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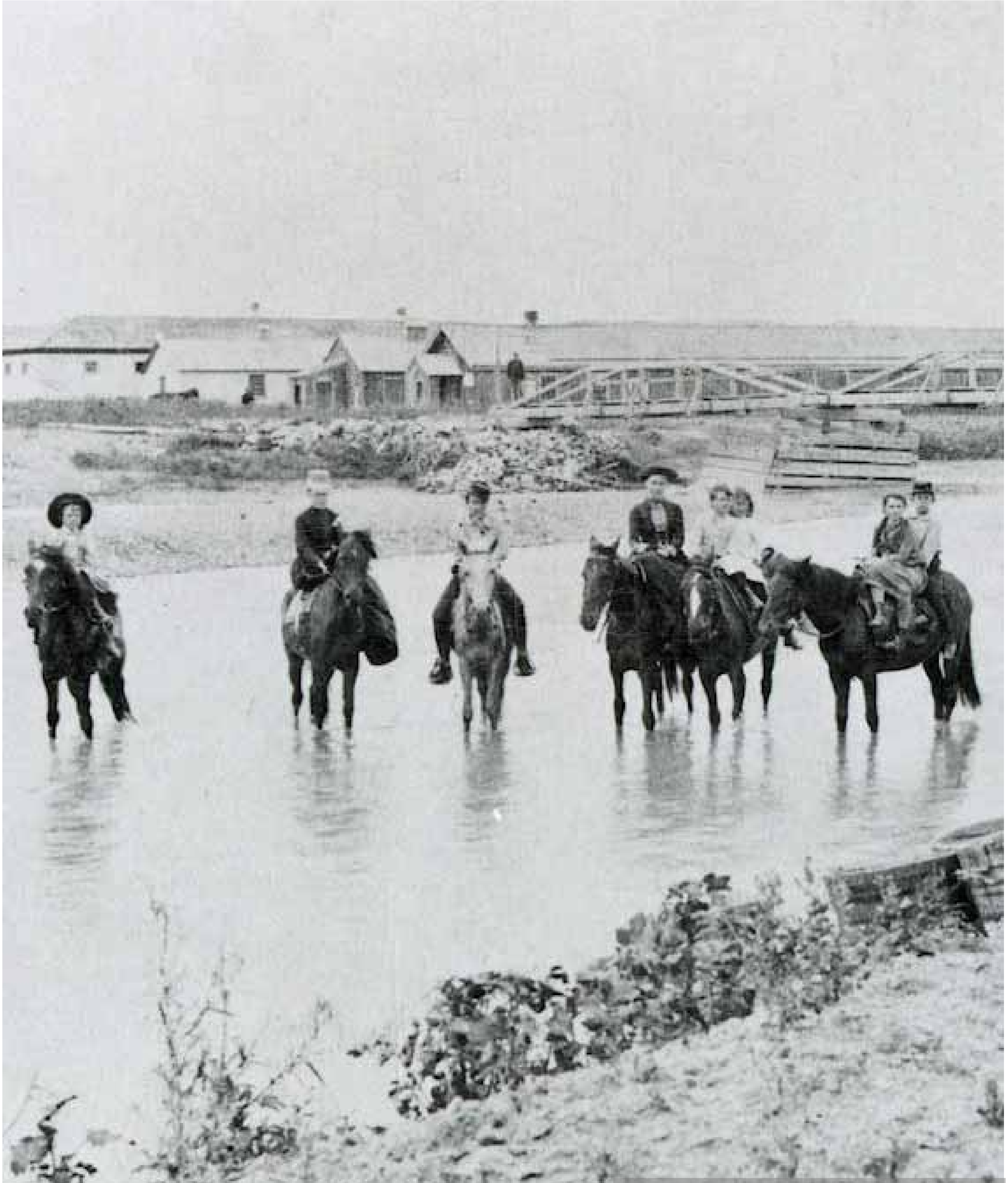
Natural Resource Program Center

Fort Laramie National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/161



ON THE COVER:
View of Fort Laramie National Historic Site, looking north across the Laramie River from its confluence with Deer Creek. Note how the fort is situated on a river terrace.
NPS image courtesy Baird Todd (NPS FOLA).

THIS PAGE:
The Laramie River was a part of life at Fort Laramie. Here officers' children ride along the river, c.1888. View is to the north.
NPS image, Louis Brechemin Collection. Courtesy Baird Todd (NPS FOLA).

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, Colorado 80225

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National Park Service
Natural Resource Program Center
Denver, Colorado

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

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

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

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Executive Summary

This report accompanies the digital geologic map for Fort Laramie National Historic Site in Wyoming, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

One of the most memorable shrines to westward expansion, Fort Laramie National Historic Site encompasses 353 ha (873 ac) of eastern Wyoming prairie. Strategically located along the Laramie River near its confluence with the North Platte River, old Fort Laramie became a primary stopping point on the Oregon and Mormon trails for explorers, trappers, traders, missionaries, emigrants, freighters, Pony Express riders, stage drivers, cowboys, and homesteaders, as well as soldiers and American Indians. From 1834 to 1890, Fort Laramie played a major role in the fur trade, the Indian Wars, and westward migration.

Located on the High Plains of Wyoming, Fort Laramie National Historic Site rests in a landscape of river terraces, floodplain deposits, and alluvium associated with the Laramie River. Tuffaceous siltstone, claystone, and cross-bedded river channel sandstones of the Paleogene and Neogene-aged White River and Arikaree formations border the Laramie River valley.

The 2003 Geologic Resources Evaluation scoping workshop identified the following geologic issues as important to management:

- erosion of river banks
- the need for surficial geologic maps
- mining and reclamation.

Erosion increases along the Laramie and North Platte rivers during spring runoff and flash flood events. Cultural resources may be uncovered by erosion, but they may also be washed away during a subsequent flood event.

Located on a terrace cut into unconsolidated Quaternary floodplain deposits, Fort Laramie National Historic Site lacks bedrock exposures. Detailed surficial geologic maps may thus be more useful for resource management than bedrock maps. Integration of surficial geologic maps with soil or vegetation maps may also provide beneficial information to management.

Mining and reclamation issues are primarily associated with past sand and gravel operations. Previous quarries near the old Fort Laramie cemetery have been reclaimed, but one site from which material was quarried to build the original fort hospital has historical significance and may be preserved.

External issues may also impact Fort Laramie National Historic Site. These include potential seismic activity, oil and gas exploration, coal mining, mining for industrial minerals and construction aggregates, uranium mining, and renewed copper and iron ore mining in the Hartville Uplift, which lies northwest of Fort Laramie.

Early in the Pleistocene epoch, approximately 2 million years ago, the Laramie River began dissecting its river valley across the High Plains. Geomorphic features in the valley record the evolution of the Laramie River before and since the construction of Fort Laramie. An idea of the ecosystem and depositional environments prior to the Pleistocene may be found in the fossils and sedimentary features in the adjacent Paleogene and Neogene (together, these time periods are commonly referred to as the "Tertiary") formations.

While Quaternary and Tertiary units characterize the landscape around Fort Laramie National Historic Site, much older Precambrian, Paleozoic, and Mesozoic rocks crop out in the Hartville Uplift. The uplift formed as a result of a mountain-building event, or orogeny, that gave rise to the Rocky Mountains approximately 75 to 35 million years ago. Basins formed adjacent to the mountain ranges, and the Hartville Uplift separates the Powder River Basin to the north from the Denver Basin to the south. Fort Laramie National Historic Site lies on the northwest margin of the areally-extensive Denver Basin that includes southeastern Wyoming, southwestern Nebraska, northwestern Kansas, and northeastern Colorado.

Rocks and geologic structures in the Hartville Uplift record a geologic sequence extending back about 3 billion years. The igneous, metamorphic, and sedimentary rock units exposed in the Hartville Uplift and in the subsurface beneath Fort Laramie National Historic Site record a complex history of tectonic events and depositional environments. [Note: see Glossary on pg. 34 for explanations of many technical terms used in this report.]

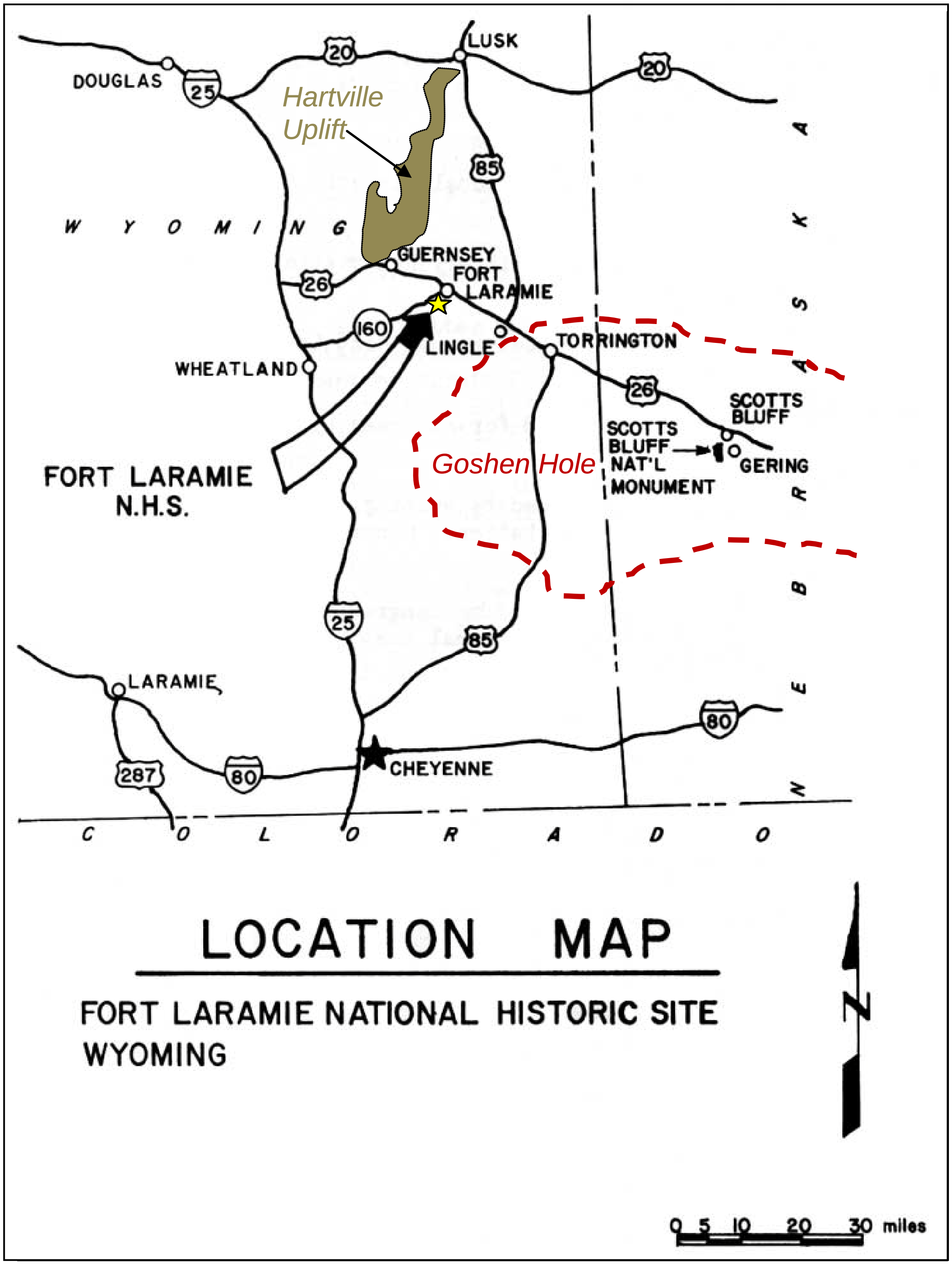

Figure 1. Location of Fort Laramie National Historic Site, Wyoming. Fort Laramie National Historic Site (yellow star) is located approximately 5 km (3 mi) southwest of Fort Laramie, Wyoming off U.S. Route 26. The Hartville Uplift (approximate area outlined in brown) lies northwest of Fort Laramie. Red dashes mark the general outline of Goshen Hole, southeast of Fort Laramie. Modified from a National Park Service figure available at: http://www.nps.gov/archive/fola/history/images/map1.jpg (accessed September 2009).

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Fort Laramie National Historic Site.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRI team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRI products.

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

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

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

For additional information regarding the content of this report and up-to-date GRI contact information please refer to the Geologic Resources Inventory Web site (http://www.nature.nps.gov/geology/inventory/, accessed September 2009).

Regional Information

Located in Goshen County, Fort Laramie National Historic Site encompasses approximately 353 ha (873 ac) of eastern Wyoming prairie (fig. 1). In 2006, the Corn Creek Irrigation District donated 16 ha (40 ac) of land at the confluence of the North Platte and Laramie rivers to the park. As of December 2009, the park's boundary had not been adjusted to include this property; however, the park expects this change to be approved (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, December 13, 2009).

The confluence of the North Platte and Laramie rivers was a strategic and important meeting place for American Indians, and served as a major transportation and communication hub for many groups. Fort Laramie played a major role in the fur trade, Indian Wars, and westward migration and expansion, becoming a primary stopping point on the Oregon and Mormon trails (NPS 1995).

Fort Laramie was constructed in the warmest region of Wyoming where summer temperatures average 27–38°C (80–100°F) but may exceed 38°C (100°F). Temperatures in the cool, breezy winters can fall below -18°C (0°F). This semi-arid region has a distinctly dry winter season; about 70% of the normal annual precipitation falls during the spring and early summer.

Geologic Setting

Fort Laramie National Historic Site lies on the western edge of the High Plains, a subregion of the Great Plains physiographic province (fig. 2). The High Plains of Wyoming slope gradually eastward from an altitude of 2,725 m (8,940 ft) at the base of the Laramie Mountains to about 1,580 m (5,180 ft) near Pine Bluffs, Wyoming (Wayne et al. 1991). The lowest elevation, 1,250 m (4,100 ft), is at the Nebraska state line along Goshen Hole, a lowland eroded into the plains surface (fig. 1). An erosional scarp with a rim that stands approximately 300 m (980 ft) or higher above the floor of the adjacent Powder River Basin marks the northern end of the High Plains surface.

Fort Laramie was built on a terrace cut into Quaternary floodplain deposits associated with the Laramie River. Although not exposed in the park, rocks present in the Fort Laramie region include the Oligocene White River Formation, an unnamed conglomerate sequence, and the early to early-middle Miocene-age Arikaree Formation (fig. 3) (McGrew 1963). The U. S. Geological Survey has raised the Arikaree Formation to "Group" status in Nebraska where the formation is subdivided into the Gering, Monroe Creek, and Harrison formations. The White River Formation is also now regarded as the White

River Group and contains the Chadron and overlying Brule formations.

No bedrock crops out in the park, but oil wells in the region have drilled into Precambrian (older than 542 million years) bedrock and younger sedimentary strata (fig. 3). In the Fort Laramie area, the contact between the Oligocene and Miocene units and the underlying strata represents an unconformity, or period of non-deposition or erosion, that spans a minimum of 31.6 million years. This unconformity between Tertiary (term referring collectively to the Paleogene and Neogene periods; see fig. 15) units and older rocks is exposed in the Hartville Uplift (McGrew 1963; Sims et al. 1997; Sims and Day 1999; Day et al. 1999).

The Hartville Uplift, an elongate northeastward-trending convex-up fold (anticline), about 72 km (45 mi) long and 24 km (15 mi) wide, lies northwest of Fort Laramie National Historic Site (fig. 1). The uplift separates the Powder River Basin to the north from the Denver Basin to the south. Subdued by erosion, the current landscape shows little evidence of past tectonic activity (McGrew 1963).

Historically, the Hartville Uplift was targeted for extensive mineral exploration. The Spanish Diggings, located on the southern flank of the Hartville Uplift about 32 km (20 mi) north of Fort Laramie, represent the oldest known economic use of geological resources in the region. Beginning approximately 10,000 years ago, American Indians fashioned weapons and tools from an especially high-quality chert (a form of quartz) that they mined from quarries extending over a mining district covering approximately 1,000 sq km (400 sq mi). Artifacts and lithic material from this area have been recovered from archaeological sites throughout the western and southwestern United States. When settlers discovered the quarries in the 1880s, they assumed them to be the remnants of gold prospecting by Spanish conquistadors, and thereby misnamed the region "Spanish Diggings." By 1935, however, research had established that the quarries had been created by American Indians (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008).

Park History

Strategically located on the central continental migration corridor, Fort Laramie served successively as log stockade, adobe trading post, and evolving military post. Whether campground, waystation, provision point, fortification, or temporary home, Fort Laramie provided travelers with a unique island of civilization where the Great Plains merges with the Rocky Mountains. Nearly every west-bound trapper, trader, and emigrant passed through the fort between 1834 and 1890. Explorers, trappers, traders, missionaries, emigrants, freighters, Pony Express riders, stage drivers, cowboys, homesteaders, soldiers, and American Indians found their way to Fort Laramie via the Oregon Trail.

Fort Laramie was preceded by Fort William and Fort John. Fort William, built in 1834 by William Sublette and Robert Campbell, was the first structure placed near the junction of the Laramie and North Platte rivers. The post quickly became an important base of operation for American and French-Canadian beaver trappers and traders. The fort was sold to the American Fur Company in 1836, but rotting log palisades and deteriorating conditions led to the nearby construction of a new adobe structure called Fort John in 1841 (Mattes 1980).

In June 1849, the United States purchased Fort John for $4,000 as part of a program that established military posts along the Oregon Trail. Finding Fort John decrepit and infested with vermin, Major W.J. Sanderson employed his men in cutting and hauling timber, quarrying stone, and burning lime. By winter, Fort Laramie consisted of a two-story block of officers' quarters, a block of soldiers' quarters, a bakery, and two stables (Mattes 1980). Named in honor of Jacques La Ramie, a French fur trapper who worked in the tributaries of the North Platte in the early 1800s, Fort Laramie became the first garrisoned post in Wyoming (fig. 4).

Whether or not a wall or stockade enclosed the fort appears to be a matter of debate. Some historians believe that the initial plans included a 2.7 -m - (9 ft) high stone wall that would enclose an area 170 by 200 m (550 ft by 650 ft). However, high costs prohibited its construction (http://www.nps.gov/archive/fola/laramie.htm, accessed September 2009). In this scenario, security at the open fort relied upon its location and its garrison of troops. Other historians believe that a wall surrounded Fort Laramie (fig. 4). In some accounts, the stockade surrounding Fort Laramie is described as 5 m (15 ft) high, build of dried bricks, with two blockhouses at two of the corners (http://www.wyomingtalesandtrails.com/photos.html, accessed September 2009).

Fort Laramie was a strategic and necessary stop for westward-bound immigrants traveling the 1,300-km (800-mi) span between Fort Kearney, Nebraska, and Fort Bridger, Wyoming. During 1850, the peak year of western migration, a steady procession of Conestoga wagons wore deep ruts into rocks of the White River Formation. In addition to the Oregon and California trails, the Mormon Trail, Bozeman Trail, Pony Express Route, Transcontinental Telegraph Line, and the Deadwood and Cheyenne Stage Route passed through Fort Laramie.

Fort Laramie primarily served as a supply post during the early 1850s when relations between emigrants and American Indians were relatively peaceful. In 1851, the United States and the Plains Indians signed the Treaty of Fort Laramie. Three years later the treaty was broken when an incident involving a passing wagon train precipitated the Grattan Fight in which an officer, an interpreter, and 29 soldiers from Fort Laramie were killed.

During Red Cloud's War in the 1860s, Fort Laramie became the primary staging ground for the U.S. Army. The 1868 Treaty of Fort Laramie marked the end of that military campaign, but not the end of the conflict between the United States and the Plains Indians. By the mid-1870s, major campaigns were being mounted against the Plains tribes. In 1874, gold was discovered in the Black Hills, which the Sioux regarded as sacred ground. The resultant gold rush violated some of the terms of the 1868 treaty and antagonized the Sioux. Fort Laramie housed troops, a communications and logistical center, and a command post during the war against leaders such as Crazy Horse and Sitting Bull.

