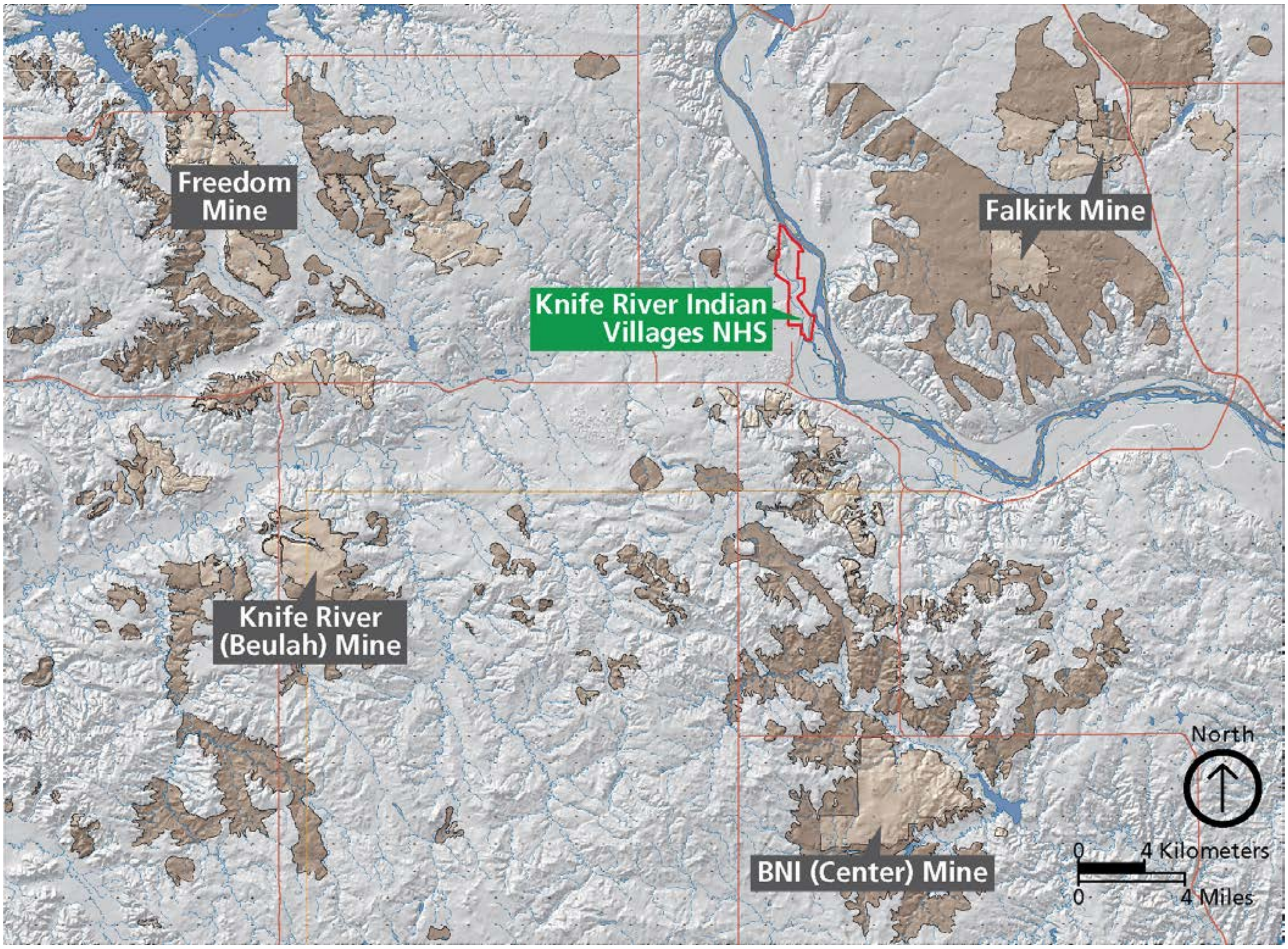

Figure 26. Coal mines in the vicinity of Knife River Indian Villages National Historic Site. In the past, 106 coal mines were active in the area. Most of these were small, underground and/or surface operations. The four mines that are currently operating (labeled) are surface coal mines. Tan areas have been, or are currently being, mined. Brown areas are economic coal deposits. NPS boundary in red. Note small area of economic coal deposit near the NPS boundary. Graphic by Jason Kenworthy (NPS Geologic Resources Division) modified from Murphy (2007), available at https://www.dmr.nd.gov/ndgs/Coalmaps/pdf/100k/hzen_100k_c.pdf (accessed 22 July 2014).

begun to reduce staff, drilling is expected to continue (The Economist 2014).

Many economic factors determine whether or not a company decides to invest in drilling in exploration of the Bakken Formation. Such a discussion is beyond the scope of this GRI. Some of these factors include well costs, maintaining leased acreage position, company debt, investor confidence, transportation costs, and technological development. How these changes affect the viewshed and infrastructure of Knife River Indian Villages National Historic Site remains to be seen.

Coal Development

Seams of lignite, an intermediate form of coal between peat and the higher grades of coal (anthracite and bituminous), are found under approximately 83,000 km^2 (32,000 mi^2) of western and central North Dakota (Hoganson and Murphy 2003). Western North Dakota's estimated 1.3 trillion tons of lignite is the single largest deposit of lignite known in the world (North Dakota Geological Survey 2014b). About 25 billion tons of this lignite is economically mineable.

Currently, 32 million tons of lignite is mined each year from six operating mines, four of which are in the vicinity of Knife River Indian Villages National Historic Site: (1) the Freedom Mine north of Beulah, the largest coal mine currently operating in the state; (2) the Knife River Mine south of Beulah; (3) the BNI Mine at Center; and (4) the Falkirk Mine across the Missouri River to the east of the historic site (fig. 26; North Dakota Geological Survey 2014b). Lignite from these four mines feeds steam boilers for electric generating plants. Because lignite is relatively expensive to transport, it is typically consumed in the state's coal-fired electric generating plants (Hoganson and Murphy 2003).

In October 2014, the Coyote Creek Mine (owned by the North American Coal Corporation) was approved and is in the planning and development stage with production scheduled to begin in May 2016 (Craig Hansen, NPS Knife River Indian Villages National Historic Site, acting superintendent, written communication, 19 December 2014; for more information, refer to http://www.nacoal.com/operations/CoyoteCreekMining.shtml, accessed 13 January 2015). The mine is located approximately 16 km (10 mi) southwest of Beulah.

In the area of the historic site, lignite is mined from the Paleocene Fort Union Group, which includes the Sentinel Butte and Bullion Creek formations (Johnson and Kunkel 1959). The sand, silt, clay, and lignite in these formations represent fluvial channel, overbank, and marsh deposits (Reiten 1983).

North Dakota's mine reclamation laws require mined lands to be restored to their original contours. At the Falkirk Mine, active mining and active reclamation occur concurrently in different parts of the mine, and mine personnel are conscientious about keeping managers at the historic site informed of their activities (Wendy Ross, NPS Knife River Indian Villages National Historic Site, superintendent, conference call, 9 July 2014).

Wind Power and Windfarms

In addition to coal, North Dakota has an abundance of wind. North Dakota is one of the leading states in wind resources, with an estimated potential at 80 m (260 ft) hub height of generating 2,983,750 gigawatt-hours of energy per year (US Department of Energy 2014). In 2013, 15.6% of North Dakota's electricity came from wind power, but the state still uses only a fraction of this potential resource (American Wind Energy Association 2014). The National Renewable Energy Laboratory (NREL) classified central North Dakota as having fair to good wind power potential (NREL 2009). Two wind farms, one to the southwest and one to the southeast, have been built in the vicinity of Knife River Indian Villages National Historic Site. The wind farm to the southeast is visible from the historic site.

The National Park Service uses a combined technical and policy approach to manage and protect park resources and values as renewable energy resources are identified and developed near NPS areas. Park resources and values that may be impacted by renewable energy development include water quantity and quality, air quality, wildlife, dark night skies, natural soundscapes, cultural resources, scenic views, soils, geologic and hydrologic processes, and visitor experience. The NPS Geologic Resources Division Renewable Energy program provides more information (National Park Service 2014c).

Paleontological Resource Inventory and Monitoring

All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (see Appendix B). As of August 2015, the Department of the Interior was developing regulations associated with the act.

Tweet et al. (2011) presented a number of recommendations regarding the paleontological resources at Knife River Indian Villages National Historic Site. They suggested that combined paleontological and archeological projects would offer the opportunity to collect fossils with little disturbance or loss of cultural material. Furthermore, fossils found in a cultural context should be documented by both a paleontologist and an archeologist, and new archeological and infrastructure excavations should consider scheduling a paleontologist to monitor and document any fossil discoveries. The NPS Geologic Resources Division can assist site managers in finding paleontological expertise.

The collections at Knife River Indian Villages National Historic Site have an unknown number of fossils, and these should be inventoried and documented by a paleontologist. A field-based paleontological resource survey can provide detailed, site-specific descriptions and resource management recommendations that are beyond the scope of this report. A field inventory of in situ paleontological resources and yearly monitoring of any significant sites should also be considered, perhaps through the partnering with other institutions. When fossil material is observed in exposed sedimentary rock, historic site staff should photo-document and monitor the material, leaving the fossils in place unless degradation by natural processes or human contact is imminent (Tweet et al. 2011).

In the *Geological Monitoring* chapter about paleontological resources, Santucci et al. (2009) described five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use.

Disturbed Lands

Although discussed in the scoping meeting (Thornberry-Ehrlich 2011) and conference call, 'disturbed land' in the form of areas in need of restoration is not a significant issue at Knife River Indian Villages National Historic Site. Scoping meeting and conference call participants (see Appendix A) noted that much of the land had been modified by agricultural practices prior to NPS ownership. Glacial erratics were removed from cultivated fields, and remnants of agricultural fields, fence lines, and roadways remain visible throughout the historic site. Prior to NPS ownership, the cultivated areas were seeded with a perennial grass cover (Nadeau et al. 2014). Natural processes of erosion and deposition are smoothing out the circles that mark the original earthlodge sites, but at unknown rates. Although no abandoned mineral lands (AML) features are identified in the NPS AML database nor Burghardt et al. (2014), an abandoned gravel quarry may be located within what is now the northern section of the park.

Earthquakes

Earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensity ranges from imperceptible by humans to total destruction of developed areas and alteration of the landscape. Until 1979, earthquakes were measured using the Richter magnitude scale which is based on a logarithmic scale from 1 to 10. Seismologists currently measure earthquake magnitude using the moment magnitude scale, which is more precise than the Richter scale but retains the same continuum of magnitude values. The Modified Mercalli Intensity Scale is a measure of the effect of an earthquake on Earth's surface. It consists of a series of key responses such as people awakening, furniture moving, chimneys damaged, and finally, total destruction. Earthquakes can directly damage historic site infrastructure, or trigger other hazards such as slope movements that may impact historic site resources, infrastructure, or visitor safety.

Although earthquakes have been felt in North Dakota, they do not pose a major hazard for Knife River Indian Villages National Historic Site (US Geological Survey 2014). The probability that an earthquake of magnitude 5.5 will occur at Knife River Indian Villages National Historic Site within the next 100 years is between zero and 1.0% (US Geological Survey 2010; fig. 27). In 1909, a magnitude 5.5 (Richter scale) and Intensity VI (Modified Mercalli scale) earthquake that was centered in Saskatchewan broke some windows and knocked articles off shelves in Dickinson, North Dakota (Bluemle 2002; US Geological Survey 2014). The 7.1 magnitude earthquake near Hebgen Lake, Montana, was felt in extreme western North Dakota in 1959. In 1968, dishes rattled and the State Capitol Building trembled (Intensity IV) from a magnitude 4.4 earthquake centered near Huff, North Dakota (Bluemle 2002; US Geological Survey 2014).

Earthquakes are primarily due to slippage along preexisting faults, and any earthquake originating in North Dakota is probably related to deeply buried structures in the Precambrian basement rocks that make up the relatively stable North American craton (see "Geologic History" section). These highly deformed Precambrian rocks probably contain numerous faults, but because they are so deeply buried, their existence and location are speculative.

Dissolution of buried salt beds may also cause surface tremors, but they are typically localized. The thick, extensive salt deposits of North Dakota are in the northwestern part of the state.

Recent surface tremors in Texas, Oklahoma, Colorado, Arkansas, and Ohio suggest that injection wells, used to dispose of fluids as part of the hydraulic fracturing process, may cause earthquakes (US Geological Survey 2011). The injection of produced water very likely triggered the majority of recent earthquakes in Oklahoma (Oklahoma Geological Survey 2015). However, the association between fracking and tremors in North Dakota has not been documented. Braile (2009), the NPS Geologic Resources Division Seismic Monitoring website (http://go.nps.gov/seismic_monitoring.cfm); accessed 13 May 2015), and the US Geological Survey Earthquakes Hazards website (http://earthquake.usgs.gov/; accessed 13 May 2015) provide more information.

