National Park Service
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Natural Resource Stewardship and Science

Fort Union Trading Post National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2015/1004

ON THE COVER
Photograph of Fort Union Trading Post National Historic Site from the Bodmer Overlook. The overlook offers an excellent panoramic view of the bluffs (old alluvial terraces) visible across the river, the reconstructed fort, surrounding prairie, and Missouri River floodplain. National Park Service photograph by Emily Sunblade.

THIS PAGE
Photograph of Fort Union Trading Post National Historic Site during one of the annual summer rendezvous. National Park Service photograph by Emily Sunblade.

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August 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.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

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. Fort Union Trading Post National Historic Site: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2015/1004. National Park Service, Fort Collins, Colorado.

NPS 463/129508, August 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 Fort Union Trading Post National Historic Site (Montana and North Dakota) on 17 August 2011 and a follow-up conference call on 7 October 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.

This GRI report was written for resource managers to support science-informed decision making. It may also be useful for interpretation. The report was prepared using available geologic information; the NPS Geologic Resources Division conducted no new fieldwork in association with its preparation. Chapters of the report discuss distinctive geologic features and processes within Fort Union Trading Post 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 GIS data. A poster (in pocket) illustrates these data. The Map Unit Properties Table (in pocket) summarizes report content for each geologic map unit.

From 1828 to 1867, Fort Union Trading Post served as a peaceful gathering place for at least nine American Indian tribes, European fur traders, explorers, and other travelers to and through the northern Great Plains. To commemorate the historical significance of this active fur trade post, Fort Union Trading Post was designated as a National Historic Landmark in 1961 and authorized as a National Historic Site and part of the National Park System in 1966.

The 180 ha (444 ac) of Fort Union Trading Post National Historic Site are 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 north-south stretches of the Missouri River and the eastern edge of the Texas Panhandle. The landscape surrounding Fort Union is a product of Pleistocene (ice age) glaciation and Holocene (post ice ages) fluvial (river) processes and consists of bluffs, river terraces, and a floodplain containing the meandering channel of the Missouri River.

When John Jacob Astor's American Fur Company chose the site for Fort Union Trading Post in 1828, it was adjacent to the confluence of the Missouri and Yellowstone rivers, but the confluence has since migrated 3.6 km (2.2 mi) downstream from the historic site. The oldest rocks in the historic site belong to the Fort Union Formation and were deposited in floodplains, lakes, and swamps between 59 million and 56 million years ago.

The historic site also lies within the Williston Basin, an extensive area larger than the state of Texas that began forming hundreds of millions of years ago. Hydrocarbons in the Williston Basin have made North Dakota the second largest oil-producing state in the country. They have also raised issues for resource managers.

Geologic features and processes in the historic site include the following:

- River Features. The Missouri River contains features common to both meandering and braided streams, including point bars, cutbanks, mid-channel bars, and islands. Fort Union Trading Post National Historic Site is adjacent to a relatively straight segment of the Missouri River that has characteristics of both braided and meandering streams. The Missouri River occupies only a small part of a much larger channel that formed from meltwater flowing from the most recent Pleistocene glacier.
- Fort Union Formation Type Section and Stratigraphic Features. The type section for the Fort Union Formation, which is the standard by which other exposures of the same strata are compared, is a compilation of many detailed descriptions from strata exposed in the Fort Union area. The Sentinel

Butte and Tongue River (Bullion Creek) members of the Fort Union Formation contain features such as cross-beds, rip-up clasts, lignite coal beds, and cycles of sandstone, siltstone, and mudstone that represent deposition in Paleocene river channels, floodplains, and swamps.

- Bodmer Overlook and Surrounding Landscape. The panoramic view from the Bodmer Overlook and the rural landscape surrounding Fort Union Trading Post National Historic Site provide a glimpse of what the region looked like in the 1800s.
- Paleontological Resources. A diverse assemblage of invertebrate, vertebrate, and plant fossils, including petrified wood, has been discovered from the Tongue River Member of the Fort Union Formation in or near Fort Union Trading Post National Historic Site. Studies of freshwater mollusks collected more than 150 years ago have helped revise upper Paleocene chronology and understanding of the epoch's ecosystems. In addition to fossils from the Paleogene Period, fossils from the Quaternary Period have been discovered in the region. Fossils associated with cultural sites have also been found. Fossils were commonly used for tools and jewelry and traded amongst American Indians throughout the northern Great Plains. Silicified peat, known as Knife River Flint, was an exceptional source of tools and projectile points and was traded throughout North America. In the early days of the fur trade, the Chouteau family, managers of the American Fur Company's Western Division, greatly contributed to scientific study of fossils from the Upper Missouri River area. Fossils that the fur traders and explorers sent back east became part of the collections of the Academy of Natural Science in Philadelphia and the Smithsonian Institution in Washington, DC. The Chouteaus helped outfit the Lewis and Clark Expedition, also known as the "Corps of Discovery," and provided valuable information about the country beyond St. Louis.
- Glacial Features. Fort Union Trading Post National Historic Site was constructed near the terminal margin of the last major glacial ice sheet that advanced into North Dakota and Montana during the Pleistocene Epoch. The regional topography is a glaciated landscape that includes moraines and till. Prior to the Pleistocene Epoch, the Missouri River flowed to Hudson Bay, but the ice sheet diverted the river's flow to the south. As the glacier melted, great quantities of meltwater carved broad valleys and floodplains that would eventually contain the much smaller modern channel of the Missouri River.
- Aeolian Features. Wind has removed fine-grained sediment from hilltops and from the base of glacial erratics in the region, creating depressions known as blowouts. Blowouts may be found on the Bodmer Overlook in the historic site.
- Volcanic Ash Layers. The Sentinel Butte Member contains layers of volcanic ash that have altered to bentonite, a clay mineral that swells when wet and shrinks as it dries. This property is responsible for the popcorn-like texture on exposed surfaces and makes the clay slippery when wet, which could compromise the integrity of trails and roads, although this is not an issue in the historic site.

The primary geologic resource management issues identified during the GRI scoping meeting and follow-up conference call include the following:

- Impacts from the Construction of Fort Peck Dam. Stream power has increased below the dam because the dam captures all upstream sediment. Increased stream power has led to increased erosion, increased channel sinuosity, and the migration of the main channel towards the south bank of the Missouri River. Riparian vegetation has been negatively impacted and some habitats of fish, aquatic insects, and mussels have been destroyed.
- Missouri River Bank Erosion. NPS staff has been monitoring erosion along the south bank of the Missouri River since 2000. Erosion appears to be triggered primarily by saturation levels of bank material in association with tension cracks. Recommendations for further monitoring include development of a Fort Union Trading Post National Historic Site Missouri River management plan, which would addresses bank protection and drainage control measures, as well as the installation of monitoring wells.
- Flooding. The upstream Fort Peck Dam regulates the flow to the Missouri River. However, in extremely wet years, such as 2011, flooding may occur and impact historic site infrastructure. Extremely wet springs are expected to increase in the northern Great Plains as global climate changes. Increased precipitation and flooding will influence sedimentation rates and bank erosion, which may affect the boundary definition of the historic site.

- Current and Potential Oil and Gas Development. Extensive oil and gas production occurs in the Williston Basin. Currently, hydraulic fracturing (fracking) of the Bakken Formation is driving exploration and development of hydrocarbons. Exploration targets may be present beneath Fort Union Trading Post National Historic Site, where the United States does not own the subsurface mineral rights. Adverse effects from increased hydrocarbon extraction include increased population, increased traffic on local roads not designed for heavy truck traffic, and excessive water demands. In addition, wildlife, soil, and air resources may be negatively impacted by oil and gas development. Increased development may also degrade the scenic quality of the historic site and its cultural landscape, which is a fundamental resource for understanding the site's historic and ethnographic contexts.
- Slope Movements. Minor slope movements occur within the historic site at Bodmer Overlook where colluvium may slump downslope.
- Earthquakes. Earthquakes have been felt in North Dakota, but they do not pose a major hazard for Fort Union Trading Post National Historic Site. There is a 0.00–0.01 probability (0%–1.0% "chance") that a moderate 5.0 magnitude earthquake will impact the historic site in the next 100 years. Disposal of waste water related to the hydraulic fracking process may lubricate fault planes and trigger earthquakes, but this has not been documented in North Dakota.
- Abandoned Mineral Lands. The NPS Abandoned Mineral Lands database documents three sites at Fort Union Trading Post National Historic Site. All three are sand and gravel quarries. Two of the sites have been leveled to form the upper (larger) and lower (smaller) parking lots at the historic site. A small sand and gravel quarry east of the reconstructed Fort Union is still used for historic site maintenance.
- Paleontological Resources Inventory and Monitoring. In situ fossils observed in the historic site are subject to inventory, monitoring, protection, and interpretation. A paleontological resource inventory and monitoring report for the Northern Great Plains Network provided recommendations.

Fort Union Trading Post was built on very young geological material. The unconsolidated sediments in the historic site are only as old as the last phase of Pleistocene glaciation, which ended about 12,000 years ago, while the oldest rocks on the slopes adjacent to the Missouri River floodplain are approximately 59 million years old. In the subsurface, sediments began accumulating in the Williston Basin approximately 500 million years ago. Although not exposed in the historic site, these rock layers tell a fascinating story of the advance and retreat of epicontinental seas and tectonic deformation resulting from continent-wide mountain-building episodes.

The modern Missouri River meanders through the historic site and past the reconstructed post. Older sediments are reworked and new alluvium is deposited in point bars and channel bars. The lateral migration of the Missouri River, bank erosion, and natural weathering processes continue to modify the landscape of Fort Union Trading Post National Historic Site.

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) for drafting many 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. Justin Tweet (NPS Geologic Resources Division) provided information regarding the fossils of the Fort Union area. Fred MacVaugh (Fort Union Trading Post NHS) provided additional photographs.

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Geologic Setting and Significance

This chapter describes the regional geologic setting of Fort Union Trading Post National Historic Site, summarizes connections among geologic resources, other resources, and historic site stories.

Geologic Setting

The 180 ha (444 ac) of Fort Union Trading Post National Historic Site (fig. 1) are 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 north-south stretches of the Missouri River and the eastern edge of the Texas Panhandle (Henry and Mossa 1995). Straddling the border of North Dakota and Montana, Fort Union Trading Post National Historic Site is 580 m (1,900 ft) above sea level and lies on the southern edge of the glaciated portion of the Coteau Slope, an area that is near the maximum extent of the most recent Pleistocene glacial advance into North Dakota (Thornberry-Ehrlich 2012).

Figure 1. Location map of Fort Union Trading Post National Historic Site. Note the meandering character of the Missouri and Yellowstone rivers and their confluence, which is now southeast of the trading post. National Park Service map, available online: http://www.nps.gov/hfc/cfm/carto.cfm.

During the Pleistocene ice ages, which began about 1.6 million years ago (fig. 2), continental glaciers periodically advanced into and retreated from present-day North Dakota and eastern Montana, which were both colder and wetter than they are today. Thick sheets of ice extended to about 80 km (50 mi) south of the present-day historic site, and a lobe of ice followed the Yellowstone River valley farther south and west all the way to Glendive, Montana, during the last (Wisconsinan) ice age. The glaciers smoothed North Dakota into a landscape of rolling hills and diverted many of the rivers, including the Missouri River, to the south. Prior to glaciation, the Missouri River flowed northeasterly toward Hudson Bay, but with its northerly route blocked by ice, the river began flowing to the southeast.

Since the end of the Pleistocene Epoch, weathering and erosion have stripped much of the glacial sediments from the region, but glacial sediments (map unit **Qgt**) still cover some of the bluffs south of the historic site (see poster, in pocket). Unconsolidated alluvial sediments (**Qal**) define the present Missouri River floodplain, including the river's north bank upon which the trade post, including the Bourgeois House and other buildings, was constructed (fig. 3). Alluvial sediments, which may include glacial outwash sand and gravel, form fan-shaped deposits or alluvial terraces (**Qac**) at the base of the bluffs north of the Trade House and adjacent to the floodplain. Erosion has carved a rugged landscape into these much older bluffs, which intersect the northern boundary of the historic site. The bluffs are composed of Fort Union Formation (**Tfsb**, **Tftr**) sediments.

The late Paleocene Epoch (approximately 59 million to 56 million years ago) Fort Union Formation consists of two members, the Sentinel Butte Member and the older Tongue River Member (fig. 4). As much as 90 m (300 ft) of interlayered gray shale and cross-bedded channel sandstone of the Sentinel Butte Member caps the bluffs (Vuke et al. 2003). Lignite coal beds are exposed near the base of the member. Several lignite beds also are prominent in the underlying Tongue River Member, which weathers to form badlands topography. The Tongue River Member contains silicified ("petrified") wood, fossils of freshwater mollusks, and plant molds. The Tongue River Member has a maximum thickness of approximately 250 m (800 ft) (Bergantino and Wilde 1998).

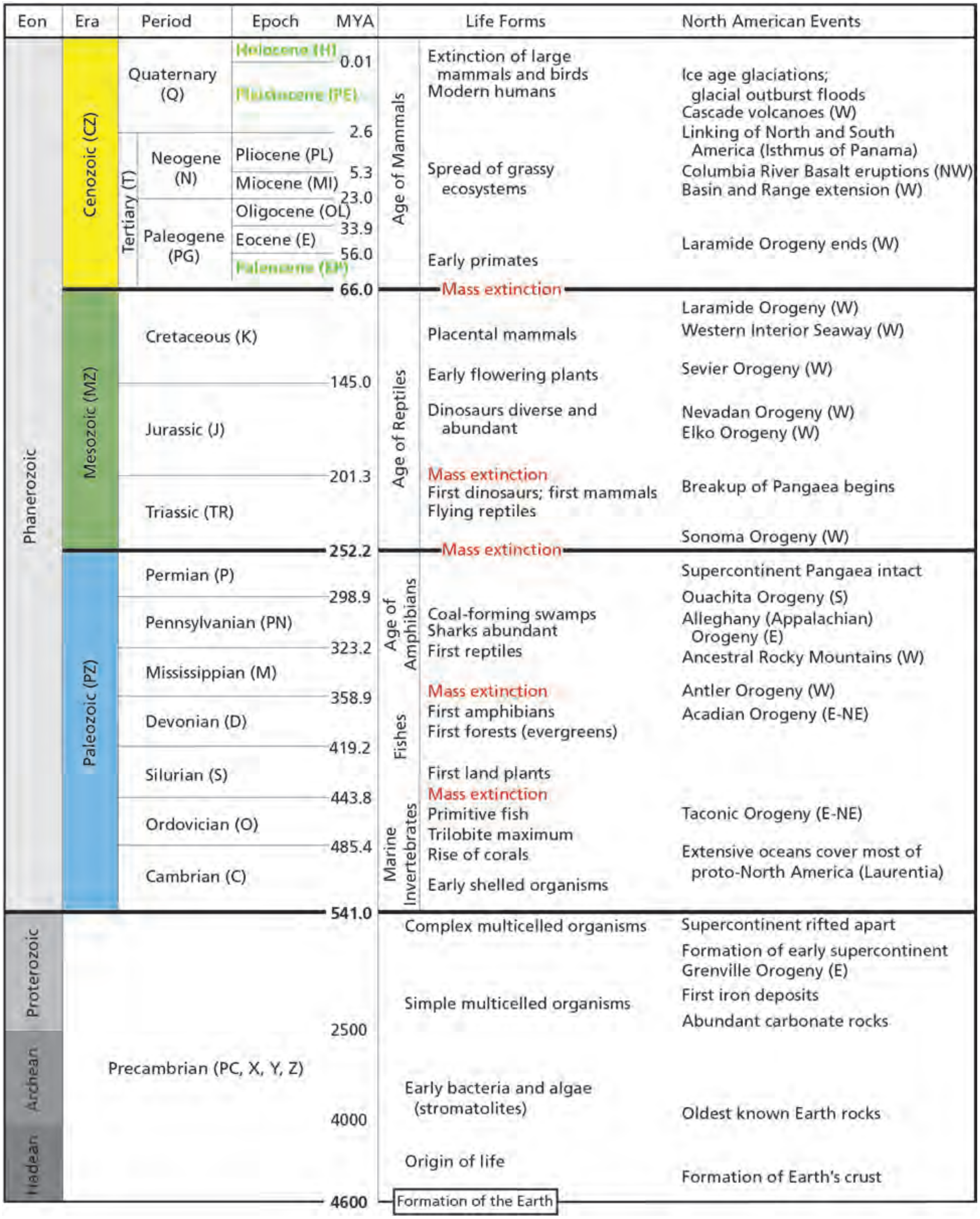

Figure 2. Geologic time scale. The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. Epochs of geologic time present in Fort Union Trading Post are indicated by green text. GRI map abbreviations for each time division 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).

Figure 3. The distinctive red-roofed Bourgeois House and visitor center at Fort Union Trading Post National Historic Site. A reproduction Red River cart is in the foreground. National Park Service photograph by Student Conservation Association intern Emily Sunblade, available online: http://www.nps.gov/fous/planyourvisit/index.htm (accessed 19 September 2014).

<table>
<tr><th colspan="2">Age</th><th colspan="2" rowspan="2">Map Unit (map symbol)</th><th rowspan="2">Description</th></tr>
<tr><th>Period</th><th>Epoch</th></tr>
<tr><td rowspan="4">Quaternary</td><td rowspan="2">Holocene</td><td colspan="2">Alluvium (Qal)</td><td>Unconsolidated gravel, sand, silt, and clay deposited in stream channels and floodplains.</td></tr>
<tr><td colspan="2">Alluvium and colluvium (Qac)</td><td>Sand, silt, and clay deposited in glacial meltwater channels.</td></tr>
<tr><td rowspan="2">Pleistocene</td><td colspan="2">Alluvial terrace deposit (Qat)</td><td>Gravel, sand, and silt deposited in terraces above modern rivers and streams.</td></tr>
<tr><td colspan="2">Till (Qgt)</td><td>Mixture of gravel, sand, silt, and clay with rare to abundant cobbles and boulders deposited by glaciers.</td></tr>
<tr><td rowspan="2">Paleogene</td><td rowspan="2">Paleocene</td><td rowspan="2">Fort Union Formation</td><td>Sentinel Butte Member (Tfsb)</td><td>Fossiliferous sandstone and mudstone deposited in channels and floodplains.</td></tr>
<tr><td>Tongue River Member (Tftr)</td><td>Cyclic layers of claystone, lignite, fossiliferous sandstone, and sandstone deposited in floodplains.</td></tr>
</table>

Figure 4. Stratigraphic column for Fort Union Trading Post National Historic Site and vicinity. Colored rows are mapped on the surface in the historic site and correspond with the colors in the Map Unit Properties Table (in pocket). Nomenclature and descriptions are from Bergantino et al. (1998) and Vuke et al. (2003). Refer to the Map Unit Properties Table (in pocket) for more information.

The historic site and surrounding rocks straddle the state line between Montana and North Dakota, which creates some nomenclatural differences for the Fort Union Formation rocks. The Fort Union Formation rocks were named after exposures throughout the Fort Union area. This GRI report and the accompanying GRI GIS data follow US Geological Survey and Montana Bureau of Mines and Geology nomenclature, which refer to the Fort Union Formation and the Sentinel Butte and Tongue River members (fig. 4). Geologic maps for North Dakota refer to the same rocks as the Fort Union Group and the Sentinel Butte Formation. The Tongue River Member is known as the Bullion Creek Formation in North Dakota.

The landscape of Fort Union Trading Post National Historic Site consists of river bluffs, river terraces, and a floodplain containing the meandering channel of the Missouri River. In 1828, John Jacob Astor's American Fur Company chose the site for the Fort Union Trading Post because it was near the confluence of the Missouri and Yellowstone rivers. Today, the confluence of the two rivers is 3.6 km (2.2 mi) southeast and downstream from the historic site. Lateral migration of the river channel across its floodplain, erosion, and weathering processes continue to modify the landscape at Fort Union Trading Post National Historic Site.

