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Bent's Old Fort National Historic Site

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2005/005

THIS PAGE:
Inside Bent's Old Fort, Bent's Old Fort NHS.

ON THE COVER:
Bent's Old Fort from the surrounding area, Bent's Old Fort NHS

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Geologic Resources Division
Natural Resource Program Center
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Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Bent's Old Fort National Historic Site. It contains information relevant to resource management and scientific research.

Bent's Old Fort National Historic Site was not established as a "geologic" park; however, its location in the Colorado Piedmont makes it part of both the human history and the geologic history of the Great Plains (Fig 1).

The focus of the resource management program at Bent's Old Fort is to maintain the historic character of the park (National Park Service, 1993). Understanding geologic processes and features that are part of the site will help resource managers reconstruct the historic landscape and anticipate natural hazards that could damage cultural resources.

At first "geologic glance," the national historic site seems simply to highlight the geologic processes that occur on a floodplain in a fluvial setting. However, in addition to flooding of the Arkansas River, many other geologic processes and features occur in the vicinity of Bent's Old Fort:

- Eolian Deposits and Wind Erosion—Windblown sand and loess (windblown dust) blanket large parts of eastern Colorado, including the south side of the Arkansas River near La Junta eastward to Kansas. In recent studies of Quaternary climate change, investigators have shown an interest in loess and eolian sand, because long loess sequences contain detailed records of Quaternary glacial- interglacial cycles. Loess is a direct record of atmospheric circulation and identification of loess representing paleowind patterns in the geologic record can test general atmospheric circulation models. In addition, widespread eolian deposits in eastern Colorado and adjacent parts of the Great Plains are important sources of information for reconstructing Quaternary aridification in the interior of North America

- Groundwater—Groundwater is the principal source of water for domestic use in the Arkansas River valley. River terrace deposits are sources of large supplies of water, and eolian deposits are major catchment areas for recharging underlying aquifers.

- Mineral Resources—The principal mineral resources in Otero and Crowley Counties are sand and gravel, which are quarried extensively for road construction. Locally some building stone has been quarried from the Dakota Sandstone, the Greenhorn Limestone, and the Fort Hays Limestone Member of the Niobrara Formation. The hearth in the kitchen of the historic site, which is original, is made of uncut pieces of limestone [probably the Greenhorn Limestone]. Clay and silt, which range in thickness from the east side to the west side of the fort, are possible sources for the manufacture of adobe blocks. Oil and mineral exploration does not take place within the local region of Bent's Old Fort, but the potential remains. Mineral rights remain outstanding on nine parcels within the historic site.

- Paleontological Resources—Potential for fossils within the boundaries of Bent's Old Fort exists in the Bridge Creek Member of the Greenhorn Limestone (Upper Cretaceous). This formation is known to contain *Durania cornupastoris*, an extinct group of bivalved (pelecypods) mollusks that are a rare find in the Western Interior. Additionally, the Pleistocene- age Louviers Alluvium has produced a mammoth (*Mammothus columbi*) tusk and a horse (*Equus* sp.) tooth in the vicinity of the national historic site. This stream- deposited sediment hosts fossils of other vertebrates, including camels and great bison, and fossil mollusks in other areas of eastern Colorado. Hence, these paleontological resources are also likely to occur within the boundaries of Bent's Old Fort National Historic Site.

- River Terraces—Alluvium (i.e., river terraces) upon which the fort sits, and in the vicinity of the site, serves as a record of climatic changes throughout the Quaternary. A major climatic cooling occurred during the Quaternary and brought on glaciation. Episodic base- level changes, primarily caused by cyclic changes in climate, are recorded by these alluvial deposits. Terrace deposits also form the most important unconsolidated groundwater aquifer in the area.

- Soil Compaction—Soils immediately around the parking lot at Bent's Old Fort National Historic Site are continuously compacted by vehicles parking outside the paved parking area. Compaction of soils reduces vegetation and increases runoff, potentially changing species characteristics. However, the area disturbed by soil compaction is small and does not significantly impact the overall vegetative system.

- Streamflow and Stream Channel Morphology—Human activities, such as removing water for irrigation during low flows of the summer, have probably impacted the geologic processes of streamflow and stream channel morphology more than any other process in the vicinity of Bent's Old Fort. Such activities have altered the character of the Arkansas River—from meandering to braided—in a relatively short period of time (i.e., 1936–1947) and alterations continue.

- Surface Water Quality and Level—The Arkansas River provided the original supply of water to the fort. Today, however, the river is polluted by particulate matter from runoff, solid waste from grazing animals, and sewage effluent from several upriver towns with marginal treatment facilities (National Park Service, 1975a). Also, the volume of the river changes rapidly in relation to spring runoff, rainfall over the watershed, and the amount of water diverted for irrigation.
- Wetlands—Wetlands occur in the area surrounding the fort, for example, the Arch wetland, the Casebolt wetland, and Day Pond. Wetlands at Bent's Old Fort National Historic Site could be serving a significant ecological purpose by acting as natural filters of pollutants. Wetlands also have the potential to serve as flood buffers.

Introduction

The following section briefly describes the regional geologic setting of Bent's Old Fort National Historic Site and the National Park Service Geologic Resource Evaluation Program.

This report serves as a starting point for understanding the geologic resources at Bent's Old Fort National Historic Site and is meant to bridge potential gaps between resource management and the historic site's geologic map.

Purpose of the Geologic Resource Evaluation Program

Geologic resources serve as the foundation of ecosystems and yield important information needed for decision making in National Park System units. The National Park Service (NPS) Natural Resource Challenge, an action plan to advance the management and protection of resources, has focused efforts to inventory the natural resources under the stewardship of the National Park Service. The geologic component is carried out through the Geologic Resource Evaluation (GRE) Program administered by the NPS Geologic Resources Division. The goal of the GRE Program is to provide each of the identified 274 "natural area parks" with a digital geologic map, a geologic evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of National Park System resources and each is designed to be user friendly to non- geoscientists. In preparing products the GRE team works closely with park staff and partners (e.g., USGS, state geologic surveys, and academics).

The GRE teams hold scoping meetings to review available data on the geology of a particular unit and to discuss associated geologic issues. Park staff are afforded the opportunity to meet with experts on the geology of their unit. Scoping meetings are usually held in each unit individually to expedite the process although some scoping meetings are multi- unit meetings for an entire Vital Signs Monitoring Network.

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Geologic Setting

The Great Plains—the words alone create a sense of space, a feeling of destiny, and a challenge. Bent's Old Fort National Historic Site was an integral part of this destiny, and the geographic backdrop was, and still is, an immense sweep of country, reaching north and south from Canada to Mexico and spreading eastward from the Rocky Mountains.

So often maligned as a drab, featureless area, the Great Plains is actually a land of contrasts and variety: canyons carved into solid rock by the water of the Pecos and Rio Grande, the seemingly endless grain fields of Kansas, the desolation of the Badlands, and the beauty of the Black Hills. The Great Plains physiographic province hosts many interesting, even spectacular, geologic features, many of which are part of the National Park System. For example, in the Black Hills of South Dakota at Mount Rushmore National Memorial, uplifted Precambrian rocks have been sculpted into the faces of four of the nation's most significant presidents. Also in South Dakota, Paleozoic limestones contain the remarkable Wind and Jewel cave systems. Magma generated during and after the Laramide uplift of the Black Hills produced a number of localized intrusions, including the spectacular Devils Tower in Wyoming. The scenic badlands of Theodore Roosevelt National Park in North Dakota are developed in Tertiary strata (see Fig 6). Oligocene sediments and a fossilized collection of early mammals that lived in the vast Serengeti- like plains of western North America are found at Badlands National Park in South Dakota, and fluvial sediments containing fossil mammal bones at Agate Fossil Beds National Monument in Nebraska record the story of mammal evolution into Miocene time. Additionally, the volcanic outpourings during post- Pleistocene time at Capulin Mountain are part of the Great Plains province.

Although generally not considered a "geologic" National Park System unit, Bent's Old Fort National Historic Site is indeed part of the geologic heritage of the Great Plains. The national historic site lies in the Colorado Piedmont section of the Great Plains province (figs. 2 and 3). The area ranges in elevation from 3,975 feet (1,212 m) at the point where the Arkansas River enters Bent County to 5,200 feet (1,585 m) north of Delhi, Colorado—a span of more than 1,200 feet (366 m). Generally speaking, the area around Bent's Old Fort consists of a series of flat to gently rolling surfaces with steep intervening slopes. The southeastern part of Otero County has been deeply cut by the Purgatoire River and its tributaries. The relief along the drainage in the rest of the area is generally much less (Weist and others, 1965).