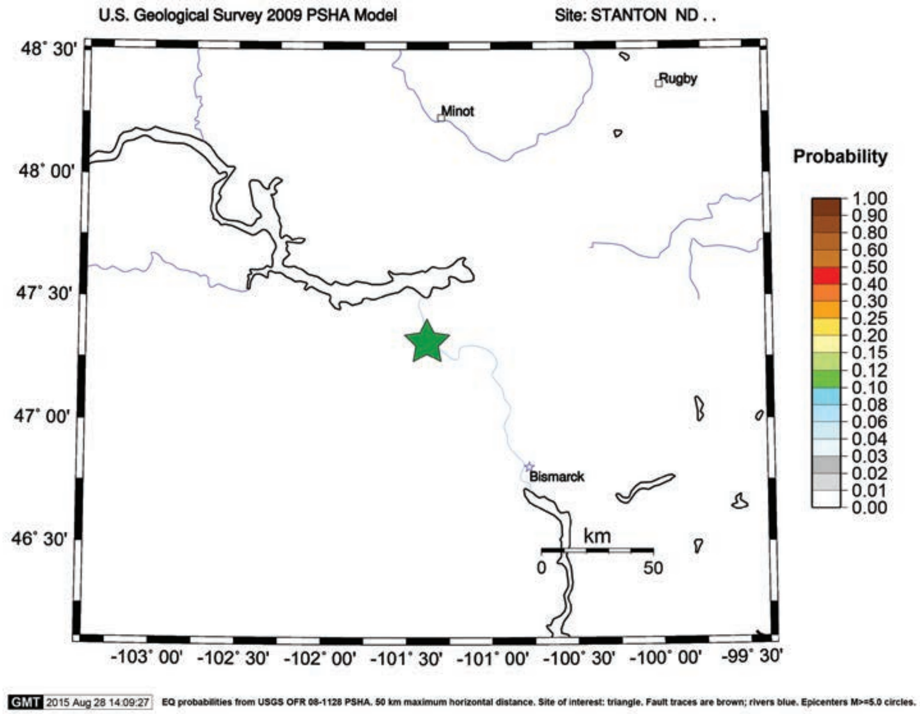

Figure 27. Earthquake probability map for Knife River Indian Villages National Historic Site. A Richter scale magnitude 5.5 earthquake has a probability of 0.00–0.01 (0%–1% "chance") of occurring near the historic site in the next 100 years. Map generated using the US Geological Survey Probabilistic Seismic Hazards Assessment (PSHA) mapping program available online: http://geohazards.usgs.gov/eqprob/2009/ (accessed 28 August 2015).

Geologic History

This chapter describes the chronology of geologic events that formed the present landscape of Knife River Indian Villages National Historic Site.

The landscape at Knife River Indian Villages National Historic Site is geologically very young (fig. 4). Most of the units are either glacial, deposited during the last phase of Pleistocene glaciation, or post-glacial, deposited after the last continental glacier retreated from North Dakota. However, the historic site is located on the margin of the Williston Basin, and within the basin, the geologic history extends back in time to the formative years of the North American craton. Precambrian deformation influenced the evolution and sedimentation of the Williston Basin, which consists primarily of carbonate rocks deposited in the Paleozoic Era and clastic rocks deposited in the Mesozoic and Cenozoic eras. The early history, which created the foundation for the current landscape, is briefly described below, followed by a description of the post-glacial history that led to the development of the terraces upon which the Hidatsa maintained their culture.

Prior to 541 Million Years Ago (Precambrian Time): Assembling the North American Craton

Approximately 2–3 billion years ago during Precambrian time, the Superior craton, which included the eastern North Dakota landmass, collided with the Wyoming craton to the west, suturing the Wyoming craton to the margin of the fledgling North American craton (fig. 28). The collision caused a north–south-trending region of deformed rock known as the "Trans-Hudson orogenic belt," which includes the Williston Basin, the present-day Knife River Indian Villages National Historic Site, and the rest of western North Dakota (Anna et al. 2013). The Trans-Hudson Orogeny (mountain-building event) included several northeast–southwest-trending, strike-slip faults and lineament zones (fig. 29; Burrett and Berry 2000; Anna et al. 2013). These strike-slip faults and lineaments were later reactivated to form north–south and northwest–southeast structures in the Williston Basin, such as the Nesson, Cedar Creek, Little Knife, and Billings anticlines, which are convex, upside-down U-shaped folds (Gerhard and Anderson 1988; Kent and Christopher 2008; Anderson 2009; Anna et al. 2013).

In the Paleozoic Era (541 million–252 million years ago), recurrent movement on the faults bent sedimentary rock layers and caused them to fold over the fault plane. These folds are known as drape folds. In the Laramide Orogeny of the Late Cretaceous–Paleogene, reactivation of Precambrian faults produced folding and strike-slip movement in the basin, and this movement generated thrust and reverses faults (fig. 29). Although the Williston Basin generally appears to be a tectonically benign depression on the North American craton, its shape was established millions of years ago during the dynamic Trans-Hudson Orogeny when Precambrian deformation resulted in down-to-the-basin normal faulting (Anna et al. 2013).

From 541 Million to 252 Million Years Ago (Paleozoic Era): Sediments Fill the Williston Basin

By the end of Precambrian time (541 million years ago), present-day North Dakota lay far inland from the proto-North American continental margin (fig. 30). However, within 50 million years, the sea had transgressed onto the continent and drowned present-day North Dakota (fig. 30). Cambrian and Early Ordovician sandstones and shale, eroded from the Transcontinental Arch, a highland that formed the northeast–southwest-trending spine of the craton, were deposited in nearshore marine environments. As sediment accumulated, the Williston Basin began to subside.

Sea level fluctuated throughout the Paleozoic, but nearshore and open marine environments persisted in the Williston Basin. During transgressions, when sea level rose, marine limestone was deposited in the basin and as sea level fell during a regression, calcareous mudstones, dolomite, and evaporates accumulated in subtidal to supratidal (just above high-tide level) environments. Although the Williston Basin contains a relatively complete Paleozoic section, sea level regressions exposed some of the formations to subaerial erosion. Most of the Paleozoic carbonates now contain oil and gas deposits (Gerhard and Anderson 1988; Anna et al. 2013; North Dakota Geological Survey 2014c).

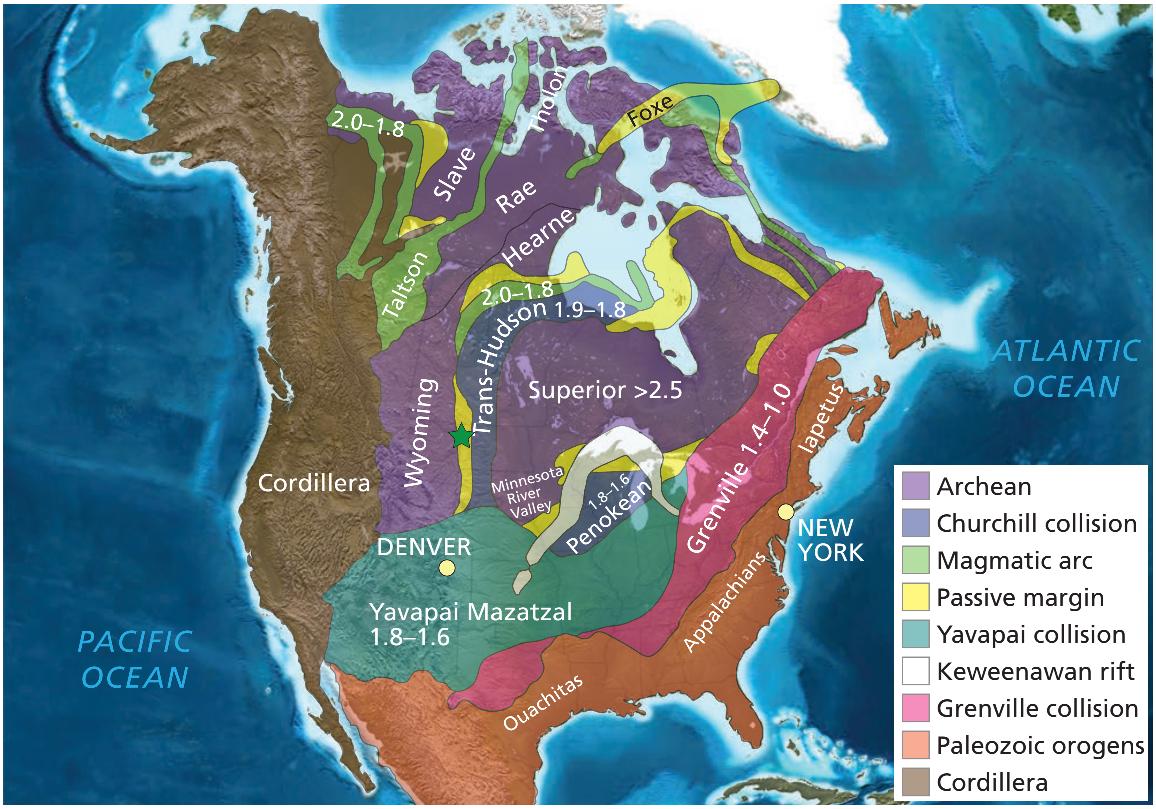

Figure 28. Map of land masses sutured together to form North America. The Trans-Hudson orogenic belt, which initiated the formation of the Williston Basin, formed when the Superior craton collided with the Wyoming craton. The green star shows the location of Knife River Indian Villages National Historic Site. The numbers represent isotopic ages in billions of years ago. Graphic by Trista Thornberry-Ehrlich (Colorado State University) using information from a US Geological Survey figure available online:http://commons.wikimedia.org/wiki/File:North_america_basement_rocks.png (accessed 23 September 2014). Basemap by Ron Blakey (Colorado Plateau Geosystems) available online: http://cpgeosystems.com/ (accessed 5 January 2015).

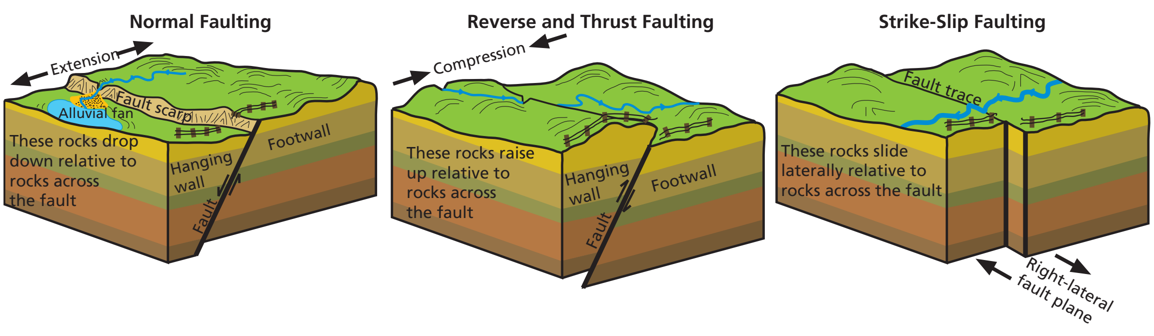

Figure 29. Schematic illustrations of three general fault types. In a fault, movement occurs along a fault plane. “Footwalls” are below the fault plane and “hanging walls” are above it. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging wall up relative to the footwall. A thrust fault is similar to a reverse fault, but has a dip angle of less than 45°. In a strike-slip fault, the relative direction of movement of the opposing plate is lateral. When movement across the fault is to the right, it is a right-lateral (dextral) fault, as illustrated above. When movement is to the left, it is a left-lateral (sinistral) fault. Precambrian-age strike-slip faults were reactivated as thrust and normal faults during the Paleozoic to form the Williston Basin. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