Geologic Significance and Historical Connections

Pleistocene glaciers crafted a landscape that would allow Fort Union to become the most important 19th century fur trading post on the upper Missouri River. When Pleistocene continental ice sheets blocked the northerly flow of the Missouri River and diverted it to the east-southeast, the river channel incised into one of the broad valleys that had been carved by vast amounts of glacial meltwater. Today, the Missouri River flowing past Fort Union Trading Post National Historic Site drains 240,000 km^2 (94,000 mi^2), an area comparable to the state of Michigan. (Simon et al. 1999; Ellis 2005).

Like the Missouri River, the Yellowstone River has a glacial past. Coincident with the continental ice sheets, alpine glaciers filled canyons in the Teton Range, and a 1,100-m (3,500-ft) thick ice cap covered the Yellowstone Plateau (Smith and Siegel 2000). When the climate warmed, torrents of glacial meltwater cut down through 250 m (800 ft) of volcanic rock to form the Grand Canyon of the Yellowstone. Fed by melting ice and punctuated by catastrophic floods when ice or debris dams broke, the Yellowstone River carved a northeasterly channel through Montana. It is currently the longest free-flowing river in the continental United States.

Sediments deposited since the most recent continental glacier retreated from present-day North Dakota and Montana provided the material for the lush grassland prairies of the Great Plains that supported immense herds of bison. The soils at Fort Union Trading Post National Historic Site developed from the complex interactions among glacial and alluvial deposits, time, climate, topography, plants, and animals. In 2006–2007, a soils map and database for the historic site was completed by the NPS Soil Resources Inventory and is available from the NPS Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/App/Reference/Profile/1049047 (accessed 7 November 2014).

Searching for a location for a new American Fur Company post and at the request of the Assiniboine Nation, Astor's company decided to build a trading post near the confluence of the Missouri and Yellowstone rivers (National Park Service 2014a). The relatively flat floodplain of the Missouri River made an excellent construction site. The trading post was built on alluvium and colluvium (**Qac**) that had been deposited by glaciers and reworked by modern fluvial processes. Glacial erratics—large stones transported by glaciers—may have been used as construction material, and the bluffs north of the post provided building stone (Fred MacVaugh, NPS Fort Union Trading Post National Historic Site, museum curator, written communication, 2 February 2015).

In the 19th century, the Missouri River was a major transportation corridor. In the spring when the rivers were running high from Rocky Mountain snowmelt, keel and Mackinaw boats from St. Louis would dock at Fort Union to trade goods and collect buffalo skins and furs. The first steamboat arrived at Fort Union in 1832 (Fred MacVaugh, written communication, 2 February 2015). Between 1828 and 1867, at least nine American Indian tribes, including the Assiniboine, Blackfeet, Cree, Crow, Sioux, Hidatsa, Mandan, Arikara, and Ojibwa, traded buffalo hides, beaver pelts, and other furs for goods from at least eight countries. Fort Union exchanged more than 25,000 buffalo robes and more

Figure 5. Painting of Fort Union Trading Post by Karl Bodmer (ca. 1843). The white bluffs on the horizon and those in the foreground are the fossiliferous coal-bearing strata of the Tongue River Member of the Fort Union Formation (Tftr). This view to the south is from what is now known as Bodmer Overlook. National Park Service image of Bodmer's print (FOUS number 2761) available online: http://www.nps.gov/fous/historyculture/index.htm (accessed 7 November 2014).

than $100,000 (approximately $3 million in 2013 dollars) in merchandise on an annual basis.

Many well-known explorers, scientists, naturalists, and artists also travelled along the Missouri River, stopping at the fort. The list includes George Catlin, John James Audubon, and Prince Maximilian of Wied (Chaky 1998). Karl Bodmer, the renowned Swiss painter, accompanied Prince Maximilian on his Missouri River expedition from 1832 to 1834, arriving at Fort Union in the summer of 1833. Bodmer chose the bluffs north of the trading post from which to sketch Fort Union and the Assiniboine people (fig. 5). Bodmer Overlook bears his name.

In 1857, Ferdinand Vandeveer Hayden, a pioneering geologist of the Rocky Mountains, studied the geology of the area, and Fielding Meek described the Fort Union Formation's classic fossil snails. In 1862, Hayden described a composite stratigraphic section of rock units from the area that included Fort Union and referred to this rock interval as the Fort Union Formation (Meek and Hayden 1862).

Before the Europeans arrived with steel, the Northern Plains tribes fashioned projectile points (arrowheads) by chipping, or knapping, flakes from a stone core with a harder rock. At Fort Union, archeologists discovered arrowheads made from Knife River Flint, which was quarried in the Knife River Valley in western North Dakota for thousands of years (fig. 6; Clayton et al. 1970). Because of its high quality, Knife River Flint was traded throughout North America. Artifacts made from Knife River Flint have been found across the country in locations as geographically distant as New York, New Mexico, and northern Canada (Clayton et al. 1970; Hoganson and Murphy 2003). The Mandan and Hidatsa, whose earthlodges are the focus of Knife River

Figure 6. Arrowheads found at Fort Union Trading Post National Historic Site. The upper three arrowheads are made from Knife River Flint. The lower three are iron, copper ("cuprous"), and brass. Penny for scale. National Park Service photograph available online: http://www.nps.gov/fous/historyculture/index.htm (accessed 19 September 2014).

Indian Villages National Historic Site in North Dakota (see GRI report by Graham 2015 [in review]), traded Knife River Flint for such items as copper, obsidian, shells, beads, cloth, and metal tools. Even after the introduction of steel, fur traders and explorers used Knife River Flint in their flintlock weapons until the mid-19th century. 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).

In 1866, the US Army built Fort Buford, 5 km (3 mi) east of Fort Union Trading Post, which was never a military fort. The following year, the Army purchased Fort Union from the North West Fur Company (the American Fur Company had folded in the 1840s) and dismantled the post. The salvaged timber and stone was transported to Fort Buford, where it was used as building material. Crews from passing riverboats scavenged the remaining wood for firewood to feed steam engines, and within a few years, only traces were left of Fort Union Trading Post. This once–dominant commercial hub had become a memory.

The landscape at Fort Union Trading Post National Historic Site proved to be ideal for the cultural exchange of ideas and material goods. In order to commemorate the rich history of Fort Union, the site was designated a national historic landmark on 4 July 1961, and on 20 June 1966, it was authorized as a national historic site and part of the National Park System. The reconstructed structures were completed in 1991. In addition to the reconstructed trading post and American Indian encampment, the Missouri River, its watershed, and the surrounding prairie, as well as the cultural landscape and viewshed are fundamental resources that are essential to understanding the cultural resources of the site and provide a tangible reminder of what the habitat was like in the 1800s (National Park Service 2013).

Geologic Features and Processes

This section describes noteworthy geologic features and processes in Fort Union Trading Post National Historic Site

During the 2011 scoping meeting (Thornberry-Ehrlich 2012) and 2014 conference call, participants (see Appendix A) identified the following geologic features and processes:

- River Features
- Fort Union Formation Type Section and Stratigraphic Features
- Bodmer Overlook and Surrounding Landscape
- Paleontological Resources
- Glacial Features
- Aeolian Features
- Volcanic Ash Layers

River Features

The Missouri River, watershed, and associated habitat are considered fundamental resources and values to Fort Union Trading Post National Historic Site (National Park Service 2013). In the 1940s, the Fort Peck Dam was built approximately 300 km (185 mi) upstream from the historic site. Prior to the dam, the Missouri River contained a high sediment load, and its channels meandered across a wide floodplain bracketed by high sandstone bluffs. Since the dam construction, channel migration across its floodplain has been minimal. The channel now meanders between the Missouri River's banks, reworking sediment into channel bars, low banks, and an emerging inner floodplain (Ellis 2005).

The Missouri River contains elements of both meandering and braided streams. Meandering rivers are sinuous and generally have a single channel (fig. 7). The meandering pattern reduces the river gradient and produces a deeper channel along the outer bank of a meander curve where the water's momentum carries the mass of the water. The greater depth leads to higher velocity at the outer bank, and the increased velocity erodes an even deeper channel. Higher velocity also increases the river's ability to carry larger-sized particles (known as a river's "competence"). In contrast, a braided stream contains a higher sediment load, multiple channels, and steeper gradient (fig. 7).

Geomorphic features common to meandering rivers include cutbanks and point bars (fig. 7). Meandering rivers whose floodplains consist of unconsolidated

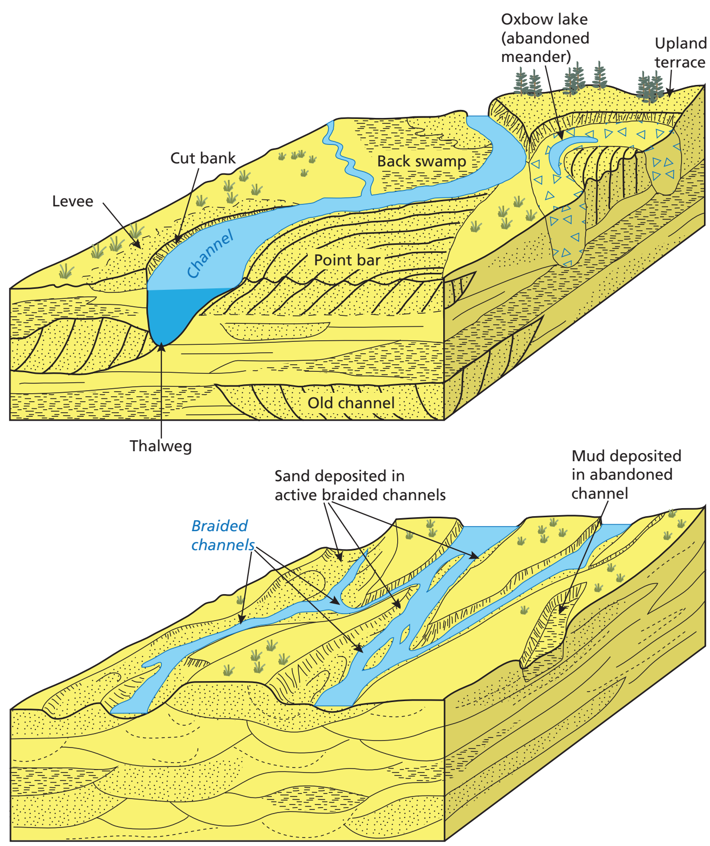

Figure 7. Schematic illustrations of meandering and braided streams. In a meandering stream (top), point bars are areas of deposition and cutbanks are areas of erosion. When a meander neck is cut off, an oxbow lake forms. The thalweg is the deepest part of a channel. Braided streams (bottom) have many channels. Sediment is deposited in mid-channel bars and islands, as well as in point bars. Fort Union Trading Post National Historic Site is adjacent to a relatively straight section of the Missouri River that contains features of both braided and meandering systems. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

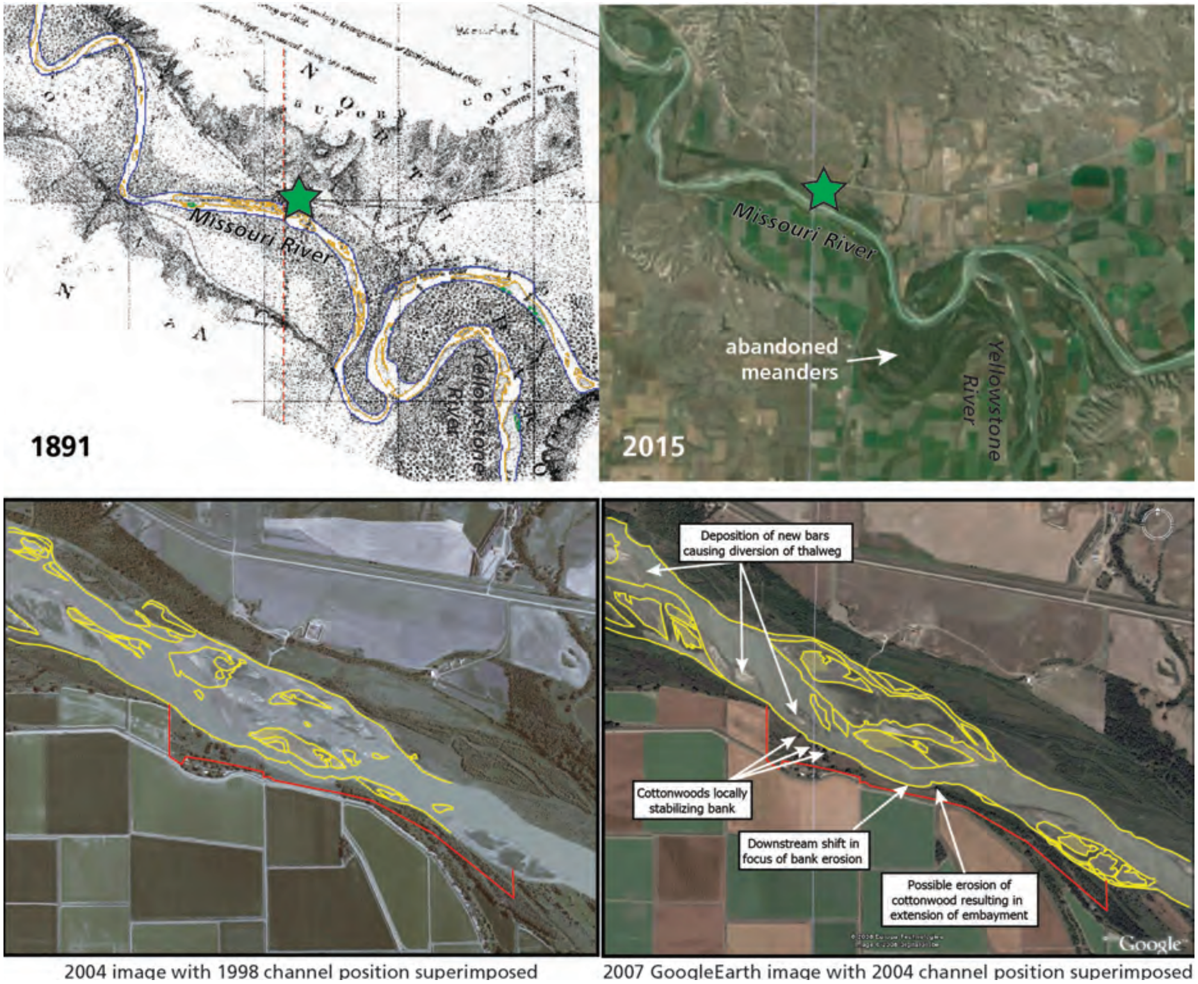

Figure 8. Illustration of the evolving Missouri River at Fort Union Trading Post National Historic Site. As illustrated in the top row, the confluence of the Missouri and Yellowstone rivers has moved to the east. Green stars indicate the location of Fort Union Trading Post National Historic Site. The bottom row illustrates the southward migration of the south bank of the Missouri within the Fort Union Trading Post National Historic Site boundary and the changes in channel features. The yellow polygons represent bars and islands in the years indicated. The solid yellow line represents the channel pattern of the year indicated. The solid red line marks the approximate boundary of the historic site. Annotated photographs from Ellis (2008, figure 4.2). A complete set of aerial photographs for the years 1939, 1949, 1958, 1966, 1980, 1983, 1995, 1998, and 2004 is available in Ellis (2005, figure 4.2).

sediment typically 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. 7). Cutbanks typically expose alluvial sediments (map unit **Qal**) that have been deposited on the floodplain or in previous channels. The channel's energy decreases on the inside of a meander loop, and sediment is deposited in a point bar (fig. 7).

Mid-channel islands and bars are common features in braided rivers (fig. 7). When the sediment load overwhelms the transport capacity of a braided stream channel, deposition occurs, causing bars and islands to form and the channel to shift.

Fort Union Trading Post National Historic Site is adjacent to a relatively straight section of the Missouri River that contains features of both braided and meandering systems (Ellis 2005). As to be expected with such a river, the morphology of the channel has changed over time (fig. 8). At Fort Union Trading Post National Historic Site, mid-stream bars have become attached to the north bank, forming lateral bars that have been stabilized by vegetation, and lateral migration to the south has resulted in south bank erosion (Ellis 2005, 2008). The channel may be switching from a predominately single channel (as in a meandering stream) to a multiple channel morphology (as in a braided stream), and new bars associated with an upstream point bar complex have been deposited farther into the channel and farther downstream (Ellis 2008). An increase in the number of channel bars has resulted in an increase in the number of bends in the river (increased sinuosity) and decreased the distance from one bend to the next.

The Yellowstone River also affects the Missouri River in the area of Fort Union Trading Post National Historic Site. In the spring of 1805, William Clark measured the Missouri and found it to be 300 m (990 ft) wide with a "deep" channel at the confluence with the Yellowstone (Ambrose 1996, p. 221). The Yellowstone River was 272 m (891 ft) wide but had a maximum depth of only 3.7 m (12 ft). From 1828 to 1867, the Missouri River channel was deep enough to allow steamships to dock below the bluff upon which Fort Union Trading Post was built. One reason Fort Union was abandoned in 1867 was because sandbars had formed along the Missouri's northern bank and boats could no longer dock below the bluff (Ellis 2005). Fort Buford, the then-newly built military post 5 km (3 mi) to the east, replaced Fort Union as the area's main trading post.

An 1891 cartographic survey shows the Missouri River's main channel flowing along the southern bank and sandbars built out beneath Fort Union (Ellis 2005). The survey also shows the Yellowstone River flowing through an exceptionally sinuous meander before entering the Missouri River. Sometime after 1891, the Yellowstone River cut through this meander and relocated the confluence approximately 3 km (2 mi) to the south. Flooding of the sediment-laden Yellowstone may cause the Missouri River to back up, which may subsequently affect the morphology of the river at Fort Union Trading Post National Historic Site (Ellis 2005). The dynamic processes associated with meandering and braided rivers have caused issues for resource managers at the site (see "Geologic Resource Management Issues" chapter).

The Missouri River also may be considered an "underfit" stream (Dury 1964). Underfit streams appear to be too small for the valley in which they flow. Glacial meltwater, flowing from the terminal margin of the last melting ice sheet, carved wide valleys in the area of Fort Union Trading Post National Historic Site. The Missouri River now flows through one of these valleys, but its stream is far less voluminous than the previous glacial meltwater channel.

Fort Union Formation Type Section and Stratigraphic Features

A type section is the reference standard against which exposures of similar strata in other locations may be compared and correlated. Type sections are typically selected for layers of sedimentary rocks that share similar characteristics, such as rock type (e.g., sandstone, shale, siltstone), color, or distinctive features (e.g., fossils). Rock strata so recognized are called a "formation." Geologists usually name formations after a geographic feature, such as a mountain, river, city, or, as in this case, a fort where the layers are best seen. Formations can be organized together into "groups" or subdivided into "members."

No single exposure serves as the type section for the Fort Union Formation. Rather, the initial detailed stratigraphic description of the Fort Union Formation came from a number of exposures in the Fort Union area that F. V. Hayden compiled in 1857 (Meek and Hayden 1862; Tweet et al. 2011). More than 700 stratigraphic sections of this unit have been studied and described in the region (Hartman 1988). In their database of formation names, the U.S. Geological Survey credits the name to "exposures at Old Fort Union," which they mistakenly state became Fort Buford (http://ngmdb.usgs.gov/Geolex/Units/FortUnion_8173.html, accessed 20 November 2014). Fort Buford, however, was constructed downstream from Fort Union in 1866, four years after the Fort Union Formation had been officially named (Meek and Hayden 1862).