The Colorado Piedmont is situated at the foot of the Rockies, largely between the South Platte and the Arkansas Rivers. After leaving the mountains, the South Platte, to the north, and the Arkansas, to the south, have excavated the Tertiary (65.5- to 1.81- million years old) sedimentary rock layers removing great volumes of sediment. These Tertiary rock units were originally deposited by shifting stream channels, floodplains, swamps, and occasional volcanic ash (Kiver and Harris, 1999). At Denver, the South Platte River has cut downward 1,500 to 2,000 feet (457 to 610 m) to the present level; no Tertiary rock layers remain in the vicinity of Bent's Old Fort. Three well- formed terrace levels flank the river's floodplain, and remnants of a number of well- formed higher land surfaces are preserved between the river and the mountains. Around the national historic site these Quaternary terraces rest unconformably upon Cretaceous shales and limestones.

Along the western margin of the Colorado Piedmont, the layers of older sedimentary rock have been sharply upturned by the rise of the mountains. The edges of these upturned layers have been eroded differentially, so that the hard sandstone and limestone layers form conspicuous and continuous hogback ridges. North of the South Platte River, near the Wyoming border, a scarp that has been cut on the rock of the High Plains marks the northern boundary of the Colorado Piedmont (Trimble, 1980).

Extending eastward from the mountain front at Palmer Lake, a high divide separates the drainage of the South Platte River from that of the Arkansas River. The crest of the divide north of Colorado Springs is generally between 7,400 and 7,600 feet (2,256 and 2,316 m) above sea level, nearly 1,500 feet (457 m) higher than Colorado Springs and more than 2,000 feet (610 m) higher than Denver (Trimble, 1980).

Much of the terrain in the two rivers valleys has been smoothed by windblown sand and silt. Northwesterly winds, which frequently blow with near- hurricane velocities, have whipped fine material from the floodplains of the streams and spread it eastward and southeastward over much of the Colorado Piedmont. Blowout dunes are the most common dune type in the vicinity of Bent's Old Fort.

In the Colorado Piedmont the erosional effects of streams are the most conspicuous features of the landscape. These fluvial features are enhanced by the steep tilting of layered rocks along the western margin of the Colorado Piedmont and modified by wind action, which has softened the landscape with a widespread cover of windblown sand and silt (Trimble, 1980).

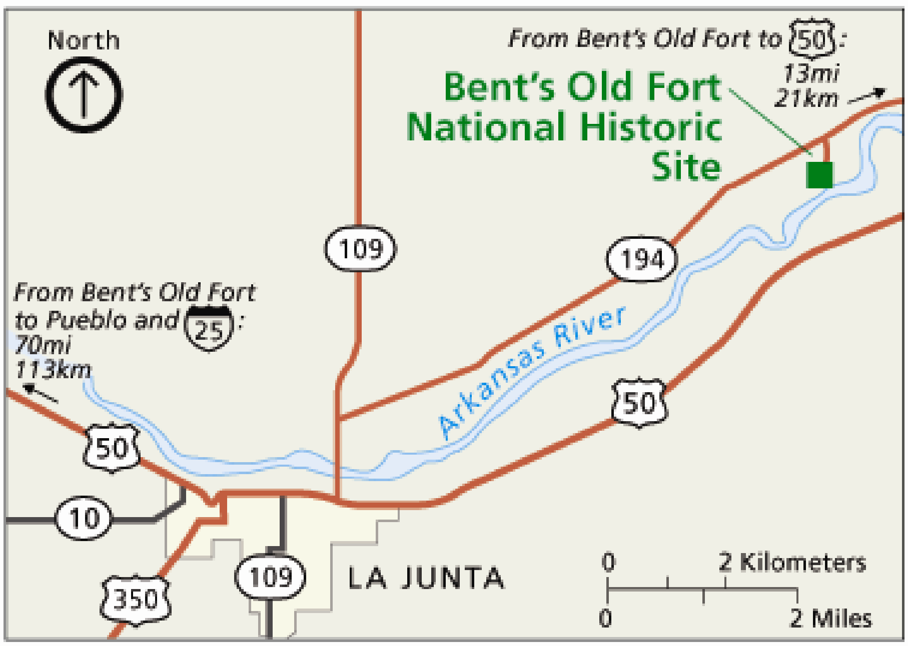

Figure 1: Location Map for Bent's Old Fort National Historic Site. Bent's Old Fort has been a crossway of travel throughout its history. Today, the national historic site is bordered on the north by Colorado 194 and on the south by U.S. Route 50. The Atchison, Topeka and Santa Fe Railroad parallels U.S. 50 and has an easement along the national historic site's southern boundary.

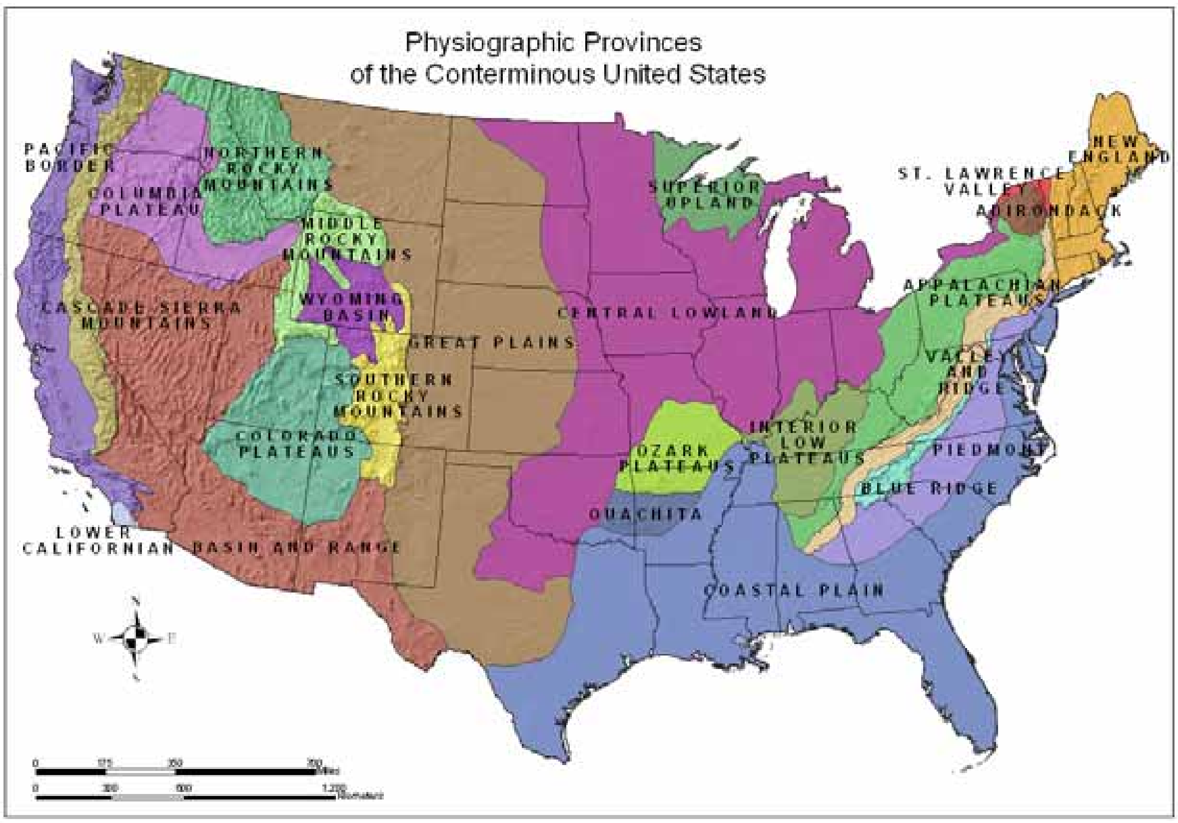

Figure 2: Physiographic Provinces of the Conterminous United States. Bent's Old Fort National Historic Site is part of the Great Plains physiographic province—an immense sweep of country reaching north and south from Canada to Mexico and spreading eastward from the Rocky Mountains.