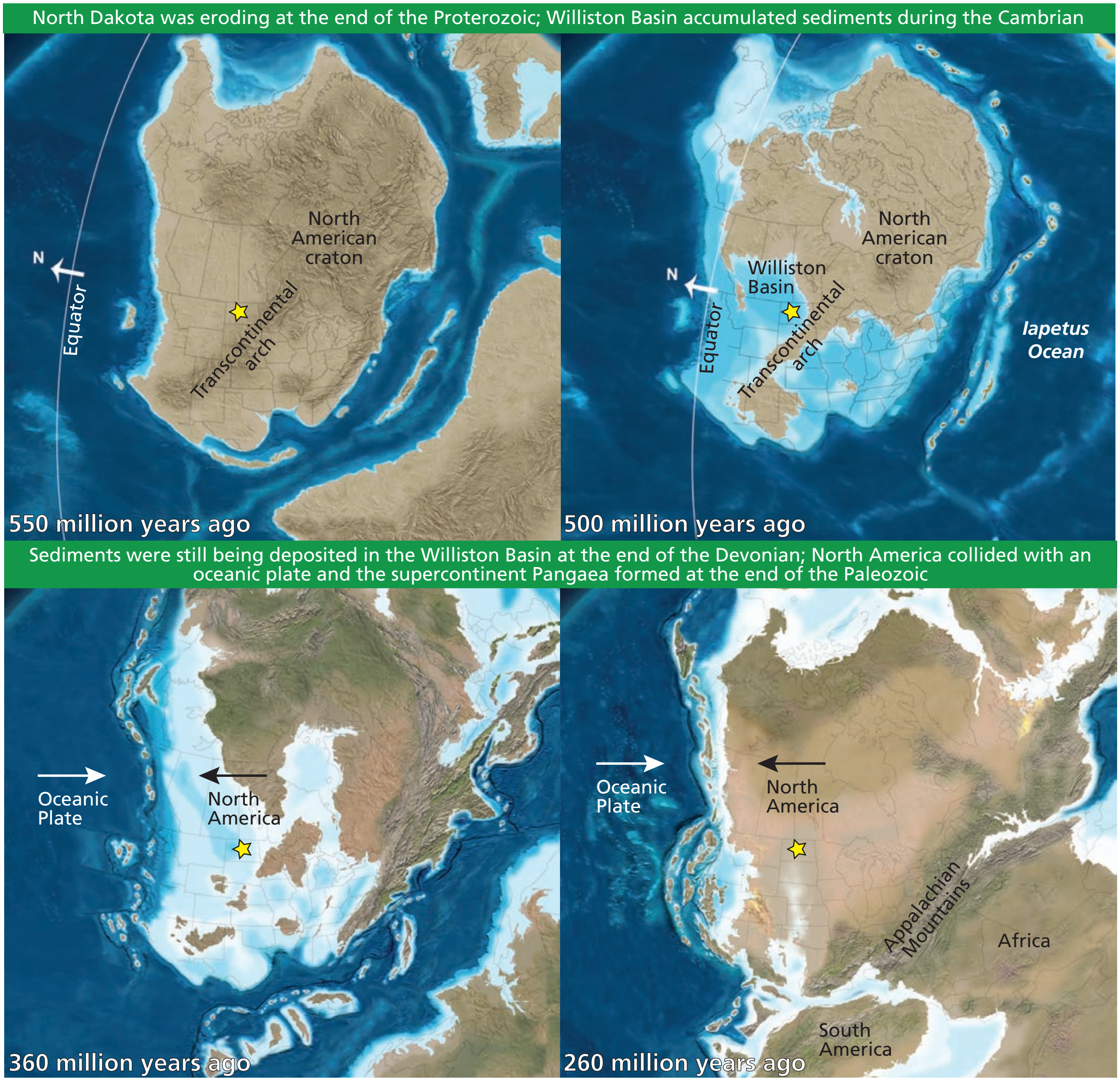

Figure 30. Paleozoic paleogeographic maps of North America. Approximately 550 million years ago (upper left), present-day North Dakota lay far inland from the craton's margin. The darker brown color represents uplands. Present-day Knife River Indian Villages National Historic Site (star) was west of the northeast–southwest-oriented Transcontinental Arch, which formed the backbone of the North American craton. Approximately 500 million years ago (upper right), shallow inland seas had inundated all but the Transcontinental Arch in the southern part of the North American craton. Approximately 360 million years ago (lower left), active subduction along the margins of proto-North America caused another major incursion of the sea onto the continent. Approximately 260 million years ago (lower right), South America and Africa were colliding with proto-North America as the supercontinent Pangaea formed in the late Paleozoic Era and Early Triassic Period. Light blue indicates shallow marine areas; darker blue represents deeper marine areas. Graphic compiled by Trista Thornberry-Ehrlich (Colorado State University) with annotations by the author. Base paleogeographic maps by Ron Blakey (Colorado Plateau Geosystems, Inc.) available online: http://cpgeosystems.com/index.html (accessed 23 July 2014).

One of the most extensive incursions of Paleozoic seas occurred approximately 382 million–346 million years ago in the Late Devonian–Early Mississippian (fig. 30). The organic-rich marine shale of the Bakken Formation records deposition in an offshore marine environment with a stratified water column, and it was the first input of clastic material into the Williston Basin since the Cambrian Period ended (LeFever 1991; Anna et al. 2013). The abundant organic matter that accumulated along with the fine-grained sediment of the Bakken Formation would eventually mature and become the source for the oil that is produced from most of the reservoirs of the Mississippian Period in the Williston Basin. Currently, horizontal drilling and hydraulic fracturing are recovering significant amounts of oil from the Bakken shale.

By the Pennsylvanian Period, which began 318 million years ago, present-day North Dakota was once again inland of the continental margin. Throughout the Paleozoic Era, continents collided and fused together to form the proto-North American continent. Along the eastern continental margin, several orogenies combined to close the Iapetus (pre-Atlantic) Ocean and form the supercontinent Pangaea (fig. 30; Hoffman 1997; Bradley 1997). By the Triassic Period, South America and Africa had sutured onto the North American continent.

From 252 Million to 66 Million Years Ago (Mesozoic Era): North Dakota Inundated by an Inland Sea

Clastic deposition in the Williston Basin continued in the Triassic and Early Jurassic periods. In the Triassic Period (252 million–201 million years ago), the supercontinent Pangaea began to split apart, opening the Atlantic Ocean and the Gulf of Mexico. Continued regression led to subaerial exposure and subsequent erosion of Permian and older units (Anna et al. 2013).

Throughout the Paleozoic and Mesozoic eras, subduction of the oceanic plate beneath the North American tectonic plate caused orogenies along the west coast and subsequent transgressions of the sea onto the continent. In the Jurassic Period (201 million–145 million years ago), subduction along the west coast initiated at least six transgressive-regressive cycles (Brenner and Peterson 1994). In the Middle Jurassic, an inland sea spread from the north into North Dakota, Montana, and Wyoming (fig. 31). Marine limestone and shallow marine and marginal marine shale, siltstone, and evaporates were deposited in the Williston Basin.

Plate collision and subduction along the western margin of North America stacked thrust sheets atop one another, causing the crust adjacent to this thrust belt to subside. With subsidence, sea water began to fill the basin from the Arctic region and the Gulf of Mexico. Episodic fluctuations in sea level occurred throughout the Cretaceous Period (145 million–66 million years ago), culminating in the formation of the most extensive interior seaway ever to bisect the North American continent (fig. 31). The Western Interior Seaway extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 4,800 km (3,000 mi; Kauffman 1977; Steidtmann 1993). During periods of maximum sea-level rise, the width of the basin reached 1,600 km (1,000 mi), which inundated the entire state of North Dakota.

Cretaceous strata are the oldest rocks exposed at the surface in North Dakota. The shallow marine sandstones and mudstones contain fossils of marine organisms, such as cephalopods and other mollusks, corals, sharks, bony fish, and large marine reptiles including mosasaurs and plesiosaurs (Hartman and Kirkland 2002; Hoganson and Murphy 2003).

When the Western Interior Seaway began to retreat, about 68 million years ago, rivers flowing from the west deposited sandstone, siltstone, and mudstone into large deltas that formed along the margin of the sea (Murphy et al. 1999; Wilf et al. 2003). In western North Dakota, the deltaic wedge of sediments is as much as 129 m (423 ft) thick (Butler and Hartman 1999).

Volcanic activity in Montana and Wyoming at the end of the Cretaceous Period contributed volcanic material to the deposits that would become the Hell Creek Formation (Butler and Hartman 1999; Hartman et al. 2014). The Hell Creek Formation includes well known dinosaur fossils, such as *Triceratops* and *Tyrannosaurus rex* (Hoganson and Murphy 2003; Liggett 2014). Research into the plants and animals found in the Hell Creek Formation of Montana and North Dakota has helped define the ecosystem of the region at the end of the Cretaceous Period. Plants in the Hell Creek Formation are dominated by large-leafed angiosperms, which were adapted to a warm, wet climate. In addition to dinosaurs, freshwater sharks, bony fish like gar,

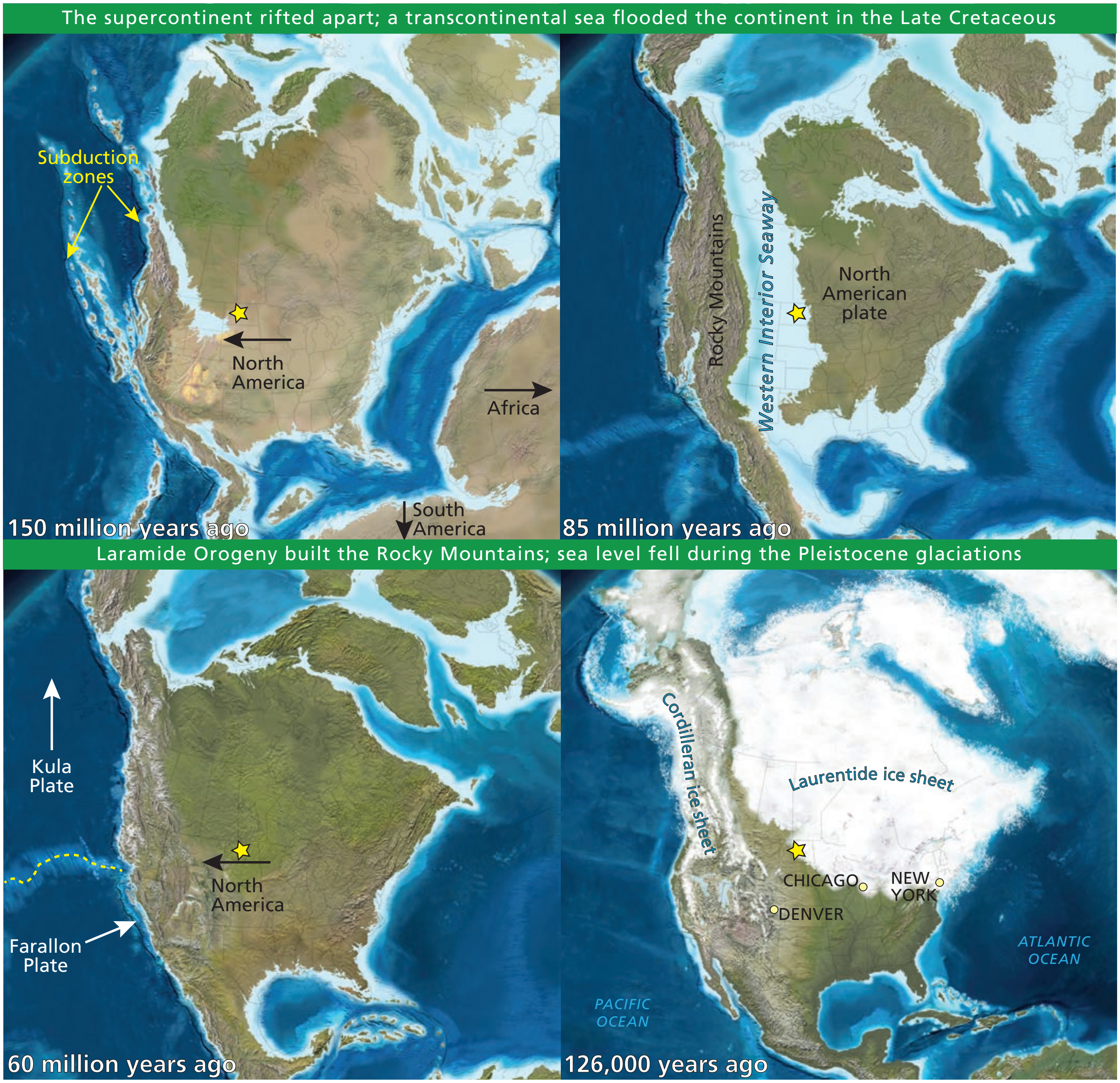

Figure 31. Mesozoic and Cenozoic paleogeographic maps of North America. Approximately 150 million years ago (upper left), an inland sea had spread into present-day North Dakota. Approximately 85 million years ago (upper right), the extensive Western Interior Seaway connected the Arctic Ocean with the Gulf of Mexico. Deltas, upon which the dinosaurs roamed, formed in western North Dakota, depositing sediments that would become the Hell Creek Formation. Approximately 60 million years ago (lower left), the undivided Sentinel Butte/Bullion Creek Formations (Tsb) formed on floodplains in the region of the present-day historic site. Approximately 126,000 years ago (lower right), continental glaciers flowed into North Dakota from the north. This was one of several episodes of glacial advance. The star represents the approximate location of present-day Knife River Indian Villages National Historic Site. Graphic by Trista Thornberry-Ehrlich (Colorado State University) with annotations by the author. Base paleogeographic maps by Ron Blakey (Colorado Plateau Geosystems, Inc.) available online: http://cpgeosystems.com/index.html (accessed 23 July 2014).

turtles, crocodiles, and amphibians were found in coastal environments (Liggett 2014).