Subsurface cores collected in the 20th century reveal a nearly complete stratigraphic section of the Fort Union Formation, which allowed for a detailed analysis of the Paleocene Epoch in North America (Hartman 1988). The stratigraphic features in the Tongue River (**Tftr**; Bullion Creek) and Sentinel Butte (**Tfsb**) members help define the depositional environments that existed in the region in the late Paleocene Epoch.

Tongue River Member

At the base of the bluffs in the Fort Union Trading Post National Historic Site region, cycles of sandstone, siltstone, and mudstone beds in the Fort Union

Figure 9. Photograph of the Tongue River Member of the Fort Union Formation. Sandstone, siltstone, and mudstone comprise the bluffs composed of the Tongue River Member just west of Fort Union in Montana. Photograph by Joseph Hartman (University of North Dakota).

Figure 10. Schematic illustration of depositional environments associated with a meandering stream. Crevasse splays, oxbow lakes, levees, and flood basins are associated with meandering rivers and contributed to the species diversity found in the Tongue River Member of the Fort Union Formation. Fossils were preserved in each of these settings. Graphic courtesy of Joseph Hartman (University of North Dakota).

Formation's older Tongue River Member (**Tftr**) suggest that sediments accumulated in a floodplain environment (fig. 9; Tibert 2001). The coarser sandstone beds mark old channels. When the channels were abandoned, finer-grained material (siltstone and clay) was deposited over the channel sand by floodwaters. Numerous lignite coal beds in the unit record the presence of swampy areas, and a rich species diversity of freshwater mollusks and other fossils have been found in lakes, floodbasins, and crevasse splays, which form when a stream breaks its levee and deposits sediment on a floodplain (fig. 10).

At the time the Tongue River Member was deposited, the Cannonball Sea, a remnant of the vast Western Interior Seaway that developed in the latest Cretaceous Period (see the "Geologic History" chapter), lay to the east in central North Dakota. Trace fossils, the brackish-water bivalve Corbula mactriformis, other molluscan species that reflect varying salinities, and foraminifera found in the Tongue River Member suggest that estuarine, marginal marine, and open marine conditions were locally present (Tibert et al. 2001; Hartman and Kirkland 2002).

Sentinel Butte Member

Fort Union Formation's younger Sentinel Butte Member (**Tfsb**) caps the bluffs in the far northeast corner of Fort Union Trading Post National Historic Site. Stratigraphic features in the Sentinel Butte Member include cross-bedded sandstone, rip-up clasts, and coal beds (fig. 11). Inclined beds of sandstone (cross-beds) indicate transportation of the original sand grains by wind or water. In the case of the Sentinel Butte Member, the size of the cross-beds and other features suggest that water produced the inclined beds of sand that filled the channel as it migrated across its floodplain. Rip-

Figure 11. Photograph of the Sentinel Butte Member of the Fort Union Formation. The lower part of the Sentinel Butte Member erodes into badlands topography. Photograph by Joseph Hartman (University of North Dakota).

up clasts are pieces of the underlying strata that have been literally ripped up from the surface. Rip-up clasts indicate a strong river current capable of scouring the channel bed. Coal beds form from the compaction and alteration of plants that were originally deposited in an anoxic environment, such as a marsh or bog that inhibited decomposition. These stratigraphic features in the Sentinel Butte Member are associated with river channels, floodplains, and swamps.

Bodmer Overlook and Surrounding Landscape

The cultural landscape of viewshed within and surrounding Fort Union Trading Post National Historic Site is a fundamental resource and value (National Park Service 2013). The Bodmer Overlook itself is considered an important resource for the historic site (National Park Service 2013). The rural landscape at the historic site provides a physical display and visual perspective of the habitat of the 1800s. North of the fort, Bodmer Overlook offers an excellent panoramic view of the bluffs (old alluvial terraces), surrounding prairie, and Missouri River floodplain (see cover). The 1.6 km (1 mi) trail at the overlook crosses alluvium and colluvium (**Qac**) and the Tongue River Member of the Fort Union Formation (**Tftr**) as it climbs to the summit of the Bodmer Overlook at an elevation of 616 m (2,020 ft) above sea level. From east to west, the panoramic view from the overlook spans the confluence of the Missouri and Yellowstone rivers to the Snowden Bridge, an historic 1913 structure that crosses the Missouri River near Mondak, the ghost town on the border of Montana and North Dakota that thrived from 1903 to 1919 (National Park Service 2013). When it was constructed, the Snowden Bridge was the longest (353 m [1,159 ft]) vertical-lift bridge in the world. The span of the bridge could be raised vertically, remaining parallel to the deck, to allow the occasional steamship to pass.

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). Body fossils are remains of an 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 July 2015, 260 parks, including Fort Union Trading Post National Historic Site had documented paleontological resources in at least one of these contexts. The NPS Geologic Resources Division Paleontology website (http://go.nps.gov/grd_paleo; accessed 15 June 2015) provides more information.

Figure 12. Photograph of the fossil freshwater snail *Melania tenuicarinata* (now considered a species of *Lioplacodes*). This snail was discovered by F. V. Hayden in the mid 1850s from at or near Fort Union Trading Post National Historic Site. National Park Service photograph by Vincent Santucci (NPS Geologic Resources Division) and Justin Tweet (NPS Geologic Resources Division).

As of 2011, fossils had yet to be documented from geologic units within Fort Union Trading Post National Historic Site (Tweet et al. 2011). However, researchers involved with the National Park Service paleontology synthesis project of 2012 discovered that in the mid 1850s, F. V. Hayden had collected the freshwater snail *Melania tenuicarinata*, now considered a species of *Lioplacodes* (fig. 12; Justin Tweet, NPS Geologic Resources Division, guest scientist, written communications, 28 October 2014 and 11 August 2015; see also Yen [1948] for taxonomic discussion). Previous specimens of *M. tenuicarinata* had been described from collections 5 km (3 mi) to 16 km (10 mi) from the fort, suggesting that Hayden's sample came near or within Fort Union Trading Post National Historic Site. Hayden probably collected the fossil from the Tongue River Member of the Fort Union Formation (Hartman 1984; Hartman and Kihm 1992, 1995).

In addition to fossil snails, petrified wood is commonly found in the Fort Union Formation. Recently, Fred MacVaugh, the museum curator at Fort Union Trading Post National Historic Site, found pieces of petrified wood at Bodmer Overlook (Fred MacVaugh, conference call, 7 October 2014). The off-white petrified wood is abundant in the Sentinel Butte Member (Joseph Hartman, University of North

Dakota, professor, written communication, 16 April 2015). At Theodore Roosevelt National Park, which is about 80 km (50 mi) southeast of the historic site, the Fort Union Formation preserves a "petrified forest" (Fastovsky and McSweeney 1991; Justin Tweet, NPS Geologic Resources Division, guest scientist, written communication, 28 October 2014; see GRI report by KellerLynn 2007).

In the Fort Union Trading Post National Historic Site region, fossil collecting for scientific study dates back to the fur trade. The St. Louis–based Chouteau family, who for decades operated the Western Department of the American Fur Company, played a significant role in collecting fossils and sending them back east for paleontologists to study. At the turn of the 19th century, they helped outfit the Lewis and Clark "Corps of Discovery" and provided valuable information about the Upper Missouri country (Chaky 1998). George Catlin was indebted to Pierre Chouteau, Jr. for his safe passage in 1832 to Fort Union, the new post at the confluence of the Yellowstone and Missouri rivers. Catlin, an amateur naturalist and well-known painter of scenes of the American West, collected fossils along with Indian artifacts, minerals, and other items, and stored them in St. Louis (Chaky 1998).

Pierre also befriended Prince Maximilian of Weid, who noted abundant shells in limestone beds near Fort Leavenworth and recognized the remains of a Mosasaurus that the Atkinson-O'Fallon Expedition to the Yellowstone River had noted in 1825 (Chaky 1998). Unfortunately, Maximilian's collections were lost when the steamer *Assiniboine* sank in 1835 near present-day Bismarck, North Dakota.

Fossils collected from the Upper Missouri River area continued to find their way to the American Fur Company in St. Louis. French explorer Joseph Nicollet reported on abundant marine fossils to his report to Congress in 1843, and the discovery by St. Louis physician Dr. Hiram A. Prout of a jawbone of a large titanothere in the White River badlands drew the interest of Dr. Joseph Leidy of the Academy of Natural Sciences of Philadelphia (Tweet et al. 2011 [see Badlands National Park section]; Chaky 1998).

When Maximilian traveled upriver in 1833, he was accompanied by Alexander Culbertson, a young man who had been hired to manage Fort Union for the American Fur Company. In 1843, Culbertson provided free passage and hospitality to John James Audubon (Chaky 1998). Audubon and his colleague Edward Harris collected fossils near the confluence of the Missouri and Yellowstone rivers. These were the first fossils scientifically collected in the vicinity of Fort Union and the first fossils collected from the American West (Hartman 1999; Tweet et al. 2011).

Culbertson accompanied Audubon to Fort Pierre in August 1843 and then continued overland to Fort Laramie. On the trail, Culberson and his traveling companion, Army Captain Stewart Van Vliet, collected fossils that Dr. Leidy would describe in two papers published in 1848. These fossils, and others collected by his brother Thaddeus in 1850, would result in intense fossil collection in the vicinity of present-day Badlands National Park (Tweet et al. 2011; see GRI report by Graham 2008).

Interest in Upper Missouri River fossils continued to grow. In 1853, much to the consternation of John Evans and Benjamin Franklin Shumard, famous geologist James Hall of Albany, New York, sent geologists Ferdinand V. Hayden and F. B. Meek to collect fossils in the White River Badlands. Evans and Shumard objected strenuously to sharing the badlands with Hayden and Meek. St. Louis scientist George Englemann and famed geologist Louis Agassiz mediated the dispute and convinced the two groups that the badlands held enough fossils for both parties (Chaky 1998; Hartman 1999).

In 1854, Hayden quit his job with Hall and returned to the West. For years he collected fossils in the Upper Missouri country. A large part of his collection was stored in the home of Pierre Chouteau, Jr.'s son, Charles (Chaky 1998). Fossil mollusks collected by F. V. Hayden and F. B. Meek between 1855 and 1860 became the "classic" Fort Union freshwater mollusk fauna (Hartman and Kihm 1992).

Fossils of the Tongue River Member (Bullion Creek Formation)

The classic nonmarine freshwater mollusks collected by Meek and Hayden have since been determined to come from the upper Tongue River Member (**Tftr**; Bullion Creek Formation) and lower Sentinel Butte Member (**Tfsb**; Sentinel Butte Formation) of the Fort Union Formation (Hartman 1994, 1999, 2004; Kihm et al. 2004). Some of Hayden's fossils may have come from exposures at or very near Fort Union Trading Post

National Historic Site.

The Tongue River Member is extremely fossiliferous, containing a diverse assemblage of invertebrate, vertebrate, and plant fossils (table 1). More than 100 taxa of fossil plants have been documented from the Wannagan Creek Quarry from the upper part of the member (Bullion Creek Formation; Erickson 1982, 1999). The petrified wood at Bodmer Overlook may be from this unit. The unit also contains abundant terrestrial mollusks (Hartman and Kihm 1992, 1995; Hartman 1999) and other invertebrates, as well as vertebrates and microfossils.

The flora and fauna record a depositional setting consisting of a low-relief coastal plain with rivers, lakes, ponds, swamps, and rainforests (Hoganson and Murphy 2003). The freshwater molluscan fauna described by Meek and Hayden is confined to strata that overlie the marine Cannonball Member of the Fort Union Formation. These strata include the Tongue River and lower part of the Sentinel Butte members, which represent the late Paleocene Epoch of North America (Hartman and Kihm 1995; Hartman 2004; see "Geologic History" chapter).

Fossils of the Sentinel Butte Member (Sentinel Butte Formation)

The upper Paleocene Sentinel Butte Member (**Tfsb**) is lithologically similar to the Tongue River Member (**Tftr**), but clay content and channel-forms provide differences in unit color and landscape character. Lignite coal is found in both units, and reddish baked sediments resulting from spontaneously burned coal adds highlights to many viewsheds. In addition, both members contain a similar overall fossil assemblage (table 1; Tweet et al. 2011). The Sentinel Butte Member includes plant macrofossils and microfossils and freshwater and terrestrial gastropods and freshwater bivalves, along with invertebrate trace fossils. Vertebrate fossils are rare (Harrington et al. 2005), but microfossils and the largest mammal that lived during the Paleocene Epoch in North Dakota, Titanoides primaevus, was described from strata not far from the historic site (Hartman and Kihm 1991). The ecosystem in which these organisms lived consisted of more floodplain and fewer marsh environments than the Tongue River (Bullion Creek) ecosystem (Royse 1972; Daly et al. 1985; Clechenko et al. 2007).

Fossils of the Oahe Formation

The Quaternary Oahe Formation (**Qal**, **Qac**, **Qat**) encompasses all post-glacial deposits in the region of the historic site (Artz 1995). Fossils are rare in the formation, but the unit does contain charcoal, burrows, and vertebrate and invertebrate remains, such as bison bones (Clayton et al. 1976).

The fossils of the Oahe Formation fall into one of two general categories: (1) Pleistocene megafauna, and (2) Holocene paleoenvironmental materials (Tweet et al. 2011). Extinct horses, ground sloths, mastodons, mammoths, and giant bison are among the Pleistocene megafauna. Pleistocene megafauna have been found near Watford City, 59 km (37 mi) southeast of the historic site, and on the shore of Lake Sakakawea, approximately 75 km (47 mi) southeast of Fort Union Trading Post National Historic Site (Tweet et al. 2011). A woolly mammoth molar recovered from the shoreline of glacial Lake Agassiz in western Cass County, North Dakota, (on the other side of the state from Fort Union Trading Post) suggests that the region consisted of tundra-like conditions about 11,500 years ago (Harrington and Ashworth 1986). Holocene paleoenvironmental fossils consist of pollen, spores, aquatic microfossils, and other material that provides clues about past climatic condisions (Hoganson and Murphy 2003).

Both categories of fossils are scarce, especially in the northern Great Plains. Because rivers have flowed through the region, less dense material is more likely to have been transported out of the area than large Quaternary fossils, such as petrified logs, mammoth teeth, or bison bones. The latter would have been transported only by high velocity flood waters.

Fossils and Cultural Resources

Knife River Flint is an example of a paleontological resource that is found in cultural settings (fig. 6). The brown, fine-grained flint formed between 50 million and 20 million years ago, although its exact age has not been determined (Clayton et al. 1970; Hoganson and Murphy 2003). It now occurs in all of the Quaternary units (**Qal**, **Qac**, **Qat**, and **Qgt**) in the historic site as a result of human use and transport. The flint was traded throughout North America in the 19th century.

Knife River Flint consists of silicified peat, which is composed of fossil plants from ponds, swamps, and

Table 1. Paleontological resources of the Fort Union Formation.

Fossils	Tongue River Member (Bullion Creek Formation) (Tftr)	Sentinel Butte Member (Sentinel Butte Formation) (Tfsb)
Invertebrates	Bivalves (freshwater) Gastropods (freshwater and terrestrial) Insects (beetles, butterflies, moths, dragonflies, damselflies) Ostracodes Arthropod trace fossils on plants Crustacean and worm burrows	Bivalves (freshwater) Gastropods (freshwater and terrestrial) Ostracodes Beetles Trace fossils
Flora	Petrified wood Water ferns Water lilies Dawn redwood Bald cypress Katsura Palms Palmettos Plane trees Magnolia	Silicified peat Roots, stumps, petrified wood fruits, leaves and other plant macrofossils
Vertebrates	Freshwater sharks Freshwater ray *Myliobatis* Bony fish (including the gar *Lepisosteus*, bowfin *Amia*, pike *Esox*, osteoglossiforms, and long-snouted *Belonostomus*) Giant salamander *Piceoerpeton* and *Scapherpeton* Frogs Turtles (snappers, pond tortoises, soft-shelled turtles) Lizards Snakes Small alligator (*Wannaganosuchus*) Birds (*Dakotornis*, *Presbyornis*) Diverse assemblage of early mammals (rodent-like arboreal forms, marsupials, early primate relatives, carnivorans) Tracks of lizards, crocodilians, birds Coprolites (fossil feces) mostly attributed to *Borealosuchus*	Rare vertebrate fossils: Fish Giant salamanders Turtles Champsosaurs Crocodilians Multituberculates Marsupials Primate relatives Pantodont *Titanoides primaevus*
Microfossils	Foraminifera (protists that secrete shells) Diatoms (algae that secrete silica shells) Spores Pollen	Fungal spores Pollen

Compiled from information in Tweet et al. (2011).

marshes. In these environments, anaerobic conditions would have decreased the rate of decomposition of organic material, allowing peat or lignite coal to form. Percolation of silica-rich groundwater altered the peat or lignite and produced the Knife River Flint.

Other fossils, such as shells, may also be found in archeological sites at the historic site, as they are at Knife River Indian Villages National Historic Site (Hoganson and Murphy 2003; see GRI report by Graham 2015 [in review]). American Indian tribes, including the Crow, Hidatsa, Mandan, and Sioux are known to have collected fossils, some of which were used for tools and jewelry (Hoganson and Murphy 2003; Mayor 2005). An overview of fossils in the National Park System in cultural resource contexts is presented by Kenworthy and Santucci (2006).

Glacial Features

Repeated glaciations (ice ages) during the Pleistocene Epoch (2.58 million to 11,700 years ago) scoured and reshaped the landscape of North Dakota and eastern Montana, including the area of present-day Fort Union Trading Post National Historic Site. Glacial features in the historic site fall into two major categories: (1) those created or carved by glaciers, and (2) those deposited by rivers flowing beneath or out of glaciers ("glaciofluvial") or deposited in lakes near glaciers ("glaciolacustrine").

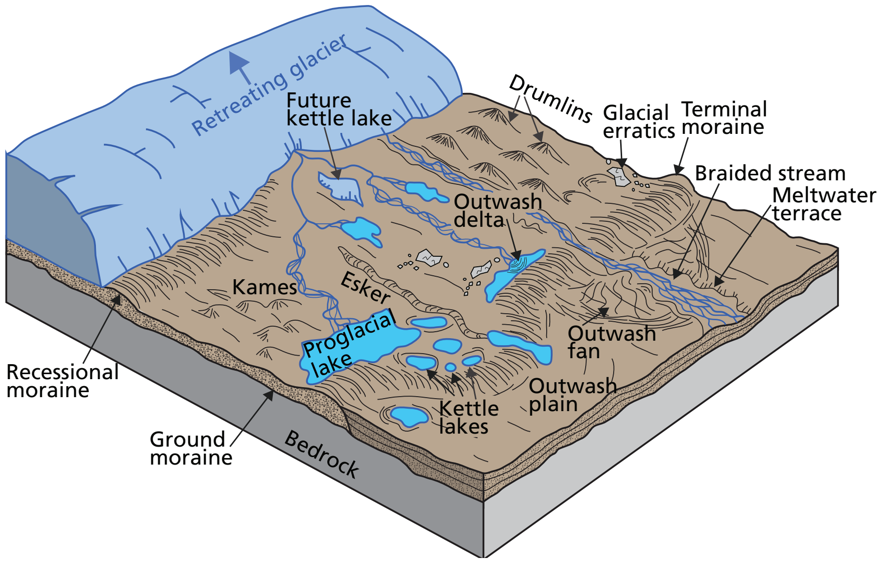

Figure 13. Schematic illustration of glacial features associated with continental ice sheets. Till and meltwater sediments are present in Fort Union Trading Post National Historic Site, and glacial erratics were used as building stone. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

Deposits and features that are the direct result of glacial ice moving across the landscape include till (**Qgt**), moraines, drumlins, kettles, glacial grooves, striations, roches moutonnées, and glacial erratics (fig. 13). Glaciofluvial or glaciolacustrine deposits and features include kames, eskers, and braided streams, as well as outwash fans, deltas, or plains (fig. 13). Many of these features occur throughout North Dakota and Montana, but not all of them are present in the historic site.