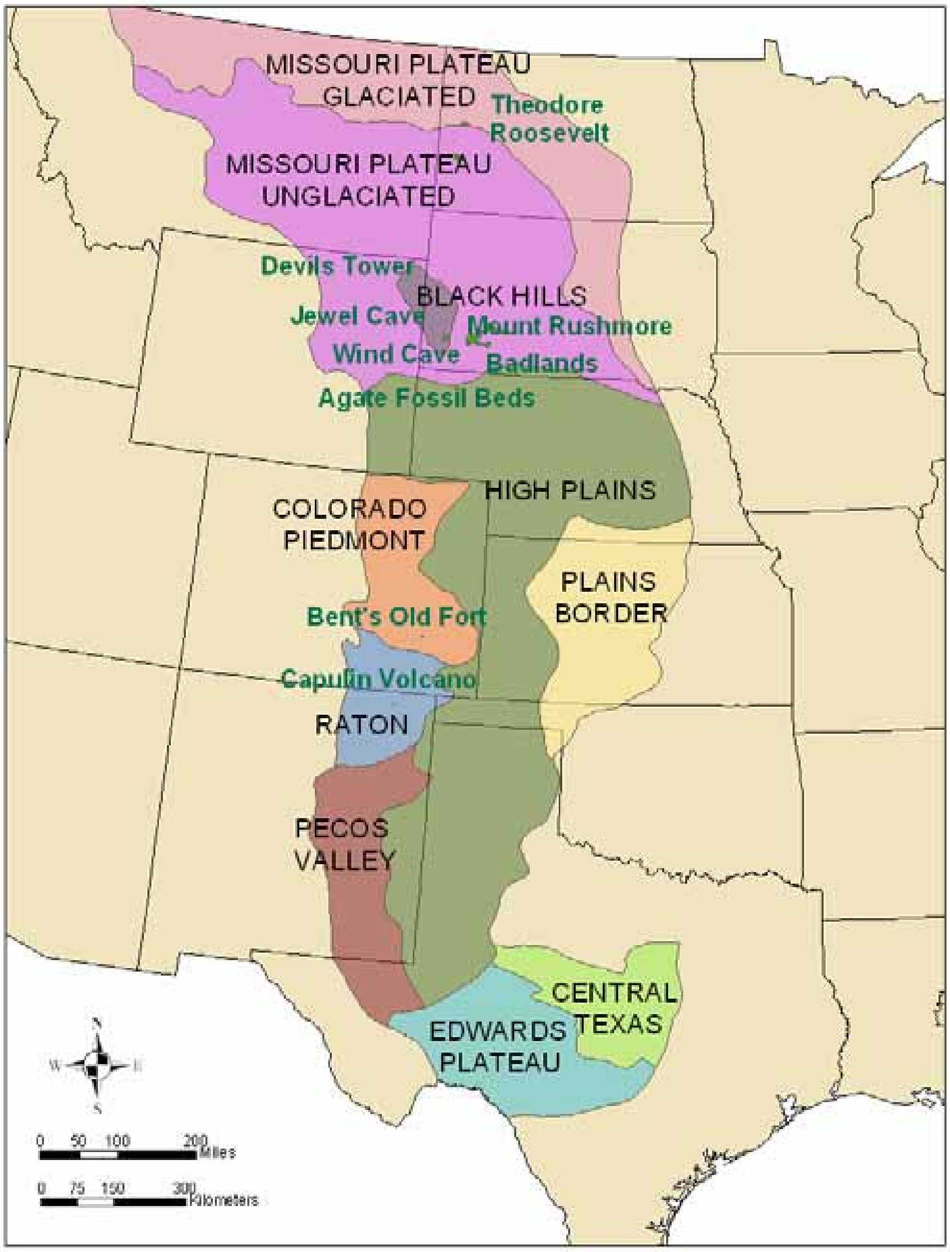

Figure 3: The Great Plains Physiographic Province. Bent's Old Fort National Historic Site is located in the Colorado Piedmont section of the Great Plains physiographic province. Other National Park System units in the Great Plains province are Agate Fossil Beds National Monument (Nebraska), Badlands National Park (South Dakota), Capulin Volcano National Monument (New Mexico), Devils Tower National Monument (Wyoming), Jewel Cave National Monument (South Dakota), Mount Rushmore National Memorial (South Dakota), Theodore Roosevelt National Park (North Dakota), and Wind Cave National Park (South Dakota).

Geologic Issues

This section identifies issues related to geology that may warrant attention from resource managers at Bent's Old Fort National Historic Site. These issues are relevant for maintenance of facilities, mitigation of hazardous conditions, and protection of resources.

Eolian Deposits, Climate Change, and Wind Erosion

Eolian (windblown) deposits blanket large parts of the west- central Great Plains. In eastern Colorado, situated at the higher and drier western margin of the Great Plains, eolian sediment covers about 60% of the area east of the Rocky Mountains. Of this eolian cover, about 30% is sand and 70% is loess (windblown dust) (Madole, 1995). The wide distribution of eolian deposits in this region was recognized almost as soon as geologic exploration began in the late 19th century (Emmons and others, 1896; Gilbert, 1896). However, the deposits were largely ignored for most of the following century, except for areas of dune sand that were mapped in connection with water- resource investigations. Loess received even less attention than eolian sand and is, therefore, underrepresented on most geologic maps, especially where it is thin (less than 5 feet [1.5 m]) or overlies rocks that produce residuum that is similar to loess, which is the case in much of the region (Madole, 1995).

In recent studies of Quaternary climate change, however, investigators have shown a renewed interest in loess and eolian sand. Much of the attention now given to loess stems from new studies of long loess sequences that contain detailed records of Quaternary glacial-interglacial cycles. Such loess sequences are thought to be a terrestrial equivalent to the foraminiferal oxygen isotope record in deep- sea sediments (Muhs and others, 1999). Loess is also a direct record of atmospheric circulation and identification of loess paleowinds in the geologic record can test atmospheric general circulation models (Muhs and others, 1999). In addition, the widespread eolian deposits of eastern Colorado and adjacent parts of the Great Plains are important sources of information for reconstructing the history of aridification in the interior of North America during the Quaternary (Madole, 1995).

Eolian sands are attractive deposits for paleoclimate reconstruction on the Great Plains for a number of reasons. First, eolian sand is highly sensitive to climatic change because stabilizing vegetation on such deposits in semiarid regions cannot tolerate significant reductions in precipitation. Second, research indicates that the eolian deposits of the Great Plains record a history of repeated windblown sand during the Holocene. Third, dune morphology and stratification, and isotopic and geochemical fingerprinting of sand source areas allow reconstruction of paleowind patterns, which in turn provide the basis for atmospheric circulation models and air mass distributions (Muhs and others, 1993).

A better understanding of how climate has varied in drought- prone regions like eastern Colorado is potentially useful for predicting and assessing potential effects of future climatic change (Madole, 1995). Shifts to a slightly drier climate could have serious socioeconomic consequences in this as well as other semiarid and arid regions. Population centers in these regions are dependent on water from river systems or on groundwater pumped from aquifers. Demands on these water resources are great and increasing. Also, drought in these regions sets the stage for massive wind erosion of agricultural land, and generation of dust storms that could adversely impact areas far downwind of source areas (McCauley and others, 1981; Péwé, 1981).

The location of Bent's Old Fort National Historic Site places it at center stage for climate change studies. In addition, land use practices in the region play an anthropogenic role in dust storms and wind erosion. For example, the primary land use in the area surrounding Bent's Old Fort is irrigated agriculture (Woods and MacDonald, 2002). However, a sale of water rights from the Fort Lyon Canal, as was under negotiation in 1992, would cause changes in land use around the national historic site. Such a sale would transfer water shares from the Arkansas River valley to Front Range cities and change the pattern of land use around Bent's Old Fort National Historic Site from agricultural to grazing (Bent's Old Fort National Historic Site, 1992). Potential outcomes for the historic site could be positive, leading to an improvement of the historic scene, or negative, resulting in incomplete restoration that acts as a seed bed for exotic plants and a source of dust. Water sales have occurred in the valley in the past with minimal success at prairie restoration. This external threat periodically surfaces as the possibility of selling water rights to urban areas is proposed (Bent's Old Fort National Historic Site, 1992).

Air quality is diminished primarily by dust from agricultural activities, and high winds. Traffic on gravel and dirt roads and agricultural burning are lesser contributors to poor air quality (National Park Service, 1993).

Bent's Old Fort National Historic Site has been free of commercial grazing since 1966. In 1975, when the fort was reconstructed, the National Park Service purchased a few horses, a pair of oxen, and a mule for use in support of the living history interpretive program. Federal land on the north side of the Arkansas River within the historic site's boundaries is used for the grazing of federally owned animals. At present Bent's Old Fort

National Historic Site has three horses, two oxen, a mule, and assorted fowl (Fran Pannebaker, Bent's Old Fort National Historic Site, written communication, May 25, 2005), which help set the historic scene at the reconstructed fort. Grazing is carefully controlled under a plan worked out in conjunction with the local soil conservation service (National Park Service, 1975a).

Flooding

Bent's Old Fort was built of adobe on the edge of a low terrace projecting southeastward into the floodplain of the Arkansas River (Swenson, 1970). Figures showing the river course and floodplain in Swenson (1970) plot Bent's Old Fort as lying at the northern edge of—but not actually in—the floodplain. However, in 1921 the "Great Pueblo Flood" crested above the level of the fort grounds causing most of the remaining original adobe walls to collapse (National Park Service, 1975a). The site also was threatened by flooding in 1965; however, floodwaters did not reach the ruins or cause any property damage (National Park Service, 1975a).