A catastrophic extinction event marks the end of the Cretaceous, and the Hell Creek Formation records the final days of the dinosaurs and many other animals and plants that went extinct 66 million years ago. Global climate cooled at that time million years ago (Wilf et al. 2003). Evidence for this climate change and asteroid impact comes from microfossils and from a thin layer of strata that contains minerals, such as iridium, that are common in asteroids, but rare under surface conditions on Earth. Quartz grains also contain fracture patterns typical to high-intensity explosions or impacts. Although not yet found in the Hell Creek Formation exposed along the Missouri River in North Dakota, this iridium layer has been found from New Mexico to western North Dakota, including at a number of sites in the Williston Basin (Hoganson and Murphy 2003; Nichols 2007; Hartman et al. 2014).

From 66 Million to 2 Million Years Ago (Cenozoic Era): Paleocene Swamps and Seas and Climate Change

Paleocene Epoch megaflora is less diverse and less heterogeneous than Cretaceous Period megaflora and is dominated by species that were common in Cretaceous bogs (Johnson 2002; Wilf et al. 2003; Bercovici et al. 2008). The Cannonball Member of the Fort Union Formation (also called the Cannonball Formation in parts of North Dakota), the remnant deposits of the last interior sea, retreated from North Dakota and Montana about 60 million years ago. In its wake, it left about 120–150 m (400–500 ft) of sandstone and mudstone containing marine fossils (Hoganson and Murphy 2003; Hartman 2004, 2015). Fossils in the Cannonball Formation represent life forms that are different from those that lived in the Cretaceous seas. The Cannonball Member does not preserve large marine reptiles or ammonites, for example, and preserves many different species of sharks, fish, and invertebrates.

The Paleocene Epoch (66 million to 56 million years ago) Sentinel Butte/Bullion Creek formations, undifferentiated (geologic map unit **Tsb**) are the oldest rock formations exposed in Knife River Indian Villages National Historic Site. Similar to the continental part of the Hell Creek Formation, the sandstone, siltstone, mudstone, and lignite beds of the Sentinel Butte and Bullion Creek formations represent deposition in channels, on floodplains and in lakes and swamps (fig. 31; Daly et al. 1985; Hoganson and Murphy 2003). Volcanic ash, drifting in from the west, altered to the swelling clay bentonite in some areas. Peat accumulated in swampy areas and was eventually transformed into North Dakota's vast lignite reserves.

Fossils of alligators, crocodiles, lizards, and other reptiles, along with subtropical plants such as magnolia, bald cypress, and palm indicate that the region had a humid, subtropical environment in the Paleocene, similar to today's climate in south Florida (Hoganson and Murphy 2003). A distinct period of global warming, known at the Paleocene-Eocene Thermal Maximum (PETM) occurred 55 million years ago. The Sentinel Butte Formation (known as the Sentinel Butte Member of the Fort Union Formation in Fort Union National Historic Site) in the Williston Basin of western North Dakota spans the Paleocene-Eocene boundary, and vegetation in the unit records the PETM (Harrington et al. 2005).

About 50 million years ago (Eocene Epoch), the climate in present-day North Dakota became cooler and drier. Plant and animal fossils from parks throughout the National Park System document this transition from a warm, "greenhouse" environment to a cooler, "icehouse" environment (fig. 32). Between 20 million and 50 million years ago, silica-rich groundwater interacted with peat to form the Knife River Flint. By 25 million years ago, the North Dakota climate was arid and cool. The landscape consisted of extensive grasslands with trees growing only along rivers (Hoganson and Murphy 2003).

From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze

The continental glaciers that flowed into North Dakota beginning about 2.6 million years ago smoothed the North Dakota landscape into rolling hills (Ehlers and Gibbard 2011). Before glaciers blocked their path, most rivers in North Dakota flowed to the north towards Hudson Bay. The glaciers diverted the rivers, including the Missouri River, to the east and south (Hoganson and Murphy 2003). Many glaciers advanced into North Dakota during the early Pleistocene Epoch, but erosion has removed most of the evidence of these advances except for large boulders, known as glacial erratics, that were left behind when the glaciers melted.

The most recent major glacial advance into what is now

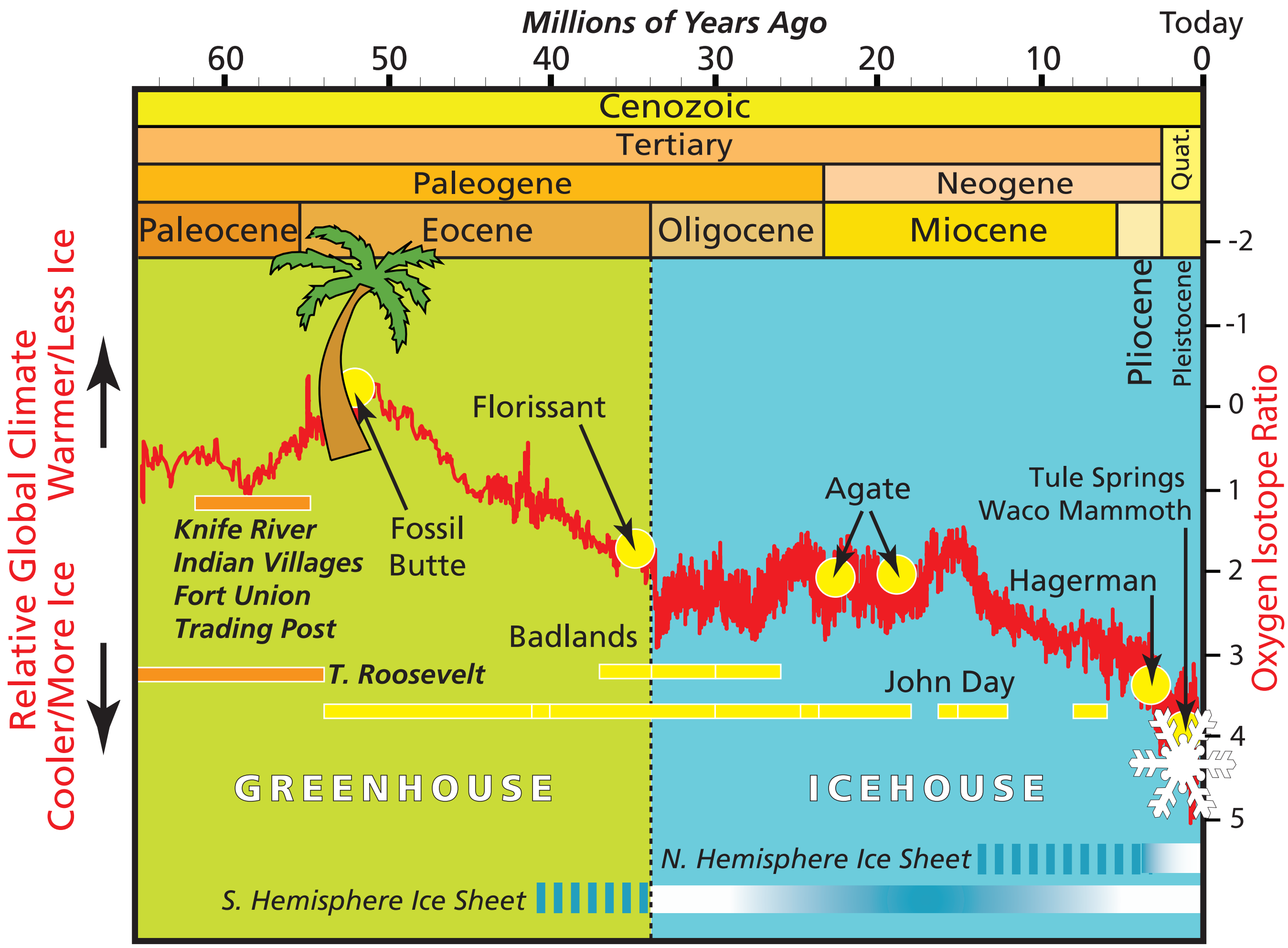

Figure 32. Illustration of relative global climate in the Cenozoic Era. During the Paleogene and Neogene periods, global climate fluctuated, influencing landscape evolution. The red line was plotted using ocean temperature data from Zachos et al. (2001, 2008). The transition from global "greenhouse" conditions with minimal polar ice sheets to "icehouse" conditions with ice sheets at one or both poles occurred near the Eocene–Oligocene boundary. The yellow dots and horizontal bars indicate the geologic ages or ranges of ages of eight NPS units established to preserve scientifically Cenozoic Era fossils and strata: Fossil Butte National Monument in Wyoming, Florissant Fossil Beds National Monument in Colorado, Agate Fossil Beds National Monument in Nebraska, Hagerman Fossil Beds National Monument in Idaho, Badlands National Park in South Dakota, John Day Fossil Beds National Monument in Oregon, Tule Springs Fossil Beds National Monument in Nevada, and Waco Mammoth National Monument in Texas. The orange bars indicate the time spanned by Paleogene deposits in the North Dakota parks (Fort Union Trading Post and Knife River Indian Villages National Historic Sites and Theodore Roosevelt National Park). Holocene (post-glacial) deposits are not included. National Park Service graphic by Jason Kenworthy (NPS Geologic Resources Division) after Kenworthy (2010, figure 5.3).

North Dakota occurred between about 70,000 to 12,000 years ago and is known as the Wisconsinan glacial stage or "ice age" (fig. 31). Two or three glacial events occurred during the Wisconsinan ice age (Hoganson and Murphy 2003). An advance occurred about 40,000 years ago, and a second one occurred about 25,000 years ago. Ice completely withdrew from North Dakota about 11,000 years ago (Brevik and Reid 2000).

When the last continental glacier was at its maximum extent, about 12,000–14,000 years ago, spruce and deciduous forests grew as far south as the southern Great Plains. When the climate warmed and the glaciers melted, the trees retreated northward, leaving behind the vast grassland of North Dakota.

Ice dammed the Missouri River at least twice, causing glacial lakes to form. Glacial Lake McKenzie filled the Missouri River valley from the border of present-day South Dakota to Riverdale (Hoganson and Murphy 2003). The McKenzie Terrace (**Qtm**) was once the shoreline of glacial Lake McKenzie.

Warming produced vast amounts of meltwater, and torrents of fresh water eroded many of the channels into Paleocene bedrock. Rivers cut downward through their floodplains, leaving them high and dry to become the Pleistocene terraces mapped in the Knife River Indian Villages National Historic Site (**Qtm**, **Qth**, **Qtst**, **Qtr**, **Qtsa**). The floodplain that is now the Hensler Terrace (**Qth**) actually formed at two different times in the late Wisconsinan. The original floodplain was flooded when ice blocked the channel and glacial Lake McKenzie formed. When the ice dam failed, the river returned to the approximate level of the original Hensler surface (Reiten 1983). This sequence of events resulted in the original Hensler floodplain pre-dating the McKenzie Terrace, but the final floodplain and subsequent Hensler Terrace post-dates the McKenzie Terrace.

The units within the Coleharbor Formation (**Qc2**, **Qc3**, **Qc4**) are associated with the final stages of Wisconsinan glaciation. The heterogeneous Unit 2 (**Qc2**) deposits were left behind by the retreating ice sheet. The fluvial deposits of Unit 3 (**Qc3**) record deposition in meltwater channels and floodplains, and the fine-grained sediment of Unit 4 (**Qc4**) are associated with lake deposition (Reiten 1983). Pieces of eroded Knife River Flint were among the sediment deposited in these units.

The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw

Alluvial and aeolian deposition and terrace development have been significantly influenced by climatic fluctuations since the end of the Pleistocene ice ages (table 6). During cool and wet climates, increased precipitation increased vegetation density, which stabilized hillslopes and decreased the amount of sediment eroded into the Knife and Missouri rivers. Consequently, the rivers incised vertically into their floodplains. Vigorous paleosol development occurred with increased precipitation, and the increased vegetation stabilized sand dunes (Reiten 1983).