Fort Union Trading Post National Historical Site is approximately 80 km (50 miles) north of the terminal margin of the last major glacial ice sheet that flowed into North Dakota and Montana during the Pleistocene Epoch. North of the historic site, the topography reflects a glaciated landscape, including moraines and deposits associated with the margin of the retreating ice sheet. As the ice sheet melted, abundant quantities of meltwater flowed down a broad valley that would eventually contain the channel of the Missouri River. Some of the coarse sand and gravel in the alluvium and colluvium (**Qac**) in the historic site represent glacial outwash deposits. The coarse deposits that settled out of these braided meltwater channels indicate a close proximity to the glacial terminus (Thornberry-Ehrlich 2012).

Aeolian Features

Strong winds that blow across North Dakota generate local landscape features known as blowouts. To form a blowout, the wind removes fine-grained sediments and leaves behind a depression floored by coarse-grained material too heavy for aeolian transport. Blowouts often occur on hilltops, such as the Bodmer Overlook, or next to large glacial erratics (boulders). In the past, bison would rub against these large boulders, removing the vegetation from the base of the erratic and exposing the fine sediment to the wind. Fossils (such as petrified wood) and resistant material (such as Knife River Flint) are commonly associated with blowouts (Thornberry-Ehrlich 2012). Blowouts are often found on hillslopes or hilltops, such as the Bodmer Overlook.

Volcanic Ash Layers

In the Sentinel Butte Member (**Tfsb**), layers of volcanic ash have been altered to bentonite, a type of clay that has a crystalline structure which accepts water molecules, so it swells when it becomes wet and shrinks when it dries out. This shrink-swell property makes the clay particularly slippery when wet and may compromise the integrity of roads and trails. It also creates a popcorn-like texture on exposed surfaces, typical of badlands topography. Bentonite occurs in the vicinity of Fort Union Trading Post National Historic Site, but it does not occur within the boundary of the historic site (conference call participants, 7 October 2014).

In addition, volcanic ash was deposited over the historic site as a result of the 1980 eruption of Mount St. Helens. The eruption spread volcanic ash as much as 1.3 cm (0.5 in) thick across North Dakota.

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 Fort Union Trading Post National Historic Site. The NPS Geologic Resources Division provides technical and policy assistance for these issues.

During the 2011 scoping meeting (see Thornberry-Ehrlich 2012) and 2014 conference call, participants (see Appendix A) identified the following geologic resource management issues:

- Impacts from the Construction of Fort Peck Dam
- Missouri River Bank Erosion
- Flooding
- Current and Potential Oil and Gas Development
- Slope Movements
- Earthquakes
- Abandoned Mineral Lands
- Paleontological Resources Inventory and Monitoring

Resource managers may find *Geological Monitoring* (Young and Norby (2009) useful for addressing some of these geologic resource management issues. An online version of *Geological Monitoring* is available at http://go.nps.gov/geomonitoring (accessed 16 June 2015). 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 from the Construction of Fort Peck Dam

Installation of the Fort Peck Dam across the Missouri River has caused significant impacts to downstream sections of the river (Ellis 2005). The dam captures all upstream sediment, allowing stream power to increase below the dam (Geologic Resources Division 2012). Increased stream power has led to increased erosion (degradation) below the dam and subsequent downstream sedimentation (aggradation) in parts of the river where sediment load and channel velocity were previously at equilibrium.

As a result of the dam, peak flows have decreased, but average discharges have increased. The dam also has changed the timing of seasonal flows. Winter flows that once occurred between April and July now occur in February and March. This change may enhance the erosive power of river ice and create backwater effects from late spring flooding on the Yellowstone River. In addition, sinuosity has intensified, and flow has become concentrated in a single channel. At Fort Union Trading Post National Historic Site, this has resulted in the attachment of channel bars to the north bank and the diversion of flow towards the south bank (fig. 8; Ellis 2005).

The construction of Fort Peck Dam also has had adverse consequences to the Missouri River ecosystem. Lack of seasonal flooding limits the amount of sediment in the river and the transportation of seeds and nutrients. Pioneer communities of cottonwood (*Populus deltoids*) and willow (*Salix hindsiana*) have decreased because they require periodic inundation by floodwaters to become established. Roots from these trees help stabilize river banks. At Fort Union Trading Post National Historic Site, cottonwoods have locally stabilized the south bank, but erosion has increased where cottonwoods have been lost (fig. 8; Ellis 2008).

The altered velocity, temperature, turbidity, nutrient concentrations, and trophic pathways of the river have also destroyed the habitat of many fish, aquatic insects, and mussel species that had adapted to pre-dam conditions (Ellis 2005). Water temperature in the river has decreased by as much as 12°C (10°F) because of water storage in the dam (Hoganson and Murphy 2003).

The upstream Fort Peck Dam and downstream Garrison Dam, which impounded Lake Sakakawea, altered the natural flow and processes of the Missouri River. Because the Missouri River is a fundamental resource in the historic site, resource managers are concerned that the altered river system, including regulated flow and bank erosion, will negatively impact visitor understanding and enjoyment (National Park Service 2013).

For Fort Union Trading Post National Historic Site, the most damaging impact from the Fort Peck Dam is increased erosion of alluvium (**Qal**) from the Missouri River's south bank. Erosion may degrade archeological sites as well as alter the river channel, which could lead to further loss of land and an eventual breach of the historic site's southern boundary.

Missouri River Bank Erosion

Monitoring data suggest that bank erosion occurs episodically and catastrophically along the Missouri River—a fundamental resource (National Park Service 2013)—in Fort Union Trading Post National Historic Site. Changes in precipitation, which influences bank saturation levels, river ice (see "River Ice" section), tension cracks, properties of bank sediments, and vegetation may trigger bank failure. According to Ellis (2008), increased saturation appears to be the main triggering mechanism for slope failure, which occurs along tension cracks (fig. 14). The failed slopes create a berm at the bank toe, but this berm does not prevent further slope failure.

Figure 14. Photograph of the south bank of the Missouri River. Deep tension cracks (dashed red line) have developed approximately 2 m (7 ft) from the bank's edge. Ultimately, bank failure will occur along this tension crack. National Park Service photograph taken on 9 March 2007 shortly before ice-out. Photograph from Ellis (2008, figure 4.3).

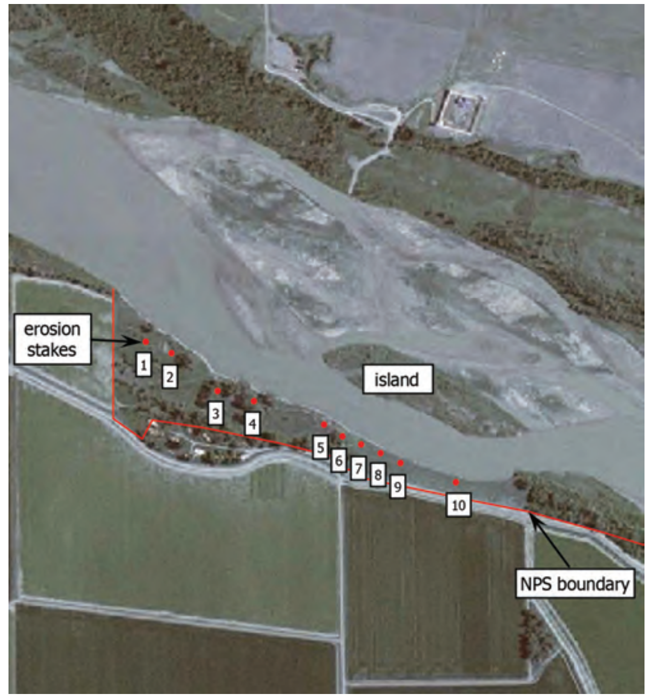

Figure 15. Map of erosion monitoring stakes along the south bank of the Missouri River. Staff at Fort Union Trading Post National Historic Site began monitoring bank erosion in 2000. Red dots indicate the locations of monitoring states. These are superimposed on a 2004 aerial photograph. The red line marks the south and west boundaries of Fort Union Trading Post National Historic Site. Extracted from Ellis (2005, figure 4.4).

Staff at Fort Union Trading Post National Historic Site has been monitoring the south bank's erosion since 2000 using monitoring stakes. The initial five stakes placed 15 m (50 ft) from the bank in 2000 were replaced with new stakes by 2005, which were placed 15 m (50 ft) farther from the original stakes (fig. 15; Ellis 2005, 2008). Researcher Lucy Ellis recommended that historic site staff also install an off-set stake from which to measure a consistent angle to the bank (Andy Banta, Fort Union Trading Post National Historic Site, superintendent, written communication, 12 February 2015).

According to Ellis (2008), the following periods of significant erosion occurred along the south bank prior to 2008, with erosion shifting downstream following each event:

- From September to December 2002, the bank between stakes 2 and 6 retreated an average of 4.6 m (15 ft) because of a rapid rise in water level.

- Between July 2003 and March 2004, the bank retreated an average of 4.3 m (14 ft) between stakes 5 and 9 because of a rapid fall in discharge from the dam.
- In March 2007, the same section of river bank (between stakes 6 and 9) once again retreated an average of 4.3 m (14 ft) because of rapid drawdown (described below).
- In addition, an unusual amount of erosion occurred at stake 8 from October 2005 to April 2006. During these months, 8.5 m (28 ft) of the south bank fell into the river.

During floods, water enters the bank and the hydrostatic pressure increases bank stability. When the river stage falls, water is expelled and this drawdown decreases pore pressure and the banks may fail. Rapid drawdown may also be caused by a rapid fall in discharge from the dam.

The average rate of erosion between stakes 6 to 11 is nearly 6 m (20 ft) per year. In 2008, the irrigation ditch in figure 16 was 40 m (130 ft) from the bank, and the south bank was expected to reach the ditch by 2015 (Ellis 2008). As Ellis (2008) pointed out, however, little confidence can be placed in these types of estimations because the Missouri River is a dynamic system with many variables, so flow and effects are difficult to predict. As of 24 November 2014, the Missouri River was within 8.2 m (27 ft) of the irrigation ditch and is now expected to reach the ditch by 2020 (Andy Banta, written communication, 24 November 2014).

Global climate change predicts a rise in precipitation in the northern Great Plains, which will subsequently increase bank saturation (Karl et al. 2009; Intergovernmental Panel on Climate Change [IPCC] 2014; Melillo et al. 2014). In the Fort Union Trading Post National Historic Site area, the annual average precipitation is projected to increase by 11% by the end of the century (IPCC 2007). The increase would be from 36.5 cm (14.4 in), which is the annual average precipitation from 1981 to 2010, to 40.5 cm (15.9 in) by 2100 CE (NOAA Satellite and Information Service 2011). In addition to changes in average conditions, extreme events such as intense storms, floods, and periodic drought will multiply and impact historic site resources (National Park Service 2014b). Very heavy precipitation in the upper Great Plains increased by 16% from 1958 to 2012, and the frequency of extreme daily precipitation events is projected to rise (Melillo et al. 2014).

In an attempt to keep open the nearby intake of the Buford-Trenton Irrigation District by shifting the thalweg away from the south bank and toward the north bank, the US Army Corps of Engineers installed bendway weirs downstream from Fort Union Trading Post National Historic Site in 1998 (fig. 16; Ellis 2005). A bendway weir is a rock sill that is placed at a bend in a river. It is angled from 20° to 30° upstream, redirects the thalweg away from the bank, and helps control current velocity. The US Army Corps of Engineers also expected the weirs to decrease erosion in the historic site. Unfortunately, the weirs were located too far downstream to prevent bank erosion in Fort Union Trading Post National Historic Site (Ellis 2005).

Because high bank saturation triggers bank failure, any bank protection design should include drainage control measures that would reduce pore-water pressure. Ellis (2008) recommended two sets of monitoring wells to be drilled to measure the hydraulic conductivity (the ease with which water moves through rock or sediment) between the irrigation ditch and the bank. In 2010, the NPS Water Resources Division drilled three monitoring wells perpendicular to the bank between stakes 7 and 8 and two wells between stakes 10 and 11 (Inglis 2010).

Ellis (2005, 2008) recommended continued monitoring of bank erosion by NPS staff and documentation of the date and location of bank failures. Because erosion may threaten the irrigation ditch, Ellis (2005, 2008) also recommended development of a Fort Union Trading Post National Historic Site Missouri River management plan that would include bank protection measures. As of November 2014, a river management plan had not been developed for the historic site (Andy Banta, written communication, 24 November 2014).

River Ice

Ice break-up ("ice-out") in the spring has the potential to trigger erosion of floodplain alluvium (**Qal**). Except for the wet spring of 2007, however, large amounts of erosion do not appear to be associated with ice break-up at Fort Union Trading Post National Historic Site (Ellis 2005, 2008).

Ice break-up is episodic, depending on the formation of ice jams. Ice jams may cause abrupt changes in river levels. Water accumulating behind ice jams may overtop

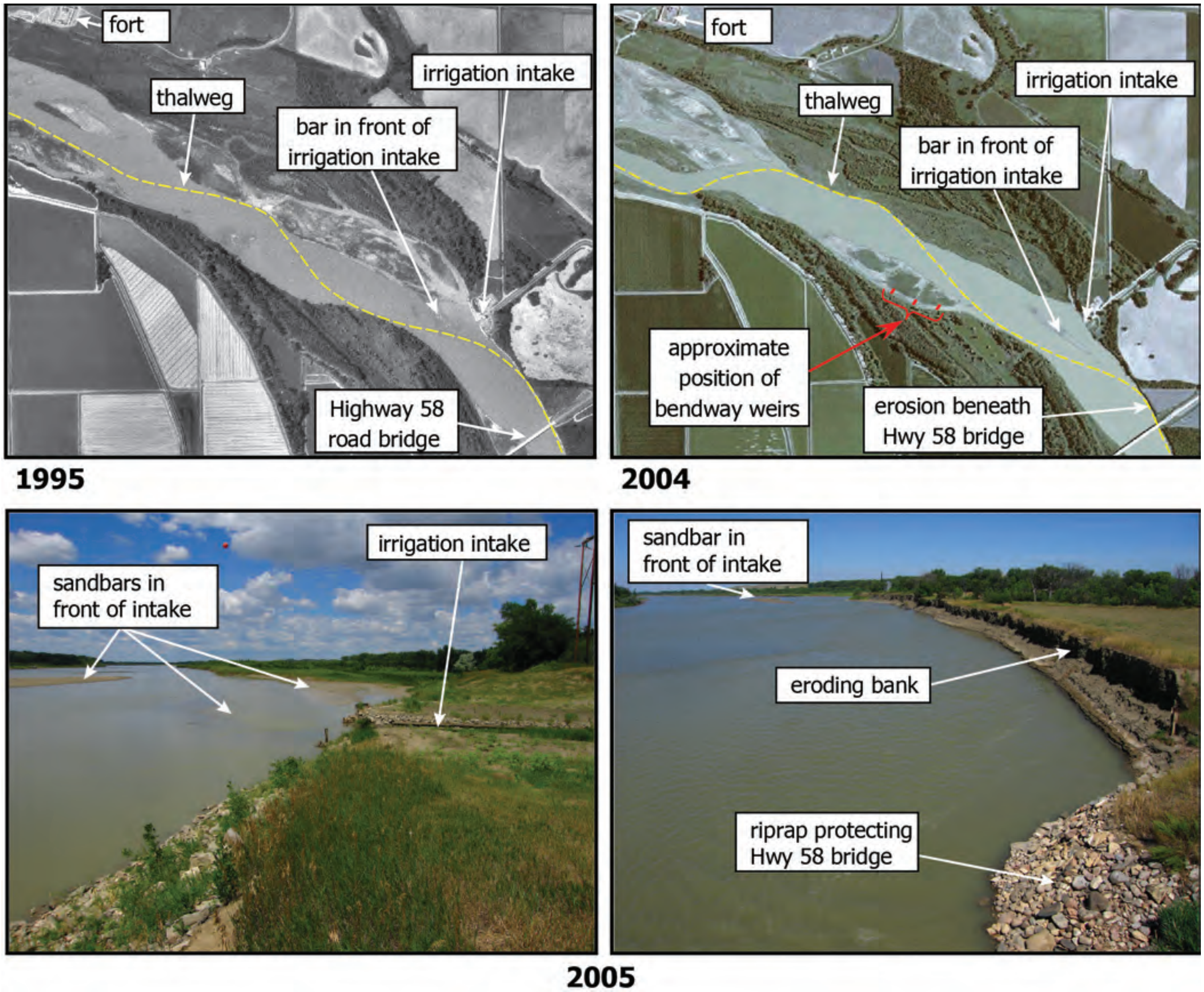

Figure 16. Photographs showing morphological impacts of bendway weirs. Installation of bendway weirs in 1998 resulted in the development of mid-channel bars in front of the Buford-Trenton irrigation intake. Photographs from Ellis (2005, figure 4.7).

the river banks. When the ice jams break apart, ice may scour the banks (Simon et al. 1999). Total ice-out occurs near the end of March (Ellis 2008). Ice thickness, which is a factor in bank erosion, is variable. In 2007, the ice was relatively thin, but in some years, it is several feet thick (Ellis 2008). In 2014, ice levels were high on the bank, but no significant damage occurred (Andy Banta, conference call, 7 October 2014).

Flooding

Fort Peck Dam regulates the flow of the Missouri River so that flooding has become less of a significant issue for Fort Union Trading Post National Historic Site, except in extreme flow years such as 2011. In extremely wet years, the tributaries below Fort Peck Dam contribute significant amounts of additional water (Andy Banta, written communication, 12 February 2015). In 2011, Montana recorded its all-time wettest spring, and North Dakota almost set a state record. The exceptionally snowy winter and spring flooded the Missouri River floodplain (National Park Service 2011). Major flood stage on the Missouri River near the historic site is 7.9 m (26 ft), and by 18 June 2011, the river had risen to 9.29 m (30.48 ft). Floodwaters inundated the Lewis and Clark Trail and the small, lower parking lot, as well as breached the south bank, sending floodwaters over the floodplain alluvium (**Qal**) (fig. 17). The river stayed high until August. Flooding on the undammed

Figure 17. Photograph of flooding at Fort Union Trading Post National Historic Site in 2011. Floodwaters inundated the Lewis and Clark Trail on the north side of the Missouri River. National Park Service photograph by Andy Banta (Fort Union Trading Post National Historic Site).

Yellowstone River may also back up into the Missouri River floodplain.

Global climate change is expected to increase the frequency of exceptionally wet springs and produce more flooding in the northern Great Plains (IPCC 2014; Melillo et al. 2014). In addition to an increase in precipitation, snowmelt is expected to begin earlier in the spring (Karl et al. 2009; IPCC 2014; Melillo et al. 2014). Heightened precipitation and flooding will influence sedimentation rates, cutbank erosion, and channel bars and islands. Severe flood events may not only inundate the lower parking lot, but also impact other infrastructure, such as low-lying park housing and maintenance facilities (Geologic Resources Division 2012). The fort, however, was built on a bluff (old river terrace), a site selected to minimize flood damage.

Current and Potential Oil and Gas Development

The historic site lies near the center of the extensive Williston Basin. The basin includes western North Dakota and parts of South Dakota, Montana, and Canada (fig. 18). The basin covers about 780,000 km^2 (300,000 mi^2), an area significantly larger than Texas. As of 2014, hydrocarbons produced from the Williston Basin made North Dakota the second largest oil-producing state in the country behind Texas.