The floodplain north of the Arkansas River is about 1 mile (1.6 km) in width, very flat, and bordered on the north by low bluffs or hills. The floodplain south of the river varies from 0.25 to 0.5 mile (0.4 to 0.8 km) in width. Hills on the south side rise more gradually than on the north, with an average rate of rise about 125 feet (38 m) per mile (1.6 km) (Fig 4). Along the floodplain, groundwater is generally within 10 feet (3 m) of the land surface (Weist and others, 1965).

The water table in the area has risen in recent years (Woods and MacDonald, 2002), which is a factor in the basement flooding at Bent's Old Fort. Investigators have attributed the rising water table to a combination of factors: (1) a decline in the amount of groundwater being pumped from the aquifer, (2) increased seepage from the Fort Lyon Canal, (3) increased deep percolation of irrigation water, and (4) aggradation of the bed of the Arkansas River leading to higher river stage and greater leakage from the river alluvial aquifer. The relative importance of these factors varies with proximity to the Arkansas River, the canal, and areas of groundwater pumping and surface irrigation (Woods and MacDonald, 2002).

Storms over the upper Arkansas River basin are generally either low- intensity, long- duration rainfall events over a large area or short duration rainfall events with high intensity over a small area. The former are most prevalent during the autumn, winter, and spring seasons. Thunderstorms are most active during July and August, although the two largest and most destructive floods on record occurred during the month of June when general storms concentrated in a series of intense cloudbursts over the foothills and plains areas (Army Corps of Engineers, 1977).

Floods on the Arkansas River are of two general types. One type, "spring floods," results from melting snow and is often augmented by storm runoff. The other, "summer floods," results entirely from storm runoff. Spring floods are characterized by comparatively moderate rates of flow of long duration with large volumes of runoff. Summer floods are characterized by high peak rates of discharge with relatively smaller volumes of runoff (Army Corps of Engineers, 1977).

Hazards to life and extent of damage caused by any flood depend on the topography of the area flooded, depth and duration, velocity of flow, rate of rise, and developments on the floodplains (Army Corps of Engineers, 1977). Velocities greater than 3 feet (0.9 m) per second are generally considered hazardous to life and property. Water flowing in excess of 4 feet (1.2 m) per second is capable of transporting sediment and causing severe erosion of stream banks and fill around bridge abutments. Where velocities drop below 2 feet (0.6 m) per second, debris and silt deposits can build up (Army Corps of Engineers, 1977). The main line of the Atchison, Topeka and Santa Fe Railway, and the branch line from La Junta to Denver, transverse the floodplain. Numerous county roads, Colorado Highway 109, and U.S. 50 and 350 also cross the floodplain (Army Corps of Engineers, 1977) (Fig 1 and 4).

Obstructions, natural and anthropogenic, within floodways impede flood flows, creating backwater and increased heights. Debris washing downstream during floods often collects against bridges or within restricted flow areas, reducing waterway openings and impeding flood flow. This creates a damming effect and, depending on the degree of clogging, causes greater backwater depths with increased overbank flooding. Also, pronounced increases in flow velocity usually occur downstream from an obstruction, thus extending the flood damage potential. Anthropogenic obstructions on or over the floodway such as dams, levees, bridges, and culverts can create more extensive flooding than would otherwise occur (Army Corps of Engineers, 1977). Along the Arkansas River levees have been constructed by local interests. These levees are generally ineffective in preventing large floods and in some instances, such as during the June 1965 flood, may increase damage done by flood waters (Army Corps of Engineers, 1977). Additionally, certain materials stored in areas subject to flooding and high velocity flood flows pose potentially dangerous situations. For example, toxic, explosive, or flammable materials are usually stored in tanks and similar floatable containers that, if unrestrained, could be carried downstream threatening distant areas. Timber, lumber, and other similar floatable material may accumulate in substantial quantities during floods clogging downstream bridge openings and causing serious hazards and damage (Army Corps of Engineers, 1977).

Historical records reference many floods in the Arkansas River valley above John Martin Reservoir, located about 20 miles (32 km) east of Bent's Old Fort. The earliest known in the area occurred in 1826. The next notable flood was in 1844. Other reported floods occurred in 1859, 1864, 1869, and 1894. These floods were generally confined between Pueblo and the present John Martin Dam, an area which includes Bent's Old Fort. Major floods were experienced at various localities in the subbasin in 1921, 1935, 1942, 1955, and 1965. The flood of 1921 was the greatest flood of record on the Arkansas River at La Junta (Army Corps of Engineers, 1977) (Fig 1).

Descriptions of the 1921 and 1965 floods, which caused damage to or threatened the fort, may be enlightening to resource managers at Bent's Old Fort National Historic Site and useful in planning for future threats from flooding at the fort. Only in rare instances has a stream experienced the largest flood possible. Severe as the maximum known flood may have been on a given stream, it is generally accepted that a larger flood will occur. Streams with similar geographic and physiographic characteristics have experienced larger floods than those in the La Junta area. Severe storms undoubtedly will occur in the area causing future floods that will equal or surpass known historic floods (Army Corps of Engineers, 1977).

Flood of June 1921

Two areas of intense rainfall were observed above Pueblo. One of these was mostly north of the towns of Florence and Canon City. The other was fairly well distributed on both banks of the Arkansas River between Portland and Pueblo. Precipitation in this latter area is reported to have been as much as 11 inches (28 cm) in six hours while in the other area reports of as much as 9 inches (23 cm) in six hours were made (Army Corps of Engineers, 1977). The rainfall in the upper area was reported to have occurred first so that runoff combined with that below to produce the largest flood ever recorded at Pueblo. The peak discharge of 103,000 cubic feet per second (2,917 m^3/s) occurred at midnight on June 3, 1921. Above La Junta the effect of valley storage on peak attrition was obscured by the inflow from tributary streams and the peak discharge at La Junta was 200,000 cubic feet per second (5,664 m^3/s). North La Junta was flooded; water was 4 to 6 feet (1.2 to 1.8 m) deep on Second Street and reached the Otero County Jail. Citizens reported that 13 persons were drowned, though some of the bodies were not found until June 9. Areas in Huerfano and Purgatoire Rivers and in Timpas, Adobe, and Horse Creeks were flooded. Heavy rains occurred on the main stem of the Arkansas River from La Junta to Lamar. Below La Junta tributary inflow was small (Army Corps of Engineers, 1977).

Flood of June 1965

Flooding is often caused by a single event. The ensuing damage is caused by the downstream progression of the flood wave. For the June 1965 floods, especially on the main river course, a series of flood waves caused progressive flooding.

Steady rains began in the Arkansas River basin in Colorado on May 22, 1965, and as much as 2.7 inches (6.8 cm) of rain was reported for a single day. The days of June 4 and 5 also received relatively high precipitation, setting the stage for "rivers to roll" beginning June 14. Colorado in general received fairly heavy rain on June 14; hail damaged some areas, particularly around Colorado Springs. Rainfall was light on June 15, torrential on June 16, and of tremendous proportions on June 17. The June 16 and 17 storms covered practically all areas in southeastern Colorado and northeastern New Mexico, with the greatest concentration of rainfall near Holly, Lamar, and Two Buttes, Colorado (Snipes, 1974).
The highest peak discharge determined on the main stem of the Arkansas River above John Martin Reservoir was 104,000 cubic feet per second (2,945 m^3/s) at a site 1.2 miles (1.9 km) downstream from Chico Creek. This peak flow resulted from nearly coincidental timing of the flood crest moving down the Arkansas River and the peak discharge of 52,200 cubic feet per second (1,478 m^3/s) from Chico Creek (Snipes, 1974).

The total runoff in the Arkansas River basin in Colorado from the June 1965 storms exceeded that of any previous flood for which records exist. John Martin Reservoir stored 320,000 acre- feet (3.9×10^8 m^3) during June 14–26, and an additional 485,000 acre- feet (5.98×10^8 m^3) of inflow downstream from the dam flowed past the station near Coolidge, Kansas, during June 17–27. Thus, the total June 1965 storm runoff at the state line, adjusted for storage in the reservoir, would be 805,000 acre- feet (9.9×10^8 m^3). Records are not available at the Coolidge station, but at Holly, only 6 miles (10 km) upstream, the total storm runoff in 1921 was 410,000 acre- feet (5.1×10^8 m^3) (Snipes, 1974.) The high runoff downstream from Lamar caused the large difference between 1965 and 1921. At Lamar the total storm runoff in 1921 was about 450,000 acre- feet (5.6×10^8 m^3), compared with 400,000 acre- feet (4.9×10^8 m^3) (adjusted for storage in John Martin Reservoir) in 1965 (Snipes, 1974).