In contrast, when the climate was warm and dry, vegetation density decreased and hillslopes became less stable. Paleosol development slowed and more sediment was eroded from hillslopes by slope wash and aeolian activity (Reiten 1983). Decreased precipitation, a lower water table, and increased sediment between 8,500 and 4,500 years ago may have caused the Knife River to become an ephemeral or braided stream. In a braided stream, the stream does not have the capacity to transport its sediment load, so the sediment aggrades (builds up), causing the channel to split and form numerous channels. Lateral accretion became the dominant type of alluvial deposition during warm, dry climates.

When precipitation increased beginning about 4,500 years ago, the Knife River transitioned into a meandering stream. Because the Missouri River received abundant runoff from the Rocky Mountains, any aggraded alluvium was probably reworked (Reiten 1983).

From 13,000 to 8,500 years ago, the Knife River incised into the Stanton Terrace (table 6). Grass and prairie paleosols replaced forest paleosols about 10,000 years ago. When climate became warmer after 8,500 years ago and the Knife River aggraded, the lower part of A terrace (**Qta**) formed due to lateral accretion. The fining-upward sediment package of A terrace can be greater than 5-m (16-ft) thick. When the climate cooled and precipitation increased, finer-grained overbank sediments were deposited on the Knife River floodplain and the upper part of A terrace developed.

With a change to drier conditions about 2,500 years ago, the valley began to fill again and the B1terrace (**Qtb**) formed above the erosion surface of A terrace. Between about 1,132 years BP and 27 years BP, an erosional surface formed on the B1 terrace, perhaps due to a change to a cooler, moist climatic episode (Reiten 1983). Following this climatic fluctuation, the B1 floodplain was reworked and the B2 terrace began to develop. About 500 years ago, the Hidatsa and Mandan began building earthlodges on the terraces overlooking the Knife and Missouri rivers. As it did when Lewis and Clark first viewed the Hidatsa villages, the Knife River continues to meander through the Knife River Indian Villages National Historic Site, reworking older sediments and depositing new alluvium in point bars and floodplains.

Table 6. Post-glacial terrace evolution and associated climate during the Holocene Epoch.

Age in Years Before Present (BP)	Formation		Terrace (map symbol)	Climate	Discussion
500–present	Oahe Formation	Upper Riverdale Member	B2 (Qtb)	Fluctuations from cool and moist to warm and dry	Alternating valley filling and valley incision. Several paleosols develop.
2,500–500		Middle Riverdale Member	B1 (Qtb)	Warm, dry	Valley filling. Vegetation density decreases; hillslopes become less stable. Minor episodes of paleosol development.
4,500–2,500		Lower Riverdale Member	Upper part of A (Qta)	Cool, moist	Incision of valley fill and deposition of fine-grained overbank sediment on floodplains. Vegetation density increases; hillslopes become more stable. Knife River becomes a meandering stream. Several paleosols develop. Floodplain forest fires. Sand dunes stabilize.
8,500–4,500		Pick City Member	Lower part of A (Qta)	Warm, dry	Valley filling. Vegetation density decreases; hillslopes become less stable. Knife River is an ephemeral, braided stream and aggrades to a level above the present level. Active aeolian sand dunes.
13,000–8,500		Aggie Brown Member	Stanton (Qtst)	Cool, moist	Incision of Stanton Terrace. Vegetation density increases; hillslopes become more stable. Forest paleosol develops and is replaced by prairie grasses and soils about 10,000 years BP.

Data and interpretations are from Reiten (1983). Climate interpretation for the most recent time period does not take global warming since the 20th century into account.

Geologic Map Data

This chapter summarizes the geologic map data available for Knife River Indian Villages National Historic Site. A poster (in pocket) displays the map data draped over imagery of the historic site and surrounding area. The Map Unit Properties Table (in pocket) summarizes this report's content for each geologic map unit. Complete GIS data are available at the GRI publications website: http://go.nps.gov/gripubs.

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, these maps portray the spatial distribution and temporal relationships of rocks and unconsolidated deposits. Geologic maps can be divided into two primary types: surficial and bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type.

Geologic maps often depict geomorphic features, structural interpretations (such as faults or folds), and locations of past geologic hazards that may be susceptible to future activity. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website, http://www.americangeosciences.org/environment/publications/mapping, provides more information about geologic maps and their uses.

Source Maps

The GRI team digitizes paper maps and converts digital data to conform to the GRI GIS data model. The GRI digital geologic map product includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, references, and figures. The GRI team used the following source to produce the digital geologic data set for Knife River Indian Villages National Historic Site. This source also provided information for this report.

Reiten, J. 1983. Quaternary geology of the Knife River Indian Villages National Historic Site. Thesis. University of North Dakota, Grand Forks, North Dakota.

GRI GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is available at: http://go.nps.gov/gridatamodel. 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 Knife River Indian Villages National Historic Site using data model version 2.1. The GRI Geologic Maps website, http://go.nps.gov/geomaps, provides more information about GRI map products.

GRI digital geologic data are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Portal/Home). Enter "GRI" as the search text and select a park.

The following components are part of the data set:

- A GIS readme file (knri_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology (table 7);
- Federal Geographic Data Committee (FGDC)–compliant metadata;
- An ancillary map information document (knri_geology.pdf) that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures;
- An ESRI map document (knri_geology.mxd) that displays the digital geologic data; and
- A KML/KMZ version of the data viewable in Google Earth (table 7)

Table 7. GRI GIS data for Knife River Indian Villages National Historic Site

Data Layer	On Poster?	Google Earth Layer?
Longitudinal Ridges	Yes, lithostratigraphic	Yes
Geologic Cross Section Lines	No	No
Morphologic Unit Boundaries	No	Yes
Morphologic Units	Yes, morphologic	Yes
Geologic Contacts	No	Yes
Geologic Units	Yes, lithostratigraphic	Yes

GRI Map Poster

Posters of the GRI digital geologic data draped over a shaded relief image of the historic site and surrounding area is included with this report. There are two posters, one illustrating the lithostratigraphic ("geologic") map data and one for the morphologic map data. Not all GIS feature classes may be included on the posters (table 7). Geographic information and selected historic site features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data set, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Map Unit Properties Tables

The Map Unit Properties Tables list the geologic time division, symbol, and a simplified description for each of the geologic map units in the GRI GIS data. Following the structure of the report, the tables summarize the geologic features, processes, resource management issues, and history associated with each map unit.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Please contact GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scale (1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 12 m (40 ft) of their true locations.

Glossary

These are brief definitions of selected geologic terms relevant to this report. Definitions are based on those in the American Geosciences Institute Glossary of Geology (5th edition; 2005). Additional terms are defined at http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.

aeolian. Describes materials formed, eroded, or deposited by or related to the action of wind.

aggradation. The building up of Earth's surface by depositional processes.

alcove. A large, deep niche formed in a precipitous face of rock.

alluvial terrace. A stream terrace composed of unconsolidated alluvium, produced by renewed downcutting of the floodplain or valley floor by a rejuvenated stream or by the later covering of a terrace with alluvium.

alluvium. Stream-deposited sediment.

anticline. A fold, generally convex upward ("A"-shaped) whose core contains the stratigraphically older rocks. Compare with "syncline."

badlands. Eroded topography characterized by steep slopes and surfaces with little or no vegetative cover; composed of unconsolidated or poorly cemented clays or silts.

base level. The lowest level to which a stream channel can erode. The ultimate base level is sea level, but temporary, local base levels exist.

bed. The smallest sedimentary stratigraphic unit, commonly ranging in thickness from about 1 cm (0.4 in) to 1 to 2 m (40 to 80 in) and distinguishable from beds above and below.

bedding. Depositional layering or stratification of sediments.

bed load. The part of the total stream load that is moved on or immediately above the stream bed.

bedrock. Solid rock that underlies unconsolidated, superficial material and soil.

bioturbation. The reworking of sediments by organisms.

braided stream. A sediment-clogged stream that forms multiple channels that divide and rejoin.

burrow. A tubular or cylindrical hole or opening, made in originally soft or loose sediment by a mud-eating worm, mollusk, or other invertebrate; may be later filled with clay or sand and preserved.

calcareous. Describes a substance that contains calcium carbonate. When applied to a rock name it implies that as much as 50% of the rock is calcium carbonate.

clast. An individual constituent, grain, or fragment of a rock or unconsolidated deposit, produced by the mechanical or chemical disintegration of a larger rock mass.

clastic. Describes rocks or sediments made of fragments of preexisting rocks.

coarse-grained. Describes a crystalline rock and texture in which the individual minerals are relatively large, specifically a sedimentary rock and texture in which the individual constituents are easily seen with the unaided eye, specifically sediment or rock whose particles have an average diameter greater than 2 mm (0.08 in).

craton. The relatively old and geologically stable interior of a continent.

cross-bed. A single bed, inclined at an angle to the main planes of stratification; the term is commonly restricted to a bed that is more than 1 cm (0.4 in) thick.

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

cross section. A graphic interpretation of geology, structure, or stratigraphy based on mapped and measured geologic extents and attitudes, depicted in a vertical plane (i.e., a cut or profile view).

cutbank. A steep, bare slope formed by lateral erosion of a stream.

degradation. The progressive wearing down or away, and the general lowering or reduction, of the Earth's surface by the natural processes of weathering and erosion.

desert pavement. A natural residual concentration of wind-polished, closely packed pebbles, boulders, and other rock fragments, mantling a desert surface where wind action or sheetwash have removed all smaller particles

downcutting. Stream erosion in which cutting is directed primarily downward, as opposed to laterally.

dune. A low mound or ridge of sediment, usually sand, deposited by the wind.

ephemeral stream. A stream that flows briefly, only in direct response to precipitation, and whose channel is always above the water table.

fault. A break in rock characterized by displacement of one side relative to the other.

fine-grained. Describes a crystalline or glassy rock and texture in which the individual minerals are relatively small, specifically a sedimentary rock and texture in which the individual constituents are too small to distinguish with the unaided eye, specifically sediment or rock whose particles have an average diameter less than 1/16 mm (0.002 in), that is, silt-size particles and smaller.

flint. The homogeneous, dark-gray or black variety of chert.

floodplain. The surface or strip of relatively smooth land composed of alluvium and adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks. A river has one floodplain and may have one or more terraces representing abandoned floodplains.

fluvial. Of or pertaining to a river or rivers.

footwall. The lower wall of a fault. Compare to "hanging wall."

freeze-thaw. The mechanical weathering process caused by alternate or repeated cycles of freezing and thawing water in pores, cracks, and other openings of rock and unconsolidated deposits, usually at the surface.

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

geomorphology. The study of the general configuration of surface landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

hanging wall. The upper wall of a fault. Compare to "footwall."

heterogeneous. Consisting of dissimilar or diverse ingredients or constituents.

homogeneous. Of uniform structure or composition throughout.

igneous. Describes a rock or mineral that solidified from molten or partly molten material; also, describes processes leading to, related to, or resulting from the formation of such rocks.

isotopic age. An age (in years) calculated from the quantitative determination of radioactive elements and their decay products.

lignite. A brownish-black coal that is intermediate in coalification between peat and subbituminous coal. Synonymous with "brown coal."

limestone. A carbonate sedimentary rock consisting of more than 95% calcite and less than 5% dolomite.

lineament. A linear topographic feature of regional extent that probably reflects an underlying crustal structure; also, any extensive linear surface feature (e.g., fault lines, aligned volcanoes, and straight stream courses).

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

lithostratigraphy. The branch of stratigraphy that deals with the description and systematic organization of the rocks of Earth's crust into distinctive named units based on the lithologic character of the rocks and their stratigraphic relations.

loess. Windblown silt-sized sediment.

lower flow regime. A condition of stream flow that is characterized by a unidirectional current and relatively low sediment transport rates.

meander. One of a series of sinuous curves, bends, loops, turns, or windings in the course of a stream, produced by a mature stream swinging from side to side as it flows across its floodplain or shifts its course laterally toward the convex side of an original curve.

medium-grained. Describes a sediment or sedimentary rock and texture in which the individual particles have an average diameter in the range of 1/16 to 2 mm (0.002 to 0.08 in), that is, sand size.

member. A lithostratigraphic unit with definable contacts; a subdivision of a formation.

metamorphic rock. Any rock derived from preexisting rocks that was altered in response to marked changes in temperature, pressure, shearing stress, and chemical environment. One of the three main classes of rock—igneous, metamorphic, and sedimentary.

normal fault. A fault in which the hanging wall appears to have moved downward relative to the footwall; the angle of dip is usually 45°–90°.

orogeny. A mountain-building event.

outwash. Glacial sediment transported and deposited by meltwater streams.

overbank deposit. Fine-grained sediment (silt and sand) deposited on a floodplain by floodwaters.

paleogeography. The study, description, and reconstruction of the physical landscape in past geologic periods.