Extensive oil and gas development in the Upper Devonian–Lower Mississippian Bakken Formation is

Figure 18. Map showing the extent of the Williston Basin. The Williston Basin (purple) extends from the Dakotas in the United States into Saskatchewan and Alberta in Canada. The green star indicates the location of Fort Union Trading Post National Historic Site. The graphic also shows part of the Great Plains province of the United States (orange) and the approximate southern limit of the ice age continental glaciers (blue line). Map graphic by Trista Thornberry-Ehrlich (Colorado State University), with basemap by Tom Patterson (National Park Service), available online: http://www.shadedrelief.com/physical/index.html (accessed 5 January 2015).

driving the current boom in the Williston Basin (fig. 19). The formation, which is widespread in the central and deeper parts of the basin, consists of three informal members: (1) lower shale member, (2) middle sandstone member, and (3) upper shale member (fig. 19). The shale members contain abundant organic matter (as much as 35% by weight), and although the formation is only as much as 49 m (160 ft) thick, it contains a tremendous amount of recoverable hydrocarbons (Bohrer et al. 2008; Pollastro et al. 2008, 2011). The geographic extent of Bakken Formation organic matter that has thermally matured into oil includes Fort Union Trading Post National Historic Site (fig. 20; Pollastro et al. 2008, 2011).

System	Rock Unit	
Quaternary	Pleistocene and Holocene	
Paleogene and Neogene (Teriary)	White River, Golden Valley, and Fort Union Group	
Cretaceous	Hell Creek	
	Fox HIlls	
	Pierre	
	Judith River	
	Pierre	
	Eagle	
	Pierre	
	Niobrara, Carlile, Belle Forche, Mowry, Newcastle, Skull Creek, and Inyan Kara	
Jurassic	Swift, Rierdon, and Piper	
Triassic	Spearfish	
Permian	Minnekahta and Opeche	
	Broom Creek	
Pennsylvanian	Amsden	
	Tyler	
Mississippian	Otter	
	Kibby	
	Madison Group	Charles
		Mission Canyon
		Lodgepole
	Bakken Formation	Upper shale
		Middle sandstone
Devonian		Lower shale
	Three Forks	
	Birdbear	
	Duperow	
	Souris River	
	Dawson Bay	
	Prairie	
	Winnipegosis	
	Ashern	
Silurian	Interlake	
	Stonewall	
Ordovician	Stony Mountain	
	Red River	
	Winnipeg Group	
Cambrian	Deadwood	
Proterozoic (Precambrian)		

Figure 19. Generalized stratigraphic column for the Williston Basin. Geologic formations shown in green produce oil; yellow units produce gas. The Cretaceous, gas-producing Judith River and Eagle formations "intertongue" in part with the Pierre Shale. Source: North Dakota Geologic Survey available online: https://www.dmr.nd.gov/ndgs/Resources/ (accessed 15 September 2014).

The Bakken Formation shale units are the principal source rocks in the hydrocarbon reservoir known as the Bakken-Lodgepole Total Petroleum System (TPS). This continuous reservoir includes a porous sandstone unit in the underlying Upper Devonian Three Forks Formation (the Sanish sand) and porous strata in the overlying Lower Mississippian Lodgepole Limestone Formation (fig. 19). 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 the energy boom in the Bakken Formation. Fracking involves the injection of water, sand, and chemicals at high pressure into horizontally drilled wells, which may extend as far as 3,000 m (10,000 ft) below the surface (fig. 21). The pressurized mixture opens gaps and cracks in the shale. These cracks are held open by the sand particles, known as proppant, so that hydrocarbons can flow into the wellbore. Recovered water is stored 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 freshwater that may be useful for farming or public consumption from the fractured shale.

The Bakken Formation is not the only Paleozoic Era unit that contains oil and gas in the Williston Basin (fig. 19). In the Buford Field, approximately 3 km (2 mi) east of the historic site, one well produces from the Ordovician Period Red River Formation, and nine wells produce from the Mississippian Period Madison Formation (fig. 19; Geologic Resources Division 2006).

Approximately 2,000 wells are producing oil and gas in the area adjacent to Fort Union Trading Post National Historic Site (fig. 22). The historic site is about 40 km

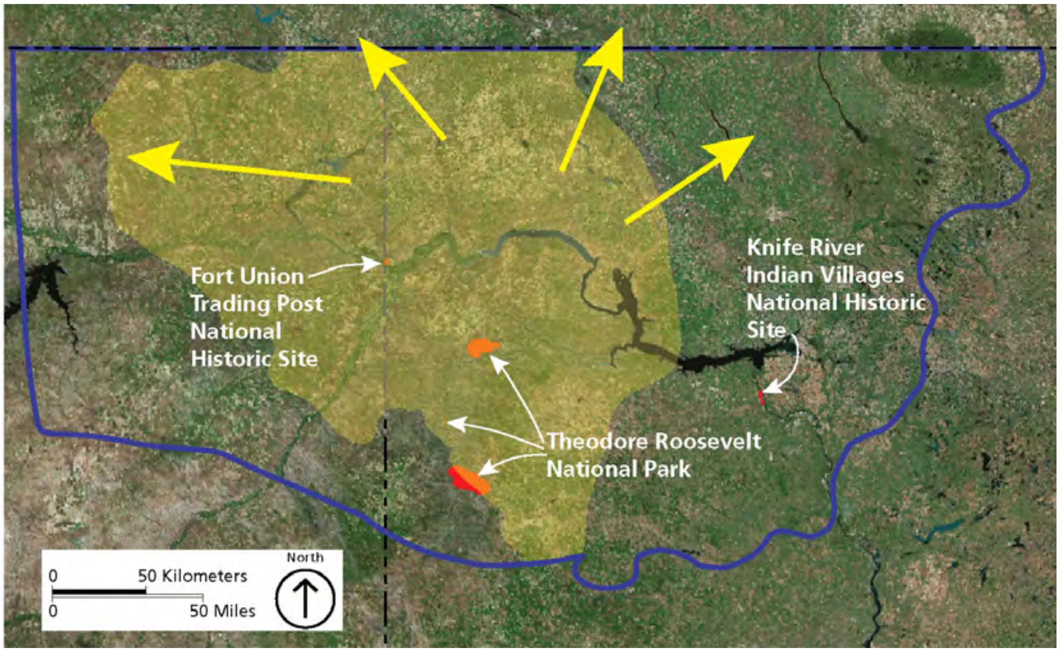

Figure 20. Geographic extent of the thermally mature shale member of the Bakken Formation (yellow). The blue line indicates the boundary of the Bakken-Lodgepole Total Petroleum System (TPS). Three NPS areas in North Dakota are labelled. Yellow arrows mark the probable oil migration pathways in the Williston 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).

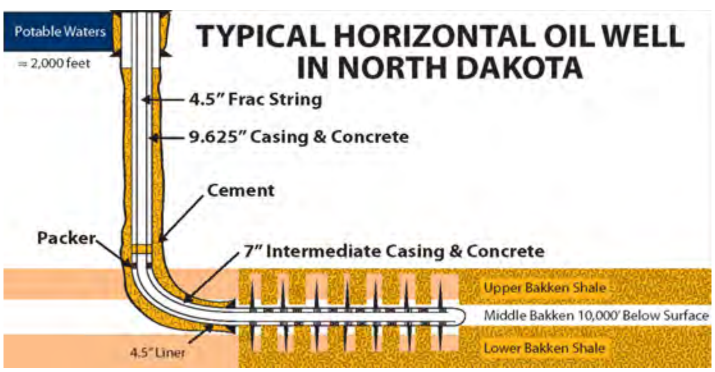

Figure 21. Schematic illustration of hydraulic fracturing. Although fracking processes occur thousands of feet below potable water sources, many safety measures are used to protect groundwater from contamination. North Dakota State Water Commission diagram available online: http://www.swc.nd.gov/4dlink9/4dcgi/getcontentpdf/pb-2419/fact%20sheet.pdf (accessed 17 November 2014).

(25 mi) southwest of Williston, North Dakota, the cultural hub of the Williston Basin (Thornberry-Ehrlich 2012). Gas flares from a producing well 1 km (0.5 mi) east of the historic site are visible from within the historic site (Geologic Resources Division 2012). In fall 2011, drilling operations occurred 1.6 km (1 mi) north of the historic site and within 1.6 km (1 mi) west of the historic site (Thornberry-Ehrlich 2012). All these operations are within North Dakota. The Nohly Field, 3 km (2 mi) southwest of the historic site, has the closest oil production within Montana. Twelve of the wells in the field produce oil from the Madison, Nisku, and Red River formations (fig. 20). Another 20,000 Bakken Formation exploratory wells are proposed, including a horizontal well adjacent to the historic site boundary (Thornberry-Ehrlich 2012). Much more drilling is occurring farther to the west in Richland County, Montana (Andy Banta, conference call, 7 October 2014). Richland County produces more oil and gas than any other county in Montana (Montana Board of Oil and Gas 2014). As of 7 October 2014, no hydrocarbon wells in Richland County had been drilled within 11 km (7 mi) of the historic site (North Dakota Industrial Commission 2014).

Although the United States owns nearly all of the surface rights within the boundary of Fort Union Trading Post National Historic Site, it does not own any of the subsurface mineral rights, meaning oil and gas beneath the site may be targeted for development. Nonfederal entities, however, must submit plans of operations for approval to the National Park Service for any proposed operations within the historic site's boundary. (Geologic Resources Division 2006, 2012). The historic site Foundation Document (National Park Service 2013) identified oil and gas development as a potential threat to multiple fundamental resources and values.

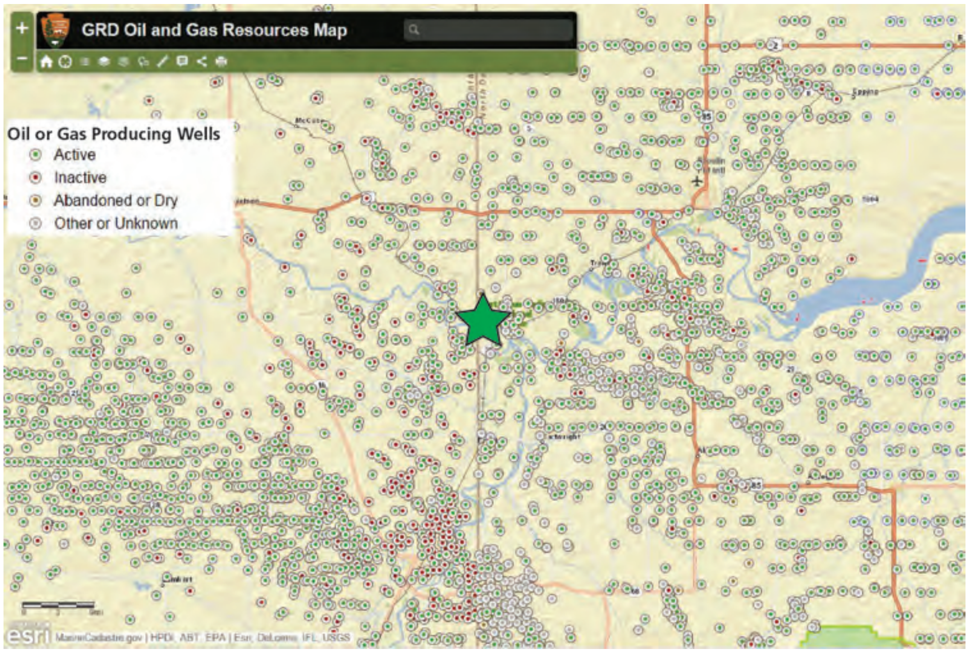

Figure 22. Oil and gas well locations in western North Dakota and eastern Montana as of June 2013. Map created 6 January 2015 with GRD Energy and Mineral Resources Interactive Map Viewer using oil and gas well data from the Environmental Protection Agency and DrillingInfo, Inc., published June 2013 (most recent data available when map produced).

With the increased development and exploration of the Bakken Formation in North Dakota and Montana, the possibility exists that further oil and gas exploration and production activities will occur in the immediate vicinity and possibly even inside Fort Union Trading Post National Historic Site (Geologic Resources Division 2006). Consequently, the geological units on the surface in the historic site (**Qal**, **Qac**, **Tfsb**, **Tftr**) may be affected by hydrocarbon exploration depending on the various geophysical and drilling techniques used and their related infrastructure, such as well pads, geophysical seismic techniques, and access roads. Such activities can compact surface materials or generate dust.

Impacts from exploration and production activities inside Fort Union Trading Post National Historic Site may be limited on account of the historic site's size. Because the historic site is small, drilling and production need not occur in the historic site. Directional drilling techniques can access any hydrocarbon exploration targets beneath the historic site. Also, well spacing is assigned by the state regulatory agency, and the present default spacing unit for new horizontal wells in the Williston Basin of North Dakota is 1,280 acres, though spacing units of 640 acres, 320 acres, or smaller are not uncommon (Great Northern Energy 2009).

Recommendations for mitigation and management strategies, including legal options, are summarized 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). 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.

Fort Union's cultural landscape and viewshed are fundamental resources, so preserving the scenic quality of the Fort Union area is a high priority for Fort Union Trading Post National Historic Site management (National Park Service 2013). Activities associated with hydrocarbon exploration and extraction that have decreased the scenic quality of the surrounding area include increased traffic on local roads, which are not designed for heavy truck traffic; construction of well pads, RV parks, and storage areas for oilfield materials; and the addition of a second rail line, which runs parallel to Highway 1804 along the historic site's northern boundary. New rail loading facilities have been constructed 11 km (7 mi) east of the historic site and about 8 km (5 mi) south of the historic site. Trucks transport materials, such as well pipe, sand, load oil, and propane that arrive by rail (Thornberry-Ehrlich 2012). Other adverse impacts include excessive wastewater demands, impacts on wildlife populations and habitats, and negative impacts to soil, water, and air resources. Long-term adverse effects on natural resources from these activities are unknown.

Other activities, such as mining sand and gravel for oil and gas operations, may also 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, North Dakota sand 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, usually for roads and well sites.

Water is a key limiting factor for oil and gas production via hydraulic fracturing in North Dakota. According to North Dakota Department of Natural Resources Director Lynn Helms, drilling the expected 2,000 new wells per year will require 42–45 million liters (11–12 million gallons) of freshwater per day (Helms 2013). Water used for hydraulic fracturing in North Dakota, however, accounts for only 4% of the consumptive water use, calculated as water input less water output that is recycled and reused (North Dakota State Water Commission 2014). By contrast, irrigation in North Dakota accounts for 56% of consumptive water use, and the average daily flow of the Missouri River at Bismarck is enough water to hydraulic fracture 6,497 wells (North Dakota State Water Commission 2014).

In addition to water used for hydraulic fracturing, wells in North Dakota require water for maintenance activities. The primary maintenance activity water is used for is to keep salt from building up in the wellbore, which restricts the flow of oil and gas. Over the life of a well, which is typically 30–40 years, maintenance water can be 25–33 million liters (6.6–8.8 million gallons) (Kiger 2013). The 40,000–45,000 wells in North Dakota will require 64–106 million liters (17–28 million gallons) of water per day for maintenance (Helms 2013).

Although the Missouri River contains abundant water, it is not available to use for fracking or well maintenance. The Army Corps of Engineers, contending that they have authority through the Flood Control Act of 1944, restricted access to Missouri River water. The State of North Dakota opposes the Corps' policy and maintains that enough water flows in the Missouri to satisfy users (North Dakota State Water Commission 2014).

Freshwater used in fracking is also expensive. In North Dakota, freshwater delivered to a well site costs between 10 cents and 14 cents per gallon, with the total water cost for hydraulically fracturing a well costing as much as $400,000 (Allison et al. 2012). In an effort to save costs, many oil and gas operators are beginning to use recycled water in hydraulic fracturing operations. Water that comes from a fractured well contains a variety of chemicals and salts and must be taken to a licensed disposal facility. Recycled frac water does not meet the water quality standards for drinking or growing crops, but it can be used to hydraulically fracture additional wells (Allison et al. 2012).

Oil and gas operators balance the cost of using recycled water with the cost of drilling injection wells to dispose of waste water in the subsurface. Injection wells, however, may also impact the viewshed and cause additional problems (see the "Earthquakes" section).

A concern of historic site managers is construction of a water depot (a distribution center for frac water) within sight of Fort Union Trading Post National Historic Site. This water depot, if constructed, may impact the historic site's cultural landscape (Fred MacVaugh, written communication, 9 February 2015).

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 falling prices 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 have begun to reduce staff, drilling is expected to continue into the foreseeable future (The Economist 2014).

Many economic factors determine whether or not a company decides to invest in exploration of the Bakken Formation. Such a discussion is beyond the scope of this GRI. However, some factors include well costs, maintaining leased acreage positions, company debt, investor confidence, transportation costs, and technological developments. How these changes affect the viewshed and infrastructure of Fort Union Trading Post National Historic Site remains to be seen. The NPS Geologic Resources Division is available to provide site managers with policy and technical assistance regarding oil and gas–development issues.

Slope Movements

Slope movements are the downslope transfer of soil, regolith, and/or rock under the influence of gravity. Soil creep, rockfalls, debris flows, and avalanches are common types of slope movements. These processes and the resultant deposits are also known as “mass wasting” and commonly grouped as “landslides.” Slope movements occur on time scales ranging from seconds to years.

Only minor slope movements occur within the historic site boundaries (Thornberry-Ehrlich 2012). The slopes composed of Tongue River (**Tftr**) and Sentinel Butte (**Tfsb**) strata at the Bodmer Overlook are the steepest in the historic site (see poster, in pocket). Higher buttes occur several kilometers north and south of the historic site. In 2010, a minor slump exposed artifacts and an American Indian burial site. Some of the items were returned to the tribe and some were re-buried in the historic site (Andy Banta, written communication, 24 November 2014). The slump had not been recognized as a potential hazard prior to its occurrence. The area was restored using an erosion mat followed by reseeding. The results of mitigation are not being monitored on a regular basis, but further slumping at the burial site has not occurred (Andy Banta, conference call, 7 October 2014).

Earthquakes

Seismic activity results in ground vibrations—shaking—that may occur when rocks suddenly move along a fault, releasing accumulated energy and causing earthquakes (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 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 NPS infrastructure, or trigger other hazards, such as slope movements that may impact NPS resources, infrastructure, or visitor safety. Should an earthquake occur, ground shaking may displace any of the geologic units (**Qal**, **Qac**, **Tfsb**, **Tftr**) exposed in Fort Union Trading Post National Historic Site.

Although earthquakes have been felt in North Dakota, they do not pose a major hazard for Fort Union Trading Post National Historic Site (US Geological Survey 2014). The probability that an earthquake of magnitude 5.5 will occur at Fort Union Trading Post National Historic Site within the next 100 years is between zero and 1.0% (fig. 23; US Geological Survey 2010). 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 a result of movement along pre-existing faults. Earthquakes originating in North Dakota are probably related to deeply buried structures in the Precambrian basement rocks that make up the relatively stable North American craton (see “Geologic History” chapter). These highly deformed Precambrian rocks probably contain numerous faults, but because they are so deeply buried, their existence and location are not well defined.

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).