Flood water drowned 14 people, and at least two other deaths were attributed to the storms and activities related to the 1965 floods. Damage amounted to more than $60 million, about $56 million in Colorado and Kansas, and the remainder in New Mexico (Snipes, 1974).

Groundwater

Otero County and the southern part of Crowley County include an area of about 1,500 square miles (3,885 km^2) in the Arkansas River valley. Groundwater is the principal source of water for domestic use by local residents, most of whom are farmers or ranchers.

Rocks in the area, which range from Late Jurassic to Holocene in age (see Fig 6), influence the availability of groundwater. Five of the rock units are major aquifers: the Wisconsin- age (see table 1) terrace deposits, the valley- fill deposits, the Nebraskan deposits, the Dakota Sandstone, and the Cheyenne Sandstone Member of the Purgatoire Formation. The Wisconsin terrace deposits are the principal source of groundwater for irrigation and municipal supplies, yielding as much as 2,000 gallons (7,570 L) per minute; they also supply water for stock and domestic use. The valley- fill deposits supply water to domestic and stock wells and in places yield as much as 400 gallons (1,514 L) per minute to a few irrigation wells. The Nebraskan- age deposits supply water to stock and domestic wells and feed springs that supply water to two towns and a private water association. The Dakota Sandstone and Cheyenne Sandstone Member of the

Purgatoire Formation are sources of artesian water for many stock and domestic wells and for some industrial, municipal, and private water- association wells. They may yield as much as 80 gallons (303 L) per minute (Weist and others, 1965).
The Wisconsin terrace deposits are the best source of large supplies of water; however, they are so heavily developed in most of the area that some wells interfere with each other (see Fig 4). Moderate supplies of water for irrigation can be obtained from the valley- fill deposits. The rest of the unconsolidated deposits yield only small amounts of water for stock and domestic purposes. Water in the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation is under artesian pressure (Weist and others, 1965).

Groundwater in the unconsolidated materials moves generally eastward over an irregular bedrock surface. Waters within the Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation move northeastward (Weist and others, 1965). The saturated zone is usually less than 40 feet (12 m) thick. Along the floodplain, groundwater is generally within 10 feet (3 m) of the land surface. In 1973, groundwater levels were recorded in the gravel deposits at depths of approximately 11 feet (3.4 m) beneath the surface (Ken R. White Company, 1973). In the immediate vicinity of the proposed seepage beds for the historic site's sewage disposal system, the water table was measured at a depth of 13 feet (4 m) (National Park Service, 1975b). These levels may rise with an increased flow of water in the Arkansas River (Ken R. White Company, 1973).

Groundwater reservoirs in the area are recharged by subsurface and surface in- flow, including precipitation (which averages 11 to 14 inches [28 to 36 cm] per year) (Weist and others, 1965), seepage from streams and irrigation canals, and spreading of water for irrigation. They are discharged by subsurface outflow, evapotranspiration, seepage into streams, and pumping from wells (Weist and others, 1965).

All groundwater in the Bents Old Fort area can be classed as sodium calcium sulfate bicarbonate in character. It is generally of fair to good quality for most uses. Water from the unconsolidated formations is rated as hard to very hard, whereas water from the two artesian aquifers is generally rated as soft to moderately hard (Weist and others, 1965).

Under conditions of low to average flow in the Arkansas River, groundwater levels in the vicinity of Bent's Old Fort are controlled primarily by the rate of surface water irrigation and leakage from the Fort Lyon Canal (see Fig 4). Under high streamflow conditions, such as those that occurred during the 1999 peak flow, a local reversal of the hydraulic gradient between the alluvial aquifer and the Arkansas River can occur. The flow of water from the river, combined with increased leakage from the Fort Lyon Canal, are a likely cause of the high water- table levels observed in the vicinity of the fort and the consequent basement flooding that occurred in 1999 (Woods and MacDonald, 2002). Proposed reductions in the flow rate of the Fort Lyon Canal may slow or even reverse the upward trend in water- table levels in the vicinity of the national historic site (Woods and MacDonald, 2002).

Potential Impacts to Groundwater

A number of factors threaten groundwater quality at Bents Old Fort National Historic Site. The national historic site is bordered on the north by Colorado 194 and on the south by U.S. Route 50. The Atchison, Topeka, and Santa Fe Railroad parallels U.S. 50 and has an easement along the site's southern boundary (Bent's Old Fort National Historic Site, 1992) (see Fig 4). Hazardous wastes are transported by truck and rail without historic site staff's knowledge. Adjacent landowners use aerial spraying and ground spraying of fertilizer and pesticides on their fields (Bent's Old Fort National Historic Site, 1992). A radioactive waste dump, called the Thatcher Dome Project, has been proposed 44 miles (71 km) southeast of La Junta. This project was shelved in 1992 and, although determining the potential economic and environmental impacts of the radioactive waste dump on groundwater quality is difficult, it presents a concern for park managers (Bent's Old Fort National Historic Site, 1992). In addition, the waste water irrigation ditch of the Fort Lyon Canal Company parallels the south side of Colorado 194, across the entrance of the historic site within the highway right- of-way. This unlined ditch contributes to surface water and groundwater supplies and appears to be modifying vegetation east of the picnic area. The tail end of the ditch crosses NPS property perpendicular to Colorado 194 in the northeast corner of the national historic site (Bent's Old Fort National Historic Site, 1992). As a result of these factors, significant potential exists for misapplication of fertilizers and pesticides that could affect NPS property or hazardous waste accidents that could affect the groundwater system in the area.

Mineral Resources

The principal mineral resources in Otero and Crowley Counties are sand and gravel, which are quarried extensively for road construction. In addition, such deposits of alluvium may be suitable for use as aggregate for concrete and as riprap (Scott, 1963). These deposits are found chiefly on top of mesas and ridges along the Arkansas River (Weist and others, 1965). Clay and silt, which range in thickness from 3 feet (0.9 m) on the east side of the fort to 7 feet (2.1 m) on the west side, are possible sources for the manufacture of adobe blocks (Ken R. White Company, 1973), which is of historic interest and potentially useful for future repairs to the fort.

Locally some building stone has been quarried from the Dakota Sandstone, the Greenhorn Limestone, and the Fort Hays Limestone Member of the Niobrara Formation (Weist and others, 1965) (see Fig 5). With respect to the national historic site, the hearth in the kitchen, which is original, is made of uncut pieces of limestone [probably Greenhorn Limestone] (Bent's Old Fort Web site, http://www.nps.gov/beol/kitchen.htm).

Oil and mineral exploration does not currently take place within the local region of Bent's Old Fort; however, the potential for future exploration and development remains (Bent's Old Fort National Historic Site, 1992). For instance, most of the limestone and dolomite reservoir beds of the central Kansas oil fields persist westward into eastern Colorado, particularly into Prowers and Bent Counties. Therefore, oil and gas reservoirs may exist in that area (Maher, 1947). Oil and gas production occurs 25–30 miles (40–48 km) east and northeast of the historic site. Three wells have been drilled within 3 miles (5 km) of the historic site, but were plugged and abandoned because they were not economically viable (Bent's Old Fort National Historic Site, 1992).

Privately held mineral rights may exist within a National Park System unit when the government acquires the surface without acquiring the mineral rights, or when private, fee- simple parcels (privately held surface and mineral rights) exist within the unit. Private mineral rights exist on nine parcels within the historic site (Bent's Old Fort National Historic Site, 1992). Should an individual or company propose exploration or development for oil and gas within the historic site, park managers would implement *36 Code of Federal Regulations Part 9, Subpart B* to permit and control operations. If exploration and development of sand, rock, or gravel is proposed on split estate land (federally held surface rights and privately held mineral rights), park managers would issue a special use permit under *36 Code of Federal Regulations Part 5* to permit and control operations. In either case, if the NPS deems the impacts of proposed exploration or development as unacceptable, federal acquisition of the mineral rights may be pursued (National Park Service, 1993).

Paleontological Resources

Durania cornupastoris

In 1991 a group of at least 28 conjoined individuals of the rudist *Durania cornupastoris*, an extinct group of bivalved (pelecypods) mollusks, were discovered and collected from the uppermost part of the Bridge Creek Member of the Greenhorn Limestone in a road cut along U.S. 50 about 5 miles (8 km) northeast of La Junta, outside the boundaries of Bent's Old Fort National Historic Site. The rudist- producing bed in the Bridge Creek Member extends into the national historic site; thus, the potential for this fossil within the boundaries exists (Scott and others, 2001).

The discovery of the cluster of rudists is an unusual find of a species that was originally described in France (Des Moulins, 1826). Aside from fairly abundant occurrences in the Niobrara Formation of Kansas, rudists are rare fossils in the Upper Cretaceous rocks of the Western Interior. The 1991 find near Bents Old Fort was the first report of this species in the area (Cobban and others, 1991). This particular find falls within the conventionally recognized range of the species but extends its geographic occurrence (Cobban and others, 1991).