The fort's importance rapidly decreased between 1886 and 1890 following the completion of the transcontinental railroad that bypassed the fort to the south. The Army abandoned the fort in 1890, the year that Wyoming gained statehood. Local citizens bought the buildings and land at auction, although the auction was poorly attended due to inclement weather and muddy roads. John Hunton, the last post sutler, bought a dozen buildings. These buildings, plus the Sutler's Store, form the primary collection of surviving Fort Laramie buildings (Mattes 1980). More than 50 buildings were moved elsewhere or dismantled for building material. When John Hunton died in 1925, local newspaper editors drew attention to the deterioration and desecration of Fort Laramie. Citizens attending the first meeting of the Wyoming Historical Landmarks Commission in 1927 also voiced concern about the fate of the old fort. Public interest grew in 1930 with the 100th anniversary celebration marking the first wagons travelling the Platte route to Oregon. National Park Service representatives visited the site in 1936, and impressed with what they saw, expressed interest in preserving Fort Laramie to Wyoming Governor Leslie Miller. Governor Miller persuaded the Wyoming legislature to buy 87 ha (214 ac) in 1937. Wyoming subsequently deeded the property to the United States. President Franklin D. Roosevelt proclaimed Fort Laramie National Monument on July 16, 1938. Fort Laramie was redesignated as a National Historic Site on April 29, 1960, when Congress enlarged the park to its current size.

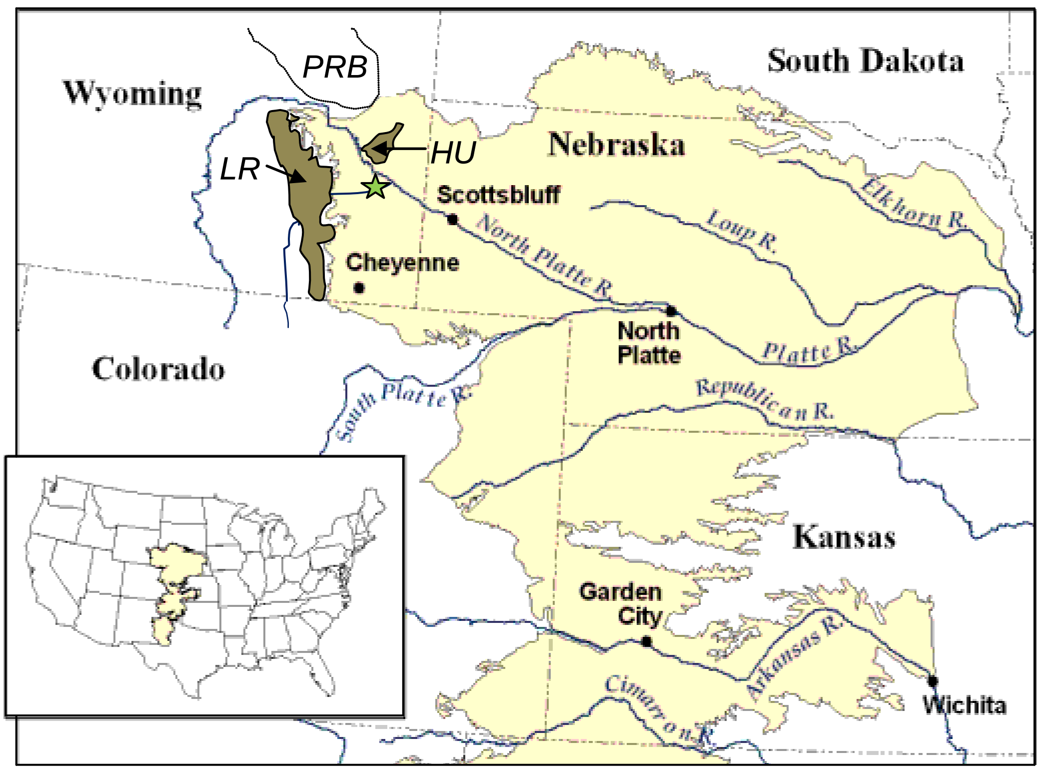

Figure 2. Northern segment of the High Plains surface. In Wyoming, the High Plains is bordered by the Laramie Range (LR) to the west and the Powder River Basin (PRB) to the north. The green star marks the approximate location of Fort Laramie National Historic Site, which lies southeast of the Hartville Uplift (HU). The inset map shows the entire extent of the High Plains surface. Modified from a U.S. Geological Survey figure, available at: http://co.water.usgs.gov/nawqa/hpgw/meetings/p0507.htm (accessed September 2009).

ERA	Period	Epoch	Formation (Fm) or Unit	Thickness in meters (feet)	General Lithology
CENOZOIC	Quaternary	Recent	unconsolidated	variable	Sand, silt, gravel
		Pleistocene	unconsolidated	variable	Sand, loess, silt, gravel
	Regional Unconformity Missing approximately 10.4 million years between the Pleistocene and early Miocene epochs				
	Tertiary (Paleogene and Neogene)	Miocene*	Arikaree Fm	200+ (700+)	Sandstone
		Miocene and Oligocene*	Unnamed Conglomerate	15-18 (50-60)	Conglomerate and sandstone
		Oligocene*	White River Fm	113-198 (370-650)	Siltstone and claystone
	Regional Unconformity Missing at least 31.6 million years between the Late Cretaceous and Oligocene epochs				
MESOZOIC	Cretaceous	Late	Lance Fm	424± (1390±)	Sandstone, shale, coal
			Fox Hills Sandstone	58± (190±)	Sandstone
			Pierre Shale	1,680± (5,520±)	Shale and sandstone
			Niobrara Fm	36-64 (117-210)	Shale and bentonite
			Frontier Fm	200± (650±)	Mostly gray shale
		Early	Mowry Fm	125-139 (410-455)	Dark gray to black shale
			Dakota (Muddy) Sandstone	11-30 (37-100)	Sandstone
			Thermopolis Shale	30-73 (100-240)	Black shale
			Cloverly Fm	21-98 (70-320)	Sandstone and shale
	Jurassic	Late	Morrison Fm	23-67 (77-220)	Shale
			Sundance Fm	64-120 (210-400)	Shale and sandstone
	Regional Unconformity Missing at least 38 million years				
	Triassic		Chugwater Group	46-183 (150-600)	Siltstone and shale
	Triassic?		Gypsum and red shale sequence	34-94 (110-310)	Gypsum and anhydrite separated by red shale
	Regional Unconformity Unknown amount of time				
PALEOZOIC	Permian?		Gypsum and red shale sequence	34-94 (110-310)	Gypsum and anhydrite separated by red shale
	Permian	Early	Minnekahta Limestone	6-12 (20-40)	Limestone
			Opeche Shale	8-9 (25-30)	Shale
	Pennsylvanian	Early to Late	Hartville Fm	200+ (700+)	Upper sandstone, limestone, dolomite, shale, basal sandstone
	Mississippian	Late			
		Early	Guernsey Fm	24-46 (80-150)	Dolomite; basal arkose
	Devonian	Late			
	Regional Unconformity Missing at least 157 million years of Upper and Middle Devonian, Silurian, Ordovician, and Cambrian rocks				
PRECAMBRIAN	Igneous and metamorphic rocks. Complex of granite, gneiss, schist, and quartzite. Age of crystalline basement is approximately 3 billion years (Day et al. 1999)				

Figure 3. Regional stratigraphic column for the Fort Laramie National Historic Site. * = Revised geologic age interpretations show the age of the White River Formation extending from the late Eocene into the Oligocene and the Arikaree Formation spanning late Oligocene and early Miocene-aged sediments (Tedford et al. 2004). Under such an interpretation, the unnamed conglomerate unit would represent late Oligocene-aged sediments. Only unconsolidated Quaternary deposits (yellow) are exposed within Fort Laramie National Historic Site, although Tertiary units (orange) are included on the reference map in Attachment 1 (McGrew 1963). Exposures of Precambrian, Paleozoic, and Mesozoic units may be found in the nearby Hartville Uplift. Modified from McGrew (1963).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Fort Laramie National Historic Site on June 12, 2002, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Three geologic issues were discussed at the scoping workshop for Fort Laramie National Historic Site (Appendix B). These issues included:

- erosion along the Laramie and North Platte rivers
- surficial geologic maps
- mining and reclamation.

Additional potential issues include minor seismic hazards and issues that may originate from activities outside the park boundaries, such as hydrocarbon exploration and mining operations. Contact the Geologic Resources Division for technical assistance.

Erosion

River erosion may expose or impact cultural resources at Fort Laramie National Historic Site. Cultural resources that have been uncovered by erosion include bison (commonly called buffalo) and elk bones attributed to historic hunting as well as the quartermaster's dump and remnants of the quartermaster's corral. However, while the exposure of these resources can add to the site's cultural history, they are often in danger of being washed away relatively quickly with further erosion.

The Laramie and North Platte rivers are meandering rivers wherein a single channel migrates back and forth across the floodplain, forming sinuous loops and curves (figs. 5 and 6). Meandering rivers erode laterally, rather than vertically, as their main current migrates from bank-to-bank. Unconsolidated sediments on the outside of each meander loop are eroded while sediment is deposited on the inside of the meander loop where the channel's energy decreases.

Both erosion and sedimentation occur at Fort Laramie National Historic Site as the Laramie River flows past the historic site (fig. 5). Over time, land is both added and subtracted from the site as the river erodes its banks. With the acreage donated in 2006, bank erosion became a concern not only with the Laramie River, but also at the confluence of the Laramie and North Platte rivers. During flood events and spring runoff, erosion may increase along both banks of the river. The volume of water released from the Grayrocks Reservoir, upstream from Fort Laramie, may also influence bank erosion.

Unique solutions may be required to decrease erosion and stabilize the river banks that border Fort Laramie National Historic Site. Rivers and river ecosystems are holistic systems where a change in one area may result in a modification in another area. In the mid-1990s, an erosion control project removed previously installed stream barbs from the Laramie River and recontoured the river bank and slope to a natural angle of repose (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, December 13, 2009). River restoration and bank stabilization are beyond the scope of this report, but park managers may consult the Water Resources Division of the National Park Service for further information (http://www.nature.nps.gov/water/, accessed September 2009).

Surficial Geologic Maps

Since no bedrock is exposed in Fort Laramie National Historic Site, detailed surficial geologic maps may prove to be more beneficial to management than bedrock maps. The 1963 bedrock map that was used to create the digital map for Fort Laramie National Historic Site (Appendix A and Attachment 1) combines the surface geology into only four Quaternary units, two of which comprise the surface geology of Fort Laramie National Historic Site (McGrew 1963). In addition, Grayrocks Reservoir, which controls the flow of the Laramie River, was created upstream from Fort Laramie National Historic Site in the 1970s. Not only does the park lack detailed descriptions of the two units, but also the general physical distribution and variety of unconsolidated material in the units may have changed since 1963. Overlaying a detailed surface geologic map onto soil and vegetation maps may also provide valuable information for resource management. The park's soils database (2006) and vegetation map (2001) have been completed through the Inventory and Monitoring program.

Mining and Reclamation

Non-federal entities hold mineral rights in the Fort Laramie area although the exact commodities are not known. The park owns subsurface mineral rights on some, but not all, of the more than 30 parcels of land that make up the park (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, December 13, 2009). Sand and gravel sites in the park near the Fort Laramie cemetery have been reclaimed. The sand and gravel quarry below the hospital will probably not be reclaimed because of its historic significance (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). The quarry provided material for the lime-grout used in the construction of the post hospital and other structures.

Seismic (Earthquake) Hazards

Although a minor concern, earthquakes do occur in the Fort Laramie area. Two earthquake epicenters greater than magnitude 2.5 or intensity III have occurred in Goshen County (Case and Green 2000). Intensity III earthquakes generate vibrations that feel similar to a passing truck and are noticeably felt indoors. The only historic earthquake with an intensity of III or greater in neighboring Platte County occurred in 1954 (Case and Green 2000; Case 2002). The epicenters of the Goshen County and Platte County earthquakes are located along the northeast-trending Whalen fault system (also called the Whalen-Wheatland fault system) that parallels the eastern border of the Hartville Uplift (McGrew 1963).

In 1984, a magnitude 5.5, intensity VI earthquake in Albany County shook the buildings at Fort Laramie National Historic Site and moved museum exhibits in the historic structures. Vibrations from an intensity VI earthquake may damage chimneys and are felt indoors and out. The 1984 earthquake cracked the wall of the Fort Laramie School and was felt in Wyoming, South Dakota, Nebraska, Colorado, Utah, Montana, and Kansas (Case and Green 2000; Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008).

Earthquakes that affected Fort Laramie have been reported in 1889, 1942, 1954, 1964, and 1992. In addition, the Post Surgeon reported a significant event in November 1882 that lasted about one minute and moved items that were not fastened down (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). In the Guernsey/Hartville area, a worst-case scenario could result in an intensity VI earthquake that may move some heavy furniture, dislodge some plaster, and damage some chimneys (Case 2002).

Potential External Issues

Oil and Gas

Fort Laramie National Historic Site and Goshen County lie on the northwest margin of the extensive Denver Basin (also known as the Denver-Cheyenne Basin, Denver-Julesburg Basin, or DJ Basin). This cratonic basin developed approximately 75 to 35 million years ago during the Laramide Orogeny (mountain-building event), and occupies parts of southeastern Wyoming, southwestern Nebraska, northwestern Kansas, and northeastern Colorado. The compressive tectonic forces that downwarped strata into the many basins in Colorado, Wyoming, and Montana also forced deeply buried rock units to the surface to form the Rocky Mountains.

Both the Denver and Powder River basins are prolific oil producers. Conceivably, oil may be present along the margin of the Denver Basin in the following hydrocarbon traps:

- up-dip stratigraphic traps where oil collects in porous and permeable rock units overlain by non-permeable strata,
- hydrogeologic traps in which groundwater pressure limits the upward flow of oil, or
- buried anticlinal structures that trap oil at the top of the convex fold (McGrew 1963; De Bruin 1993).

The potential impact to Fort Laramie National Historic Site from increased oil and gas exploration in southeastern Wyoming is not known, but Wyoming Oil and Gas Conservation Commission records suggest that such impact would be limited. Fort Laramie lies in central Goshen County near the border with Platte County to the west. Currently, no hydrocarbons are being produced in either county. In 2005, oil production ceased in Goshen County. Platte County has not produced oil or gas since 1994. The park owns subsurface mineral rights on some, but not all, of the more than 30 parcels of land that make up the park (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, December 13, 2009).

In the Public Land Survey System which is used to describe the location of oil wells and oil fields in Wyoming and other western states, Fort Laramie lies within Township 26 North and Range 64 West (T26N, R64W). For information regarding the organization and nomenclature of the Public Land Survey System, refer to http://www.nationalatlas.gov/articles/boundaries/a_plss.html (accessed September 2009). Table 1 identifies the oil fields in Goshen County and Platte County and the production activity in each field (Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us/, accessed September 2009).

The limited number of successful wells and production data suggest that further exploration in the immediate area of Fort Laramie is doubtful. Even when the oil fields in Goshen County were active, production was restricted to one or two wells in all but the Torrington field. Torrington, the oldest and most productive field in the county, had a maximum of four wells producing from 1982 to 1986.

In the Hawk Springs and Yoder fields, production steadily decreased from their initial discovery until they were abandoned. In the Springer field, production increased when a second well was added in 1988, but by 1993, production became sporadic. Fewer than 100 barrels of oil were produced in January, February, and November of 1993, and the field was subsequently abandoned. By 1991, only one well in the Torrington field produced any hydrocarbons. From 1996 until it was abandoned in 2005, the well produced less than 100 barrels of oil a month. No oil or gas was produced from Torrington Field from November 2004, when 46 barrels of oil were produced, until March 2005, when 2 barrels of oil were reported.

Production in Platte County is limited to the Chugspring field (T24N, R66W), the field closest to Fort Laramie National Historic Site and the only field in Platte County. Infrequent production and relatively minimal quantities of oil and gas characterize the Chugspring field. Except for two months in 1984 when two wells produced oil, only one well operated in the field. No oil was pumped from Chugspring from 1985 until 1993 when one well yielded 135 barrels of oil over three months. The last production came from one well in December 1994 that produced 88 barrels of oil (Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us, accessed September 2009).

Exploratory wells drilled to find new oil fields are called wildcat wells. No wildcat wells were drilled in Goshen County from 2000 to 2005. In 2005, six wildcat wells were permitted to be drilled south of Fort Laramie. Only two of these wells were drilled, and neither discovered oil or gas (table 2). In 2006, Kestrel Energy Inc. drilled the London Flats No. 1-29H exploratory well in T25N and R63W, approximately 6 km (4 mi) southeast of Fort Laramie National Historic Site. The well produced minor amounts of oil from the Cretaceous Niobrara Formation, but was plugged and abandoned in October 2008 (Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us, accessed September 2009).

From 2007 to September 2009, four wildcat wells were drilled north of Fort Laramie in Goshen County, but none of these discovered reservoirs of oil or gas (table 2). One well targeted the Jurassic Sundance Formation; one drilled to the Mississippian Amsden Formation; and data on the other two wells remain confidential (Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us/, accessed September 2009).

Cretaceous formations are also primary targets in the hydrocarbon-rich Powder River Basin, north of the Hartville Uplift. The Shawnee Field (T32N, R69W) lies approximately 56 km (35 mi) northwest of the Fort Laramie area on the southern flank of the Powder River Basin (McGrew 1963; De Bruin 1993; Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us, accessed September 2009). As an indication of the Shawnee Field's productivity, September 2009 production totaled 356 barrels of oil and 521 million cubic feet (mcf) of gas from Cretaceous rocks. The Hartville Uplift effectively segregates any hydrocarbons in the Powder River Basin from migrating into the Denver Basin.

Coal Deposits

No state produces more coal than Wyoming. Thirty-nine states use Wyoming coal, and in 2008, Wyoming coal mines produced a record 424.24 million metric tons (467.64 million tons) of coal, approximately 39% of total U.S. coal production (Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/coal, accessed September 2009). Coal generates about 50% of the nation's electricity, and Wyoming coal accounts for 30% of this total. Furthermore, Wyoming has more than twice the in-place coal resources of any other state in the contiguous United States. Only Alaska contains more in-place coal than Wyoming (Moore and Shearer 1993; Cook 2003).

Any potential impacts from coal mining such as an increase in particular matter and dust that might devalue the viewscape at Fort Laramie National Historic Site would probably result from increased production in the nearby Goshen Hole Coal Field (fig. 7). In comparison to other coal fields in Wyoming, however, the potential for economic coal development in the Goshen Hole Coal Field appears to be limited.

The only formation in the Goshen Hole Coal Field that contains coal beds is the Upper Cretaceous Lance Formation. Except for the Black Hills Coal Field in northeastern Wyoming, all other coal fields in Wyoming extract coal from three or more formations (Moore and Shearer 1993). Furthermore, coal seams in the Lance Formation are rare (3 or fewer seams). Abundant (more than 10 seams) coal beds exist in the Green River, Hanna, Hams Fork, Wind River, Jackson Hole, and Rock Creek coal fields (fig. 7). Lance Formation coal beds are also thin, ranging in thickness from a maximum of 0.6 m (2 ft) to less than 0.3 m (1 ft). In contrast, coal beds over 9 m (30ft) thick are found in the Powder River, Green River, and Jackson Hole coal fields (Moore and Shearer 1993; Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/coalweb/, accessed September 2009).

Goshen Hole Coal Field contains the fewest remaining in-place resources of the 10 Wyoming coal fields (Cook 2003). In-place resources in Goshen Hole amount to 209 million metric tons (230 million short tons). In contrast, the Powder River Coal Field contains 930,197 million metric tons (1,025,366 million short tons) of remaining in-place coal resources (Cook 2003). With only five of Wyoming's 10 coal fields currently producing, Goshen Hole Coal Field may see little activity in the near future.

Industrial Minerals

Mining for industrial minerals also poses minimal concern for Fort Laramie National Historic Site management, but industrial minerals do exist in the area. Industrial minerals include rocks and minerals that are not produced as sources of metals, excluding mineral fuels (Harris 1993). Industrial mineral occurrences in the Fort Laramie area include decorative stone, limestone, and diatomite.