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

paleosol. An ancient soil layer preserved in the geologic record.

Pangaea. A supercontinent that existed from about 300 to about 200 million years ago and included most of the continental crust of the Earth, from which the present continents were derived by fragmentation and continental drift.

peat. An unconsolidated deposit of semicarbonized plant remains in a water-saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75%). It is an early stage or rank in the development of coal; carbon content is about 60% and oxygen content is about 30% (moisture-free). Structures of the vegetal matter may or may not be visible, depending on the degree of organic matter degradation.

point bar. A low ridge of sand and gravel deposited in a stream channel on the inside of a meander, where flow velocity slows.

radiocarbon age. An isotopic age expressed in years and calculated from the quantitative determination of the amount of carbon-14 remaining in an organic material. Synonymous with "carbon-14 age."

radiometric age. An age (in years) calculated from the quantitative determination of radioactive elements and their decay products. The preferred term is "isotopic age."

regression. Long-term seaward retreat of the shoreline or relative fall of sea level.

reverse fault. A contractional high-angle (greater than 45°) dip-slip fault in which the hanging wall moves up relative to the footwall.

ripple marks. The undulating, approximately parallel and usually small-scale pattern of ridges formed in sediment by the flow of wind or water.

sand. A clastic particle smaller than a granule and larger than a silt grain, with a diameter ranging from 1/16 to 2 mm (0.0025 to 0.08 in).

sand sheet. A large irregularly shaped plain of aeolian sand, lacking the discernible slip faces that are common on dunes.

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

sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

sedimentary. Pertaining to or containing sediment.

sedimentary rock. A rock resulting from the consolidation of loose sediment that has accumulated in layers; it may be "clastic," consisting of mechanically formed fragments of older rock; "chemical," formed by precipitation from solution; or "organic," consisting of the remains of plants and animals. One of the three main classes of rock—igneous, metamorphic, and sedimentary.

sedimentation. The process of forming or accumulating sediment into layers, including the separation of rock particles from parent rock, the transportation of these particles to the site of deposition, the actual deposition or settling of the particles, the chemical and other changes occurring in the sediment, and the ultimate consolidation of the sediment into solid rock.

sheetflood. A broad expanse of moving, storm-borne water that spreads as a thin, continuous, relatively uniform film over a large area in an arid region and that is not concentrated into well-defined channels; its distance of flow is short and its duration is measured in minutes or hours, commonly occurring after a period of sudden and heavy rainfall.

sheet flow. The downslope movement or overland flow of water, in the form of a thin, continuous film, over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.

sheetwash. A sheetflood occurring in a humid region. Also, the material transported and deposited by such a sheetflood. Used as a synonym of "sheet flow" and "sheet erosion."

slope wash. Soil and rock material that is or has been transported down a slope under the force of gravity and assisted by running water not confined to channels; also, the process by which slope-wash material is moved.

sorting. The dynamic process by which sedimentary particles having some particular characteristic (such as similarity of size, shape, or specific gravity) are naturally selected and separated from associated but dissimilar particles by the agents of transportation.

strata. Tabular or sheetlike layers of sedimentary rock; layers are visually distinctive from other layers above and below. The singular form of the term is stratum, but is less commonly used.

stratification. The accumulation, or layering, of sedimentary rocks as strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

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. A planar surface along the sides of a stream valley representing the remnants of an abandoned floodplain, stream bed, or valley floor produced during a former stage of erosion or deposition.

structure. The attitudes and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusion.

subaerial. Describes a condition or process that exists or operates in the open air on or immediately adjacent to the land surface.

supratidal. The coastal area just above high tide level.

terrace. Any long, narrow, relatively level or gently inclined surface (i.e., a bench or steplike ledge) that is bounded along one edge by a steeper descending slope and along the other edge by a steeper ascending slope, thus breaking the continuity of the slope; commonly occurs along the margin and above the level of a body of water, marking a former water level.

thalweg. The line connecting the lowest/deepest points along a stream bed; the line of maximum depth.

thrust fault. A dip-slip fault with a shallowly dipping (less than 45°) fault surface where the hanging wall moves up and over relative to the footwall.

till. Unstratified drift deposited directly by a glacier without reworking by meltwater and consisting of a mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

transgression. Landward migration of the sea as a result of a relative rise in sea level.

unconformable. Describes strata that do not succeed the underlying rocks in immediate order of age or in parallel position, especially younger strata that do not have the same dip and strike as the underlying rocks. Also, describes the contact between unconformable rocks.

unconformity. A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, resulting from either a change that caused deposition to cease for a considerable span of time or erosion with loss of the previously formed record.

upper flow regime. A condition of stream flow that is characterized by a unidirectional current and relatively high sediment transport rates.

water table. The surface between the saturated zone and the unsaturated zone. Synonymous with "groundwater table" and "water level."

Wisconsinan. Pertaining to the classical fourth glacial stage of the Pleistocene Epoch in North America, following the Sangamonian interglacial stage and preceding the Holocene Epoch.

yardang. A long, irregular, sharp-crested, undercut ridge between two round-bottomed troughs, carved on a plateau or unsheltered plain in a desert region by wind erosion, and consisting of soft but coherent deposits (such as clayey sand). It lies in the direction of the dominant wind.

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Additional References

This chapter lists additional references, resources, and websites that may be of use to resource managers. Web addresses are valid as of August 2015. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

- NPS Geologic Resources Division (Lakewood, Colorado) *Energy and Minerals; Active Processes and Hazards; Geologic Heritage*: http://nature.nps.gov/geology/
- NPS Geologic Resources Inventory: http://www.nature.nps.gov/geology/inventory/index.cfm.
- NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://www.nature.nps.gov/geology/gip/index.cfm
- NPS Views program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://www.nature.nps.gov/views/

NPS Resource Management Guidance and Documents

- Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html
- 1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- 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 (Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado): http://nature.nps.gov/geology/monitoring/index.cfm
- NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): http://www.nps.gov/dsc/technicalinfocenter.htm

Climate Change Resources

- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- US Global Change Research Program: http://globalchange.gov/home
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Geological Surveys and Societies

- North Dakota Geological Survey: https://www.dmr.nd.gov/ndgs/
- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

- National geologic map database (NGMDB): http://ngmdb.usgs.gov/
- Geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html
- Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")
- Publications warehouse (many publications available online): http://pubs.er.usgs.gov
- Tapestry of time and terrain (descriptions of physiographic provinces): http://tapestry.usgs.gov/Default.html

Appendix A: Scoping Participants

The following people attended the GRI scoping meeting for Knife River Indian Villages National Historic Site, held on 16 August 2011, or the follow-up report writing conference call, held on 9 July 2014. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.

2011 Scoping Meeting Participants

Name	Affiliation	Position
Eric Brevik	Dickinson State University	Associate Professor of Geology and Soils
Tim Connors	NPS Geologic Resources Division	Geologist
Joseph Hartman	University of North Dakota	Chester Fritz Distinguished Professor, School Director
Lisa Norby	NPS Geologic Resources Division	Geologist
Tim Shepherd	NPS Northern Great Plains Network	Data Manager
Wendy Ross	Knife River Indian Villages National Historic Site	Superintendent
Trista Thornberry-Ehrlich	Colorado State University	Geologist

2014 Conference Call Participants

Name	Affiliation	Position
Eric Brevik	Dickinson State University	Chair, Department of Natural Sciences; Professor of Geology and Soils
Tim Connors	NPS Geologic Resources Division	Geologist
John Graham	Colorado State University	Geologist, Report Writer
Joseph Hartman	University of North Dakota	Director, Harold Hamm School of Geology and Geological Engineering; Professor
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI Reports Coordinator
Kerry Moss	NPS Geologic Resources Division	External Energy and Minerals Program Coordinator
Kara Paintner-Green	NPS Northern Great Plains Network	Network Coordinator
Wendy Ross	Knife River Indian Villages National Historic Site	Superintendent

Appendix B: Geologic Resource Laws, Regulations, and Policies

The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to National Park Service minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of July 2015. Contact the NPS Geologic Resources Division for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC § 5937** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands.	**36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted. Regulations in association with 2009 PRPA are being finalized (July 2015).	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.
Rocks and Minerals	**NPS Organic Act, 16 USC § 1 et seq.** directs the NPS to conserve all resources in parks (including rock and mineral resources), unless otherwise authorized by law.	**36 CFR § 2.1** prohibits possessing, destroying, disturbing mineral resources… in park units.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: -only for park administrative uses; -after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; -after finding the use is park's most reasonable alternative based on environment and economics; -parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; -spoil areas must comply with Part 6 standards; and -NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

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

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims	**Mining in the Parks Act of 1976, 16 USC § 1901 et seq**. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 CFR Parts 6 and 9A. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.
Nonfederal Oil and Gas	**NPS Organic Act, 16 USC § 1 et seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).	**36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights to -demonstrate bona fide title to mineral rights; -submit a plan of operations to NPS describing where, when, how they intend to conduct operations; -prepare/submit a reclamation plan; and -submit a bond to cover reclamation and potential liability.	**Section 8.7.3** requires operators to comply with 9B regulations.
Nonfederal minerals other than oil and gas	**NPS Organic Act, 16 USC §§ 1 and 3** **Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq.** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a § 5.3 business operation, and § 5.7 – Construction of buildings or other facilities, and to comply with the solid waste regulations at Part 6. **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation , and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.

NPS 468/129640, September 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

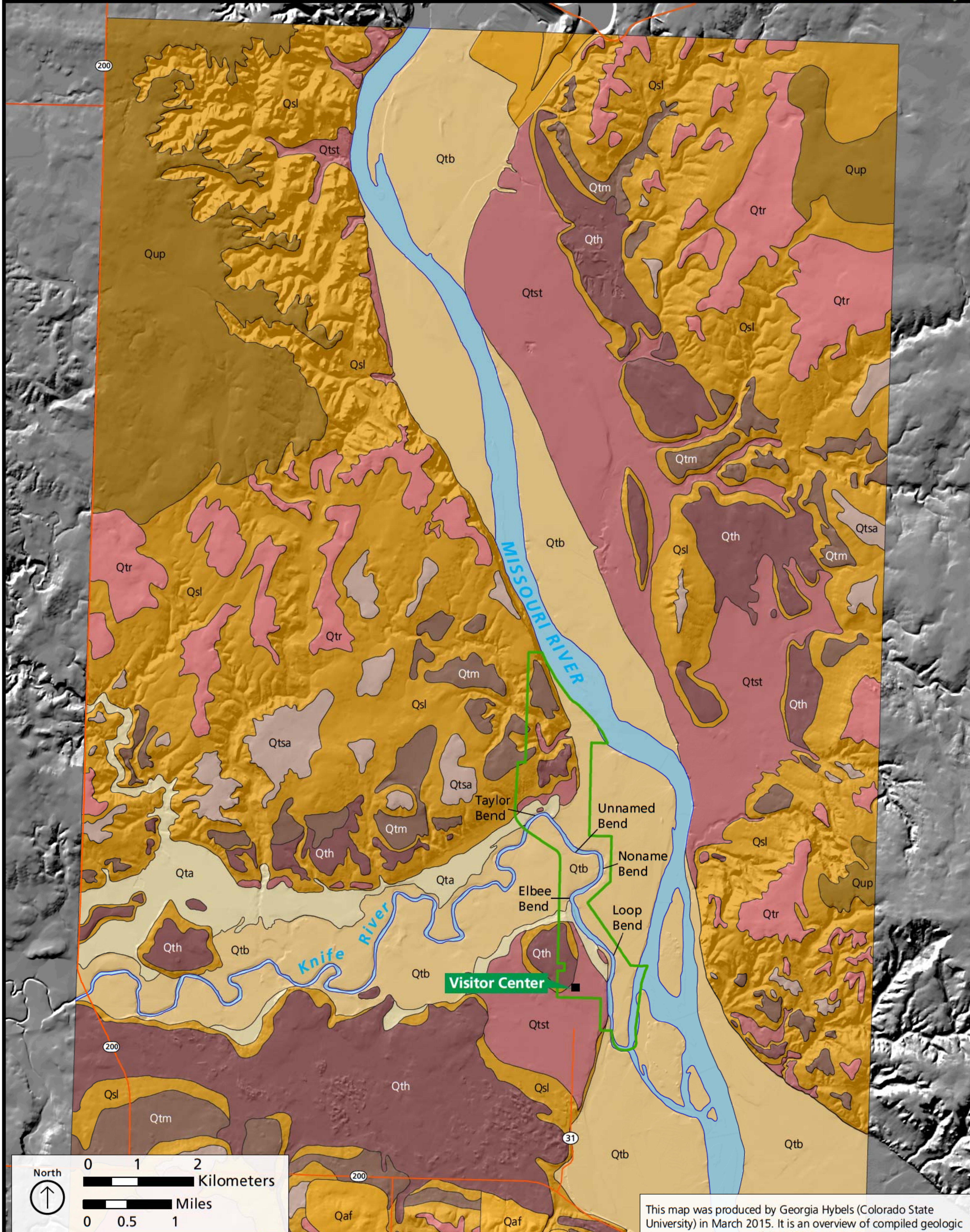
www.nature.nps.gov

Morphologic Map of Knife River Indian Villages NHS

North Dakota

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science



NPS Boundary

Infrastructure

- visitor center
- roads

Geologic Units

Symbol	Unit
water	water
Qup	Uplands (Holocene)
Qsl	Slopes (Holocene)
Qaf	Altered land and fill (Holocene)
Qtb	Terrace B (Holocene)
Qta	Terrace A (Holocene)
Qtsa	Sakakawea terrace (Pre-Late Wisconsinan)
Qtr	Riverdale terrace (Pre-Late Wisconsinan)
Qtst	Stanton terrace (Pleistocene)
Qth	Hensler terrace (Pleistocene)
Qtm	McKenzie terrace (Pleistocene)

This map was produced by Georgia Hybels (Colorado State University) in March 2015. It is an overview of compiled geologic data prepared as part of the NPS Geologic Resources Inventory. This map is not a substitute for site-specific investigations.