Investigators envision the species living in a low- to moderate- energy environment, marked by only occasional influxes of sediment that suffered little or no subsequent reworking by currents (Cobban and others, 1991). They suggest that the demise of this *Durania* "bouquet" was caused by increasing turbidity (or other environmental change) that inhibited effective feeding by mantle marginal particle entrapment (Skelton, 1979).

Mammothus columbi

Jackson Moore, a NPS archaeologist, discovered a fragmentary mammoth tusk at Bent's Old Fort. He collected tusk fragments between 1963 and 1966. The remains were found in a gravel bed overlying a white limestone unit (Moore, 1973). The fragments have been tentatively identified as *Mammothus columbi* (N. Russel, personal communication, 2000). According to the historic site's museum records, archaeologist Jerry Dawson collected an additional three mammoth tusk fragments in 1992 (Scott and others, 2001).

Louviers Alluvium

According to Scott (1963), the Louviers Alluvium in the Kassler quadrangle (Colorado) contains a large assemblage of fossil mollusks and vertebrates, including mammoths, camel, and great bison. Louviers Alluvium is an early Wisconsin- age terrace deposit. Weist and others (1965) mapped two Wisconsin- age terrace deposits (Qtw_1 and Qtw_2) in the vicinity of the national historic site, and Tweto (1979) mapped a gravel and alluvium deposit that he described as consisting of Broadway and Louviers alluvium (Qg) near Bent's Old Fort. The lower Wisconsin- age terrace deposit (Qtw_2) is the potentially fossiliferous unit in the national historic site. For example, during mapping, investigators found a horse (*Equus* sp.) tooth in a gravel pit (Weist and others, 1965). Although no research has been performed or inventory made, the paleontological resources found in this deposit in the Kassler quadrangle also could be in the vicinity of Bent's Old Fort (K. McKinney, U.S. Geological Survey, written communication, April 2004). In addition, the fragments of mammoth tusk now in the national historic site's collection are likely from the Louviers alluvium (K. McKinney, U.S. Geological Survey, written communication, April 2004).

Soil Compaction

Physical degradation of soils results from activities such as land clearing, erosion, and compaction by machinery. Soil structure may be altered so that infiltration capacity and porosity are decreased, and bulk density and resistance to root penetration are increased. Such soils have impeded drainage and are quickly saturated: the resultant runoff can cause accelerated erosion and transport of pollutants such as pesticides (Berger and Iams, 1996). At Bent's Old Fort National Historic Site soils immediately around the parking lot are continuously compacted by vehicles parking outside the paved parking area. Compaction of soils reduces vegetation and increases runoff, possibly changing species characteristics (National Park Service, 1993). However, the area disturbed by soil compaction is small (about 0.25 acres [0.1 ha]) and does not significantly impact the overall vegetative system (National Park Service, 1993). Existing developed areas (i.e., roads, buildings, paving, and paths) cover approximately 8 acres (3.2 ha) of the national historic site (National Park Service, 1993).

Streamflow and Stream Channel Morphology

The Arkansas River is a perennial but highly regulated river; the flow of its tributaries depends on precipitation and return flow from irrigation. Horse Creek is the only tributary north of the Arkansas River. South of the river, the Apishapa and Purgatoire Rivers, Timpas Creek, and Crooked Arroyo are the principal tributaries (Weist and others, 1965).

The flow of the Arkansas River is affected by numerous upstream diversions and the Pueblo Dam. The dam lies approximately 62 miles (100 km) upstream from the historic site and effectively separates this section of the Arkansas River from its headwaters in the Rocky Mountains. The mean annual discharge at La Junta (U.S. Geological Survey gauge no. 07123000) is 261 cubic feet per second (7.4 m^3/s), and the mean annual flow for the period following the closure of the Pueblo Dam in 1974 is 7,203 cubic feet per second (204 m^3/s) (Woods and MacDonald, 2002).

Since 1936 the amount of water diverted from the Arkansas River for irrigation has increased dramatically (Swenson, 1970). The irrigation season typically extends from March through September. Irrigation water is obtained primarily from the Fort Lyon Canal, which lies 1.5 miles (2.5 km) north of Bent's Old Fort and flows from west to east approximately parallel to the Arkansas River (see Fig 4). The diversion point for the canal lies approximately 12 miles (20 km) upstream from the historic site. Some irrigation water also is obtained by pumping groundwater from the alluvial aquifer (Woods and MacDonald, 2002). Investigators believe that removing water from the Arkansas River during the low flows of summer is responsible for the river becoming more braided in character (Swenson, 1970).

A study in 1970 shows that human activities altered the character of the Arkansas River in a relatively short period of time (i.e., 1936–1947), and alterations continue. In the early 1990s, the Colorado Department of Transportation requested assistance from the U.S. Army Corps of Engineers to stabilize the banks of the Arkansas River in the reach of river that parallels Colorado 194, at the northeast corner of Bent's Old Fort National Historic Site. Flooding in the past caused closure of the road, which is a significant issue for visitation and access to the site because Colorado 194 is the primary transportation corridor. The project used rock groins on the north bank to force flow onto the south side. Project groins were designed to have vegetated slopes. Final drawings showed all the groins outside the historic site's boundary and not within the fort's view shed. The final project proposal was reviewed by staff at Bent's Old Fort National Historic Site (Bent's Old Fort National Historic Site, 1992) and the project was completed by 1994.

In addition, the banks of the Arkansas River are eroding northward along the Fort Lyon Canal. Assistance from the NPS Water Resources Division and engineering assistance will be necessary to determine and reduce the environmental effects of this waste water ditch in terms of water level and impacts of chemicals (Bent's Old Fort National Historic Site, 1992).

Special Note: On the frequently asked questions (FAQ) page of the Bent's Old Fort's Web site (http://www.nps.gov/beol/parkinfo.htm), question 6 asks "Has the river changed course?" The answer: "It changed course every year during the time of the fort due to annual flooding" is misleading and should probably be changed to reflect historical records. "During the time of the fort" (i.e., 1833–1849) records state that the Arkansas River was about 300 yards from the fort, but they do not say if it was this close on the south or east, or describe any changes over time. Also, no maps or charts showing the relative position of the fort and the Arkansas River are known (Swenson, 1970).

An appropriate answer should incorporate the fact that the first survey of the area was not made until July and August 1869. Swenson (1970) evaluated the data gathered at that time and concluded that "Despite the fact that the Arkansas River, in the reach near Bent's Old Fort, has well- developed meanders and the river is flowing on easily erodible material, there has been relatively little shift of the stream since 1869. Little progressive migration of meanders downstream has occurred."

In addition, the use of "annual flooding" in the FAQ answer is misleading because annual floods have not occurred, as noted from the previous discussion of flooding and the floods of 1921 and 1965.

Surface Water Quality and Level

The Arkansas River provided the original supply of water at the fort (Bent's Old Fort National Historic Site Web site, http://www.nps.gov/beol/swbastion.htm). Today, however, the river is polluted by particulate matter from runoff, solid waste from grazing animals, and sewage effluent from several upriver towns with marginal treatment facilities (National Park Service, 1975a). Also, the volume of the river changes rapidly in relation to spring runoff, rainfall over the watershed, and the amount of water diverted for irrigation.

Wetlands

The area surrounding the fort includes several wetlands (Woods and MacDonald, 2002). The 52- acre (21- ha) Arch wetland lies on the Arkansas River floodplain immediately north of the fort. National Park Service personnel report that the Arch wetland has gradually increased in extent over the last 15–20 years. The 1- acre (0.4- ha) Casebolt wetland lies approximately 1,476 feet (450 m) southwest of the fort in a meander bend of the Arkansas River, and the 0.5- acre (0.2- ha) Day Pond is located adjacent to the Arkansas River about 984 feet (300 m) southwest of the fort (Woods and MacDonald, 2002).

The Arch wetland is supported by groundwater inflows from the adjacent upland. Reductions in the flow rate of the Fort Lyon Canal would probably reduce groundwater inflows and may therefore lower water levels and cause a decline in the size of Arch wetland (Woods and MacDonald, 2002).

Although analysis has not been conducted, wetlands at Bent's Old Fort National Historic Site have the potential to serve a significant ecological purpose by acting as natural filters of pollutants (National Park Service, 1993). Fertilizers, organic products, and other chemicals used on the agricultural lands surrounding the national historic site may be reducing the quality of the subsurface waters, and the wetlands could be sequestering and filtering these pollutants. Wetlands also have the potential to serve as flood buffers (Berger and Iams, 1996).