In the Goshen Hole area, bedded potash (potassium carbonate) is present in the subsurface. Northeastern Platte County contains mines or quarries that produce limestone, mineral pigment, and railroad ballast (Harris 1993). The military mined limestone from a quarry just west of Guernsey, Wyoming to make lime grout. The park still contains a pile of unburned limestone from the Late Devonian or Early Mississippian-aged Guernsey Formation (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, December 13, 2009).

Construction Aggregate

Construction aggregate consists of sized, or crushed and sized, rock material that may be used in a variety of construction products. Considered to be industrial minerals, aggregates range in size from large boulders used as riprap to finely-ground, flour-sized particles used in paint, glass, plastic, medicine, agricultural feed, soil conditioners, and many other industrial and household products. Construction aggregate forms more than 90% of asphalt pavement and 80% of concrete. About 48% of all construction aggregate is sand and gravel; the remaining 52% consists of crushed stone (Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/industrial/aggregate.aspx, accessed September 2009).

Construction aggregates are the fourth most important (by value) mineral product produced in Wyoming after oil and gas, coal, and trona (natural sodium carbonate-bicarbonate, or soda ash, used in soaps, detergents, inorganic chemicals, water purification, and other products and processes). In 2006, Wyoming produced 19,344,445 metric tons (21,323,600 short tons) of construction aggregate (Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/Topics/IndustrialMinerals/aggregate.aspx, accessed September 2009).

One of the most abundant natural resources, construction aggregates are also the least expensive of all mined products. Transportation costs from the mine to the point of use are usually the primary expense to the consumer. In order to keep transportation costs from exceeding the cost of the product, aggregate sources are usually located as close as possible to the point of use. Locating economical aggregate sources close to population centers may create conflicts between aggregate producers and local populations.

Extensive alluvial and terrace sand and gravel deposits are distributed throughout the northern part of the Fort Laramie area (fig. 8) (McGrew 1963; Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/Topics/IndustrialMinerals/aggregate.aspx, accessed September 2009). Unconsolidated Pleistocene terrace gravel deposits up to 6 m (20 ft) thick are found locally along the North Platte and Laramie rivers (fig. 8). Potential issues that may arise from sand and gravel mining include the disruption of the riparian ecosystem, a change in stream dynamics (including increased sedimentation), and increased bank erosion.

Potential quarries on Bureau of Land Management (BLM) acreage adjacent to Fort Laramie National Historic Site may present management issues in the future. Some of these quarries are additionally sited on historic trails. In the past, Goshen County operated a construction aggregate quarry 0.8 km (0.5 mi) southwest of the park, and the BLM has periodically expressed interest in opening gravel quarries in the area (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). The degree to which construction aggregate mining will present a resource management issue for Fort Laramie National Historic Site is not known.

Copper and Iron Mining in the Hartville Uplift

Metal production began in the Hartville Uplift as early as 1880 with copper mining (Sims and Day 1999). Soldiers from Fort Laramie were the first to stake mining claims near Sunrise, Wyoming. From 1882 to 1912, the Hartville region produced at least 6,800 metric tons (1.5 million pounds) of copper and 0.9 metric tons (2,000 pounds) of silver (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). Miners also found small quantities of gold.

As copper production decreased, miners extracted iron deposits that were associated with the copper. Iron mining began with the Sunrise Mine in 1898 and continued for almost a century (fig. 9). Historically one of the most prolific iron mines west of the Mississippi, the Sunrise Mine closed in 1980, succumbing to cheaper foreign iron and rising transportation costs. By that time, the Hartville district had produced about 41 million metric tons (90 billion pounds) of iron ore (Sims and Day 1999).

Significant metals production has not occurred in Wyoming since iron ore mining ended at South Pass (southwestern Wyoming) in 1984. However, with the rapid increase in the metal's prices in recent years, exploration has increased for Wyoming's gold, platinum, copper, iron, rare earth elements, titanium, and related metals. Remaining iron deposits in the Hartville Uplift may offer the most significant potential for renewed mining (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008).

Increased mining activity in the Hartville Uplift may indirectly impact Fort Laramie National Historic Site. Sediment load may increase in tributaries and trunk channels within the Laramie River and North Platte River drainage systems, which may, in turn, modify bank erosion at old Fort Laramie and at the confluence of the two rivers. Depending on the level of mining activity, there may be increased development near Guernsey or Fort Laramie, which might encroach upon the park's boundaries.

Uranium mining

Although Wyoming is rich in uranium, uranium mining should present only a minor issue for park management. Wyoming has led the nation in uranium ore production since 1995 and contains the nation's largest uranium reserves. Uranium ore deposits primarily occur in Paleocene and Eocene sandstones in basins that lie west and northwest of Goshen County (Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/Topics/Uranium/originUranium.aspx, accessed September 2009).

While almost every county contains uranium mineralization, Goshen County does not contain any uranium fields (Harris and King 1993). Wyoming's only currently active uranium mine, the Smith Ranch-Highland operation, extracts uranium ore from the southern Powder River Basin in west-central Converse County, approximately 122 km (76 mi) northwest of Fort Laramie National Historic Site (Wyoming State Geological Survey, http://www.wsgs.uwyo.edu/WSGSgroups/Uranium/Default.aspx, accessed September 2009).

Nine water samples were collected from springs and wells issuing from Tertiary rocks in or near the Fort Laramie area during 1955, and one sample was collected from a stream (McGrew 1963). Samples from the springs and wells in the Miocene Arikaree Formation averaged 15.1 parts per billion (ppb) uranium, and those from the Oligocene White River Formation averaged 20 ppb. For comparison, the Environmental Protection Agency's (EPA) maximum contaminant level for uranium in a public water supply is 30 ppb. Analysis of the stream sample measured 3 ppb uranium.

One rock sample collected in the White River Formation about 32 km (20 mi) southeast of the Fort Laramie area in Goshen Hole contained 118 ppb uranium. A sample of conglomerate from the lower part of the White River Formation collected about 3 km (2 mi) south of Fort Laramie contained 0.004% uranium oxides. Low-grade uranium ore typically contains between 0.01 and 0.25% uranium oxide, suggesting that the sample collected near the park should not result in increased uranium exploration in the immediate vicinity.

However, geologic units containing uranium do occur in southeastern Wyoming (table 3) (Harris and King 1993). In the past, significant uranium production came from the Ogallala, Wasatch, and Fort Union formations. Should future economic conditions warrant increased uranium exploration, these units in Goshen County may become exploration targets. If mining does occur, open-pit uranium mining operations may pose environmental and aesthetic issues for Fort Laramie resource managers.

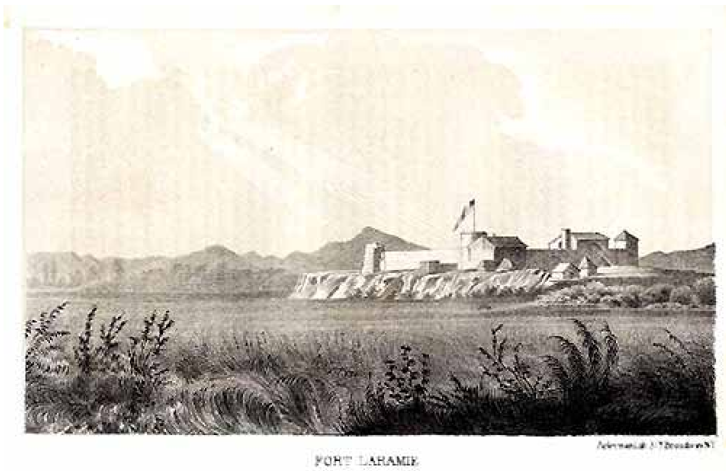

Figure 4. Fort Laramie, 1850. Engraving from the 1849-1850 expedition led by Captain Howard Stanbury and guided by Jim Bridger. In this engraving, a wall surrounds the fort. Compare the steep bluffs and broad expanse of the Laramie River with the present channel geometry and river banks in figures 5 and 6, which postdate the construction of the upstream Grayrocks Dam. Engravings, sketches, and historic photographs are available at Wyoming Tales and Trails, http://www.wyomingtalesandtrails.com/photos.html (accessed September 2009).

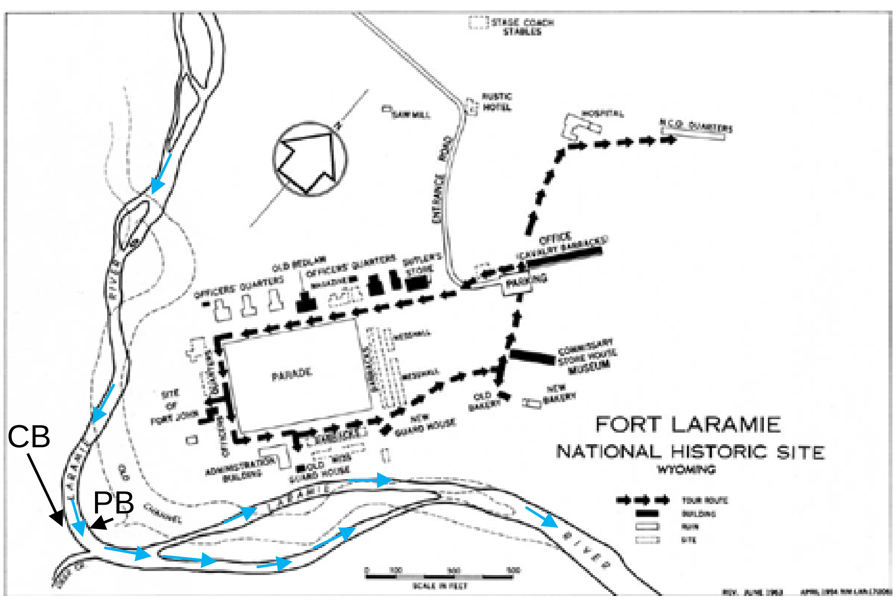

Figure 5. Past and present meandering pattern of the Laramie River at Fort Laramie National Historic Site. Blue arrows indicate current direction. Bank erosion occurs along the outside of the meander loop, called a cutbank (CB); sedimentation occurs along the inside of the meander loop, called a point bar (PB). Eroding laterally across its floodplain, the Laramie River continually changes its position on the landscape. The "old channel" may be the channel seen in figure 4. Islands forming in the Laramie River reflect a dynamic equilibrium between the river's energy and its sediment load, which are influenced by discharge from Grayrocks Reservoir. Map modified from a National Park Service graphic, http://www.nps.gov/history/history/online_books/hh/20/hh20s.htm (accessed September 2009).

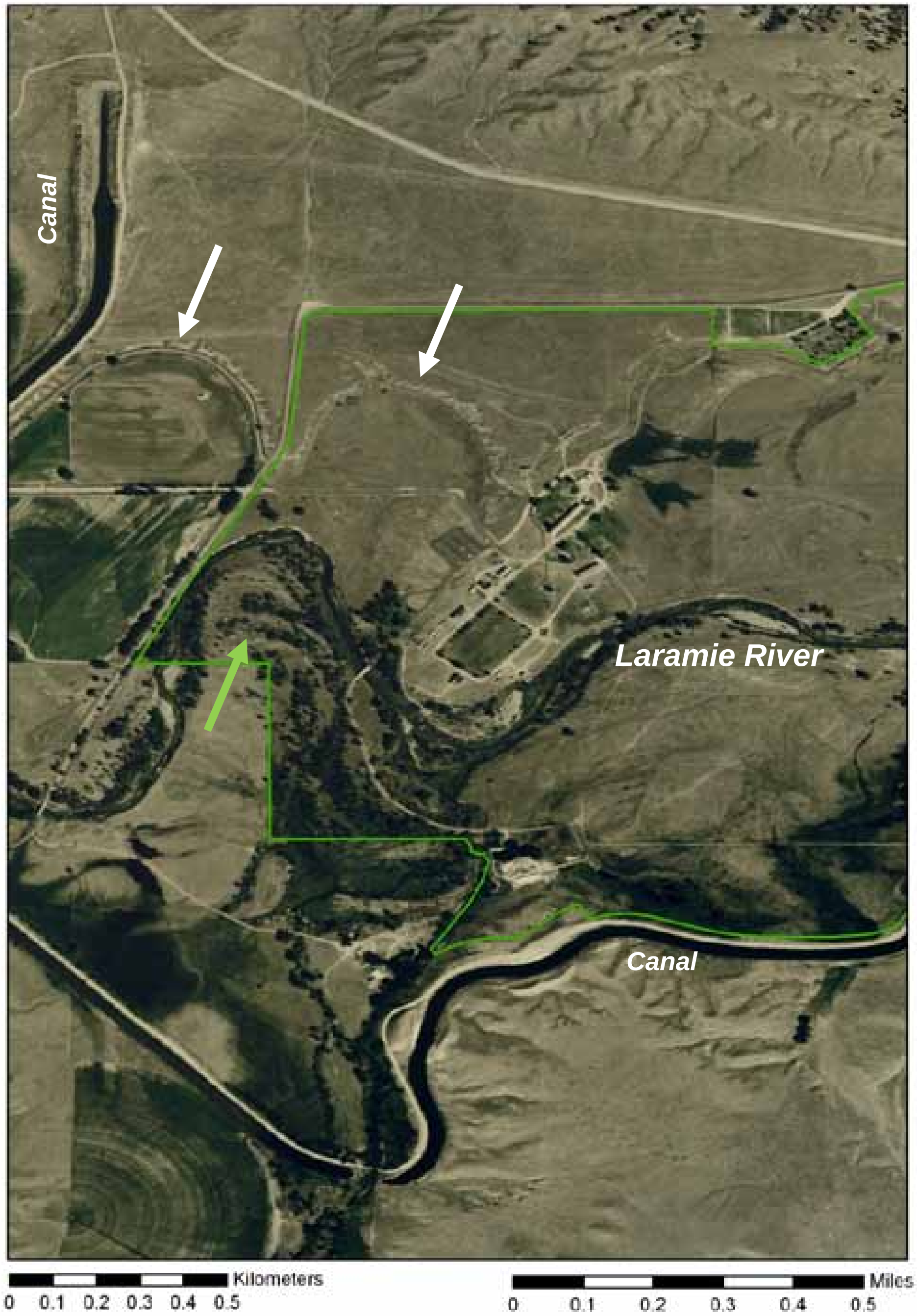

Figure 6. Aerial image of the western portion of Fort Laramie National Historic Site (green line represents park boundary). The current channel of the Laramie River meanders across the middle of the image. Abandoned meanders and terraces mark the edge of the modern floodplain (white arrows). Vegetation patterns (green arrow) west of the main fort area suggest the courses of previous river channels. Compiled from ESRI Arc Image Service, USA Prime Imagery.

Table 1. Oil and gas fields in Goshen and Platte counties, listed by date of discovery. Data from the Wyoming Oil and Gas Conservation Commission, available at: http://wogcc.state.wy.us/ (accessed September 2009).

Field	General Location	Discovered	Cumulative Production in barrels of Oil (Gas in MCF*)	Target Formation	Date of last Production	Current Activity
Torrington	T24N-R61W Goshen Co.	1955	565,045 (66,215)	Dakota (Cretaceous)	03/2005	None
Springer	T23N-R62W Goshen Co.	1974	22,130 (30)	Codell Sand (Cretaceous)	10/1993	None
Chugsprings	T24N-R66W Platte Co.	1975	1,048 (1,868)	Codell Sand, Dakota, Frontier, Niobrara (Cretaceous)	12/1994	None
Hawks Springs	T20N-R62W Goshen Co.	1983	9,840 (491)	Dakota (Cretaceous)	01/1987	None
Yoder	T22N-R61W Goshen Co.	1985	20,138 (0)	Dakota (Cretaceous)	09/1989	None

* MCF: million cubic feet

Table 2. Exploratory (wildcat) oil and gas wells drilled in Goshen County from 2000 to September 2009. Data from the Wyoming Oil and Gas Conservation Commission, available at: http://wogcc.state.wy.us/ (accessed September 2009).

Current Operator	Well Name	Location (sec, T, R)	Date Drilled (mm/dd/yyyy)	Target Formation	Total Depth*	Status
Kestrel Energy	Hereford 1	10, T21N, R63W	11/07/2005	Fox Hills (Cretaceous)	1,234	Abandoned: 11/15/2005
Kestrel Energy	Twin Buttes 1	7, T24N, R63W	11/16/2005	Fox Hills (Cretaceous)	1,970	Abandoned: 12/04/2005
Samson Oil & Gas USA (original: Kestrel Energy)	London Flats 1-29H	29, T25N, R63W	05/04/2006	Niobrara (Cretaceous)	9,173	Completed: 08/03/2006 Abandoned: 10/03/2008
Thunder Hill Exploration	Badger Ranch 9-1	9, T28N, R63W	04/26/2007	Amsden (Mississippian)	3,500	Abandoned: 06/22/2007
Diamond Peak Energy	Rollins Petch 24-6	24, T28N, R62W	05/03/2008	Sundance (Jurassic)	5,520	Abandoned: 05/08/2008
Thunder Hill Exploration	Badger Ranch 32-1	32, T29N, R63W	Confidential Record (No Completion or Production Reported)			
Diamond Peak Energy	Six Mile Creek 1	24, T28N, R62W	Confidential Record (No Completion or Production Reported)			

* Depth is measured in feet from the surface of the ground.

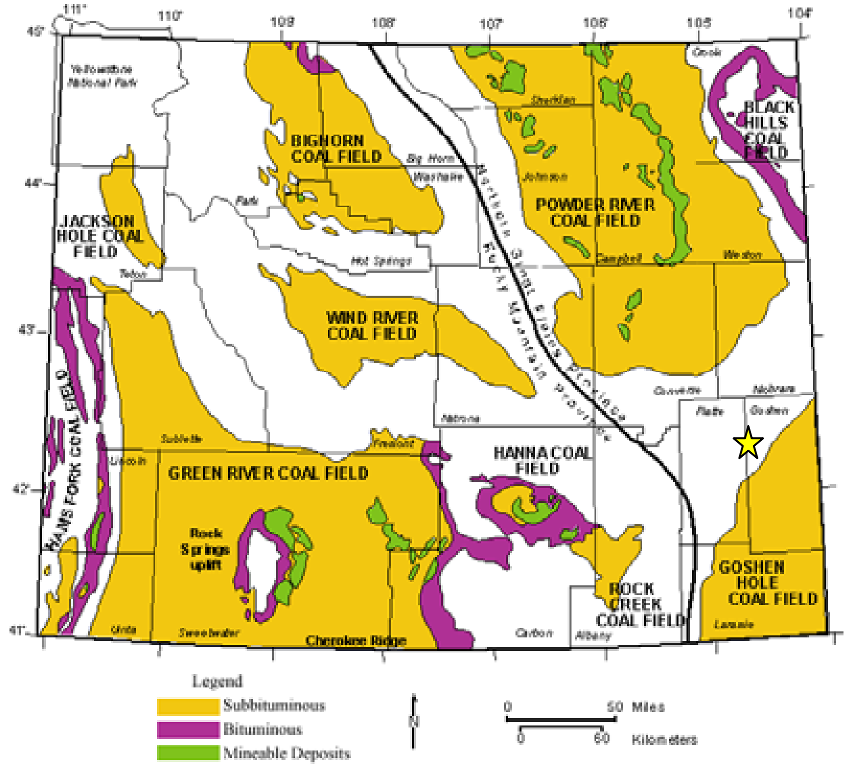

Figure 7. Wyoming coal fields underlie approximately 54% of the state (Cook 2003). The yellow star marks the approximate location of Fort Laramie National Historic Site. Fields with the most recent production include the Powder River, Green River, Hanna, Bighorn, and Hams Fork coal fields. Modified from Moore and Shearer (1993).