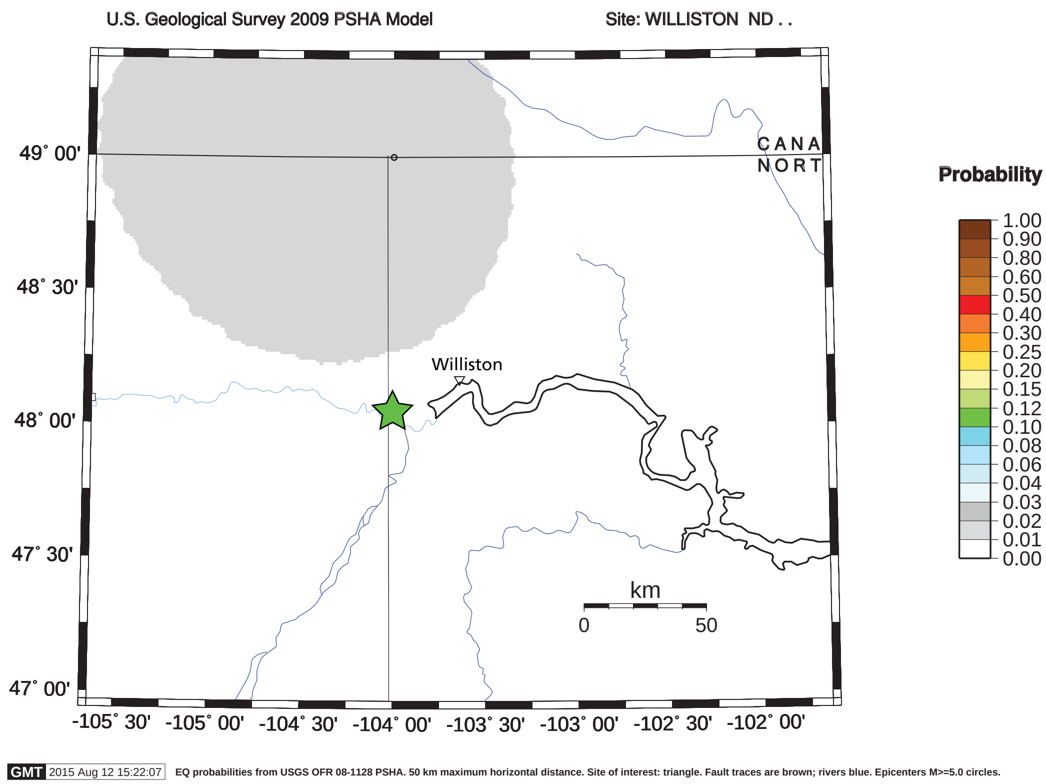

Figure 23. Earthquake probability map for Fort Union Trading Post National Historic Site. A Richter scale magnitude 5.5 earthquake has a probability of 0.00–0.01 (0%–1% "chance") of occurring near the historic site in the next 100 years. Map generated using the US Geological Survey Probabilistic Seismic Hazards Assessment (PSHA) mapping program available online: http://geohazards.usgs.gov/eqprob/2009/ (accessed 12 August 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.

Abandoned Mineral Lands

According to the NPS Abandoned Mineral Lands (AML) database, three AML sites occur within Fort Union Trading Post National Historic Site (Burghardt et al. 2014). All three were sand and gravel quarries. Two have been leveled and form the lower parking lot. Quarry operations had dug through the base of the old fort, but after the historic site was established, the slope was re-contoured to its pre-quarry appearance (Geologic Resources Division 2012).

The third site is an abandoned gravel quarry of limited areal extent immediately east of the reconstructed Fort Union (fig. 24). The gravel deposits are most likely a mix of glacial, fluvial, and colluvial sediments (**Qgt**, **Qal**, **Qac**; Thornberry-Ehrlich 2012). According to a 2001 National Park Service memorandum by Gregory Eckert, the quarry was carved out of the historic riverbank and has the same cut and slope as the bank (Andy Banta, written communication, 24 November 2014). No visitor trail leads to the quarry, and it is unlikely to pose a safety issue. The quarry is overgrown with weeds, but it may continue to be used for maintenance purposes in the future.

Paleontological Resources 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, Department of the Interior regulations associated with the Act were still being developed.

Tweet et al. (2011) presented a number of recommendations regarding the paleontological resources at Fort Union Trading Post National Historic Site, including the following:

- Investigate Paleocene Epoch rocks (**Tfsb**, **Tftr**) and museum collections in the historic site to identify fossils.
- Document in situ occurrences of fossils with field inventories and monitoring any significant sites.

- Encourage historic site staff to observe, photo-document, and monitor any occurrence of fossils, while conducting their usual duties. Unless the fossils are subject to degradation by natural processes or human activities, they should be left in situ. Staff should also be encouraged to participate in any paleontological field studies with trained paleontologists.
- Document any fossil found in a cultural context and requesting the input of an archeologist.
- Request a trained paleontologist to be on site for any future archeological excavations or infrastructure developments.

The NPS Geologic Resources Division is available for assistance with any of these recommendations. In addition, the *Geological Monitoring* chapter about paleontological resources written by 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.

Unless collected or stabilized, fossils exposed on the surface may be destroyed by erosion. Vital sign 1 focuses on geologic characteristics, such as lithology, bedding, slope of strata, and geochemistry of the rock unit that influence erosion rates. Vital sign 2 relates to external climatic factors, such as precipitation, temperature, and freeze-thaw processes (Santucci et al. 2009).

Geohazards (vital sign 3) consist of a variety of geologic processes and hazards that may threaten the stability of fossil sites. Some of these geohazards include local or regional volcanism, earthquakes, geothermal activity, glacial activity, and slope movements (Santucci et al. 2009). These potential catastrophic geohazards may pose a limited threat to Fort Union Trading Post National Historic Site.

Vital sign 4 pertains to fossil sites associated with areas submerged by or adjacent to water resources, such as the Missouri River in the case of Fort Union Trading Post National Historic Site. The stability of any fossil site associated with the Missouri River bank will depend on such hydrologic factors as fluctuating water levels, precipitation, bank saturation, and ice jams. Hydrologic processes may influence both sedimentation and erosion rates, which may impact the exposure and stability of fossil sites (Santucci et al. 2009).

Vital sign 5 focuses on human-related threats. Whether intentional or unintentional, human activities can threaten the stability of fossils sites. Santucci et al. (2009) offer procedures to monitor public use and prevent human impacts to in situ fossils.

Not all of these vital signs may be appropriate for Fort Union Trading Post National Historic Site. Resource managers may select from these vital signs and develop a monitoring program specific to the needs of the historic site.

Figure 24. Photographs of the small gravel quarry just east of the reconstructed trade post at Fort Union Trading Post National Historic Site. The left image shows the view from east to west across the quarry. The right view shows the view from west to east. National Park Service photographs by Andy Banta (Fort Union Trading Post National Historic Site).

Geologic History

This chapter describes the chronology of geologic events that formed the present landscape of Fort Union Trading Post National Historic Site.

The landscape at Fort Union Trading Post National Historic Site is geologically very young (fig. 2). Most of the units were deposited between 70,000 and 12,000 years ago, either during the last phase of Pleistocene glaciation (ice age) or after the last continental glacier retreated from North Dakota and Montana. But the historic site also rests in the center 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 Paleozoic Era carbonate rocks and clastic sedimentary rocks deposited in the Mesozoic and Cenozoic Eras. The early history is briefly described below, followed by a description of the post-glacial history that led to the current landscape.

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

A craton is an old, geologically stable interior of a continent. In the Precambrian, the Superior craton, which included present-day eastern North Dakota, collided with the Wyoming craton to the west, suturing the two cratons together to form the fledgling North American craton (fig. 25). The collision deformed a north–south trending region known as the "Trans-Hudson orogenic belt," which included what would become the Williston Basin and the present-day landscape of Fort Union Trading Post National Historic Site. A fault and lineament zone that was part of the Trans-Hudson Orogeny (mountain-building episode) formed the northeast–southwest-trending spine of the craton and was later singled-out and renamed the Transcontinental Arch (Anna et al. 2013). Today's Williston Basin was established during the Trans-Hudson Orogeny when Precambrian deformation formed normal faults along which the basin dropped down (Burrett and Berry 2000; Anna et al. 2013).

Precambrian faults were later reactivated by further tectonic activity to form buried north–south and northwest–southeast structures in the Williston Basin. These zones of weakness would become the Nesson, Cedar Creek, Little Knife, and Billings anticlines, which are convex, upside-down canoe-shaped folds (Gerhard and Anderson 1988; Kent and Christopher 2008; Anderson 2009; Anna et al. 2013). These subsurface structures formed east and south of the current Fort Union Trading Post National Historic Site. During the Laramide Orogeny, approximately 70 million to 5 million years ago (Late Cretaceous–Early Paleogene periods; fig. 2), reactivation of Precambrian faults produced additional folding and faulting. These structures would later become traps for oil and gas.

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

By the end of the Precambrian, present-day North Dakota and eastern Montana lay far inland from the continental margin (fig. 26). In the Early Cambrian Period, however, sea level rose and drowned the present-day Fort Union region (fig. 26). Cambrian and Early Ordovician (approximately 541 million–471 million years ago) sandstones and shale eroded from the Transcontinental Arch were deposited in near-shore marine environments. As sediment accumulated, the Williston Basin began to subside.

Sea level fluctuated throughout the Paleozoic Era, but near-shore 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 (regression), calcareous mudstones, dolomite, and evaporates accumulated in subtidal to supratidal environments. Although the Williston Basin contains a relatively complete Paleozoic section, sea level regressions exposed some of the strata to subaerial erosion.

One of the most extensive incursions of Paleozoic seas occurred in the Late Devonian–Early Mississippian, from approximately 385 million to 345 million years ago (fig. 26). The organic-rich marine shale of the Bakken Formation records deposition in a relatively deep, offshore marine environment. Since about 541 million years ago (Cambrian Period; fig. 2), carbonate environments had dominated this area of western North America. The Bakken Formation documents

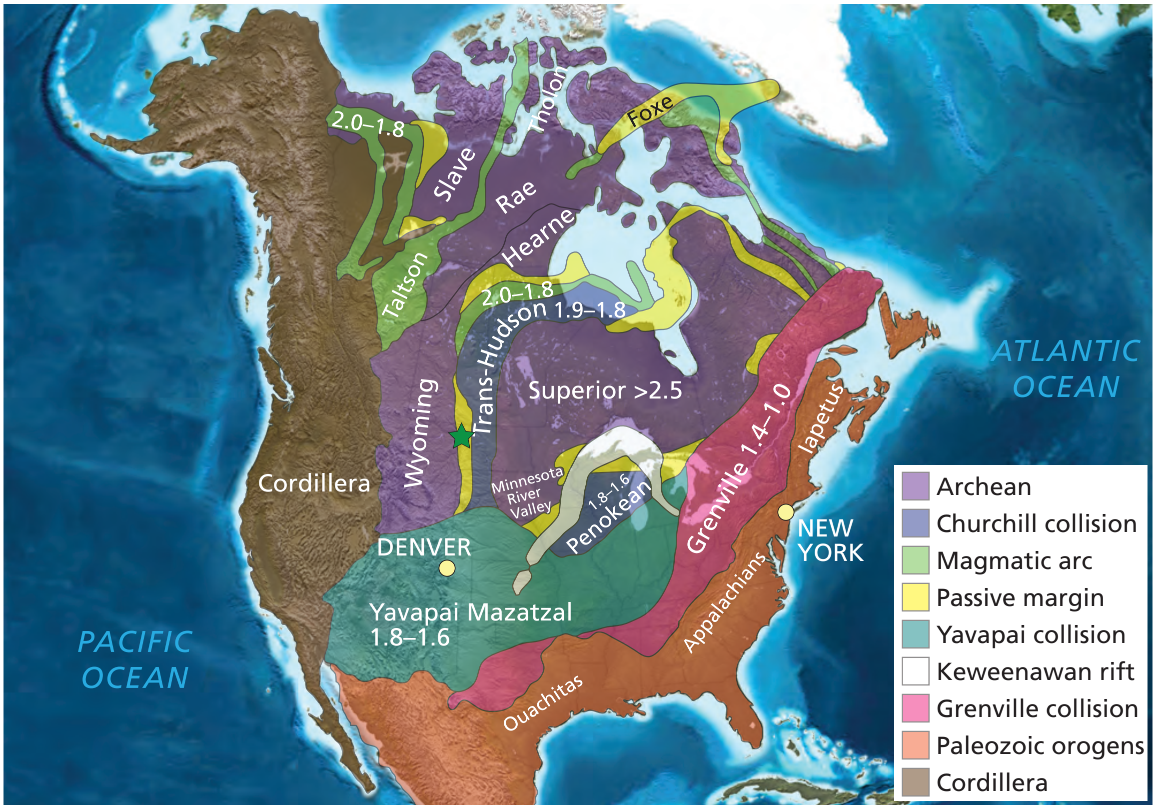

Figure 25. Map of land masses sutured together to form North America. The Trans-Hudson orogenic belt, which initiated the formation of the Williston Basin, formed when the Superior craton collided with the Wyoming craton. The green star shows the location of Fort Union Trading Post National Historic 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).

the first input of clastic material into the Williston Basin following hundreds of millions of years of carbonate deposition (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 of oil that is produced from the Mississippian Period reservoirs in the Williston Basin (Gerhard and Anderson 1988; Anna et al. 2013; North Dakota Geological Survey 2014b).

By the Pennsylvanian Period, which extends from 318 million years to 299 million years ago, present-day North Dakota and eastern Montana were once again inland of the continental margin. Throughout the Paleozoic Era (541 million–252 million years ago), 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, build the Appalachian Mountains, and form the supercontinent Pangaea (fig. 26; Hoffman 1997; Bradley 1997). By about 252 million years ago (Triassic Period; fig. 2), South America and Africa had sutured onto the North American continent.

From 252 Million to 66 Million Years Ago (Mesozoic Era): North Dakota, Montana, and an Inland Sea

Clastic deposition in the Williston Basin continued in the Triassic and Early Jurassic periods. In the Triassic Period, 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).

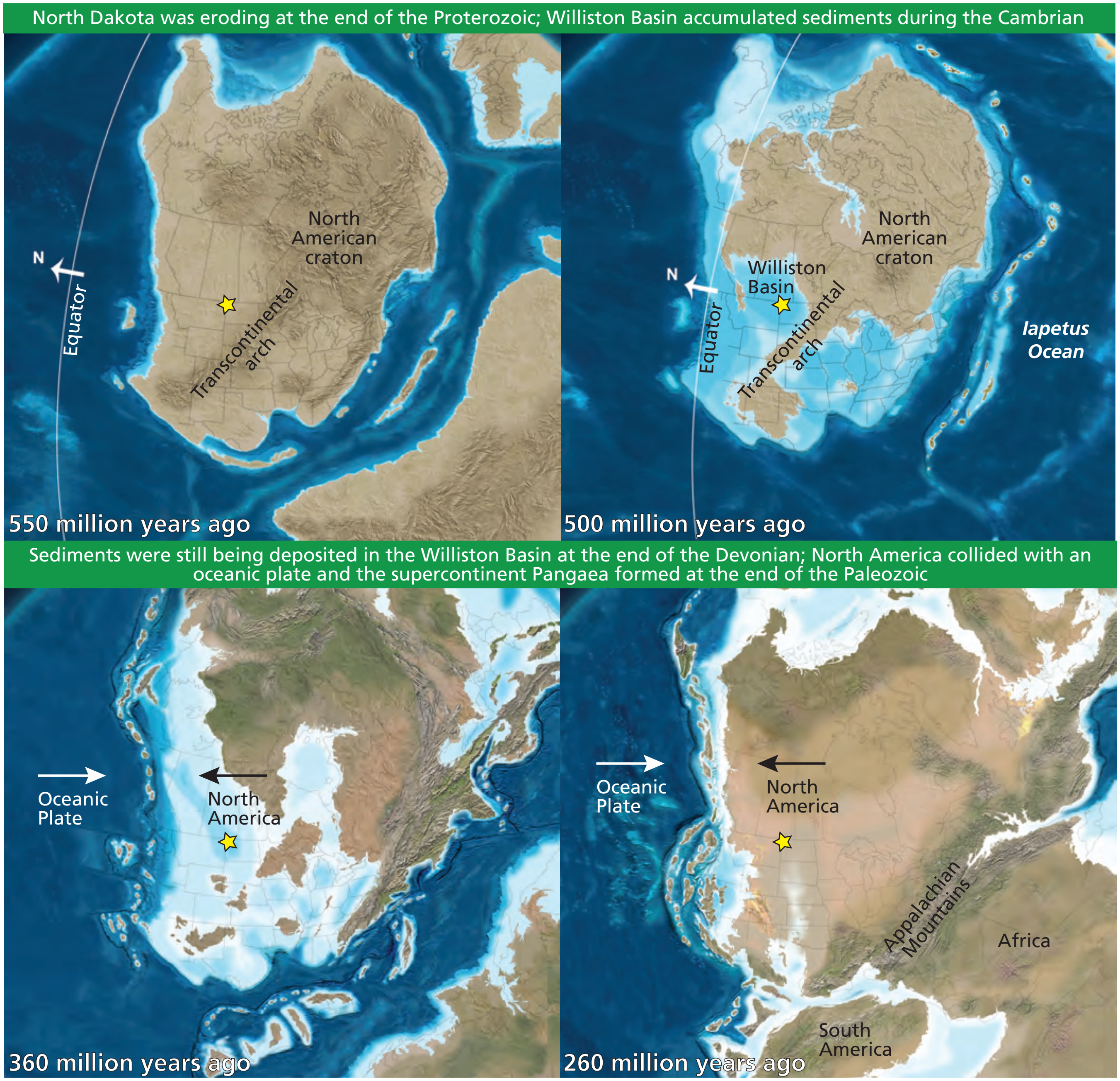

Figure 26. Paleozoic paleogeographic maps of North America. Approximately 550 million years ago (upper left), present-day North Dakota lay far inland from the craton's margin. The darker brown color represents uplands. Present-day Fort Union Trading Post National Historic Site (star) was west of the 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).

Throughout the Paleozoic and Mesozoic eras, subduction of the oceanic plate beneath the North American tectonic plate constructed mountains along the west coast, and seas variously transgressed onto, and regressed from, the continent's interior (Brenner and Peterson 1994). In the Middle Jurassic Period, an inland sea spread from the north into North Dakota, Montana, and Wyoming (fig. 27). Normal 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 again filled the basin, although on a much grander scale. Episodic fluctuations in sea level occurred throughout the Cretaceous Period, culminating in the formation of the most extensive interior seaway ever to bisect the North American continent (fig. 27). 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) and inundated the entire state of North Dakota.

The shallow marine sands and muds of the Western Interior Seaway became the Pierre Shale, which is about 210 m (700 ft) thick at its type section near Pierre, South Dakota. The Pierre Shale contains abundant marine fossils, 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). The Pierre Shale now lies about 500 m (1,700 ft) beneath Fort Union Trading Post National Historic Site, and it becomes progressively shallower to the west (Bergantino and Wilde 1998; Vuke et al. 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 (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; Hartman et al. 2014).

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 famous 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. Freshwater sharks, bony fish-like gar, turtles, crocodiles, and amphibians inhabited coastal environments (Johnson 2002; Nichols 2007; Liggett 2014).

A catastrophic extinction event marks the end of the Cretaceous Period. The Hell Creek Formation records the final days of the dinosaurs and many other animals and plants that went extinct about 66 million years ago. In the Fort Union Trading Post National Historic Site region, vegetation in the Hell Creek Formation represents an angiosperm-dominated woodland environment consisting of small- to medium-sized trees (Johnson 2002). Fossils found in the Cretaceous portion of the Fort Union Formation disappear immediately above the Cretaceous–Paleogene (K–P) boundary (Wilf et al. 2003). The catastrophic event eliminated the entire dominant megaflora in the upper Hell Creek Formation and 70%–90% of Cretaceous macrofossil species (Johnson 2002; Wilf et al. 2003; Nichols 2007).

An abrupt change in global temperature also occurred at the K–P boundary. Studies of terrestrial plant fossils and planktonic marine foraminifera indicate that although climate warmed during the final 300,000 to 500,000 years of the Cretaceous Period, reaching a maximum temperature between 65.8 million and 65.6 million years ago, global climate cooled about 65.5 million years ago, and this cooling trend continued across the K–P boundary (Johnson 2002; Wilf et al. 2003).