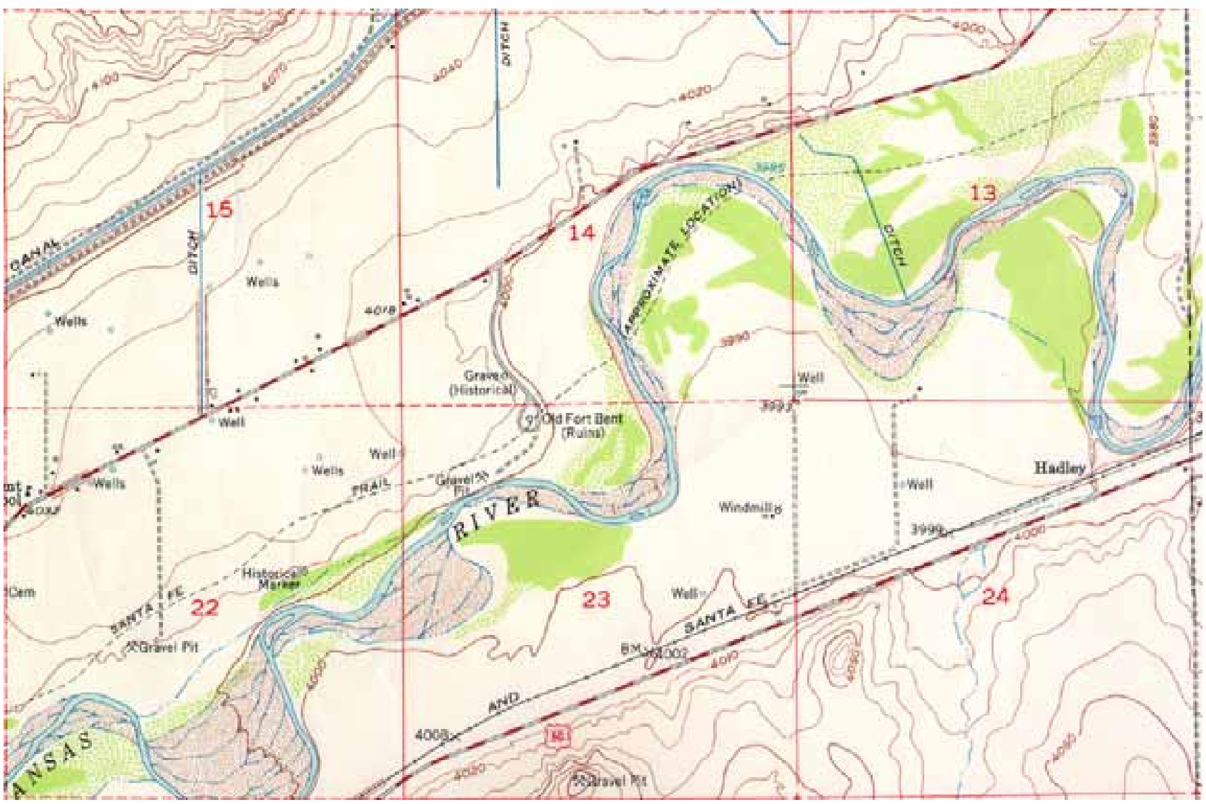

Figure 4: Topographic Map of the Vicinity of Bent's Old Fort National Historic Site. Bent's Old Fort lies on the northern edge of the Arkansas River floodplain. Note the number of wells on the 1953 map and the location of the Fort Lyon Canal (northwest corner of the map area). Also note the locations of highways 50 and 194 and the Atchison, Topeka and Santa Fe Railway in relation to the fort "ruins." This topographic map was published before Bent's Old Fort was authorized as a national historical site. *Source*: USGS Hadley, Colorado, quadrangle (1953).

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes at Bent's Old Fort National Historic Site.

The Great Plains contains thick layers of rock that formed in oceans, and younger layers of rocks deposited by streams. These rocks have been affected by tectonic movements, carved by streams, dissolved by groundwater, and blown by winds. All of these agents have played important roles in determining the landscape and the landforms of the Great Plains, but streams were the most influential.

Arkansas River

The Arkansas River is a broadly meandering stream in the vicinity of Bent's Old Fort National Historic Site. It flows approximately 6 miles (10 km) to cover a linear distance of 3 miles (6 km). The river's meanders are developed on a floodplain that, in general, is less than 0.75 mile (1.2 km) wide. The floodplain is entirely developed in unconsolidated materials, underlain by 30 to 40 feet (9 to 12 km) of fill. The river gradient is about 5 feet per mile (1.5 m/1.6 km), and the sediment load carried is moderately heavy, consisting largely of silt and sand in this reach of the river. During the period of stream gauging recorded at La Junta, the flow of the Arkansas River ranged from no flow to 200,000 cubic feet per second (5,664 m^3/s) (Swenson, 1970). Large diversions of water are made for irrigation, which accounts in part for the wide range in discharge of the stream. Discharge is also affected by rapid snowmelt in the mountains and cloudbursts within the basin, which can cause heavy flooding in the area. The maximum flood recorded occurred on June 4, 1921; it resulted from a cloudburst during a period of heavy snowmelt (Swenson, 1970).

Meandering Streams

Streams that flow upon floodplains, whether erosional or depositional, move in sweeping bends called meanders. Meanders change position by eroding sideways and slightly downstream. The sideways movement occurs because the maximum velocity of the stream shifts toward the outside of the bend, causing erosion of the outer bank. At the same time the reduced current at the inside of the meander results in the deposition of coarse sediment, especially sand. Thus by eroding its outer bank and depositing material along its inner bank, a stream moves sideways without changing its channel size. Due to the slope of the channel, erosion is more effective on the downstream side of a meander. Therefore, in addition to growing laterally, the bends also gradually migrate down the valley.

Changes have occurred in the river's channel morphology over time. The presence of meander scallops on the edges of the terraces bordering the floodplain and more or less filled oxbow lakes confirm meandering in the past (Swenson, 1970). Evaluation of available data—i.e., surveys from 1869 and 1882 and aerial photographs from November 20, 1936—indicate that little significant lateral migration of the meanders or shifting of the Arkansas River occurred between 1869 and 1936. Furthermore, very little shifting of the river's course occurred in the reach of the river that runs past the fort or downstream from the fort between November 1936 and July 1947. However, major changes in the stream took place in upstream reaches: the rather straight course of 1869 through 1882—more or less maintained through 1936—became very sinuous by 1947.

Another major change also took place during the period between 1936 and 1947: the Arkansas River became a braided stream. Islands were few and of small size in 1936, but they became numerous and of large size by 1947; this tendency has remained. Since 1936 the amount of water diverted from the river for irrigation has increased significantly. Investigators believe that removal of water during the low flows of summer is responsible for the development of the more braided character of the Arkansas River (Swenson, 1970).

Oxbow Lakes

Sometimes the downstream migration of a meander is slowed when it reaches a more resistant portion of the floodplain. This allows the next meander upstream to "catch up." Gradually the neck of land between adjacent meanders is narrowed. When they get close enough, the river may erode through the narrow neck of land to the next loop. Also, when at flood stage the stream may have the energy to break through the divide between two loops, making a shorter channel segment. The new segment is called a cutoff. Because of its shape, the abandoned bend is referred to as an oxbow lake. Standing water in an oxbow that was isolated by a cutoff then sealed with alluvium is called an oxbow lake. Its surface is the water table.

Cutoffs occur not only on the floodplains but in incised meanders, where, by penetrating divides, they make the tunnel from which natural bridges evolve (Wyckoff, 1999).

Braided Streams

The development of braided channels is favored by several factors. The most important factors leading to their development are large bed load and readily erodible bank material, which enable channel shifts to occur with relative ease. Once formed, bars in braided channels can become rapidly vegetated and thereby stabilized as islands. Highly variable discharge is typical of many braided rivers. By promoting alternating channel degradation and aggradation, large fluctuations in

discharge often suppress the establishment of vegetation on braided- channel bars (Summerfield, 1991).
As discharge declines after a flood, the coarse bed load is the first to be deposited in the channel. This material forms the nucleus of bars that grow downstream as the flow velocity is reduced and finer sediment accumulates. With further decreases in discharge the water level progressively falls and the bars are gradually exposed. During subsequent floods, some or all of the bars in a braided channel may be submerged depending on the discharge attained. During large floods braided channels can experience major diversions of flow (Summerfield, 1991).