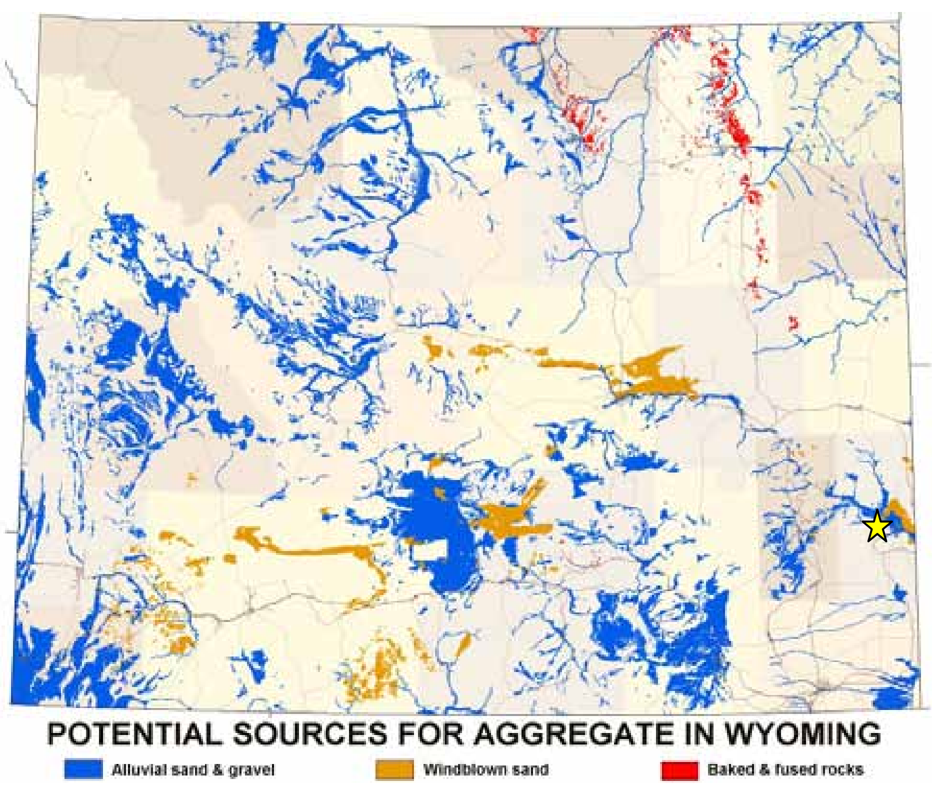

Figure 8. Sand and gravel (aggregate) deposits in Wyoming. The yellow star marks the approximate location of Fort Laramie National Historic Site. Modified from Harris (2004) and available at http://www.wsgs.uwyo.edu/Topics/IndustrialMinerals/aggregate.aspx (accessed September 2009).

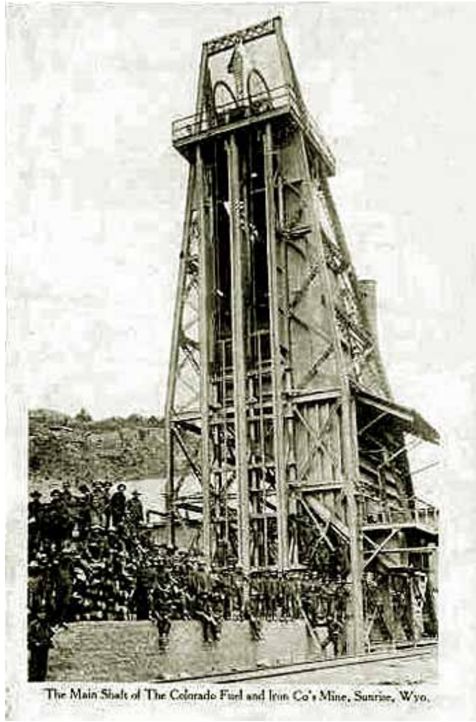

Figure 9. The main shaft of the Sunrise Mine in 1907. Photograph available at Wyoming Tales and Trails, http://www.wyomingtalesandtrails.com/nplatte2.html (accessed September 2009).

Table 3. Geologic units in southeastern Wyoming that host known uranium occurrences (Harris and King 1993).

Age (millions of years)	**Geologic Unit**
Miocene (5.3-23.0)	Ogallala Formation Arikaree Formation
Oligocene (23.0-33.9)	White River Formation Brule Formation Chadron Formation
Eocene (33.9-55.8)	Wasatch Formation Wind River Formation
Paleocene (55.8-65.5)	Fort Union Formation
Cretaceous (65.5-145.5)	Fox Hills Sandstone Pierre Shale Mesaverde Formation (Group) Cloverly Formation
Jurassic (145.5-199.6)	Morrison Formation
Pennsylvanian and Permian (251.0-318.1)	Casper Formation
Pennsylvanian (299.0-318.1)	Fountain Formation
Mississippian (318.1-359.2)	Madison Limestone
Cambrian (488-542)	Deadwood Formation Flathead Sandstone
Precambrian (>542)	undifferentiated

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Fort Laramie National Historic Site.

Fort Laramie National Historic Site lies almost entirely within mapped flood-plain deposits (McGrew 1963). Consequently, recent geomorphic features dominate the immediate Fort Laramie landscape. Quaternary (2.588 million years ago to present) terrace gravel deposits along the Laramie and North Platte rivers can be as thick as 6 m (20 ft), and represent at least three stages of vertical stream erosion. Finer grained sediments and gravel deposits are locally derived from weathered Oligocene (33.9 to 23.03 million years ago) and Miocene (23.03 to 5.332 million years ago) rocks. Some of the gravel may also have been derived from rocks in the Laramie Mountains and Hartville Uplift through which the streams flow.

The Fort Laramie region, however, includes a variety of older stratigraphic features, fossils, and geologic structures. These features allow geologists to reconstruct the geologic past, which is presented in the "Geologic History" section of the report.

Geomorphic Features

Laramie River Features

Grayrocks Dam controls the flow of the Laramie River between Grayrocks Reservoir and the confluence with the North Platte River at Fort Laramie. Constructed in the late 1970s, Grayrocks Dam provides cooling water to a 1,500 megawatt coal-fired power plant, part of the Missouri Basin Power Project. The reservoir also provides many recreational opportunities.

McGrew's 1963 geologic map of the Fort Laramie area shows the tight meandering pattern of the Laramie River prior to construction of Grayrocks Dam. The deepest part of the river's current, that which contains the maximum depth and therefore the greatest amount of energy, is called the *thalweg*. The thalweg migrates from bank to bank, laterally eroding unconsolidated sediment and creating the river's sinuous pattern (figs. 5 and 6). The steep, outside curve of a meander is called a *cutbank* (fig. 10). Erosion of the cutbank adds material to the suspended sediment load of the river. On the opposite shore, away from the thalweg, the current decreases and sediment falls out of suspension to form a *point bar* (fig. 10).

Laramie River floodplain deposits and meander loops do not extend across the valley, suggesting that today's Laramie River did not erode the full width of the valley (McGrew 1963). Rivers that appear to be too small to have eroded the valleys through which they flow are termed *underfit* rivers. The Laramie River may be an underfit river, but the reason for this is not clear.

Underfit streams may result from such natural processes as stream capture, glacial activity, or climatic variations. Stream capture usually occurs at higher elevations when the headwaters of one stream are diverted into another stream having greater erosional activity and flowing at a lower elevation. Alpine glaciers often carve valleys much larger than the rivers that eventually flow through them. The Laramie River begins in Colorado's Front Range, flows north through the Laramie Basin located adjacent to the western flank of the Laramie Range, and cuts a deep canyon through the mountains before flowing northeast towards the confluence with the North Platte River. Neither stream capture nor glacial erosion appears to be the cause of the diminished size of the Laramie River compared to its valley.

However, the climate during the most recent Pleistocene "ice age," approximately 110,000 to 12,000 years ago, was much wetter than it is today. Conceivably, the Laramie River carried a greater volume of water during the Pleistocene than it does today. A greater volume of water would have led to increased discharge rates, increased lateral erosion, and meander loops that would have defined the width of the valley. As the climate became more arid, the amount of water in the Laramie River decreased, leading to subsequent decreases in erosion and radii of meander loops.

North Platte River Features

In contrast to the underfit Laramie River, the North Platte River meanders from valley wall to valley wall, although not in the immediate Fort Laramie area. Significant meandering begins about 5 km (3 mi) east of the park, where the North Platte Valley widens from approximately 2.0 km (1.25 mi) to 6.8 km (4.25 mi).

Since 1909, the Whalen Diversion Dam, located between Guernsey and Fort Laramie, has been diverting water from the North Platte River as part of the North Platte Project. The North Platte Project provides irrigation for about 91,500 ha (226,000 ac) from Guernsey, Wyoming to Bridgeport, Nebraska (http://www.usbr.gov/projects/Project.jsp?proj_Name=North+Platte+Project, accessed September 2009). Water is diverted into the Fort Laramie Canal, south of the river, and into the Interstate Canal on the north side of the river.

Laramie and North Platte River Valleys

The west-to-east-trending Laramie and North Platte rivers and their respective river valleys intersect Wyoming's north-trending mountain ranges and faults at high angles, suggesting they post-date the deformation events that created these structural features (fig. 11) (McGrew 1963). For example, both river valleys intersect the Miocene-age Whalen fault system at approximately 60° to 90°, and the canyon cut by the Laramie River across the north-south Laramie Range trends west-east. In similar fashion, the North Platte River, which flows into Wyoming from Colorado, crosses Wyoming's northwest-trending Medicine Bow Mountains at a high angle.

The reason for the apparent lack of structural control on the orientation of the river valleys reflects a transition from depositional environments in the early Tertiary to erosional episodes in the late Tertiary and Quaternary. Deformation during the Late Cretaceous-Eocene Laramide Orogeny formed the Rocky Mountains and associated north-south trending basins such as the Powder River and Green River basins. The absence of Paleocene (66.5 to 55.8 million years ago) and Eocene (55.8 to 33.9 million years ago) deposits in southeastern Wyoming probably reflects either nondeposition on a topographically high region or uplift of the region followed by erosion. However, by the end of the Miocene, approximately 5.33 million years ago, fluvial sediments and volcanic ash had filled the Rocky Mountain basins and covered the crests of the Laramie Mountains (Wayne et al. 1991).

By the time a change from deposition to erosion began approximately 5 million years ago, the Laramie River had established its course in the sediments that buried the Laramie Range. About 2 million years ago, the river began to vertically erode into the buried mountain range, eventually cutting a deep canyon that now transects the range (Lageson and Spearing 1988). Rejuvenated streams, regional uplift, and increased precipitation and runoff due to climate change may all have played a role in the transition to an erosional landscape (Reheis et al. 1991). Regional erosion proceeded to etch out the present High Plains and the west-to-east trending Laramie and Platte River valleys.

Regional Stratigraphic Features

Arikaree Formation

Widely exposed in the Fort Laramie area, the Arikaree Formation may be as thick as 210 m (700 ft) (McGrew 1963). The formation contains white, siliceous, tubular structures and numerous calcareous (containing calcium carbonate), pipe-like sandstone concretions, called pipy concretions (fig. 12). The tubular structures are believed to be root casts. The elongate, pipy concretions range from a few centimeters to more than 2.4 m (8 ft) in length and from less than 2.54 cm (1 in) to more than 0.6 m (2 ft) in diameter. The northeast-trending, long axes of these concretions parallel bedding planes, which suggests that they may have originated from calcite precipitation as groundwater flowed through the original sediments (McGrew 1963). In some areas, calcite precipitation around sand grains has formed calcite-sand crystals that measure up to 1.9 cm (0.75 in) in diameter and 5 cm (2 in) in length.

The Arikaree Formation may be subdivided into three distinct rock units. The orange-gray, 60–90 m- (200–300 ft-) thick lower unit consists of loosely-cemented, fine- to medium-grained sandstone that weathers into vertical cliffs and columnar-type badlands. High clay content in the matrix of the unit produces the orange-gray color. A few thin beds of volcanic tuff, ranging from a few centimeters to 0.9 m (3 ft) thick, are included in this unit.

The 60-m- (200 -ft) thick middle unit consists of light-gray, fine- to medium-grained calcareous sandstone and fresh-water limestone. The middle unit contains more white siliceous root casts and carbonate than the lower unit. Calcareous, pipy sandstone concretions are common throughout. Because of pronounced stratification and numerous hard calcareous layers, the middle unit weathers to a broad undulating surface in contrast to the steep, badland-type topography typical of the underlying and overlying strata. The undulating surface forms the high plain on the divide between the Laramie River and Goshen Hole.

Poorly-cemented, fine- to medium-grained, orange-gray sandstone is again present in the 60-m- (200 -ft) thick upper unit, which contains both calcareous and sandstone layers. Calcareous sandstone concretions are common. This unit contains more siliceous root casts than either the lower or middle units. In places, a complex network of siliceous tubes forms layers several meters thick. Where exposed, these layers weather to a very hard, rough surface. Thick, poorly cemented sandstone beds lie between hard, calcareous concretionary ledges, and as in the lower unit, weather into vertical cliffs and columnar-type badlands.

Unnamed Conglomerate

An unnamed conglomerate sequence crops out north of Cherry Creek in the Goshen Hole area and along the north bank of the North Platte River on McGrew's map (1963). It is also exposed near Grayrocks Dam where Grayrocks Road descends toward the reservoir, and near the historic Hog Ranch just 5 km (3 mi) east of the park (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). At Grayrocks Dam and Hog Ranch, the unit is approximately 6 m (20 ft) thick. Along the northwest rim of Goshen Hole north of Cherry Creek, the unit measures 15-18 m (50-60 ft) thick.

The well-cemented, cross-bedded conglomerate consists of unsorted, rounded to subrounded, coarse-grained sand, pebbles, cobbles, and boulders up to 0.3 m (1 ft) in diameter. The clasts are composed of Precambrian granite, gneiss, quartzite, and schist and Paleozoic quartzite, limestone, dolomite, and siltstone derived from the Guernsey and Hartville formations (McGrew 1963).

White River Formation

White River Formation strata exposed northwest of the historic Fort Laramie and west of the Whalen fault system comprise the oldest rocks in the Fort Laramie area. The lower part of the formation consists of 24 m (80 ft) of variegated gray, green, white, pink, and maroon bentonitic claystone while the upper part of the formation consists of approximately 88-174 m (290-570 ft) of orange-gray siltstone and silty claystone. Coarse-grained sandstone, deposited in Oligocene river channels, and lens-shaped layers of conglomerate are common. Thin, white, tuff beds in the formation record Oligocene volcanic activity to the west.

Fossils

Fossils dating from the late Eocene through the late Pleistocene have been found in the Fort Laramie region. In the late 1800s, the military from Fort Laramie often escorted Othniel C. Marsh, Yale's famous dinosaur hunter, on expeditions into the territory. Officers would often collect fossils from the area on other occasions, as well. Through the years, anecdotal information suggests that some Oligocene – Miocene fossils may have been discovered near the fort (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). This section reviews some of the more notable discoveries in the area.

Caution is warranted when interpreting older geology and paleontology publications. During the 1990s, paleontologists' understanding of the chronology and biostratigraphy of the Eocene, Oligocene, and Miocene increased dramatically. For example, many fossils and rocks previously considered to be early Oligocene are now considered late Eocene in age. Where appropriate, revised chronology (from the Paleobiology Database, http://paleodb.org, accessed November 2009 and Tedford et al. 2004) is utilized in this section, and thus may differ from that in McGrew (1963). Likewise many taxonomic assignments have been modified since McGrew's publication. The original identification from her publication is reported in quotation marks; updated identifications (from the Paleobiology Database, http://paleodb.org, accessed November 2009) are given in parentheses.

Vertebrate fossils have been collected from many horizons within the White River Formation (McGrew 1963). The diagnostic fossil rodent of late Eocene age, *Cylindrodon*, marks the change to Oligocene faunas about 12 m (40 ft) above the lithologic change from the variegated bentonitic claystone to the overlying, orange-gray siltstone.

Oligocene fossils of a three-toed horse, *Miohippus*, and two primitive hypertragulids (an extinct ungulate family), *Hypisodus* and *Leptomeryx*, were discovered near the top of the unnamed conglomerate unit northwest of the park (McGrew 1963).

Arikaree Formation strata have yielded one of the most significant records of Miocene fossils in the world at Agate Fossil Beds National Monument, located 80 km (50 mi) northeast of Fort Laramie. A similar, although much less diverse, Miocene fossil record is represented by discoveries from the Fort Laramie region. The age of the Arikaree Formation in the Fort Laramie area is based partly on stratigraphic position and partly on fossil oreodonts, which are extinct, sheep-size, cud-chewing plant-eaters (McGrew 1963). The lower unit in the Fort Laramie area contains both "*Cyclopidius lullianus*" (now *Leptauchenia major*) and "*Mesoreodon megalodon*" (now *Desmatochoerus megalodon*) that McGrew suggested were correlative with the Gering or Monroe Creek formations in the Arikaree Group of Nebraska. Tedford and others (2004) consider these formations late Oligocene in age. Part of the upper unit of the Arikaree in the Fort Laramie area is late Oligocene or early Miocene age, based on the fossil oreodont, "*Phenacocoelus stouti*" (now *Merycoides longiceps*).

The Miocene fossil rodent burrow, *Daemonelix,* was discovered in the middle unit of the Arikaree Formation at "register cliff," 19 km (12 m) west of Fort Laramie National Historic Site (Steve Fullmer, NPS, Fort Laramie NHS park ranger, written communication, October 30, 2008). This burrow indicates a stratigraphic position and age equivalent to the Harrison Formation, also within the Arikaree Group, at Agate Fossil Beds and Scotts Bluff national monuments. Called the "Devils Corkscrew," the *Daemonelix* structure is an elongate spiral burrow of the extinct rodent *Palaeocastor*. Such burrows can be up to 3 m (10 ft) long (fig. 13).

A fossil rodent, "*Palustrimus*," (now *Entoptychus*) was discovered 10 km (6 mi) west-northwest of Fort Laramie National Historic Site in 1960 (Black 1960). The type specimen for this fossil had been lost since 1950. Other vertebrate genera at the site included the extinct rodents *Prosciurus*, *Pormylagaulus*, *Heliscomys*, and *Palaeocastor*.

A Pleistocene fossil mammoth tooth in the University of Wyoming collections that was discovered in "the high hill" east of Wheatland may have come from terrace gravel deposits (McGrew 1963). Tributaries of the North Platte and Laramie Rivers actively dissect valley alluvium, and in 1963, charcoal layers were observed in Cottonwood and Little Cottonwood draws, Cherry Creek Valley, and Eagles Nest Canyon, south of the park (McGrew 1963). *Bison* sp. remains in the charcoal layers in Cherry Creek Valley date the valley alluvium to the latest Pleistocene or younger. The skull of a mountain sheep, *Ovis canadensis* Shaw, collected from Little Cottonwood Draw alluvial deposits, also suggests a late Pleistocene to Holocene age.

Structural Features

Normal faults (fig. 14) that displace Tertiary deposits have been mapped west of Fort Laramie National Historic Site as part of the northeast-southwest trending Whalen fault system (McGrew 1963). The faults generally trend north 45° east. The main fault dips from 74° to 77° to the southeast. It separates the Arikaree Formation, on the downthrown side of the fault (southeast), from the unnamed conglomerate and White River Formation, on the upthrown side of the fault (northwest). Displacement along the main fault in the Fort Laramie area is about 180 m (600 ft).

In 1963, McGrew mapped a small anticline (convex fold) west of the Fort Laramie area. Oriented parallel to the Hartville Uplift, the upright fold contained a few isolated exposures of rocks in some low hills that McGrew termed the Moonshine Hills (McGrew 1963). These hills now lie beneath the surface of Grayrocks Reservoir.

Anticlines and synclines (concave folds) result from tectonic compression and may be associated with reverse, or thrust, faults (fig. 14). The Rocky Mountains, including the nearby Laramie Range, and north-south trending basins in Wyoming resulted from compression during the Laramide Orogeny that folded and thrust strata from west to east.