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

Paleocene megaflora is less diverse and less heterogeneous than Cretaceous 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, the remnant deposits of the last interior

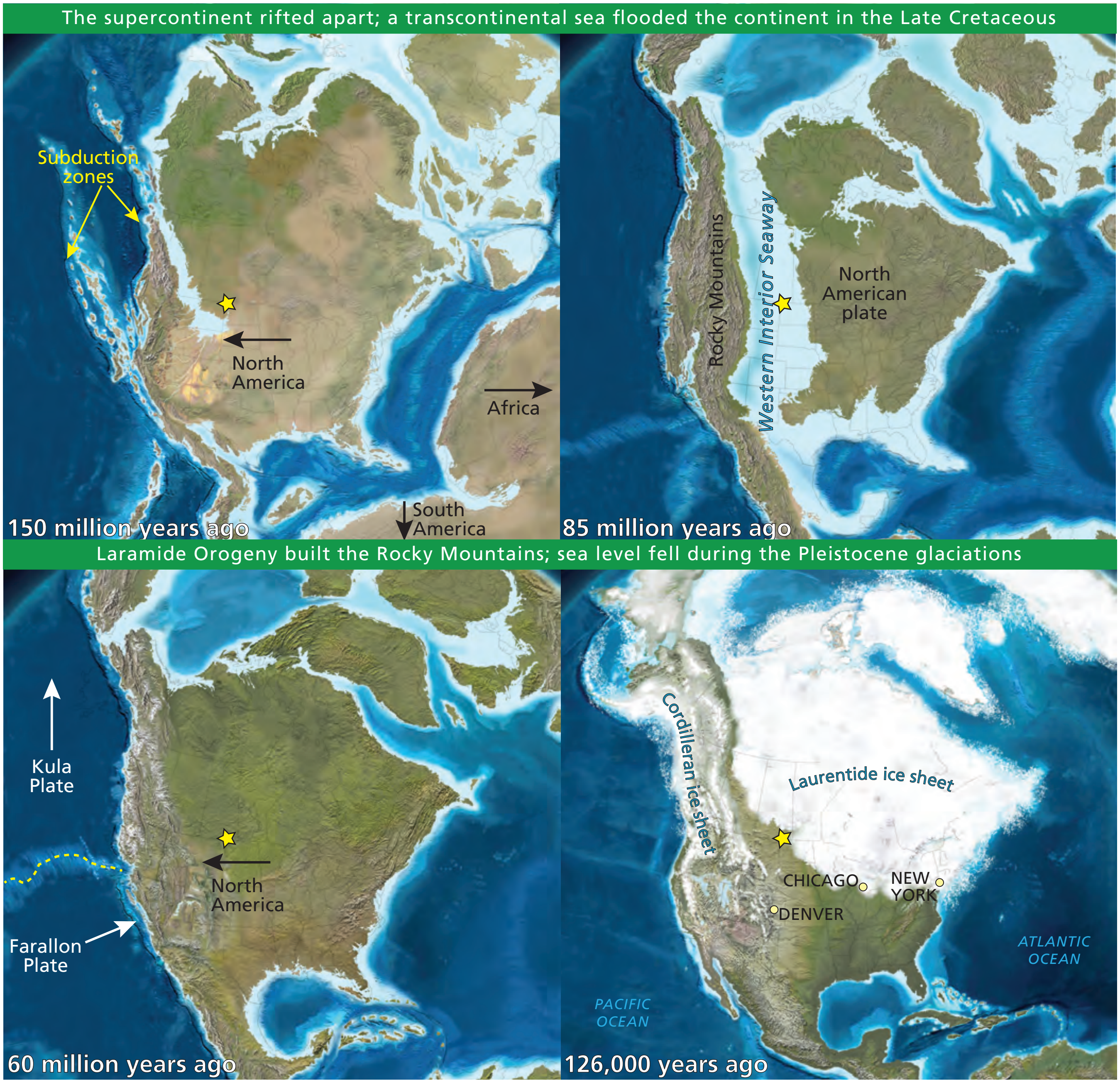

Figure 27. Mesozoic and Cenozoic paleogeographic maps of North America. Approximately 150 million years ago (upper left), an inland sea had spread into present-day North Dakota. Approximately 85 million years ago (upper right), the extensive Western Interior Seaway connected the Arctic Ocean with the 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 Tongue River (Tftr) and Sentinel Butte (Tsb) formations formed on floodplains in the region of the present-day historical 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 Fort Union Trading Post 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).

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 (also called the Cannonball Formation in parts of North Dakota) (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 Formation does not include large marine reptiles or ammonites, for example, and includes many different species of sharks, fish, and invertebrates.

The Paleocene Fort Union Formation (map units **Tfsb**, **Tftr**) is the oldest rock formation exposed in Fort Union Trading Post 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 Tongue River (Bullion Creek) members represent deposition in channels, on floodplains and in lakes and swamps (fig. 27; Daly et al. 1985; Hoganson and Murphy 2003). Volcanic ash, drifting in from the west, altered to bentonite (swelling clay) in some areas. Peat accumulated in swampy areas and was eventually transformed into North Dakota's vast lignite reserves.

According to Hartman (2004), mollusk diversity remained relatively low until the final regression of the Cannonball Sea in the upper part of the Paleocene Epoch, so that the classic terrestrial mollusk fauna, much of which was collected at exposures along the Upper Missouri River and near Fort Union Trading Post National Historic Site, is confined to strata overlying the marine Cannonball Member of the Fort Union Formation. Fauna in the Tongue River (Bullion Creek) and lower part of the Sentinel Butte members thus represents an upper Paleocene interval of time between about 61 million and 58 million years ago (Hartman 2004; Kihm et al. 2004; Hartman 2015). The results of these investigations suggest that the duration of Tongue River deposition was much shorter than previously interpreted (Hartman and Kihm 1995; Hartman 2004).

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 during the Paleocene Epoch, similar to today's climate in southern 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 Member of the Fort Union Formation 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, the climate 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. 28). Between 50 million and 20 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 and Montana beginning about 1.6 million years ago smoothed the landscape into rolling hills and scraped away whatever sediment had been deposited above the Fort Union Formation in the Fort Union area. Before glaciers blocked their path, most rivers in North Dakota flowed to the north on their way to Hudson Bay. The glaciers diverted the rivers, including the Missouri River, to the east and south (Hoganson and Murphy 2003). Many glaciers advanced into present-day North Dakota and Montana during the early Pleistocene, but subsequent erosion has removed most evidence of these advances from the Fort Union area except for remnants of till (**Qgt**) and large boulders, known as glacial erratics, deposited when the glaciers melted.

The most recent major glacial advance into what is now North Dakota occurred between about 70,000 to 12,000 years ago and is known as the Wisconsinan ice age (fig. 27). Two or three glacial events occurred during the Wisconsinan (Hoganson and Murphy 2003). A pulse of glacial ice flowed into North Dakota about 40,000 years ago, and a second event occurred about 25,000 years ago. Ice ultimately withdrew from North Dakota for good about 12,000 years ago. The unconsolidated, heterogeneous mixture of clay, silt, sand, gravel, cobbles, and boulders (**Qgt**) mapped on the bluffs south of the historic site are remnants of the most recent glacial advance into the Fort Union area.

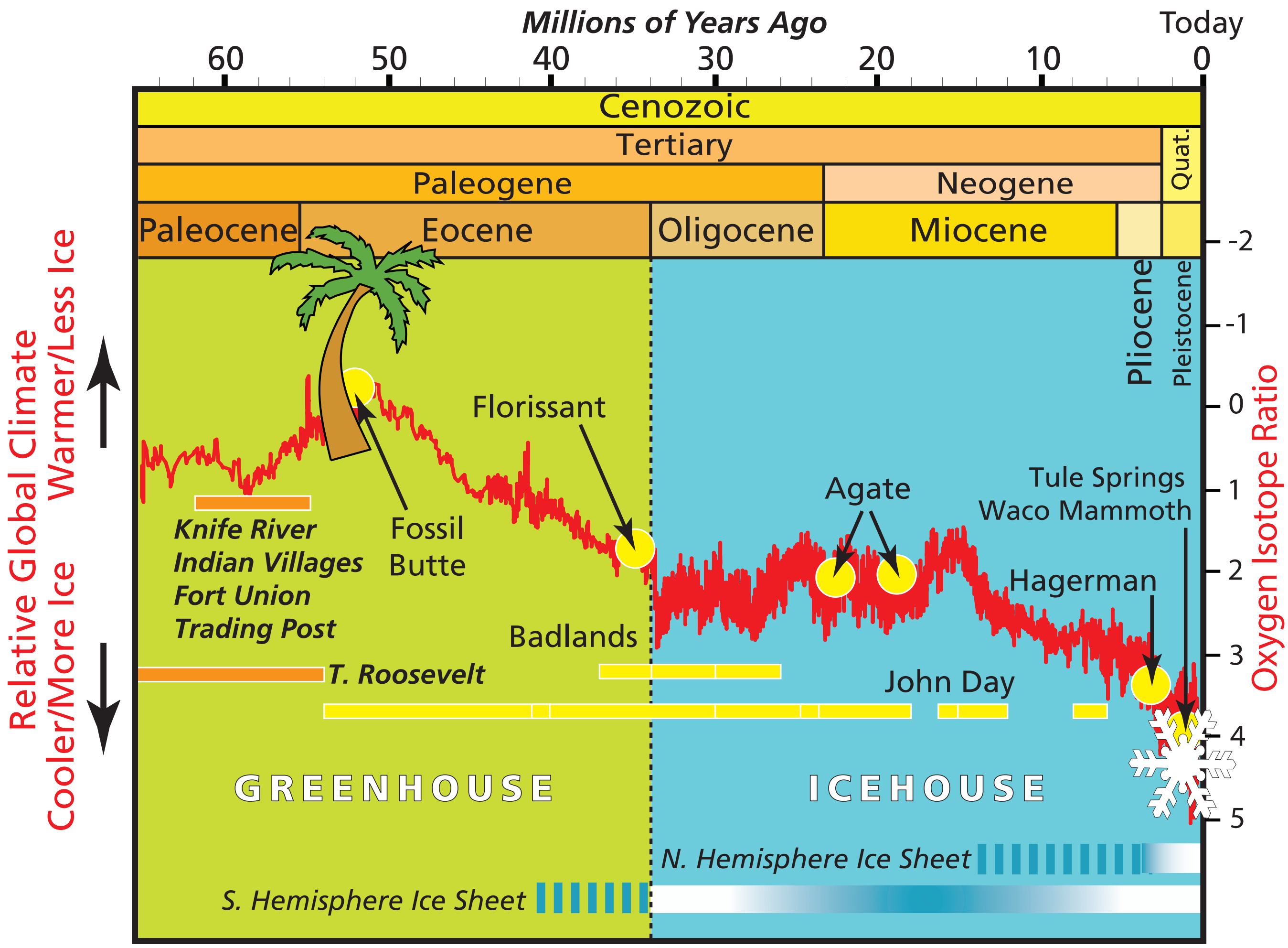

Figure 28. Illustration of relative global climate in the Cenozoic Era. During the Paleogene and Neogene periods, global climate fluctuated, influencing landscape evolution. The red line was plotted using ocean temperature data from Zachos et al. (2001, 2008). The transition from global "greenhouse" 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 (Knife River Indian Villages and Fort Union Trading Post 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).

When the last continental glacier was at its maximum extent, about 14,000–12,000 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 the northern Great Plains.

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, North Dakota, in Mclean County (Hoganson and Murphy 2003). Remnants of Lake McKenzie are preserved in Knife River Indian Villages National Historic Site, approximately 220 km (135 mi) southeast of Fort Union Trading Post National Historic Site, where the McKenzie Terrace (**Qtm**) marks the former shoreline. The undifferentiated Tongue River–Sentinel Butte (Bullion Creek) Members can be traced to the Knife River Indian Villages National Historic Site area, where similar Fort Union, it is the oldest unit in that historic site (Reiten 1983; see GRI report by Graham 2015 [in review]).

Warming produced vast amounts of meltwater, and the torrents of freshwater eroded many channels into Paleocene bedrock. Rivers cut downward through their floodplains, leaving them high and dry to become the bluffs visible from today's Fort Union Trading Post National Historic Site. These processes also created the Pleistocene terraces mapped in Knife River Indian Villages National Historic Site (Reiten 1983; see GRI report by Graham 2015 [in review]). Alluvial terrace deposits (**Qat**) in the Fort Union Trading Post National Historic Site range in age from Pleistocene to Holocene; glacial meltwater may have formed some of them.

To the west, melting alpine glaciers fed rivers like the Yellowstone with vast amounts of meltwater and debris. Carving a northeasterly channel through eastern Montana, the Yellowstone River met the Missouri River channel just south of Fort Union Trading Post.

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 ice ages (table 2). When climate was cool and wet, precipitation increased vegetation density, which stabilized hillslopes and decreased the amount of sediment eroded into rivers. As a consequence, the Missouri and Yellowstone rivers incised vertically into their floodplains. Increased precipitation promoted soil development, and increased vegetation stabilized sand dunes (Reiten 1983).

In contrast, when the climate was warm and dry, vegetation density decreased and hillslopes became less stable. Soil development slowed and more sediment was eroded from hillslopes by slope wash and aeolian activity (Reiten 1983). In the geologic record, grass and prairie paleosols replaced forest paleosols about 10,000 years before present (BP) and the climate became warmer after 8,500 years BP (Reiten 1983).

Drier conditions occurred about 2,500 years BP. These climatic changes are recorded in the Holocene terraces in Knife River Indian Villages National Historic Site (Reiten 1983); similar evidence may be found in the area of Fort Union Trading Post National Historic Site. About 500 years ago, the Hidatsa and Mandan began building earthlodges on the terraces overlooking the Knife and Missouri rivers. In the 19th century, a profitable fur trade between American Indian tribes and Euro-American traders resulted in the construction of Fort Union Trading Post. Although its flow is currently regulated by Fort Peck Dam, the Missouri River continues to meander past Fort Union Trading Post National Historic Site, as it did in the 1800s, reworking older sediments (**Qat**, **Qac**) and depositing new alluvium (**Qal**) in point bars and floodplains.

Table 2. Summary of Holocene (post-glacial) climate in the Fort Union region.

Age in Years Before Present	Climate	Landscape
500–0	Fluctuations from cool and moist to warm and dry	Alternating between valley filling and valley incision. Paleosols formed and current soil developed.
2,500–500	Warm, dry	Valley filling. Vegetation density decreased; hillslopes became less stable. Minor episodes of paleosol formation.
4,500–2,500	Cool, moist	Incision of valley fill and deposition of fine-grained overbank sediment on floodplains. Vegetation density increased; hillslopes became more stable. Several paleosols formed. Floodplain forest fires occurred.
8,500–4,500	Warm, dry	Valley filling. Vegetation density decreased; hillslopes became less stable. Active aeolian sand dunes occurred in the area of Knife River Indian Villages National Historic Site and possibly Fort Union Trading Post National Historic Site.
13,000–8,500	Cool, moist	Vegetation density increased; hillslopes became more stable. A forest paleosol formed and was replaced by prairie grasses and soils about 10,000 BP.

Data and interpretations are from Reiten (1983).

Geologic Map Data

This chapter summarizes the geologic map data available for Fort Union Trading Post 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 sources to produce the digital geologic data set for Fort Union Trading Post National Historic Site. These sources also provided information for this report.

Bergantino, R. N., and E. M. Wilde. 1998 (revised 2007). Geologic map of the Culbertson 30' × 60' quadrangle (bedrock emphasis), northeastern Montana (scale 1:100,000). Open-File Report 359. Montana Bureau of Mines and Geology, Butte, Montana.

Vuke, S. M., E. M. Wilde, and L. N. Smith. 2003 (revised 2011). Geologic and structure contour map of the Sidney 30' × 60' quadrangle, eastern Montana and adjacent North Dakota (scale 1:100,000). Open-File Report 478. Montana Bureau of Mines and Geology, Butte, Montana.

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 Fort Union Trading Post 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 from the unit list.

The following components are part of the data set:

- A GIS readme file (fous_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 3);
- Federal Geographic Data Committee (FGDC)–compliant metadata;
- An ancillary map information document (fous_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 (fous_geology.mxd) that displays the digital geologic data; and
- A KML/KMZ version of the data viewable in Google Earth (table 3)

Table 3. GRI GIS data for Fort Union Trading Post National Historic Site

Data Layer	On Poster?	Google Earth Layer?
Geologic Attitude and Observation Points	No	No
Geologic Contacts	No	Yes
Geologic Units	Yes	Yes
Geologic structure contour lines (top of Pierre Shale)	No	Yes

GRI Map Poster

A poster of the GRI digital geologic data draped over a shaded relief image of the historic site and surrounding area is included with this report. Not all GIS feature classes are included on the poster (table 3). Geographic information and selected historic site features have been added to the poster. 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 Table

The Map Unit Properties Table lists 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 table summarizes 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 poster. Based on the source map scale (1:100,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 51 m (167 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.

ablation. All processes by which snow and ice are lost from a glacier, including melting, evaporation (sublimation), wind erosion, and calving.

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

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

alluvium. Stream-deposited sediment.

alpine glacier. A small glacier in a mountain range (i.e., not an ice cap or ice sheet) that usually originates in a cirque and may flow down into a valley previously carved by a stream. Synonymous with "mountain glacier" and "valley glacier."

angiosperm. A plant with true flowers, in which the seeds, resulting from double fertilization, are enclosed in an ovary, comprising the fruit.

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

avulsion. The sudden cutting off or separation of land by a flood or an abrupt change in a stream course.

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

bentonite. Soft clay or greasy claystone composed mostly of the clay mineral smectite, formed by the chemical alteration of glassy volcanic ash in contact with water.

bivalve. Having a shell composed of two distinct, but equal or nearly equal, movable valves, which open and shut.

blowout. A general term for a small saucer-, cup-, or trough-shaped hollow or depression formed by wind erosion on a preexisting dune or other sand deposit, especially in an area of shifting sand or loose soil, or where protective vegetation is disturbed or destroyed.

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

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.

carbonate. A mineral group composed of carbon and oxygen plus an element or elements; for example calcite, $CaCO_3$; and dolomite, $CaMg(CO_3)_2$.

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.

claystone (sedimentary). An indurated rock with more than 67% clay-sized minerals.

colluvium. A loose, heterogeneous, and incoherent mass of rock fragments and soil material deposited via surface runoff or slow continuous downslope creep; usually collects at the base of a slope or hillside, but includes loose material covering hillsides.

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.

delta. The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area; resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, and currents.

drift. All rock material (clay, silt, sand, gravel, and boulders) transported and deposited by a glacier, or by running water emanating from a glacier.

drumlin. A low, smoothly rounded, elongated oval hill, mound, or ridge of till that formed under the ice margin and was shaped by glacial flow; the long axis is parallel to the direction of ice movement.

esker. A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified sand and gravel that was deposited by a subglacial or englacial stream flowing between ice walls or in an ice tunnel or a stagnant or retreating glacier, and was left behind when the ice melted.

estuary. The seaward end or tidal mouth of a river where freshwater and seawater mix.

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

flood basin. The tract of land covered by water during the highest known flood.

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.

fluvial channel. A natural passageway or depression produced by the action of a stream or river.

footwall. The lower wall of a fault.

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

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

fossil. A remain, trace, or imprint of a plant or animal that has been preserved in the Earth's crust since some past geologic time; loosely, any evidence of past life.

glacial erratic. A rock fragment carried by glacial ice deposited at some distance from the outcrop from which it was derived, and generally, though not necessarily, resting on bedrock of different lithology.

glacial groove. A deep, wide, usually straight furrow cut in bedrock by the abrasive action of a rock fragment embedded in the bottom of a moving glacier; it is larger and deeper than a glacial striation, ranging in size from a deep scratch to a glacial valley. Syn: groove (glacial geology).

glaciofluvial. Pertaining to the meltwater streams flowing from wasting glacier ice, and especially to the deposits and landforms produced by such steams, as kame terraces and outwash plains.

glaciolacustrine. Pertaining to, derived from, or deposited in glacial lakes, especially referring to deposits and landforms composed of suspended material transported by meltwater streams flowing into lakes bordering a glacier.

ground moraine. An accumulation of till after it has been deposited or released from the ice during ablation, to form an extensive area of low relief,

hanging wall. The upper wall of a fault.

hydraulic conductivity. The ease with which water moves through spaces or pores in soil or rock.

incision. Downward erosion by a stream, resulting in a deepened channel and commonly a narrow, steep-walled valley.

intertonguing. The overlapping of markedly different rocks through vertical succession of wedge-shaped layers; results in the disappearance of sedimentary bodies in laterally adjacent masses.

kame. A low mound, knob, hummock, or short irregular ridge, composed of stratified sand and gravel deposited by a subglacial stream as a fan or delta at the margin of a melting glacier; by a superglacial stream in a low place or hole on the surface of the glacier; or as a ponded deposit on the surface or at the margin of stagnant ice.

kettle. A steep-sided, usually basin- or bowl-shaped hole or depression, commonly without surface drainage, in glacial-drift deposits, often containing a lake or swamp; formed by the melting of a large, detached block of stagnant ice (left behind by a retreating glacier) that had been wholly or partly buried in the glacial drift.