The source map used in creation of the digital geologic data was:

Reiten, J. 1983. Quaternary Geology of the Knife River Indian Villages National Historic Site, North Dakota (scale 1:24,000). Masters thesis. University of North Dakota, Department of Anthropology and Archeology.

As per source map scale and U.S. National Map Accuracy Standards, geologic features represented here are within 12 m (40 ft) of their true location.

All digital geologic data and publications prepared as part of the Geologic Resources Inventory are available at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. Enter “GRI” as the search text and select a park from the unit list.

Morphologic Map Unit Properties Table: Knife River Indian Villages National Historic Site

Gray-shaded map units are not mapped within Knife River Indian Villages National Historic Site.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
		Bedrock surface (without terraces) mantled with a thin layer of Paleocene sediments, till, and loess. Rolling hills with generally less than 15° slopes interspersed with closed depressions and sloughs. The 600-m (2,000-ft) contour marks the lower contact with **Qtr** or **Qsl**.	Rolling hills, closed depressions, and till.	None reported.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—This region above the Missouri River and Knife River valleys is north of the historic site and records the effects of erosion on the topography carved from the last Pleistocene ice age.
	Slopes (Qsl)	Breaks between terraces or between the uplands and the highest terrace present. Includes rugged badlands (15°–90° slopes) cut into Paleocene sediments and smooth breaks between fluvial terraces (< 10° slopes). Most slopes are at least partially covered with colluvium.	Rugged badlands; smooth breaks in slopes.	**Slope Movement**—Steep slopes may be subject to sheetwash. Potential slope failure.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—The age of the slopes is variable, but they are younger than the terrace immediately above them.
		Areas altered by anthropogenic activities such as construction and coal mining. Includes unfilled pits, spoil piles, and reclaimed land associated with coal mining.	None reported.	**Impacts Resulting from the Garrison Dam**—Includes areas disturbed during the construction of Garrison Dam. **Disturbed Land**—Mandans and Hidatsas cultivated much of the area, which was seeded with perennial grass prior to NPS ownership.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—Recent construction activities. Not mapped within the historic site at the scale of the enclosed GIS map.
	B terrace (Qtb)	Current terrace forming adjacent to the Knife and Missouri rivers. A composite of two, relatively flat terraces (**B1** and **B2**) up to 6 m (20 ft) above the Knife and Missouri rivers at elevations from 509–520 m (1,670–1,710 ft). Floodplain sand dunes, partially filled channels, and the present channel cause up to 6 m (20 ft) of relief. **B2 terrace**. Light-colored lower unit of pale-brown to very light brown, silty sand, which contains vertical iron stains, iron-stained siltstone nodules, and carbonate nodules. **B1 terrace**. Light-colored, sandy, upper part overlying 1–3 m (3–10 ft) of dark colored silty clay, which contains carbonate nodules. Darker colors are the result of soil development.	**Terraces as Landscape Features**—Meander scars are easily identifiable from the air. **B2 terrace:** Surface ranges up to 5 m (16 ft) above river level and includes the modern floodplain. The terrace fill is inset into either **Qta** or **B1**. Outcrop characteristics are similar to **Qta**. Contains climbing ripple cross-beds, small-scale cross-beds, flat beds, and convoluted beds. **B1 terrace:** Relatively flat surface from 4–6 m (13–20 ft) above river level. Uncomformably overlies **Qta**. **Paleontological Resources**—**B2 terrace** contains terrestrial and aquatic gastropod shells, bivalve shells, large mammal bones, wood, and charcoal. Fossils used as cultural artifacts may be found. Dark-gray silty clay of **B1 terrace** contains bones of large mammals, unidentified organic material, terrestrial gastropods, and thin bands of charcoal.	**Impacts Resulting from the Garrison Dam**—Narrow active channel is confined between banks of **Qo7**, which forms **Qtb**. **Flooding on the Knife River**—Inundation due to overbank flooding caused by ice jams, rapid ice melt, and/or seasonal flood events. **Bank Erosion on the Knife River**—Erosion caused by ice gouging, precipitation, Missouri River backflow, and lateral migration of the channel. **Impacts of Bank Erosion on Archeological Sites and Infrastructure**—Erosion threatens archeological sites (Elbee and Taylor bends) and Mercer County Road 18 (Taylor Bend), the Two River hiking trail (Loop Bend), and the historic site boundary (Noname Bend). **Paleontological Resource Inventory and Monitoring**—Field-based, park-specific survey, inventory, and identification of fossils in museum collection should be considered. Combined archeological and paleontological projects will collect fossils with little disturbance to cultural material.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—**B2 terrace** began forming approximately 500 years BP when the climate began fluctuating between cool, moist conditions and warm, dry conditions. **B1 terrace** began forming about 2,500 years BP in a warm, dry climate. Vegetation density decreased and hillslopes became less stable. Flooding and lateral erosion resulted in overbank (vertical accretion) and point bar (lateral accretion) deposits.

Gray-shaded map units are not mapped within Knife River Indian Villages National Historic Site.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY (Holocene)	A terrace (Qta)	Fill terrace found between the 515-m (1,690-ft) and 522-m (1,710-ft) contours, 6–8 m (20–26 ft) above river level. Restricted to the Knife River valley. Divided into lower and upper units. *Upper unit*. Pale-brown, clayey silt and dark-grayish-brown silty clay containing several paleosols. Capped by up to 1 m (3.3 ft) of grayish-brown loess. Vertical accretion deposits that accumulated as sediments settled out of overbank flood waters. *Lower unit*. Light-brown to gray, fine- to medium-grained, silty sand and clay. Sand, which can be > 5 m (16 ft) thick, mostly accumulated by lateral accretion in point bars.	**Terraces as Landscape Features**—Identified by its elevation limits, escarpments between upper and lower units, characteristic stratigraphy of each unit, and lack of meander scars on the surface. *Upper unit*. No distinct bedding. Contains discontinuous layers of charcoal, terrestrial gastropods, carbonate nodules, bones of large mammals, and artifacts. The dark-colored bands (paleosols) contain disseminated organic materials. *Lower unit*. High- and low-angle, small-scale cross-beds, climbing ripple cross-beds, and horizontal beds. **Paleontological Resources**—Fossils used as cultural artifacts may be found in **Qta**. *Upper unit*. Terrestrial gastropods, bones of large mammals, discontinuous charcoal layers, and disseminated organic material.	**Flooding on the Knife River**—Potential inundation due to overbank flooding caused by ice jams, rapid ice melt, and/or seasonal flood events. **Bank Erosion on the Knife River**—Potential erosion caused by ice gouging, precipitation, Missouri River backflow, and lateral migration of the channel. **Impacts of Bank Erosion on Archeological Sites and Infrastructure**—Erosion threatens archeological sites (Elbee and Taylor bends) and Mercer County Road 18 (Taylor Bend), which are in the area of **Qta**. **Paleontological Resource Inventory and Monitoring**—Field-based, park-specific survey, inventory, and identification of fossils in museum collection should be considered. Combined archeological and paleontological projects will collect fossils with little disturbance to cultural material. **Slope Movement**—Reworked by slopewash.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—The upper part of **Qta** formed from about 4,500 to 2,500 years BP in a cool, moist climate that increased vegetation density, stabilized hillslopes, and caused the Knife River to have a meandering channel pattern. Overbank deposits predominate. Floodplain forest fires produced charcoal layers. Radiocarbon dates from charcoal range from 3,900 years BP to 2,900 years BP. The lower part of **Qta** began forming about 8,500 years BP when a warm, dry climate decreased vegetation density, allowing more sediment to erode into the Knife River. Decreased precipitation, lower water levels, and an increase in sediment load led to lateral accretion (point bars) and aggradation. Without the stabilizing effect of vegetation, sand dunes became active.
QUATERNARY (Pleistocene)	Sakakawea Terrace (Qtsa)	Named after Lake Sakakawea because it forms a level surface at about the same elevation (560–570 m [1,840–1,870 ft]) as the maximum pool level of the lake. Stratigraphy similar to **Qtr**.	**Terraces as Landscape Features**—Cut terrace 51–61 m (170–200 ft) above river level with slopes of < 5°. Flat to gently undulating, well-drained surface.	Not mapped in the historic site.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—This pre-Wisconsinan former river floodplain was modified by glacial deposition and stream and slopewash erosion. Younger than **Qtr** and older than lower elevation terraces.
QUATERNARY (Pleistocene)	Riverdale Terrace (Qtr)	Highest terrace mapped in the vicinity of the historic site. Cut terrace at elevations between 579–600 m (1,900–1,970 ft), which is 67–90 m (220–290 ft) above river level. Typically consists of Paleocene fluvial sediment overlain by 1 m (3.3 ft) of gravel, which is overlain by 1–2 m (3.3–6.6 ft) of till. Capped by < 1 m (3.3 ft) of loess.	**Terraces as Landscape Features**—Flat to gently undulating, well-drained surface with slopes of <5°. Less relief, better drainages, and more surface and near-surface fluvial sand and gravel than **Qup**. An arbitrary upper limit of the 600-m (2,000-ft) contour marks the highest contact between **Qtr** and **Qup**. Identified by elevation. Slopes generally form escarpments between terraces.	Not mapped in the historic site.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—The oldest terrace identified in the area, **Qtr** is probably pre-Wisconsinan and post-Pliocene. Vertical incision transformed this former fluvial floodplain into a terrace. Subsequent deposition of till and erosion by streams and slope wash modified the original terrace surface, making **Qtr** more difficult to identify than the lower terraces.
QUATERNARY (Pleistocene)	Stanton Terrace (Qtst)	Lowest Pleistocene terrace identified in the area. Fill terrace between elevations of 517–524 m (1,700–1,720 ft). It is 8–15 m (26–49 ft) above river level. Composed of more than 2 m (6.6 ft) of poorly sorted, flat-bedded to massive sand and gravel and capped by up to 5 m (16 ft) of aeolian silt or sand that grades into and is interbedded with overbank silt and clay near tributaries. Where the surface is overlain by deposits of younger alluvial silt and clay, **Qtst** is difficult to differentiate from **Qta**.	**Features that Connect Geology and Archeology**—Flat surface provided locations for the Hidatsa villages in the historic site. **Terraces as Landscape Features**—Identified by its elevation limits and flat, well-drained surface with slopes < 5°. Tributary terraces grading into **Qtst** commonly have steeper slopes and extend to higher elevation.	**Bank Erosion on the Knife River**—Potential erosion caused by ice gouging, precipitation, Missouri River backflow, and lateral migration of the channel. **Slope Movement**—Potential slope movement due to bluff collapse.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—**Qtst** formed as the last glacier was retreating from North Dakota, from 13,000 to 8,500 years BP. The climate was cool and moist, allowing vegetation density to increase and hillslopes to become more stable. Forests were replaced by grasslands about 10,000 years BP.
QUATERNARY (Pleistocene)	Hensler Terrace (Qth)	Fill terrace 527–542 m (1,730–1,780 ft) above sea level and between 17–31 m (56–100 ft) above river level. Composed of up to 16 m (52 ft) of fluvial sand and gravel and capped by up to 10 m (33 ft) of aeolian sand or up to 5 m (16 ft) of loess.	**Terraces as Landscape Features**—Flat, gently undulating, well-drained surface with slopes < 5°. Identified by its relatively flat surface between specific elevation limits.	**Slope Movement**—Potential slope movement due to bluff collapse.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—**Qth** formed at two different times. The original **Qth** floodplain formed during late Wisconsinan time, but the terrace was drowned when glacial Lake McKenzie formed. When the ice dam breached and Lake McKenzie drained, the river returned to approximately the original **Qth** surface.
QUATERNARY (Pleistocene)	McKenzie Terrace (Qtm)	Mean elevation of 548 m (1,800 ft). Parts of this terrace are present between 33–42 m (110–140 ft) above river level. Surface is preserved either as a terrace cut into Paleocene sediments or till, or as a fill terrace underlain by sand or gravel. Much of the surface is overlain by up to 10 m (33 ft) of aeolian sand or up to 5 m (16 ft) of loess.	**Terraces as Landscape Features**—Flat to gently sloping, well-drained surface with slopes < 5°. **Qtm** was once the shore of glacial Lake McKenzie. About 500 m (1,600 ft) north of the historic site, the terrace is composed of 2 m (6.6 ft) of large-scale, high-angle, cross-bedded gravel, which are backbeach (backshore) deposits. Identified by its flat surface within its specific elevation limits.	**Slope Movement**—Potential slope movement due to bluff collapse.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—Glacial Lake McKenzie filled during the late Wisconsinan glaciation and occupied parts of south-central North Dakota east of the present location of Bismarck, near the town of McKenzie. Lake silts indicate a minimum lake level of 533 m (1,750 ft) above sea level. The cross-bedded gravels within **Qtm** are backbeach (backshore) deposits.