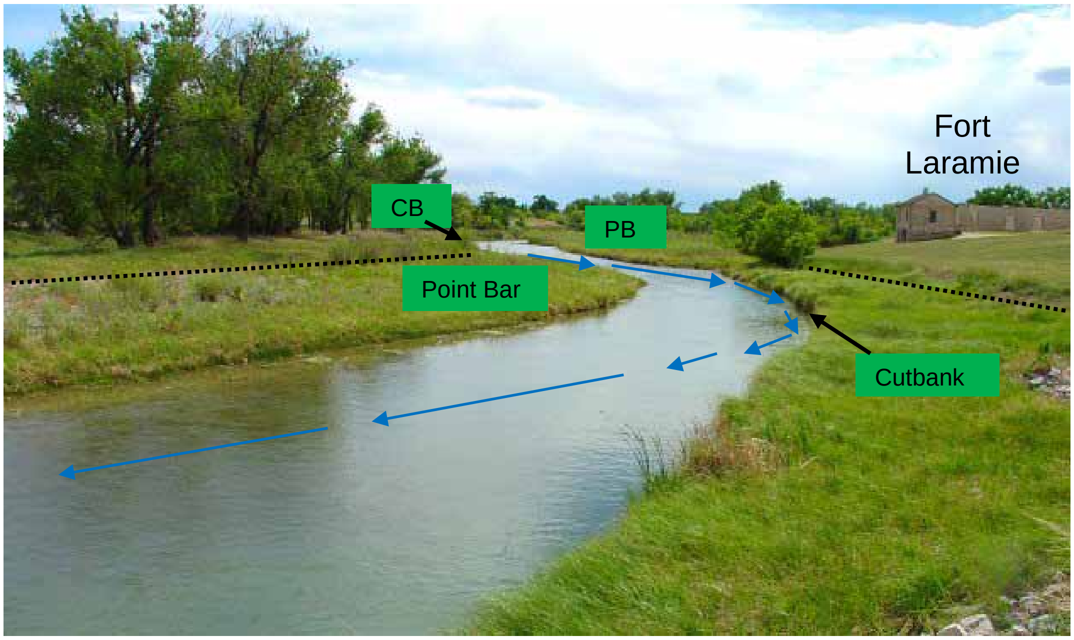

Figure 10. The Laramie River as seen from Fort Laramie National Historic Site. The river is an 'underfit' stream, seemingly too small to have eroded the valley in which it flows. The blue arrows approximate the thalweg's flow pattern. Erosion occurs at the cutbank (CB); deposition occurs at the point bar (PB). The dashed, black lines demarcate the boundaries between active fluvial erosion and deposition from an older river terrace. The cutbank is eroding towards the river terrace upon which Fort Laramie is located. Compare the present cutbank with the bluffs in figure 4. Photograph modified from http://www.trainweather.com/june12004.html, courtesy of Ken Ziegenbein (accessed September 2009).

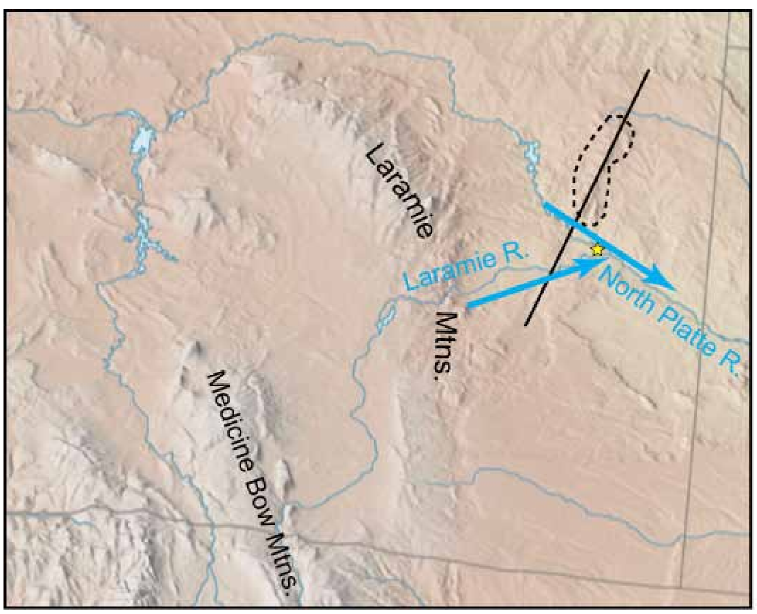

Figure 11. Relief map of southeastern Wyoming showing the river valleys of the Laramie and North Platte rivers (blue arrows) crossing Wyoming's Laramie Range, Hartville Uplift (dashed outline), and Whalen fault system (thick black line) at high angles. In this figure, the Whalen fault system includes the Whalen fault, Wheatland fault, and minor anticlines such as the Grayrocks anticline, all of which are oriented northeast-southwest. The yellow star marks the approximate location of the Fort Laramie National Historic Site. Base map modified from the public domain Physical Map of the Coterminous United States by Tom Patterson (http://www.shadedrelief.com/, accessed November 2009).

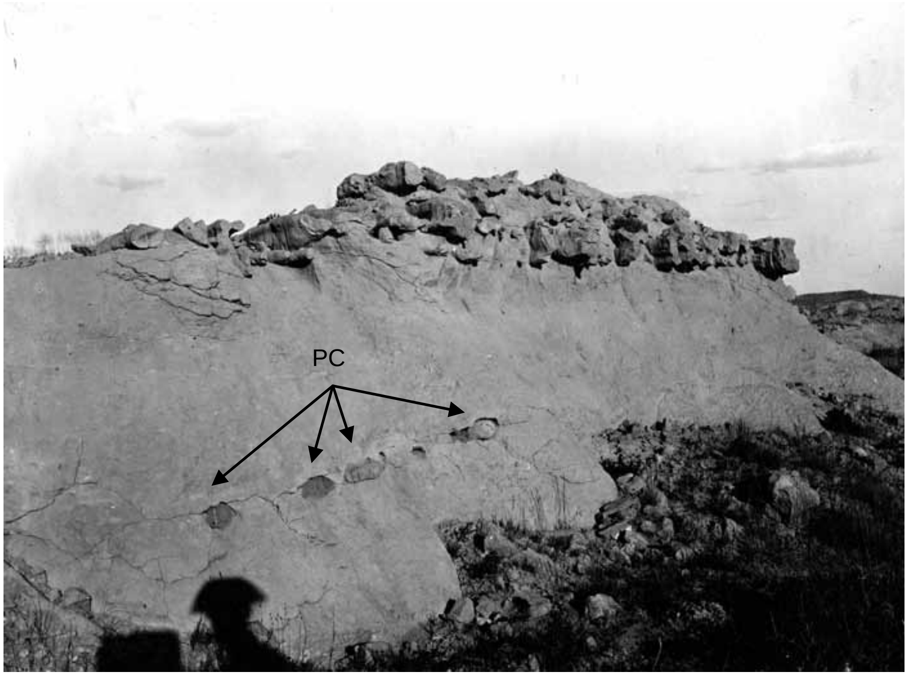

Figure 12. Pipy concretions (PC) in the Arikaree Formation in neighboring Scotts Bluff County, Nebraska. Modified from a photograph taken in 1897 by N. H. Darton of the U.S. Geological Survey and available at http://libraryphoto.cr.usgs.gov/index.html (accessed September 2009).

Figure 13. Vertical display case protects the corkscrew burrow, *Daemonelix*, at Agate Fossil Beds National Monument, Nebraska. Photograph courtesy of Jason Kenworthy, NPS.

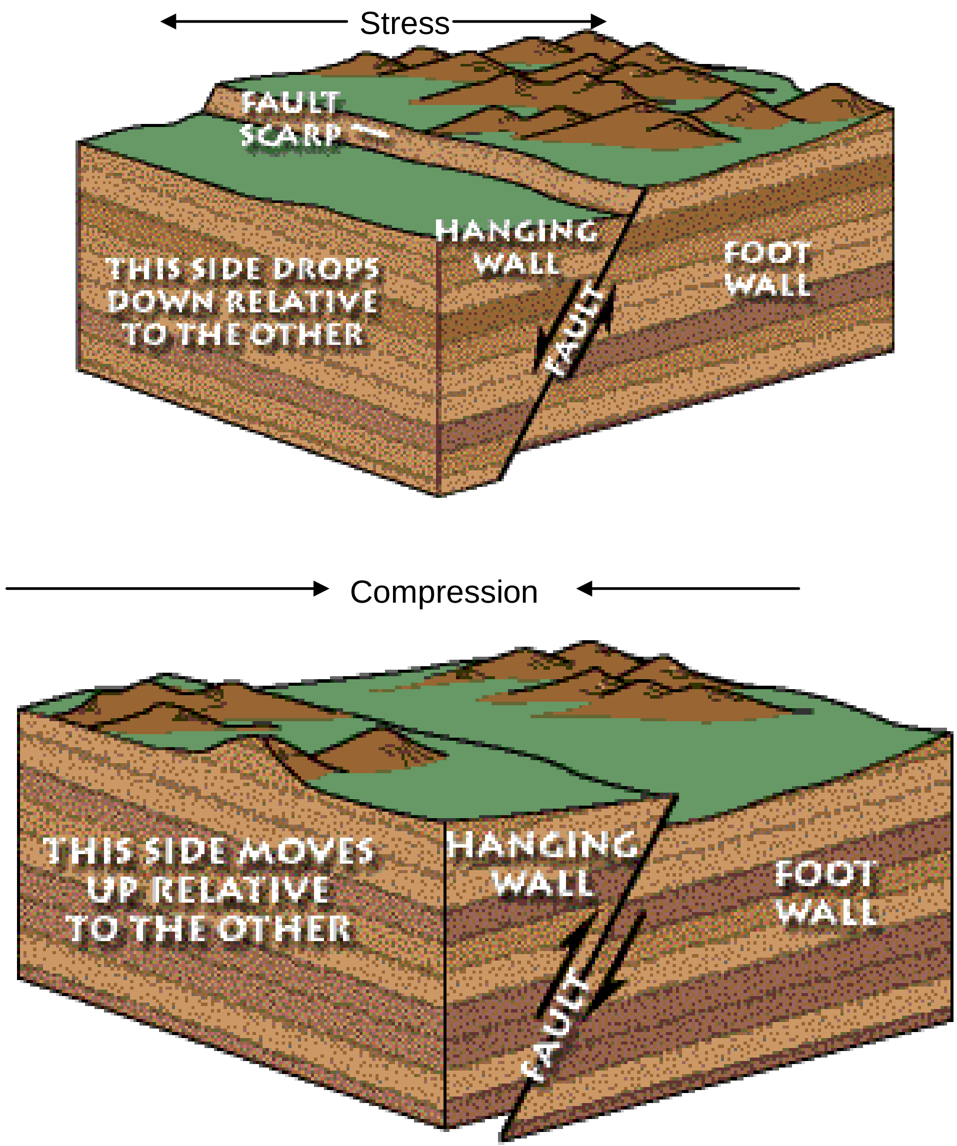

Figure 14. Schematic illustrations of normal and reverse faulting. In the upper diagram, extensional stress creates a normal fault wherein rocks in the "hanging wall" above the fault plane move downward relative to rocks in the "footwall" below the fault plane. These terms developed as a result of early mining geology. Imagine walking down the fault plane in a mine. The rocks upon which you walk are in the "footwall" while those that hang above your head are in the "hanging wall." In a "reverse" fault (lower diagram), the hanging wall has moved up relative to the footwall due to compression. The only difference between a "reverse" fault and a "thrust" fault lies in the angle of the fault plane from the surface of the Earth. If the angle is more than about 15%, the fault is a "reverse" fault; if 15% or less, it's a "thrust" fault. Reverse faults typically juxtapose older (underlying), hanging wall strata against younger, footwall strata. The Laramie Range resulted from reverse faulting during the Laramide Orogeny. Diagrams from the U.S. Geological Survey, available at http://geomaps.wr.usgs.gov/parks/deform/gfaults.html (accessed September 2009).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Fort Laramie National Historic Site. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Fort Laramie National Historic Site formed the basis of the "Geologic History," "Geologic Features and Processes," and "Geologic Issues" sections of this report. Geologic maps are essentially two-dimensional representations of complex three-dimensional relationships. The various colors on geologic maps illustrate the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships to other natural resources and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps do not show where the next landslide, rockfall, or volcanic eruption will occur, but mapped deposits show areas that have been susceptible to such geologic hazards. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by various geomorphic features that are shown on geologic maps. For example, alluvial terraces may preserve artifacts, and formerly-inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 15) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to erosion, potential hazards, paleontological and cultural resources, mineral occurrence, and suitability as habitat or for recreational use.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following reference map is the source data for the GRI digital geologic map for Fort Laramie National Historic Site:

McGrew, Laura W. 1963. *Geology of the Fort Laramie area, Platte and Goshen Counties, Wyoming.* Scale 1:31,680. U.S. Geological Survey, Bulletin 1141-F. Reston, VA: U.S. Geological Survey.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, increasing the overall quality and utility of the data. GRI digital geologic map products include data in ESRI shapefile and coverage GIS formats, FGDC metadata, a Windows HelpFile that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map with appropriate symbology. GRI digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/, accessed September 2009).

Map Unit Properties Table: Fort Laramie National Historic Site

Colored rows indicate map units exposed within the borders of Fort Laramie National Historic Site.

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources†	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
QUATERNARY (Holocene)	Flood plain deposits (Qfp)	Silt, fine-grained sand, and some gravel in the present floodplains, channel bars, and islands of the North Platte and Laramie rivers. Derived from Oligocene and Miocene rocks.	Low.	Site of historic fort's buildings.	Flash flooding.	Unknown.	Bison and elk bones; possible American Indian sites.	Sand and gravel.	Grasses, trees, other floodplain vegetation.	Suitable for most uses, including hiking, picnicking, camping.	None.
QUATERNARY (Holocene)	Sand and loess (Qsl)	Wind-blown silt and fine sand, which form soil mantle on broad, relatively flat surfaces, such as the bottom of Goshen Hole and the surface of the High Plains. Commonly thin deposits, but may locally be 6 m (20 ft) thick. Not exposed in Fort Laramie National Historic Site.	Low.	Ranchland with windmills, pipelines, and unimproved roads.	None.	None.	Thin deposits; possible American Indian sites.	Aggregate sand.	High Plains vegetation: e.g., prairie grasses, prickly pear cacti.	Suitable for most uses, including hiking, picnicking, camping.	None.
QUATERNARY (latest Pleistocene–Holocene)	Tributary valley alluvium (Qta)	Mostly silt and sand with gravel lenses, but also includes some unstratified silt, sand, and talus veneer on slopes below some of the steep escarpments of Oligocene and Miocene rocks along the southeast rim of the Laramie River valley.	Low.	Good. Contains roads and buildings.	Flooding.	Cherry Creek valley: *Bison bison*; Little Cottonwood Draw: *Ovis canadensis* Shaw (mountain sheep) skull.	Charcoal layers.	Sand and gravel.	High Plains vegetation: e.g. prairie grasses, prickly pear cacti.	Suitable for most uses, including hiking, picnicking, camping.	None.
QUATERNARY (Pleistocene)	Gravel (Qg)	Gravel and boulder deposits with some silt, fine sand, and bentonitic clay lenses capping hills above the present flood plain of North Platte and Laramie rivers and the divide between Deer and Cherry creeks. Not exposed in Fort Laramie National Historic Site.	Under normal conditions, gravel and boulders are relatively resistant to erosion.	Contains gravel pits, pipelines, unimproved roads.	None.	Mammoth tooth.	Possible American Indian sites.	Gravel.	High Plains vegetation: e.g. prairie grasses, prickly pear cacti.	Suitable for most uses, including hiking, picnicking, camping.	None.
	REGIONAL UNCONFORMITY (At least 31.6 million years of missing time in the rock record.)										
TERTIARY (Miocene*)	Arikaree Formation* (Ta)	Light-gray, orange-gray, fine- to medium-grained, loosely cemented sandstone containing many hard, pipe-shaped, calcareous sandstone concretions and siliceous root casts. Over 200 m (700 ft) thick. Not exposed in Fort Laramie National Historic Site. Upper unit: Orange-gray, fine- to medium-grained, soft, massive, sandstone; exposed northwest of Fort Laramie National Historic Site; hard, common calcareous sandstone concretions similar to Middle unit; spherical concretions common and may fuse to form clusters and ledges; weathers to vertical cliffs and steep columnar-type badlands; siliceous root casts more abundant than in Lower and Middle units; thin claystone and tuff beds locally interbedded with sandstone; high clay content in matrix. Thickness: 60 m (200 ft). Middle unit: Light-gray, fine- to medium-grained, calcareous and tuffaceous sandstone and fresh-water limestone; more carbonate and white, siliceous root casts than Lower unit; sandstone concretions common; chert nodules; weathers to a broad, undulating surface that forms the high plain on the divide between the Laramie River and Goshen Hole. Thickness: 60 m (200 ft). Lower unit: Orange-gray, fine- to medium-grained, massive, loosely-cemented sandstone; weathers into vertical cliffs and columnar-type badlands; high clay content in matrix; sandstone concretions in irregularly spaced layers either as individual pipes or fused into concretionary ledges; locally, crystalline calcite precipitated around sand grains; hard, white siliceous root casts throughout unit; a few thin tuff beds. Thickness: 60-90 m (200-300 ft).	Variable. Lower unit forms vertical cliffs and badlands; Middle unit contains hard, calcareous layers; Upper unit forms ledges and cliffs.	Sparsely populated but contains roads, pumping station, pipelines, windmills, and other structures.	Potential rockfall and slumping.	Fossils used to relative age-date formation in area: Upper unit: Oreodont "*Phenacocoelus stouti*" (now *Merycoides longiceps*). Middle unit: fossil rodent burrow, *Daemonelix* Lower unit: Oreodonts "*Cyclopidius lullianus*" (now *Leptauchenia major*) and "*Mesoreodon megalodon*" (now *Desmatochoerus megalodon*).	Unknown. Possible American Indian sites.	Calcite sand crystals.	Sparse High Plains vegetation: e.g. short prairie grasses, prickly pear cacti.	Suitable for most uses, including hiking, picnicking, camping.	Arikaree at Agate Fossil Beds National Monument, 80 km (50 mi) northeast of Fort Laramie, contains one of the most significant records of Miocene fossils in the world.

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources†	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
TERTIARY (Oligocene and Miocene*)	Unnamed conglomerate* (Tcg)	Chiefly gray, coarse-grained sandstone and conglomerate. Both Upper and Lower units contain layers of orange-gray siltstone similar to the upper part of the White River Formation. Locally, calcareous matrix is red stained. Exposures along northwest rim of Goshen Hole north of Cherry Creek and northwest of the map area, north of North Platte River. Thickness: variable; 15-46 m (50-150 ft) in outcrops, thicker in subsurface. Not exposed in Fort Laramie National Historic Site. Upper unit: Gray, fine- to medium-grained conglomeratic sandstone. Some areas are mostly gray, massive, fine- to medium-grained sandstone with only scattered pebbles. Hard, dark-gray, pipe-shaped calcareous sandstone concretions present throughout. Thickness: 15-30 m (50-100 ft). Lower unit: Gray, loosely- to well-cemented, cross-bedded to massive conglomerate with rounded to subrounded coarse-grained sand, pebbles, cobbles, and boulders as much as 0.3 m (1 ft) in diameter; matrix is fine-grained sand and silt generally cemented with calcium carbonate. Thickness: 15 m (50 ft).	High for gray, well-cemented conglomerate that forms cliffs and ledges; loosely cemented red conglomerate is less resistant. Weathers into boulder-strewn rounded hills.	Sparsely populated but intersected by roads, pipelines, and other structures.	No potential hazard for the park.	Fossils used to relative age-date unit in area: *Miohippus* sp., *Hypisodus* sp., *Leptomeryx* sp.	Unknown. Possible American Indian sites.	None.	Sparse High Plains vegetation: e.g. short prairie grasses, prickly pear cacti.	Limited exposures; usually forms slopes associated with overlying *Ta*.	None.
TERTIARY (Oligocene*)	White River Formation* (Twr)	Mostly siltstone and claystone; thin white tuff beds locally present throughout the formation. Difficult to map Lower and Upper units separately. Thickness: 113-198 m (370-650 ft). Not exposed in Fort Laramie National Historic Site. Upper unit: Orange-gray, calcareous, sandy, tuffaceous siltstone and silty claystone; few gray, coarse-grained, conglomeratic, cross-bedded channel sandstone beds present throughout unit but abundant in lower part. Thickness: 88-174 m (290-570 ft). Lower unit: Variegated maroon, gray, green, pink, and white bentonitic claystone interbedded with numerous gray and greenish-gray, coarse-grained, conglomeratic, cross-bedded channel sandstone beds. Poor exposures; gradational lithologic change to Upper unit. Thickness: 24 m (80 ft).	Moderate. Siltstone and claystone more resistant than unconsolidated sediments but less resistant than overlying conglomerate.	Limited aerial extent west of Whalen Fault System.	Bentonitic soils may generate mass wasting (landslides, slumps).	Diagnostic fossil rodent suggestive of late Eocene age: *Cylindrodon*. Many vertebrate fossils collected from formation in Fort Laramie area.	Unknown. Possible American Indian sites.	Bentonite; chert.	Forms badland topography with very little vegetation in southeastern Wyoming.	Badlands topography might limit recreational activities.	Produced small amounts of oil and gas in Shawnee Field, 56 km (35 mi) northwest of Fort Laramie.