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

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).

littoral. Pertaining to the benthic ocean environment or depth zone between high water and low water; also, pertaining to the organisms of that environment. Synonymous with "intertidal."

meander. One of a series of sinuous curves, bends, or turns 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.

meandering stream. A stream containing meanders.

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

mollusk. A solitary invertebrate such as gastropods, bivalves, and cephalopods belonging to the phylum Mollusca. Range: Lower Cambrian to Holocene.

moraine. A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited mostly by direct action of a glacier.

morphology. The shape of the Earth's surface.

mudstone. An indurated mud having the texture and composition of shale, but lacking its fine laminations or fissility.

neritic. Describes the ocean environment or depth zone between low tide and 200 m (660 ft), or between low tide and approximately the edge of the continental shelf; also, describes the organisms living in that environment.

oil field. A geographic region rich in petroleum resources and containing one or more wells that produce, or have produced, oil and/or gas.

orogeny. A mountain-building event.

outwash. Stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier. The coarser material usually is deposited nearer to the ice.

outwash delta. Outwash forming a delta in a body of water.

outwash fan. A fan-shaped accumulation of outwash deposited by meltwater streams in front of the end moraine of a glacier.

outwash plain. A broad, gently sloping sheet of outwash deposited by meltwater streams flowing from the front of or beyond a glacier, and formed by coalescing outwash fans.

paleoenvironment. An environment in the geologic past.

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).

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

proglacial lake. A lake formed just beyond the frontal margin of an advancing or retreating glacier, generally in direct contact with the ice.

recessional moraine. An end or lateral moraine built during a temporary but significant pause in the final retreat of a glacier.

regolith. From the Greek "rhegos" (blanket) + "lithos" (stone), the layer of unconsolidated rock material that forms the surface of the land and overlies or covers bedrock; includes rock debris of all kinds, volcanic ash, glacial drift, alluvium, loess, and aeolian deposits, vegetal accumulations, and soil.

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

roche moutonnée. A glacially sculpted, elongated bedrock knob or hillock.

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

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.

siltstone. A clastic sedimentary rock composed of silt-sized grains.

strata. Tabular or sheetlike layers of sedimentary rock that 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 channel. A long, narrow depression shaped by the concentrated flow of stream water.

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

striations (glacial). One of a series of long, delicate, finely cut, commonly straight and parallel furrows or lines inscribed on a bedrock surface by the rasping and rubbing of rock fragments embedded at the base of a moving glacier, usually oriented in the direction of ice movement; also form on the rock fragments transported by a glacier.

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

subduction. The process of one lithospheric plate descending beneath another.

subduction zone. A long, narrow belt in which subduction takes place.

subtidal. Describes the ocean environment or depth zone between low tide and 200 m (660 ft), or between low tide and approximately the edge of the continental shelf. Synonymous with "neritic" and "sublittoral."

supratidal. Pertaining to the shore area marginal to the littoral zone, just above high-tide level. Synonymous with "supralittoral."

syncline. A generally concave upward fold of which the core contains the stratigraphically younger rocks. Opposite of "anticline."

terminal moraine. The end moraine, extending across a glacial valley as an arcuate or crescentic ridge, that marks the farthest advance or maximum extent of a glacier.

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 belt. A series of mountainous foothills adjacent to an orogenic belt, which forms due to contractional tectonics.

thrust sheet. The body of rock above a large-scale thrust fault whose surface is horizontal or very gently dipping.

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.

trace fossil. A fossilized feature such as a track, trail, burrow, or coprolite (dung), that preserves evidence of an organism's life activities, rather than the organism itself. Compare to "body fossil."

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

trophic. Of or pertaining to nutrition.

underfit stream. A stream that appears to be too small to have eroded the valley in which it flows. Also, a stream whose volume is greatly reduced or whose meanders show a pronounced shrinkage in radius.

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.

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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

- Montana Bureau of Mines and Geology: http://www.mbmg.mtech.edu/
- 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 Fort Union Trading Post National Historic Site, held on 17 August 2011, or the follow-up report writing conference call, held on 7 October 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
Ken Anderson	Fort Union Trading Post National Historic Site	Maintenance worker
Andy Banta	Fort Union Trading Post National Historic Site	Superintendent
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
Mine Hodgkinson	Fort Union Trading Post National Historic Site	Maintenance worker supervisor
Lisa Norby	NPS Geologic Resources Division	Geologist
Tim Shepherd	NPS Northern Great Plains Network	Data manager
Trista Thornberry-Ehrlich	Colorado State University	Geologist
Loren Yellowbird	Fort Union Trading Post National Historic Site	Chief ranger

2014 Conference Call Participants

Name	Affiliation	Position
Andy Banta	Fort Union Trading Post National Historic Site	Superintendent
Eric Brevik	Dickinson State University	Professor of geology and soils, department chair
John Graham	Colorado State University	Geologist
Joseph Hartman	University of North Dakota	Chester Fritz Distinguished Professor, School director
Edward Kassman	NPS Geologic Resources Division	Oil and gas policy and regulatory specialist
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI reports coordinator
Fred MacVaugh	Fort Union Trading Post National Historic Site	Museum curator
Kerry Moss	NPS Geologic Resources Division	External energy and minerals program coordinator
Kara Paintner	NPS Northern Great Plains Network	Network coordinator
Carmen Thomson	NPS Midwest Region	Regional I&M coordinator

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 463/129508, August 2015

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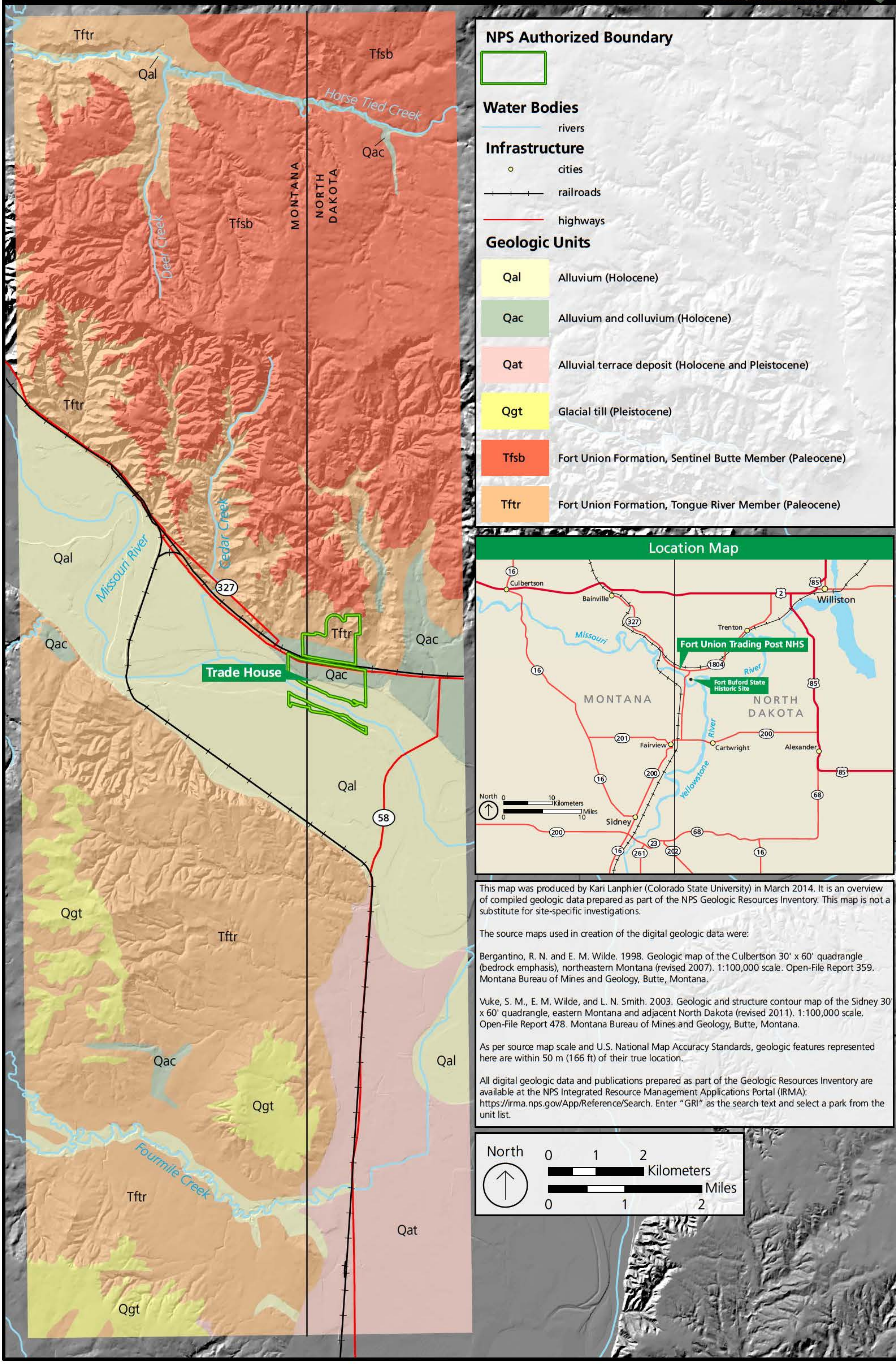
Geologic Map of Fort Union Trading Post NHS

Montana, North Dakota

National Park Service
U.S. Department of the Interior
Geologic Resources Inventory



This map was produced by Kari Lanphier (Colorado State University) in March 2014. 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 maps used in creation of the digital geologic data were:

Bergantino, R. N. and E. M. Wilde. 1998. Geologic map of the Culbertson 30' x 60' quadrangle (bedrock emphasis), northeastern Montana (revised 2007). 1:100,000 scale. Open-File Report 359. Montana Bureau of Mines and Geology, Butte, Montana.

Vuke, S. M., E. M. Wilde, and L. N. Smith. 2003. Geologic and structure contour map of the Sidney 30' x 60' quadrangle, eastern Montana and adjacent North Dakota (revised 2011). 1:100,000 scale. Open-File Report 478. Montana Bureau of Mines and Geology, Butte, Montana.

As per source map scale and U.S. National Map Accuracy Standards, geologic features represented here are within 50 m (166 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.

Map Unit Properties Table: Fort Union Trading Post National Historic Site

Colored map units are mapped within Fort Union Trading Post National Historic Site. Colors correspond to those on geologic map poster. Bold text refers to sections in report.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY (Holocene)	Alluvium (Qal)	Brown, olive, and gray boulders, cobbles, gravel, sand, silt, and clay deposited in stream channels and on floodplains. Deposits are poorly to well sorted, poorly to well stratified, and clasts may be as much as 0.6 m (2 ft) in diameter. Generally less than 6 m (20 ft) thick, but locally as much as 12 m (40 ft) thick.	**River Features** Cutbanks, point bars, mid-channel bars, and islands. **Paleontological Resources** Potential to yield Pleistocene megafauna and Holocene paleoenvironmental fossils, including trace fossils (burrows), charcoal, vertebrate fossils, such as bison bones, pollen, spores, and aquatic microfossils. **Qal** contains Knife River Flint (silicified plant material) associated with archeological (cultural resource) sites.	**Missouri River Bank Erosion** Erosion along the south bank of the Missouri River has caused active slumping and may intersect an irrigation ditch in the future. The Missouri River may eventually breach the southern boundary of Fort Union Trading Post National Historic Site. **Flooding** Flooding on the Missouri River during extremely wet years and backup from flooding on the Yellowstone River may inundate low-lying areas of the park. **Current and Potential Oil and Gas Development** Well pads, drill rigs, geophysical seismic activity, and access roads may erode and/or compact **Qal**. Drilling activities may also impact the viewshed. **Earthquakes** Potential earthquakes may occur due to secondary waste fluid disposal associated with the hydraulic fracturing process. These fluids may lubricate buried faults and cause the faults to slip, resulting in movement on the surface of **Qal**. This connection has not been demonstrated in North Dakota. **Abandoned Mineral Lands** A small abandoned quarry east of the reconstructed Fort Union contains a mix of **Qal**, **Qac**, and **Qgt**. The quarry is unlikely to pose a safety issue for visitors and is overgrown with weeds. **Paleontological Resources Inventory and Monitoring** Fossils found in the historic site, museum collections, or associated with archeological (cultural resource) sites should be inventoried and/or monitored.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw** The Missouri and Yellowstone rivers created modern floodplains and channels within the broad meltwater channels that formed at the end of the Pleistocene ice ages.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
		Sand, silt, and clay in glacial meltwater channels. Colors reflect that of older Quaternary and Paleogene units from which sediment was derived. May locally overlie glacial outwash deposits. Thickness not determined.	**Bodmer Overlook and Surrounding Landscape** The trail to the overlook crosses **Qac**. **Paleontological Resources** Potential to yield Pleistocene megafauna and Holocene paleoenvironmental fossils, including trace fossils (burrows), charcoal, vertebrate fossils, such as bison bones, pollen, spores, and aquatic microfossils. **Qac** contains Knife River Flint (silicified plant material) associated with archeological (cultural resource) sites. **Glacial Features** Coarse sand and gravel from glacial outwash.	**Current and Potential Oil and Gas Development** Well pads, drill rigs, geophysical seismic activity, and access roads may erode and/or compact **Qac**. Drilling activities may also impact the viewshed. **Slope Movements** Downslope movement of colluvium may occur. **Earthquakes** Potential earthquakes may occur due to secondary waste fluid disposal associated with the hydraulic fracturing process. These fluids may lubricate buried faults and cause the faults to slip, resulting in movement on the surface of **Qac**. This connection has not been demonstrated in North Dakota. **Abandoned Mineral Lands** A small abandoned quarry east of the reconstructed Fort Union contains a mix of **Qal**, **Qac**, and **Qgt**. The quarry is unlikely to pose a safety issue for visitors and is overgrown with weeds. **Paleontological Resources Inventory and Monitoring** Fossils found in the park, museum collections, or associated with archeological (cultural resource) sites should be inventoried and/or monitored.	**The Past 12 Thousand Years (Cenozoic Era): Holocene Thaw** Sediments filled the broad meltwater channels that formed at the end of the Pleistocene ice age.
	Alluvial terrace deposit (Qat)	Brown and gray, dominantly well-rounded gravel, sand, and silt in terrace remnants at elevations ranging from 1.5 m (5 ft) to 110 m (360 ft) above modern rivers and streams. Deposits are generally well sorted, but poorly to well stratified, with thicknesses generally less than 6 m (20 ft).	**Paleontological Resources** Potential to yield Pleistocene megafauna and Holocene paleoenvironmental fossils. These may include trace fossils (burrows), charcoal, vertebrate fossils, such as bison bones, pollen, spores, and aquatic microfossils. **Qat** contains Knife River Flint (silicified plant material) associated with archeological (cultural resource) sites.	None documented.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze** When the glaciers melted, vast amounts of meltwater spread gravel, sand, and silt across the region. Modern rivers and streams incised into these ancient deposits and left them as terraces above newly developed floodplains.
	Till (Qgt)	Heterogeneous mixture of brown and gray clay, silt, sand, and gravel with rare to abundant cobbles and boulders. Locally contains lenses and stringers of moderately well sorted clay, silt, sand, or gravel. Thickness is generally less than 9 m (30 ft), but may be as much as 30 m (100 ft).	**Paleontological Resources** **Qgt** contains Knife River Flint (silicified plant material) associated with archeological (cultural resource) sites. **Glacial Features** Heterogeneous mixture of sediment left behind when the glaciers melted.	None documented.	**From 2 Million to 12 Thousand Years Ago (Cenozoic Era): Pleistocene Deep Freeze** The landscape was covered by a heterogeneous mixture of sediments when the last phase of Pleistocene glaciation ended with the melting of the continental ice sheet from western North Dakota and eastern Montana.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
		Dark-gray shale locally underlain by orange- brown or brown, iron oxide-stained, cross-bedded channel sandstone with medium- to coarse-grained, poorly sorted clasts. Gray or brown, easily eroded mudstone about 6 m (20 ft) thick underlies the sandstone locally. Erosion has removed the upper part of member. Thickness in the map area is about 90 m (300 ft). North Dakota Geological Survey assigns these rocks to the Sentinel Butte Formation of the Fort Union Group.	**Fort Union Formation Type Section and Stratigraphic Features** Cross-bedded sandstone, rip-up clasts, and lignite coal beds. **Paleontological Resources** Abundant freshwater mollusks. Similar diverse fossil assemblage as **Tftr**, including invertebrate, vertebrate, and many plant fragments of petrified wood. **Aeolian Features** Blowouts on hilltops. **Volcanic Ash Layers** Volcanic ash altered to bentonite.	**Current and Potential Oil and Gas Development** Well pads, drill rigs, geophysical seismic activity, and access roads may erode and/or compact these units. Drilling activities may also impact the viewshed. **Slope Movements** Downslope movement may displace these strata, which form the steepest slopes in the park. **Earthquakes** Potential earthquakes may occur due to secondary waste fluid disposal associated with the hydraulic fracturing process. These fluids may lubricate buried faults and cause the faults to slip, resulting in movement on the surface. This connection has not been demonstrated in North Dakota. **Paleontological Resources Inventory and Monitoring** Fossils found in the park, museum collections, or associated with archeological (cultural resource) sites should be inventoried and/or monitored.	**From 66 Million to 2 Million Years Ago (Cenozoic Era): Paleocene Swamps and Floodplains and Climate Change** Once the Cannonball Sea retreated from the Fort Union region, sediments were deposited in river channels, avulsions, floodplains, lakes, and swamps. Peat that accumulated in swampy areas would eventually become part of North Dakota's lignite reserves. Volcanic ash, drifting in from the west, would alter to bentonite, a clay mineral with shrink-swell characteristics.
		Yellow, orange, or tan, fine- to medium-grained sandstone and thinner interbeds of yellowish-brown, orange, or tan siltstone and light-colored mudstone and clay. Consists of four basic stratigraphic layers, often in cycles. From lowest to highest, these cycles include: (1) gray claystone and siltstone, often containing plant and mollusk fossils; (2) a lignite layer; (3) yellow siltstone and sandstone, which may contain plant and mollusk fossils; and (4) sandstone deposits. The clay in the unit is not prone to swelling. Generally poorly cemented and weathers to badlands topography. Some relatively resistant sandstone beds form caprocks. Thickness is about 250 m (800 ft). North Dakota Geological Survey assigns these rocks to the Bullion Creek Formation of the Fort Union Group.	**Fort Union Formation Type Section and Stratigraphic Features** Cycles of sandstone, siltstone, and mudstone; also contains lignite coal beds. **Bodmer Overlook and Surrounding Landscape** The summit of the overlook is on **Tftr**. **Paleontological Resources** Abundant freshwater mollusks. Diverse assemblage of invertebrate, vertebrate, and plant fossils (table 1). Includes eroded pieces of petrified wood on Bodmer Overlook. **Aeolian Features** Blowouts on hilltops.		