Based on Reiten (1983). Pleistocene terraces are listed in the order they appear in the knri_geology.pdf (see GRI GIS data) and on the geomorphic map. Terraces are not listed in chronological order.

Lithostratigraphic Map of Knife River Indian Villages NHS

North Dakota

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

NPS Boundary

Infrastructure

visitor center

roads

Longitudinal Ridges

linear trend, known or certain

Geologic Units

water

Qo7 Oahe Formation, unit 7 (Holocene)

Qo6 Oahe Foramtion, unit 6 (Holocene)

Qo5 Oahe Formation, unit 5 (Holocene to Late Wisconsinan)

Qc4 Coleharbor Formation, unit 4 (Holocene to Pre-Wisconsinan)

Qc3 Coleharbor Formation, unit 3 (Holocene to Pre-Wisconsinan)

Qc2 Coleharbor Formation, unit 2 (Holocene to Pre-Wisconsinan)

Tsb Sentinel Butte/Bullion Creek Formations, undivided (Paleocene)

This map was produced by Georgia Hybels (Colorado State University) in March 2015. It is an overview of compiled geologic data prepared as part of the NPS Geologic Resources Inventory. This map is not a substitute for site-specific investigations.

The source map used in creation of the digital geologic data was:

Reiten, J. 1983. Quaternary Geology of the Knife River Indian Villages National Historic Site, North Dakota (scale 1:24,000). Masters thesis. University of North Dakota, Department of Anthropology and Archeology.

As per source map scale and U.S. National Map Accuracy Standards, geologic features represented here are within 12 m (40 ft) of their true location.

All digital geologic data and publications prepared as part of the Geologic Resources Inventory are available at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. Enter "GRI" as the search text and select a park from the unit list.

Lithologic Map Unit Properties Table: Knife River Indian Villages National Historic Site

Gray-shaded units are not mapped within Knife River Indian Villages National Historic Site.

Age	Map Unit (Symbol)		Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY (Holocene)	Oahe Formation	Unit 7 (Qo7)	Silt, clay, sand, and gravel. Variable in color, sorting, and thickness. Deposited primarily as alluvium, but also contains colluvium. *Alluvium*. Interlayers of yellowish-brown and grayish-brown calcareous clay, silt, and very fine- to coarse-grained sand. Contains sedimentary structures common to rivers, cultural artifacts, and fossils. Ranges in thickness from < 1 m (3 ft) to > 12 m (39 ft). Underlies alluvial terraces and the modern floodplain along the Knife and Missouri rivers. *Colluvium*. Deposits reflect upslope source material: (1) brown to gray, silty clay below steep slopes of Paleocene sediment, (2) grayish-brown to dark-gray pebble loam at the base of hillslopes composed of till or gravel, and (3) sandy silt similar to **Qo5** below loess covered slopes.	**Features that Connect Geology and Archeology**—Forms the modern floodplain of the Knife River. The unit contains cultural artifacts. **Paleontological Resources**—Contains fossils of terrestrial and aquatic gastropods, bison, elk, and other mammal bones. Bioturbation by plants, earthworms, rodents, and humans has disrupted most of the primary sedimentary structures. **Fluvial Geomorphic Features**—Contains climbing ripple cross-beds, flat beds, large- and small-scale cross-beds, diffuse beds, lenses of charcoal, and wood. Secondary deposits include carbonate nodules and iron- stained siltstone nodules.	**Impacts Resulting from the Garrison Dam**—Narrow active channel confined by banks of **Qo7**. **Flooding of the Knife River**—Inundation due to ice jams, rapid ice melt, and seasonal flood events. **Bank Erosion on the Knife River**—Erosion caused by ice gouging, precipitation, Missouri River backflow, and lateral migration of the channel. **Impacts of Bank Erosion on Archeological Sites and Infrastructure**—Erosion threatens archeological sites (Elbee and Taylor bends), Mercer County Road 18 (Taylor Bend), the Two River hiking trail (Loop Bend), and the historic site boundary (Noname Bend). **Slope Movement**—River bank collapse. **Paleontological Resource Inventory and Monitoring**—Field-based, park-specific survey, inventory, and identification of fossils in museum collection should be considered. Combined archeological and paleontological projects will collect fossils with little disturbance to cultural material.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—Poorly bedded sand, silt, and clay represent vertical accretion (overbank) deposits. Lateral accretion (point-bar) deposits consist of sand and silt containing climbing ripple cross-beds, large and small scale cross-beds, and thin clay layers. Gravel and coarse sand represent channel-lag deposits. Some alluvium has been reworked by aeolian and colluvial processes. The alluvial deposits represent upper flow regime, lower flow regime, and stagnant water of river channels and floodplains. Colluvium was deposited in swales, intermittent stream valleys, and at the base of hillslopes.
QUATERNARY (Holocene)	Oahe Formation	Unit 6 (Qo6)	Light-yellowish-brown to very-dark-brown, well-sorted, fine- to medium-grained aeolian sand, which has been reworked from the terraces and floodplains. Forms dune topography and a continuous sand sheet that grades into silt of **Qo5**. Up to 10 m (33 ft) thick.	**Features that Connect Geology and Archeology**—May contain cultural artifacts. **Fluvial Geomorphic Features**—Contains low-angle cross-bedding and flat bedding. Paleosols in floodplains. **Aeolian Features**—Contains sand dunes, sand sheets, and blowouts.	None reported.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—Vegetation stabilized the dunes or sand sheet. Paleosols formed during episodes of increased precipitation. The dunes became unstable during dry periods. A species of *Populus* dated at 325 years BP in an adjacent unit suggests that the uppermost paleosol probably began forming roughly at that time. Paleosol development ceased in 1928 CE with the initiation of the Dust Bowl in the 1930s.
QUATERNARY (Pleistocene and Holocene)	Oahe Formation	Unit 5 (Qo5)	Alternating layers of light-brown and dark-brown, generally massive, very fine-grained sandy silt with a few pebbles and cobbles. The dark-colored bands are less well sorted and contain more organic material than the light-colored bands. Maximum thickness is 5 m (16 ft). Only mapped where it is at least 1 m (3.3 ft) thick. Accumulations > 1 m (3.3 ft) are restricted to flat-lying areas, such as terraces having slopes < 5°. Divided into four members based on color and stratigraphy (in ascending order): (1) pale-brown silt of the Mallard Island Member, (2) light-brown to very dark-brown silt of the Aggie Brown Member, (3) light-gray to pale-yellow silt of the Pick City Member, and (4) grayish-brown silt of the Riverdale Member.	**Features that Connect Geology and Archeology**—May contain cultural artifacts. **Paleontological Resources**—Common fossils are terrestrial gastropods and bone fragments of large mammals. This unit is bioturbated and contains rodent burrows and other burrows, possibly made by insects. **Aeolian Features**—Loess from pulverized rock fragments.	**Slope Movement**—Potential erosion of unit with increased precipitation and flooding due to global climate change. **Paleontological Resource Inventory and Monitoring**—Field-based, park-specific survey, inventory, and identification of fossils in museum collection should be considered. Combined archeological and paleontological projects will collect fossils with little disturbance to cultural material.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw**—Wind eroded silt from unstable floodplains and deposited it on the terraces and uplands as loess, some of which was subsequently reworked by slope wash and floodwaters. Dark-colored layers contain more humic material than light-colored layers and represent a cool, moist climate when vegetation increased and hillslopes stabilized. Lighter colored layers represent warm, dry climates when hillslopes became unstable due to sparse vegetation, and silt was removed from the unstable hillslopes by slope wash or wind.
QUATERNARY (Pleistocene and Holocene)	Coleharbor Formation	Unit 4 (Qc4)	Light- to grayish-brown layers of moderately well-sorted, fine-grained sand, silt, and clay deposited on the uplands. Often covered by postglacial marsh or slough sediment.	**Lake (Lacustrine) Features**—Contains fine laminations in some outcrops and disturbed and convoluted beds of silt and clay. No fossils.	Not mapped in the historic site.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—Deposited in glacial lakes or water-filled depressions on till by density currents.

Gray-shaded units are not mapped within Knife River Indian Villages National Historic Site.

Age	Map Unit (Symbol)		Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY (Pleistocene and Holocene)	Coleharbor Formation	Unit 3 (Qc3)	Light-gray, brown, and reddish-brown, poorly to moderately well-sorted silty sand, sand, and gravel composed of a heterogeneous mixture of igneous, metamorphic, and sedimentary rock fragments. Commonly found below terrace surfaces and is covered in many places with a thin layer of aeolian or alluvial sediment of the Oahe Formation. Thickness ranges from <1 m (3 ft) in cut terraces to >20 m (70 ft) in fill terraces.	**Fluvial Geomorphic Features**—High-angle, large-scale and trough cross-bedding resulting from glacial meltwater. Locally folded and faulted.	**Slope Movement**—Potential erosion with increased precipitation and flooding due to global climate change.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—Sediment was deposited in river beds (fluvial), meltwater channels (glaciofluvial), and along shorelines (beach). Part of **Qc3** was deposited on ice, causing faulting and folding of the sand and gravel after the ice melted. **Qc3** overlies Paleocene deposits and is interlayed with lake sediment of **Qc4** and till of **Qc2**.
		Unit 2 (Qc2)	Unsorted gray to light-olive-brown, pebbly clay-loam containing occasional cobbles and boulders. No distinct bedding. No fossils.	**Glacial Features**—Till (unsorted mixture of clay, silt, sand, gravel, and boulders).	None reported.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze**—Deposited as till. Various units have been differentiated along the bluffs of Lake Sakakawea.
PALEOGENE (Paleocene)	Sentinel Butte/ Bullion Creek Formations, undivided (Tsb)		All Paleocene deposits cropping out in the study area are included within the undivided Bullion Creek/Sentinel Butte Formations. These formations consist of poorly lithified yellow, brown, gray, and white sand, silt, silty clay, and clay, with some carbonaceous shale and lignite. **Tsb** is generally found along streams and hillslopes where erosion has removed younger material.	**Paleontological Resources**—Pollen, plant macrofossils (roots, stumps, petrified wood fruits, leaves), fungal spores, freshwater bivalves and gastropods, ostracodes, fish, giant salamanders, turtles, champsosaurs (aquatic reptiles), crocodilians, mammals, and invertebrate trace fossils have been found in the formations outside Knife River Indian Villages National Historic Site. **Fluvial Features**—Sand, silt, silty clay, and clay deposited in channel, overbank, and marsh environments.	**External Energy Issues: Coal Development**—Limited exposures of lignite are found in **Tsb** in the surrounding region. They do not present an issue for the historic site. **Paleontological Resource Inventory and Monitoring**—Field-based, park-specific survey, inventory, and identification of fossils in museum collection should be considered. Combined archeological and paleontological projects will collect fossils with little disturbance to cultural material.	**From 66 Million to 2 Million Years Ago (Cenozoic Era): Paleocene Swamps and Seas and Climate Change**—**Tsb** represents channel, overbank, and marsh deposits that formed in humid, subtropical environments similar to the climate of south Florida today.

Based on Reiten (1983).