Map reference: McGrew, L. W. 1963. Geology of the Fort Laramie area, Platte and Goshen Counties, Wyoming. Scale 1:31,680. Bulletin 1141-F. Reston, VA: U.S. Geological Survey.

† = The taxonomic classification of many fossils found in the Fort Laramie area has been revised since McGrew's publication. Updated taxonomic assignments are given in parentheses, based upon data in the Paleobiology Database (http://paleodb.org, accessed November 2009).

* = Revised geologic age interpretations show the age of the White River Formation extending from the late Eocene into the Oligocene and the Arikaree Formation spanning late Oligocene and early Miocene-aged sediments (Tedford et al. 2004). Under such an interpretation, the unnamed conglomerate unit would represent late Oligocene-aged sediments.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Fort Laramie National Historic Site, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

The Oligocene (33.9 to 23.03 million years ago) White River Formation contains the oldest rocks exposed in the Fort Laramie area (fig. 15). However, Precambrian outcrops in the core of the Hartville Uplift to the northwest record a geologic history beginning approximately 3,000 million years ago (Day et al. 1999; Sims and Day 1999). Furthermore, subsurface data collected from oil and gas exploratory wells and surface data from the Black Hills and surrounding mountain ranges provide an excellent summary of the Paleozoic and Mesozoic history of eastern Wyoming.

Precambrian (4,600 to 542.0 million years ago)

The Precambrian, which spans a time period from 4,600 to about 542 million years ago, represents approximately 88% of Earth's history (fig. 15). Precambrian basement rocks of Wyoming belong to three major geologic terranes, the Archean (4,000 to 2,500 million years ago) Wyoming craton, the Paleoproterozoic (2,500 to 1,600 million years ago) Trans-Hudson orogenic belt bordering the Wyoming craton to the east, and the Paleoproterozoic Colorado orogenic belt in southeastern Wyoming. Approximately 1,780 to 1,750 million years ago, the Wyoming craton collided with the Trans-Hudson and Colorado terranes (Sims et al. 2001).

The Wyoming craton consists primarily of two basic rock units—igneous granite and metamorphic gneiss and migmatite. Granitic plutons in the core of the craton formed approximately 2,800 to 2,500 million years ago. Deformation and metamorphism along the active margin of the craton produced the gneiss and migmatite found along the eastern and southern margins of the Wyoming craton. Northeast-southwest trending faults that extend from South Dakota to the Wyoming-Colorado border cut intensely deformed Archean cratonic rocks in the Hartville Uplift and mark the suture zone where the Trans-Hudson and Colorado orogenic belts accreted to the Wyoming craton (Day et al. 1999; Sims and Day 1999; Sims et al. 2001).

By the end of the Precambrian, a transcontinental arch, or series of highlands, had formed along the spine of the evolving North American continent (fig. 16). Approximately 60 million years ago during the Laramide Orogeny, reverse faults (fig. 14) vertically displaced basement blocks of Precambrian rock as much as 9,250 m (30,000 ft). Subsequent erosion has molded the uplifted rocks into Wyoming's present-day topography (Sims et al. 2001).

Paleozoic Era (542.0 to 251.1 million years ago)

Although the Paleozoic Era (251 to 542 million years ago) accounts for only 6% of Earth's history, the abundance and variety of fossils and sedimentary features preserved from that era allows detailed interpretations of the various depositional environments and ecosystems. By the beginning of the Paleozoic, North America lay south of the equator, and Wyoming lay far inland from the continent's western margin (fig. 16).

In contrast to the active margins of the Precambrian, passive margins surrounded North America at the dawn of the Cambrian (542.0 to 488.3 million years ago). Cambrian landscapes were devoid of all vegetation. Blowing sand, silt, and clay blanketed the continents. By the Late Cambrian, however, shallow seas flooded the North American continent, leaving behind extensive sequences of marine sandstones, shale, and fossil-bearing limestones.

Cambrian-age quartzite (metamorphosed sandstone) crops out in the Hartville Uplift, but the oldest Paleozoic strata in the subsurface beneath Fort Laramie belong to the Late Devonian – Early Mississippian Guernsey Formation (McGrew 1963). Well over 157 million years of Earth history is missing in the unconformity between the Guernsey Formation and the underlying Precambrian rocks (fig. 3).

Although deposited far from the western margin of North America, the Guernsey Formation resulted from the tectonic collision between the North American and Pacific lithospheric plates. During Middle Devonian to Middle Mississippian time (approximately 398 to 326 million years ago), ongoing subduction along the western margin of North America caused a series of marine transgressions that deposited marine sediments throughout the northern and western part of Wyoming (Boyd 1993). The pink arkose (feldspar-rich sandstone) in the lower Guernsey Formation records a Late Devonian regression in the area when the shoreline migrated back to the west. The dolomite (calcium-magnesium carbonate) in the upper part of the Guernsey Formation represents the return of warm, shallow seawater. The upper Guernsey correlates to the extensive Early Mississippian Madison Limestone of central Wyoming and the Pahasapa Limestone of the Black Hills region (fig. 17).

Strata of the Late Mississippian to Permian Hartville Formation record a Late Mississippian regression and subsequent episodic Pennsylvanian and Early Permian transgressive and regressive cycles (Boyd 1993).

Incursions of marine and nonmarine depositional environments produced a complex stratigraphy of terrestrial red beds, marine carbonates, sandstone, and phosphatic and cherty strata. During the Pennsylvanian and Permian periods, the South American landmass collided with the southern margin of North America, generating the forces responsible for the ancestral Rocky Mountains in Colorado (fig. 18). The Opeche Shale, Minnekahta Limestone, and gypsum and red shale sequence (fig. 3) represent the final transgressive-regressive cycle to affect southeastern Wyoming at the end of the Paleozoic.

Mesozoic Era (251.0 to 65.5 million years ago)

Triassic Period (251.0 to 199.6 million years ago)

By the Early Triassic (251.0 to 245.9 million years ago), the major landmasses had come together to form a supercontinent called Pangaea. At least three regional transgressive-regressive episodes impacted Wyoming in the Triassic. The reddish siltstones, shales, and calcareous sandstones of the Chugwater Group, exposed in the Hartville Uplift, represent near-shore and tidal flat environments formed during fluctuating sea levels in eastern Wyoming (Picard 1993; Dubiel 1994).

Jurassic Period (199.6 to 145.5 million years ago)

Landmasses began migrating to their current positions around the globe as tectonic forces dismantled Pangaea by the Early Jurassic (199.6 to 175.6 million years ago). Two major transgressive and regressive episodes spread a shallow epicontinental seaway, called the Sundance Sea, into Wyoming from the north and flooded large portions of the Western Interior of North America, a physiographic province bordered to the west by a rising mountain range and to the east by the stable North American craton (fig. 19) (Brenner 1983; Picard 1993; Peterson 1994). At this time, Wyoming lay within 15°-20° North latitude, and the abundance of red beds, rocks such as gypsum that form from evaporation, and shallow-water carbonates of the Sundance Formation suggest that the Middle Jurassic (175.6 to 161.2 million years ago) paleoclimate in the Fort Laramie region was generally warm and dry (Saleeby and Busby-Spera 1992).

The Upper Jurassic (161.2 to 145.5 million years ago) Morrison Formation represents a widespread non-marine complex that covers most of the Western Interior. Alluvial fans, streams, and lakes spread across the region during the final retreat of the Sundance Sea (Picard 1993). World-renowned for its dinosaur fossils, the Morrison Formation of Wyoming, Colorado, and Utah became a primary destination for paleontologists in the 1800s, and still is today. The formation also contains significant uranium in fluvial sandstone deposits.

Cretaceous Period (145.5 to 65.5 million years ago)

As mountains rose in the west and the roughly north-south Western Interior Basin subsided during the Cretaceous, the Gulf of Mexico continued to rift open in the south, and marine water began to spill into the basin. At the same time, marine water began to transgress from the Arctic region in the north. The Lower Cretaceous (145.5 to 99.6 million years ago) Cloverly Formation, Thermopolis Shale, Muddy Sandstone, and Mowry Shale record complex, episodic fluctuations of relative sea level and deposition in near-shore to off-shore environments as the seaway expanded.

The Cretaceous seaway was the most extensive interior seaway ever to cover the continent (fig. 20). 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 transgression, the width of the basin reached 1,600 km (1,000 mi).

The Upper Cretaceous (99.6 to 65.5 million years ago) Frontier Formation consists of a complex system of marginal- and shallow-marine environments. A return to off-shore marine conditions produced the limestone of the Niobrara Formation. As the sea gradually receded in the latest Cretaceous, relative sea level fell, and Pierre Shale offshore marine environments gave way to near-shore marine Fox Hill Sandstone environments and eventually to the river and deltaic environments of the Lance Formation (fig. 3).

Cenozoic Era (65.5 million years ago to present)

Paleogene Period (65.5 to 23.03 million years ago)

The growth of the Rocky Mountains as a result of the Late Cretaceous to early Tertiary (75 to 35 million years ago) Laramide Orogeny presents a perplexing geologic puzzle. Typically, mountains form approximately 320-640 km (200-400 mi) inland from a subduction zone boundary. The Rocky Mountains, however, developed hundreds of kilometers inland from the western margin of North America. The answer to this puzzle may lie in the angle of the subducting slab (fig. 21).

Typically, the oceanic plate at a subduction zone sinks at a fairly high angle. Volcanoes at the surface mark the location of the subducting plate. During the Late Cretaceous, the angle of the subducting plate may have flattened, causing the focus of melting and mountain building to move far inland (fig. 21). Tremendous reverse faults cut into ancient plutonic and metamorphic basement rocks, driving them to the surface, and creating the modern Rocky Mountains, including the Laramie Mountains and Hartville Uplift. These reverse faults have steeply dipping fault planes at the surface that curve and become nearly horizontal at depths up to 9 km (5.7 mi) below sea level (Gries 1983; Erslev 1993).

Following the Laramide Orogeny, the region was extensively eroded. If Paleocene and Eocene sediments were deposited southeast of the Hartville Uplift in Wyoming, they were subsequently removed by erosion prior to deposition of the Oligocene White River Formation.

East of the Laramie Mountains, thick, fine-grained pyroclastic debris and conglomeratic, cross-bedded channel sandstone spread over broad floodplains during the Oligocene (33.9 to 23.03 million years ago) (McGrew

1963). Rivers flowed from west to east. Volcanism in northwestern Wyoming may have been a source for the volcanic debris found in the sediments. Non-volcanic, clastic material probably originated in the Laramie Mountains and other uplifts to the west.

Neogene Period (23.03 to 2.588 million years ago)

Regional uplift during the latest Oligocene and earliest Miocene rejuvenated streams, which proceeded to cut conspicuous channels into underlying Oligocene deposits. These channels became filled with conglomerate and conglomeratic sandstone.

Miocene (23.03 to 5.33 million years ago) channels cut fine- to medium-grained, tuffaceous sandstones. Miocene channel-cutting activity, however, occurred to a lesser degree than that during the Oligocene. Arikaree channel deposits include conglomerates derived from nearby Precambrian and Paleozoic rocks and sand, sandstone pebbles, and concretions reworked from the previously deposited Arikaree Formation (McGrew 1963). Alluvial plains formed and were blanketed in places by volcaniclastic loess (wind-blown deposits). Locally, lakes and ponds formed, leaving behind freshwater limestones.

Miocene fossils of insectivores, rodents, lagomorphs (rabbit and pika families), oreodonts, equids (horse family), antilocaprids (extinct except for the pronghorn), rhinocerotids, and an amphicyonid (extinct bear dog) have been collected from the Fort Laramie and Hartville areas (McGrew 1963; Flanagan and Montagne 1993).

The Whalen fault system resulted from a period of extensive block faulting that followed the deposition of the Arikaree Formation in the Fort Laramie area (McGrew 1963; Flanagan and Montagne 1993). The youngest rocks cut by these northeast-trending faults are of early middle Miocene age. Surface evidence of the faults roughly parallels the trends of buried Laramide-age folds, which suggests that the faults were controlled by pre-existing folds and fractures in older rocks.

Limited deposition during the Pliocene (5.332 to 2.588 million years ago) took place in eastern Wyoming. No Pliocene-age rocks, however, are known from the Fort Laramie area.

Quaternary Period (2.588 million years ago to present)

The great continental ice sheets of the Pleistocene (2.588 million years ago to 11,700 years ago) did not reach Fort Laramie (fig. 22). In addition, the Laramie Mountains to the west were not glaciated. They did, however, experience a climate similar to that at the immediate margins of glaciers and ice sheets.

The Pleistocene was primarily a time of erosion in the Fort Laramie area. Approximately 2 million years ago, the Laramie River began cutting its narrow canyon through the Laramie Range (Lageson and Spearing 1988). Abundant gravel was eroded from the Laramie Range and transported into the high plains of southeastern Wyoming (Wayne et al. 1991). Periodic uplift produced channel downcutting and several erosional levels or river-cut terraces. In the Fort Laramie area, terrace gravels are as thick as 6 m (20 ft). Local sediments include stream deposits of fine-grained sand and silt and wind-blown, loess deposits.

Although not as strong as in the Pleistocene, northwesterly wind patterns continued into the Holocene (11,700 years ago to the present), distributing loess deposits into southeastern Wyoming and Nebraska (Wayne et al. 1991). Holocene uplift of the Fort Laramie area has resulted in stream dissection of thick deposits of valley alluvium.

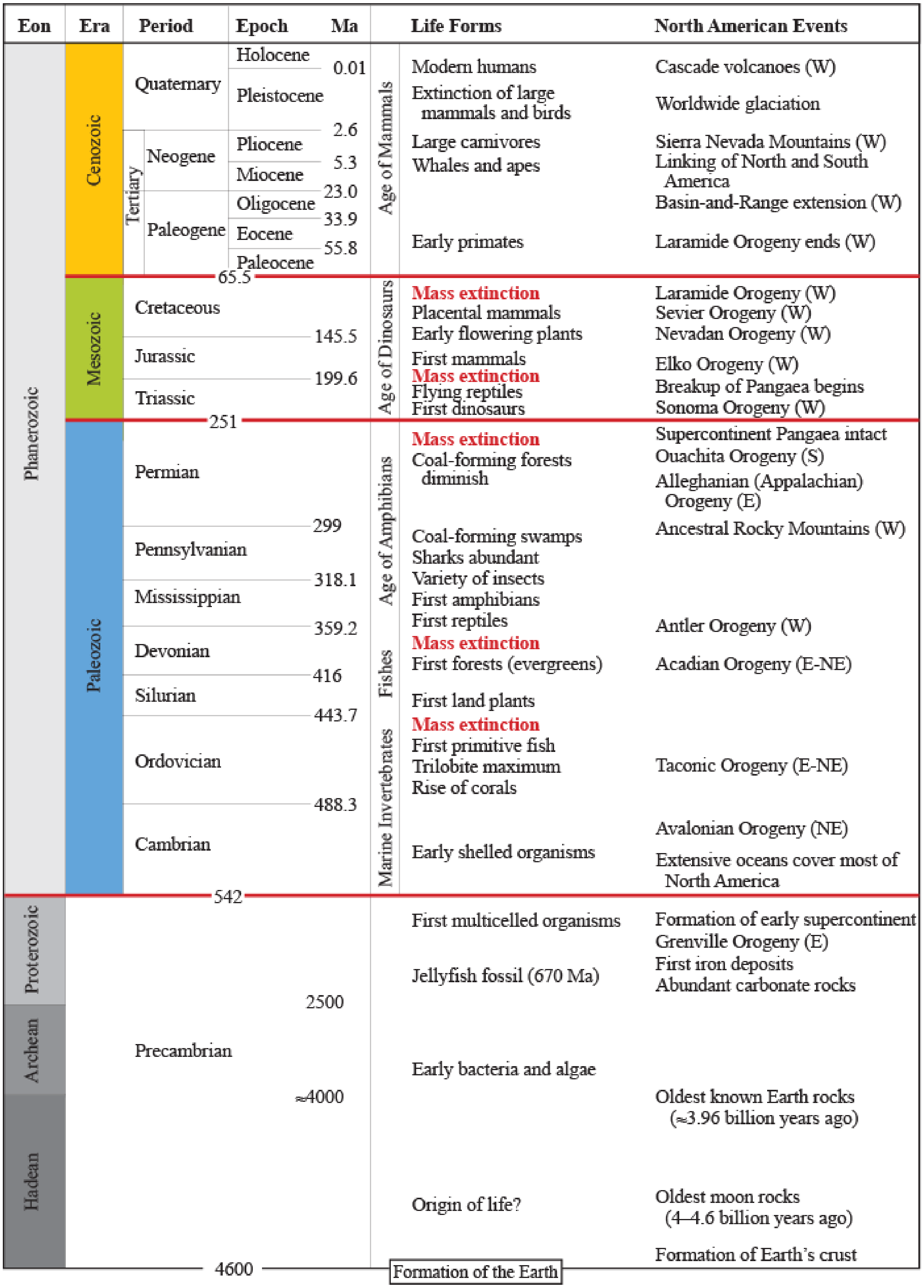

Figure 15. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, (http://pubs.usgs.gov/fs/2007/3015/) with additional information from the International Commission on Stratigraphy (http://www.stratigraphy.org/view.php?id=25). Accessed September 2009.

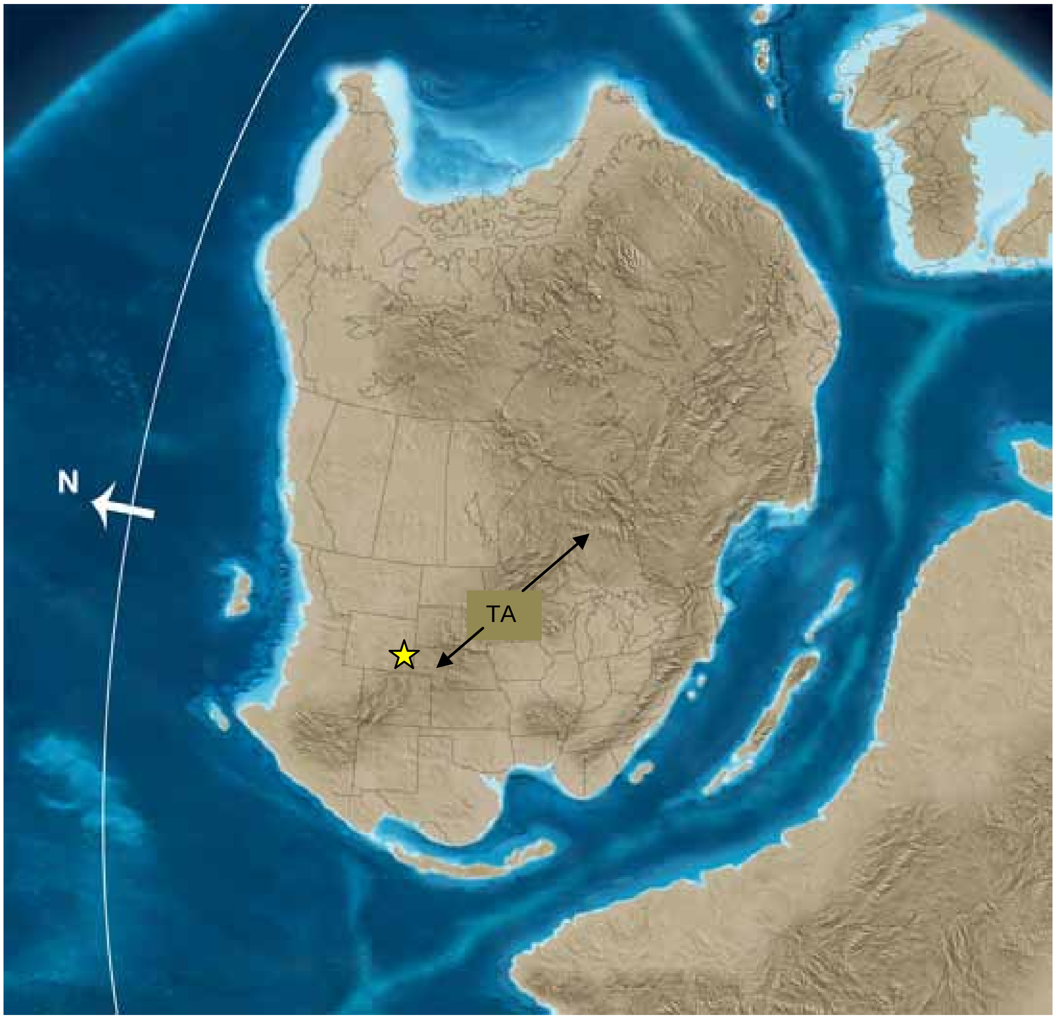

Figure 16. Late Precambrian to Early Cambrian paleogeographic map of North America. Approximately 550 million years ago, North America lay south of the equator (white line on left). Precambrian orogenies had accreted new land to the North American craton, leaving a series of northeast-to-southwest trending highlands from Hudson Bay to Arizona, often referred to as the Transcontinental Arch (TA). The yellow star in today's southeastern Wyoming marks the approximate locations of Fort Laramie National Historic Site and the Hartville Uplift. Brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Late Precambrian map of Dr. Ron Blakey (Northern Arizona University), Available online at: http://jan.ucc.nau.edu/rcb7/namPC550.jpg (accessed September 2009).

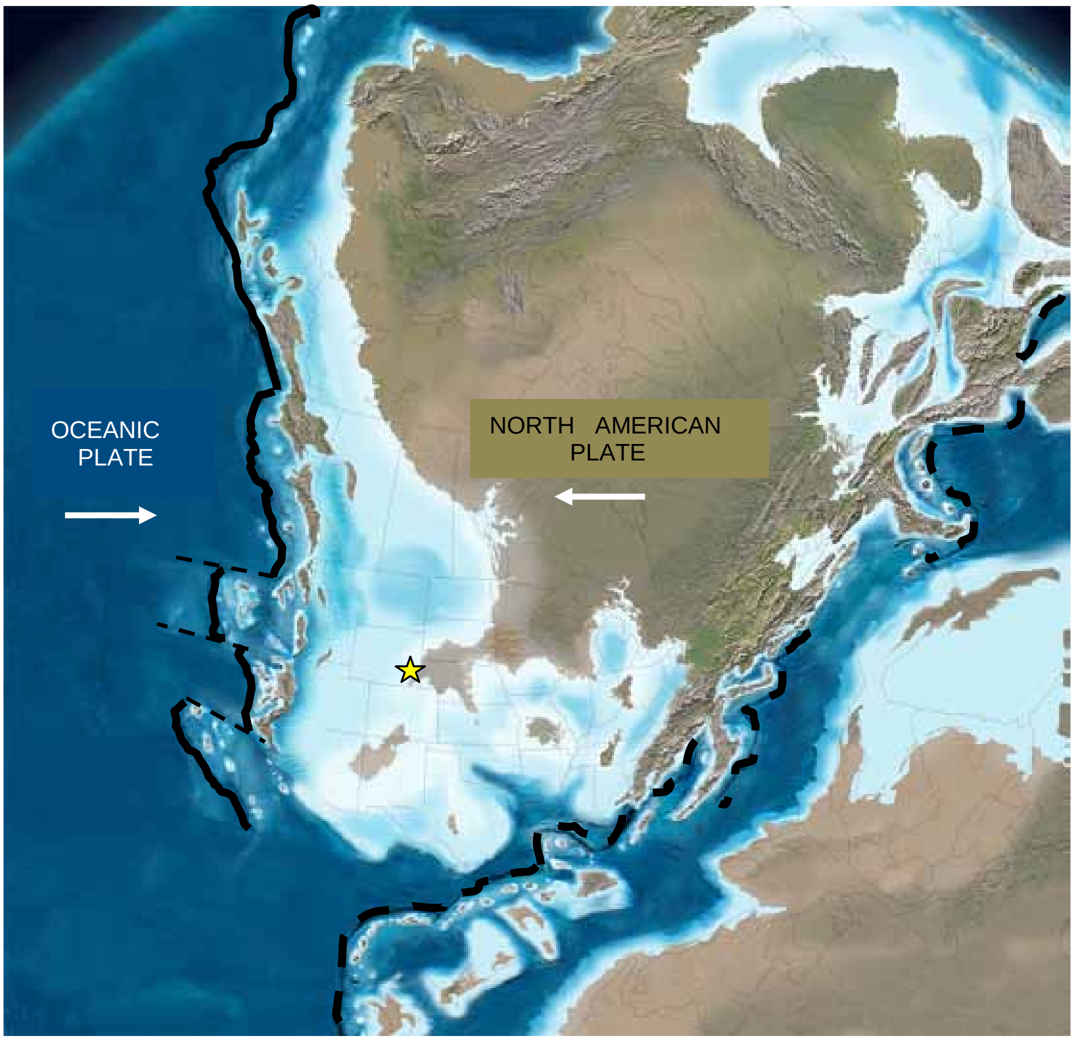

Figure 17. Early Mississippian paleogeographic map of North America. About 345 million years ago, tectonic collision and subduction of the oceanic plate beneath the western margin of North America (thick black line) caused a marine transgression onto the North American continent. Dashed black line marks the approximate location of the subduction zone along the east and southern coasts of North America. The yellow star represents the approximate location of today's Fort Laramie National Historic Site. Brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Early Mississippian map of Dr. Ron Blakey (Northern Arizona University), Available online at: http://jan.ucc.nau.edu/rcb7/namM345.jpg (accessed September 2009).

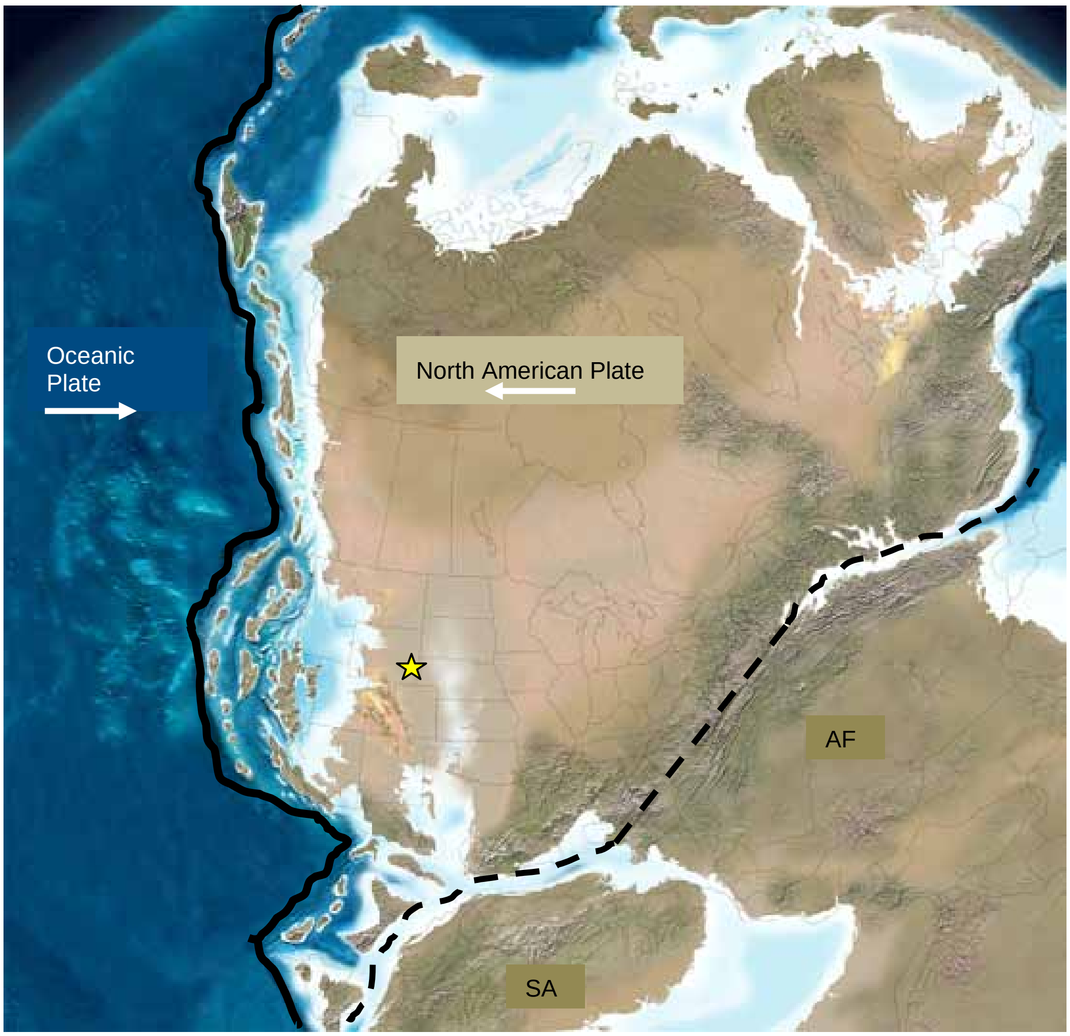

Figure 18. Late Permian paleogeographic map of North America. By 260 million years ago, the major landmasses had almost completely formed the supercontinent, Pangaea. Africa (AF) had collided with North America to form the Appalachian Mountains, while South America (SA) continued to close the proto-Gulf of Mexico. Forces from the collision of North America with South America were felt far inland and formed the northwest-southeast-trending Ancestral Rocky Mountains exposed in Colorado and New Mexico. The yellow star represents the approximate location of today's Fort Laramie National Historic Site. The black line marks the subduction zone between the North American lithospheric plate and the oceanic plate. The dashed line marks the approximate location of the suture zone between North America and Africa and South America. Brown and yellowish-brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Late Permian map of Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namP260.jpg (accessed September 2009).

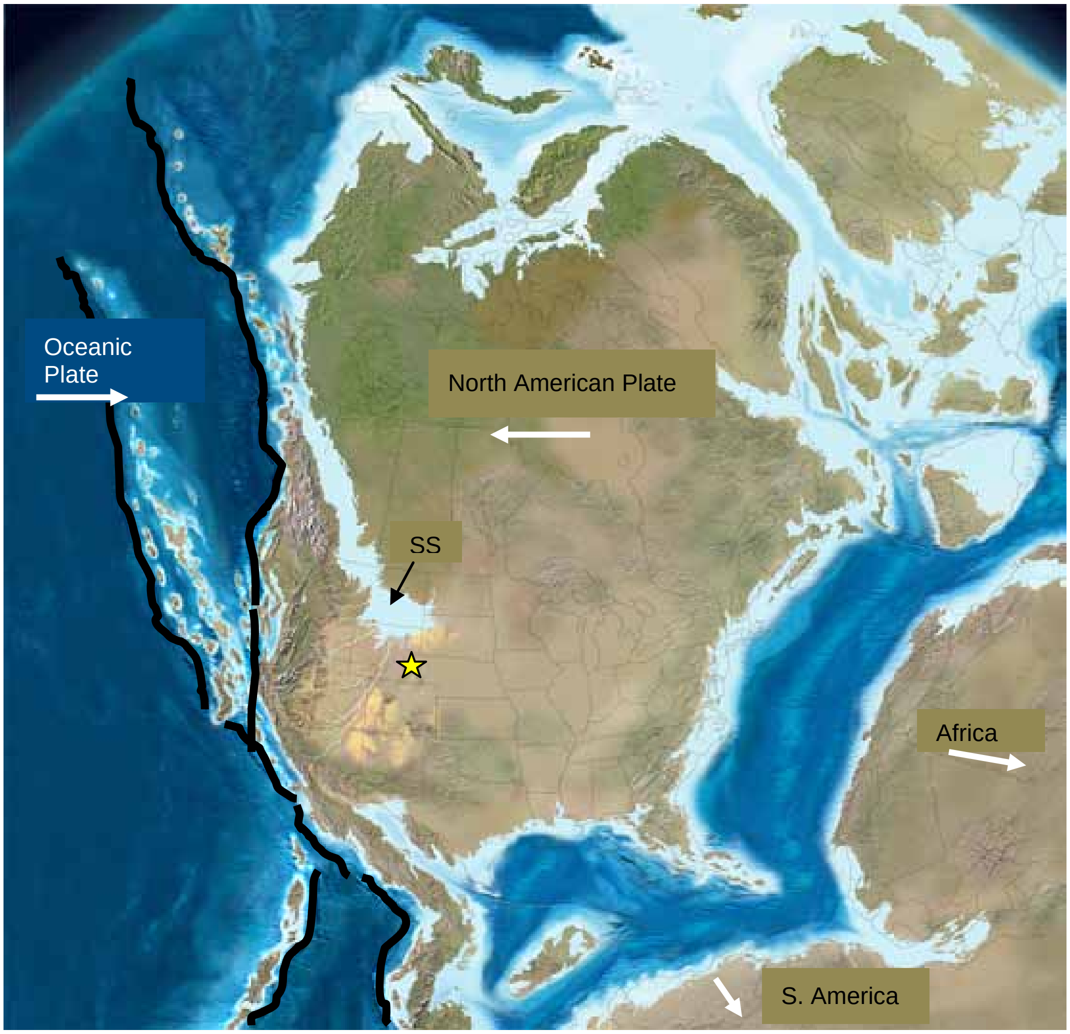

Figure 19. Late Jurassic paleogeographic map of North America. About 150 million years ago, the last of the Sundance Sea (SS) retreated from Wyoming and dinosaurs inhabited the terrestrial environments of the Morrison Formation. Plate collisions produced renewed uplift and mountains along the western margin of North America (Nevadan Orogeny), while along the east coast, the Atlantic Ocean and Gulf of Mexico continued to open. The yellow star represents the approximate location of today's Fort Laramie National Historic Site. The thick black line marks the approximate location of the subduction zone along the western margin of the North American plate. Brown and yellowish-brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Late Jurassic map of Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namJ150.jpg (accessed September 2009).

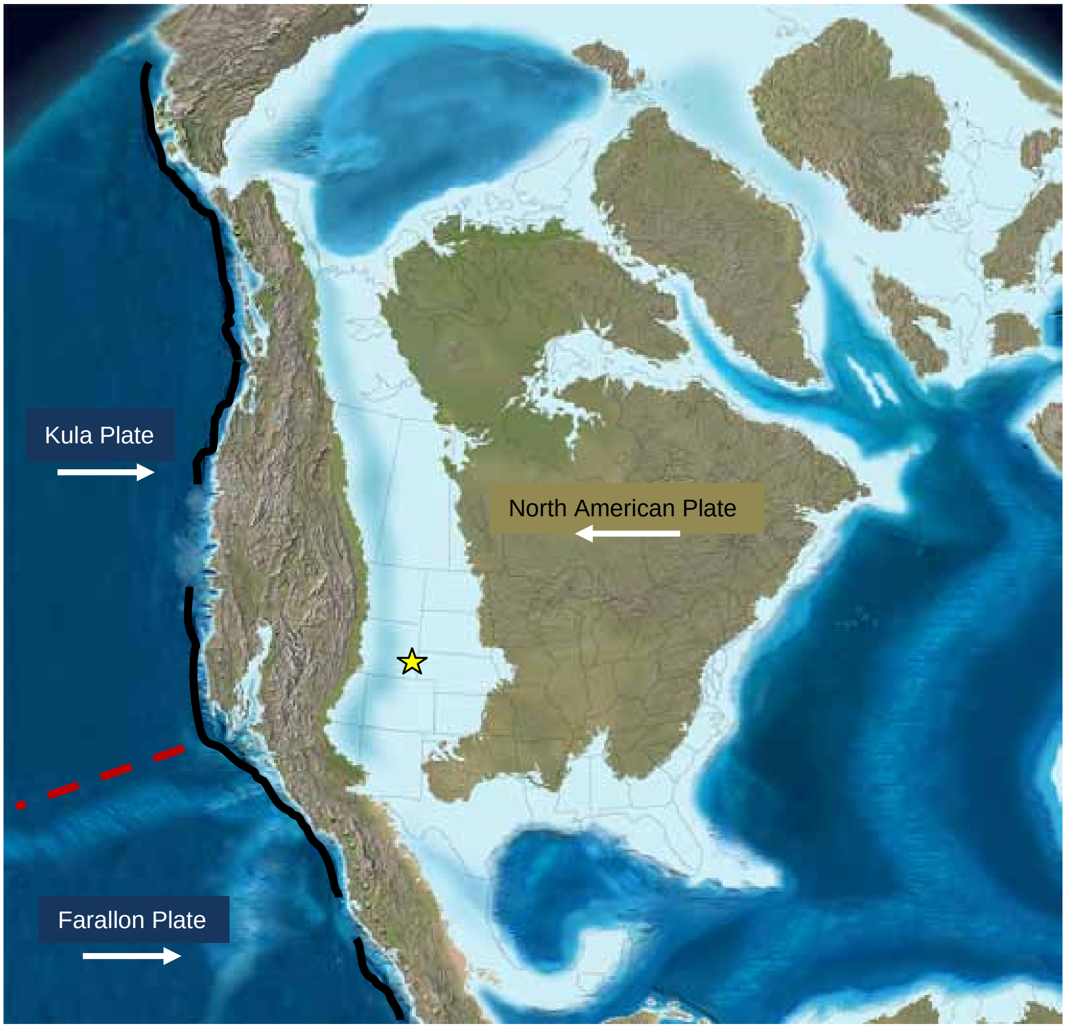

Figure 20. Late Cretaceous paleogeographic map of North America. About 85 million years ago, a shallow seaway had inundated the Western Interior province of North America, and eastern Wyoming lay underwater. The Sevier Orogeny, caused by subduction of the Kula and Farallon plates beneath the North American plate, deformed the western margin into a linear chain of mountains. The yellow star represents the approximate location of today's Fort Laramie National Historic Site. The thick black line marks the approximate location of the subduction zone. The dashed red line is the approximate location of the spreading center separating the Farallon and Kula plates. Brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Late Cretaceous map of Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namK85.jpg (accessed September 2009).

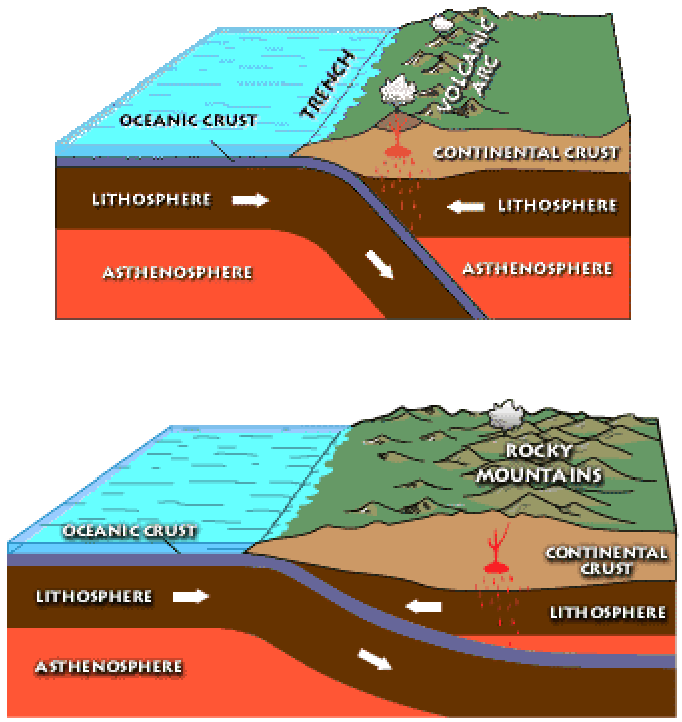

Figure 21. Growth of the Rocky Mountains. In the upper sketch, the oceanic plate typically sinks at a fairly high angle, and a volcanic arc forms above the subducting plate. During the Laramide Orogeny, the subducting plate became significantly flatter as seen in the lower sketch. Compressive forces and melting were felt much farther inland than normal, giving rise to the Rocky Mountains. Schematic from the U.S. Geological Survey, available online at: http://geomaps.wr.usgs.gov/parks/province/rockymtn.html (accessed September 2009).

Figure 22. Paleogeographic map of the North American continent during the Pleistocene Epoch of the Quaternary Period. Approximately 0.126 million years ago, continental ice sheets and alpine glaciers resulted from a wetter, cooler climate. Alpine glaciers generated a greater volume of runoff in the Fort Laramie National Historic Site region (yellow star) than is present today. White color denotes ice, brown colors denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. Modified from the Quaternary map of Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namQ.jpg (accessed September 2009).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.

active margin. A tectonically active margin where lithospheric plates converge, diverge or slide past one another (also see "passive margin"). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountain front into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

anhydrite. A mineral consisting of anhydrous calcium sulfate, which is gypsum without its water of crystallization. Readily alters to gypsum.

anticline. A fold, generally convex upward, whose core contains the stratigraphically-older rocks.

arkose. A feldspar-rich sandstone, commonly coarse-grained and pink or reddish.

ash (volcanic). Fine pyroclastic material ejected from a volcano (also see "tuff").

asthenosphere. The relatively weak layer or shell of the Earth below the lithosphere.

badlands. Topography characterized by steep slopes, surfaces with little or no vegetative cover, composed of unconsolidated or poorly cemented clays or silts, sometimes with soluble minerals such as gypsum or halite.

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

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.

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

bedding. Depositional layering or stratification of sediments.

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

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

block (fault). A crustal unit bounded by faults.

calcareous. Describes rock or sediment that contains calcium carbonate.

chemical sediment. A sediment precipitated directly from solution (also called nonclastic).

chert. A extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz (syn: flint).

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

clastic. Describes rock or sediment made of fragments of pre-existing rocks.

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

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

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

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented rounded clasts larger than 2 mm (0.08 in).

continental crust. The crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

continental shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone only gentle warping compared to the intense deformation of bordering crust.

craton. The relatively old and geologically stable interior of a continent (also see "continental shield").

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions (e.g., direction and depth).

crust. Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

cryptocrystalline. Describes the texture of a rock consisting of crystals that are too small to be recognized and separately distinguished even under the ordinary microscope.

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

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

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

delta. A sediment wedge deposited where a stream flows into a lake or sea.

diatom. A microscopic, single-celled alga that secretes walls of silica, called frustules. Diatoms live in freshwater or marine environment.

diatomite. A light-colored, soft silica-rich sedimentary rock, consisting chiefly of diatoms.

dip. The angle between a bed or other geologic surface and horizontal.

dip-slip fault A fault with measurable offset where the relative movement is parallel to the dip of the fault.

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

epicenter. The point on Earth's surface that is directly above the focus of an earthquake.

epicontinental. Situated on the continental shelf or on the continental interior, as an 'epicontinental sea.'

fault. A subplanar break in rock along which relative movement occurs between the two sides.

feldspar. A group of abundant, light-colored to translucent silicate minerals that may contain potassium, sodium, calcium, barium, rubidium, and strontium along with aluminum, silica, and oxygen.

floodplain. The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks.

foliation. A preferred arrangement of crystal planes in minerals; in metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas.

footwall. The mass of rock beneath a fault surface (see "hanging wall").

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

fracture. Irregular breakage of a mineral. Any break in a rock (e.g., crack, joint, fault).

gneiss. A foliated rock formed by regional metamorphism, in which bands of light-colored minerals alternate with bands of dark minerals.

granite. A plutonic rock that has visible crystals of quartz (10–50%) and potassium and sodium-rich feldspar (65–90%). Mica and amphibole minerals are also common.

gypsum. The most common sulfate mineral (calcium sulfate). Frequently associated with halite and anhydrite in evaporites.

hanging wall. The mass of rock above a fault surface (see "footwall").

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

joint. A semiplanar break in rock without relative movement of rocks on either side of the fracture surface.

lens. A sedimentary deposit characterized by converging surfaces, thick in the middle and thinning out toward the edges, resembling a convex lens.

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

lithology. The physical description of a rock, especially its color, mineral composition, and grain size.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50 to 100 km (31 to 62 mi) thick, that encompasses the crust and uppermost mantle.

loess. Windblown silt-sized sediment, generally of glacial origin.

matrix. The fine grained material between coarse (larger) grains in igneous rocks or poorly sorted clastic sediments or rocks. Also refers to rock or sediment in which a fossil is embedded.

meander. Sinuous lateral curve or bend in a stream channel.

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

metamorphic. Pertaining to the process of metamorphism or its results. One of the three main classes or rocks—igneous, metamorphic, and sedimentary

metamorphism. Literally, "change in form." Metamorphism occurs in rocks through mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

microcrystalline. A rock with a texture consisting of crystals that are small enough to be visible only under the microscope.

migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

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

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 mi) thick and generally of basaltic composition.

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.

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

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

Pangaea. The single supercontinent that existed during the Permian and Triassic periods.

passive margin. A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America. (also see "active margin").

phosphatic. Pertaining to or containing phosphates; esp. a sedimentary rock containing phosphate minerals.

pipy concretion. A hard, compact mass or aggregate of mineral matter formed in an elongate, or pipe-like, shape.

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.

pluton. A body of intrusive igneous rock.

plutonic. Describes igneous rock intruded and crystallized at some depth in the Earth.

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

pyroclast. An individual particle ejected during a volcanic eruption.

quartzite. Very hard, metamorphosed sandstone.

radiometric age. An age expressed in years and calculated from the quantitative determination of radioactive elements and their decay products.

red beds. Sedimentary strata composed largely of sandstone, siltstone, and shale that are predominantly red due to the presence of ferric iron oxide (hematite) coating individual grains.

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

relative age dating. Determining the chronological placement of rocks, events, or fossils with respect to the geologic timescale and without reference to their radiometric age.

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

riprap. A layer of large, durable, broken rock fragments irregularly thrown together in an attempt to prevent erosion by waves or currents and thereby preserve the shape of a surface, slope, or underlying structure.

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

roundness. The relative amount of curvature of the "corners" of a sediment grain, especially with respect to the maximum radius of curvature of the particle.

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

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

scarp. A steep cliff or topographic step resulting from displacement on a fault, or by mass movement, or erosion.

schist. A strongly foliated rock formed by dynamic metamorphism that can be readily be split into thick flakes or slabs.

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

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

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

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

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

slope. The inclined surface of any geomorphic feature or rational measurement thereof. Synonymous with gradient.

strata. Tabular or sheetlike masses or distinct layers of rock.

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

stream. Any body of water moving under gravity flow in a clearly confined channel.

stream terrace. One of a series of level surfaces in a stream valley, flanking and more or less parallel to the present stream channel. It is above the level of the stream and represents the dissected remnants of an abandoned floodplain, streambed, or valley floor produced during a former stage of erosion or deposition.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

subrounded. Partially rounded sedimentary particle having many of its edges and corners noticeably rounded off to smooth curves.

suture. The linear zone where two continental landmasses become joined.

syncline. A downward curving (concave up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

terrace. A relatively level bench or steplike surface breaking the continuity of a slope (also see "stream terrace")

terrestrial. Of or relating to land, Earth, or its inhabitants.

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

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

topography. The general morphology of the Earth's surface, including relief and locations of natural and anthropogenic features.

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

trend. The direction or azimuth of elongation of a linear geologic feature.

tuff. Generally fine-grained, igneous rock formed of consolidated volcanic ash.

tuffaceous. A non-volcanic, clastic sedimentary rock that contains mixtures of ash-size pyroclasts.

unconformity. An erosional or non-depositional surface bounded on one or both sides by sedimentary strata that marks a period of missing time.

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

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

volcanic. Related to volcanoes. Igneous rock crystallized at or near the Earth's surface (e.g., lava).

wildcat well. An exploratory well drilled for oil or gas on a geologic feature not yet proven to be productive, or in an unproven territory, or to a zone that has never produced or is not known to be productive in the general area.

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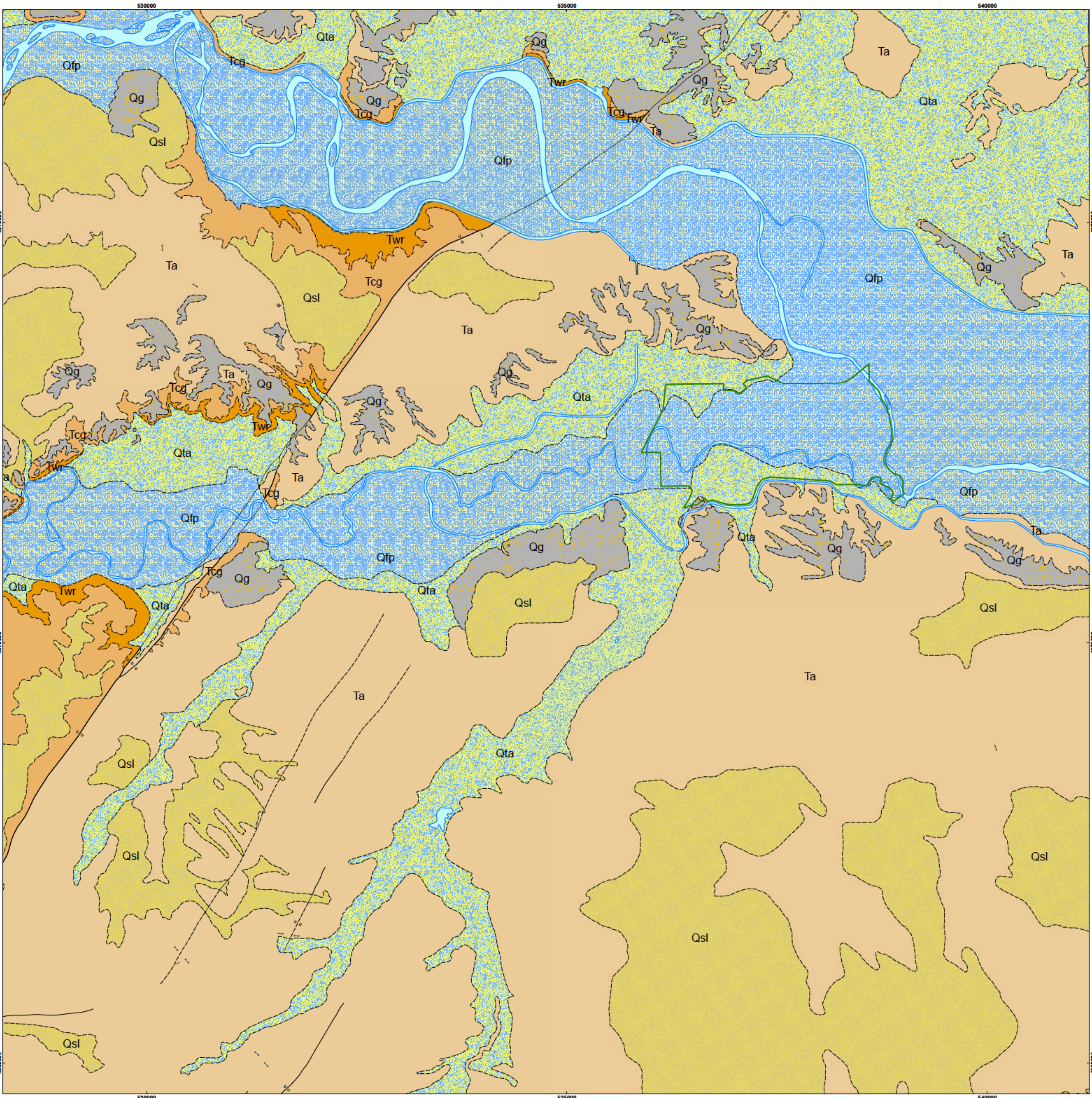
Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Fort Laramie National Historic Site. For a poster-size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resources Inventory publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Geologic Map of Fort Laramie National Historic Site



UTM Zone 13N NAD 83

NPS Boundary

Mine Point Features
- gravel pit
- dry hole
- dry hole with show of oil
- water sample locality

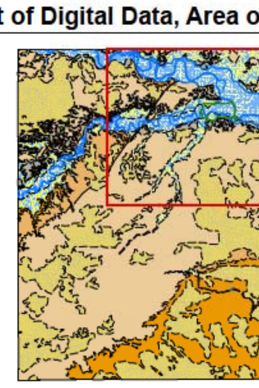
Geologic Attitude and Observation Localities
- strike and dip of beds
- apparent dip of beds
- dip of fault plane
- upthrown side of fault
- downthrown side of fault

Faults
- unknown offset/displacement fault, inferred
- high-angle fault, known or certain
- high-angle fault, approximate
- high-angle fault, concealed

Geologic Contacts
- known or certain
- approximate
- inferred
- map boundary
- water/shoreline

Geologic Units
- water
- Qfp - flood plain deposits
- Qta - tributary valley alluvium
- Qsl - sand and loess
- Qg - gravel
- Ta - Arikaree Formation
- Tcg - unamed conglomerate
- Twr - White River Formation

Full Extent of Digital Data, Area of Detail in Red



0 1 2 3 Kilometers

0 1 2 Miles

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

McGrew, Laura W. 1963. *Geology of the Fort Laramie area, Platte and Goshen Counties, Wyoming.* Scale 1:31,680. Bulletin 1141-F. U.S. Geological Survey.

Digital geologic data and cross sections for Fort Laramie National Historic Site, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

Produced by the Geologic Resources Inventory

July 2009

Appendix B: Scoping Summary

The following excerpts are from the GRI scoping summary for Fort Laramie National Historic Site. The contact information and Web addresses in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Summary

A Geologic Resources Inventory (GRI) workshop was held for Agate Fossil Beds NM (AGFO), Scotts Bluff NM (SCBL), and Fort Laramie NHS (FOLA) on March 3-4, 2003. The purpose was to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), AGFO, SCBL, FOLA, Fossil Butte NM (FOBU), and the University of Nebraska were present for the workshop.

This involved field trips to various points of interest in AGFO and SCBL, as well as a half-day scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the GRD, and the on-going GRI. Round table discussions involving geologic issues for AGFO, SCBL and FOLA included the status of geologic mapping efforts, interpretation, sources of available data, and action items generated from this meeting. Because of time and logistical limitations, FOLA did not get a site visit during the scoping session.

Existing Geologic Maps and Digital Data

After the bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for AGFO, SCBL, and FOLA. The USGS and other entities have published numerous quadrangles in the area at various scales and of variable vintage. Also of note is that digital data sets for the vegetation of AGFO, SCBL and FOLA have been produced, and can be downloaded from the USGS at http://biology.usgs.gov/npsveg/products/parkname.html

As for soils, according to NPS Soil Scientist Pete Biggam, mapping and digitizing is complete for SCBL and AGFO, and is in internal review with NPS. Therefore, they are not currently available for download. Of note, both are part of county datasets that need to be clipped down to park boundaries and Pete still need the textual document that accompanies the maps. FOLA data is inapplicable (old and out of date), and is inactive currently as of today according to Pete.

Fort Laramie NHS

There are already a few USGS large-scale geologic maps covering the area. These include the following:

- McGrew, L. 1963. *Geology of the Fort Laramie area, Platte and Goshen Counties, Wyoming*. Scale 1:31,680. Bulletin 1141-F. Reston, VA: U.S. Geological Survey.
- Sims, P.K., and W.C. Day. 1999. *Geologic map of Precambrian rocks of the Heartville Uplift, southeastern Wyoming*. Scale 1:24,000. Geologic Investigations Series I-2661. Reston, VA: U.S. Geologic Survey. http://pubs.usgs.gov/imap/i-2661/12661.pdf.
- Sims, P.K., W.C. Day, G.L. Snyder, and A.B. Wilson. 1997. *Geologic map of Precambrian rocks along part of the Hartville Uplift, Guernsey and Casebier Hill quadrangles, Platte and Goshen Counties, Wyoming*. Scale 1;24,000. Miscellaneous Investigations Series I-2567. Reston, VA: U.S. Geological Survey.

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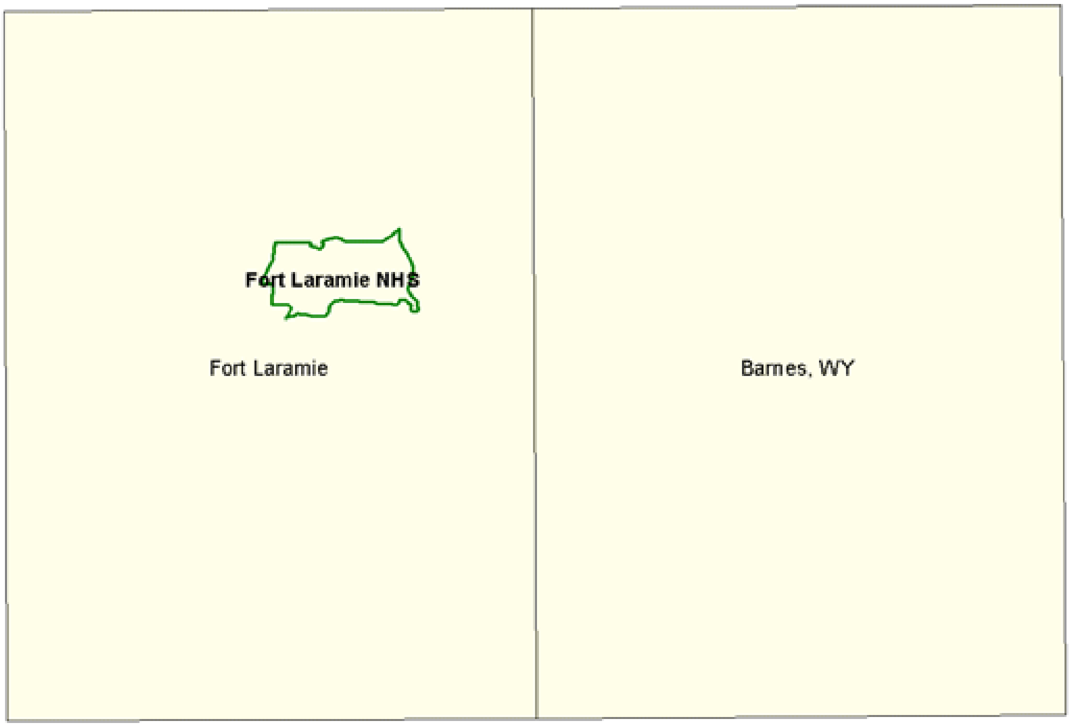
It is not known if any of these maps have been converted to digital GIS files, so Tim Connors will be following up with the Wyoming State Geological Survey and the USGS for any knowledge of these maps.

Specifically Mentioned Park Management Needs Related to Geology at FOLA

Tammy Benson mentioned that increased erosion is occurring in the springtime along the Laramie and Platte Rivers, and is subsequently uncovering "cultural" resources (buffalo and elk bones attributed to hunting). The park is located on a terrace, but no bedrock is exposed in the park, so it is likely that surficial geologic-, soils- and vegetation maps will be more useful than bedrock maps of the park. The park has some man-made wetlands and "hardpan". Mineral rights exist in the area and are held by non-federal entities; the exact commodities are unknown at this point. Additionally, Tammy mentioned the park has sand and gravel sites in the park that might need reclamation. These are located near the Fort Laramie cemetery and below the hospital.



Guadrangles of interest for Fort Laramie NHS.

List of Attendees for FOLA, AGFO, and SCBL GRI Scoping Meeting

NAME	AFFILIATION	TITLE	PHONE	E-MAIL
Tammy Benson	NPS-FOLA	chief ranger	307-837-2221	Tammy_Benson@nps.gov
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Fort Laramie National Historic Site

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/161

National Park Service
Director • Jonathan Jarvis

Natural Resource Stewardship and Science
Associate Director • Bert Frost

Natural Resource Program Center
The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring, and Evaluation, and Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross-cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the National Park System.

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National Park Service
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