Eolian Deposits

Eolian (windblown) sediment covers 60% of Colorado east of the Rocky Mountains; about 30% of the sediment is sand and 70% is loess (windblown dust). The Arkansas River eolian sand area, which covers 220 square miles (570 km^2), consists mainly of a belt of dunes, generally 0.2 to 0.4 miles (0.3 to 0.6 km) wide, along the south side of the river from near La Junta, Colorado, eastward to Kansas (Madole, 1995). Voegeli and Hershey (1965) described the eolian sand as flanking the Arkansas River from just west of the confluence of Big Sandy Creek and the Arkansas River eastward to the Kansas state line. They noted that the dune sand in this area has a maximum thickness of about 82 feet (25 m) but averages 33 feet (10 m). Blowout dunes are the most common dune type in the area (Madole, 1995). Blowout dunes are large accumulations of sand derived from a "blowout"—a saucer- or trough- shaped hollow formed by wind erosion in a preexisting sand deposit.

Gilbert (1896), working along the Arkansas River and the Black Squirrel sand area, was the first to conclude that streams were the primary source of eolian sand in the area. Since then, many studies have reached this conclusion. However, although streams are the principal source of eolian sand, they are not the only source; in places, eolian sediment apparently is derived from residuum of Upper Cretaceous and Tertiary sedimentary rocks (Madole, 1995).

Quartz is the dominant mineral in the area's eolian sand; feldspar is also present in amounts that appear to vary with sediment source (Madole, 1995). Although very fine sand tends to be dominant in dunes, most eolian- sand deposits contain all sizes of sand and some silt and clay. Few data are available with which to evaluate how sand size varies with local source area or deposit age. However, sand size does tend to decrease systematically downwind away from the South Platte River (Shroba, 1980; Muhs, 1985).

The roundness and sorting of sand grains appear to vary with sediment source. Grains derived from the floodplains and channels of large streams, such as the South Platte and Arkansas Rivers, tend to be rounded and well sorted, whereas a high percentage of the grains derived from small tributaries to these rivers are commonly sub- angular and not well sorted (Madole, 1995).

Presently, most dune sand in the vicinity of Bents Old Fort is stable and covered with vegetation (see Fig 5). Whereas blowout dunes are the most common type in areas south of the Arkansas River, parabolic dunes are dominant throughout northeast and central Colorado (Madole, 1995). Parabolic dunes are sand dunes with long, scoop- shaped forms, convex in the downwind direction so that their horns point upwind. When perfectly developed, parabolic dunes viewed from above approximate the form of a parabola. Except for the dune belt flanking the south side of the Arkansas River, dune fields are few, small, and widely scattered in southeastern Colorado (Madole, 1995).

River Terraces

Changes in channel gradient, discharge, or sediment load can lead to a river channel incising its floodplain. The original floodplain is thereby abandoned and is left as a relatively flat bench, known as a river terrace, which is separated from the new floodplain below by a steep slope. The fort at Bent's Old Fort National Historic Site sits on such a terrace. River terraces can also be cut into bedrock, in which case they are covered by only a thin sediment veneer.

River terraces are inclined downstream but not always at the same inclination as the active floodplain. A valley side may contain a vertical sequence of terraces. The lowest is the youngest and may retain traces of floodplain morphology, while the highest is the oldest and is usually partly degraded. Terraces can be either paired—forming when vertical incision is rapid in comparison with the lateral migration of the river channel, or unpaired—forming where lateral shifting of the channel is relatively rapid; this results in the river cutting terraces alternately on each side of the valley floor.

Terraces can be formed under a wide range of circumstances. Many episodes of channel entrenchment and terrace formation probably arise from changes in base level or fluctuations in climate, although tectonic deformation along river courses can also lead to terrace development (Summerfield, 1991). (Base level is the theoretical limit or lowest level toward which erosion of the Earth's surface constantly progresses but seldom, if ever, reaches. In particular, base level refers to the level below which a stream cannot erode. The general or ultimate base level for the land surface is sea level, but temporary base level may exist locally.)

During the Quaternary Period (see Fig 6) a major climatic cooling caused glaciation. Episodic base- level changes are recorded by alluvial deposits, such as terraces, in the Front Range and eastern Colorado. These changes are thought to be caused mainly by cyclic changes in climate, but could partly be a result of uplift that continued into Holocene time (Epis and others, 1980).

The alluvium in the vicinity of Bent's Old Fort National Historic Site serves as a record of climatic changes throughout the Quaternary Period. Geologists have studied, described, and named these deposits. The ages of these deposits correspond to the glacial episodes that occurred on continental and regional scales. Depending on the scale a particular investigator applied during his or her study, the names of the deposits vary (Table 1). In addition, during the 1960s investigators conducted much of the work for the glacial chronology of Colorado. Reports from studies of the early 1960s typically retain continental terminology because the glacial chronology for Colorado had not been worked out yet.

The occurrence of caliche—gravel and sand cemented with calcium carbonate—in the various Pleistocene deposits is diagnostic for determining the age of terraces. Generally, the youngest deposits contain the least caliche (Weist and others, 1965).

Structural Features

Otero and Crowley Counties lie near the southern end of the Denver basin, a large syncline that extends northward to Wyoming. The area surrounding Bent's Old Fort National Historic Site is bounded on the east and southeast by the Las Animas arch and on the south and southwest by the Apishapa uplift. The Las Animas arch, also termed the Sierra Grande arch, is one of the largest structural features in the vicinity of the historic site. Rich (1921) describes the arch as "a probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado." Both of these regional anticlines start at the Sierra Grande uplift near the New Mexico state line.

These major structural features combine to give the general northward or northwestward dip to the consolidated beds throughout most of Otero and Crowley Counties. In the southwestern part of Otero County the effects of the Apishapa uplift are more pronounced, and the beds generally dip northeastward. Dips are generally between 1° and 3° but locally may be as much as 36° (Patton, 1923). Dips greater than 3° are more common south of the Arkansas River. Locally, abrupt changes in both the amount and direction of dip occur (Weist and others, 1965).

Small faults in the area are numerous; most of them are in the Codell Sandstone Member of the Charlile Shale and the Fort Hays Limestone Member of the Niobrara Formation (see Fig 5). These faults are usually nearly vertical and have a displacement of less than 40 feet (12 m). Few of the faults can be traced for as much as a mile (1.6 km) before they lose their identity in less competent beds (Weist and others, 1965).

Duce (1924) defined two local structural features in southern Otero County. The first is the Ayer flexure, a small monoclinal fold—a local steepening in an otherwise uniform gentle dip—just east of Ayer siding, which he described as an unclosed dome with the southern end open. It has no topographic expression and appears as an inlier—an area or group of rocks surrounded by rocks of younger age—of Greenhorn Limestone (Weist and others, 1965). The other feature is the Black Hill dome southeast of Bloom siding. It is a small dome imposed on a monocline. Most of the dome is south of Otero County (Weist and others, 1965).

Table 1. Sequence of Quaternary Deposits

Epoch	Continental glaciation	Regional glaciation	Deposit
Holocene			Loess and eolian sand
			Piney Creek Alluvium
			Pre- Piney Creek Alluvium
Pleistocene	Wisconsin	Pinedale	Broadway Alluvium
		Bull Lake	Louviers Alluvium
	Illinoian	Pre- Bull Lake	Slocum Alluvium
	Kansan		Verdos Alluvium
	Nebraskan		Rocky Flats Alluvium
			Nussbaum Alluvium

***Sources*: Scott (1963) and Tweto (1979).**
***Note*: Nussbaum alluvium—also considered a Quaternary deposit (Epis and others, 1980)—formed through pedimentation rather than terrace formation. That is, the surface formed through backwearing and removal of debris by rill wash and unconcentrated flow rather than lateral planation by steep-gradient streams. Not all geologists agree with this description of pediment genesis, however.**

Map Units and Properties

This section provides a description for and identifies many characteristics of the rock units in the vicinity of Bent's Old Fort National Historic Site. The following table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table.

The table that comprises this section is meant to compliment the digital geologic map of Bent's Old Fort National Historic Site. The data files associated with the digital map provide the names of deposits and map symbols (see included CD); however, no descriptions of the deposits or rocks are included. The digital geologic map shows the floodplain area in the immediate vicinity of the fort. Therefore, this section of the report also includes rocks mapped in T23S, R54W of Otero County during a 1965 water- supply study (Fig 5).

The table provides readily available information for resource managers about the rock formations and deposits in the vicinity of the historic site. The table provides descriptions and correlates rock units from three sources:

Linn, S., 1999, Geologic map of Bent's Old Fort National Historic Site and vicinity, Otero and Bent Counties, Colorado [unpublished map]: Lakewood, Colorado, National Park Service, scale 1:24,000.

Tweto, O., 1979, Geologic map of Colorado: Reston, Virginia, U.S. Geological Survey, scale 1:500,000.

Weist, W.G., Jenkins, E.D., and Horr, A., 1965, Geology and occurrence of ground water in Otero County and southern part of Crowley County, Colorado: U.S. Geological Survey Water- Supply Paper 1799, 85 p., 4 plates, scale 1:125,000.

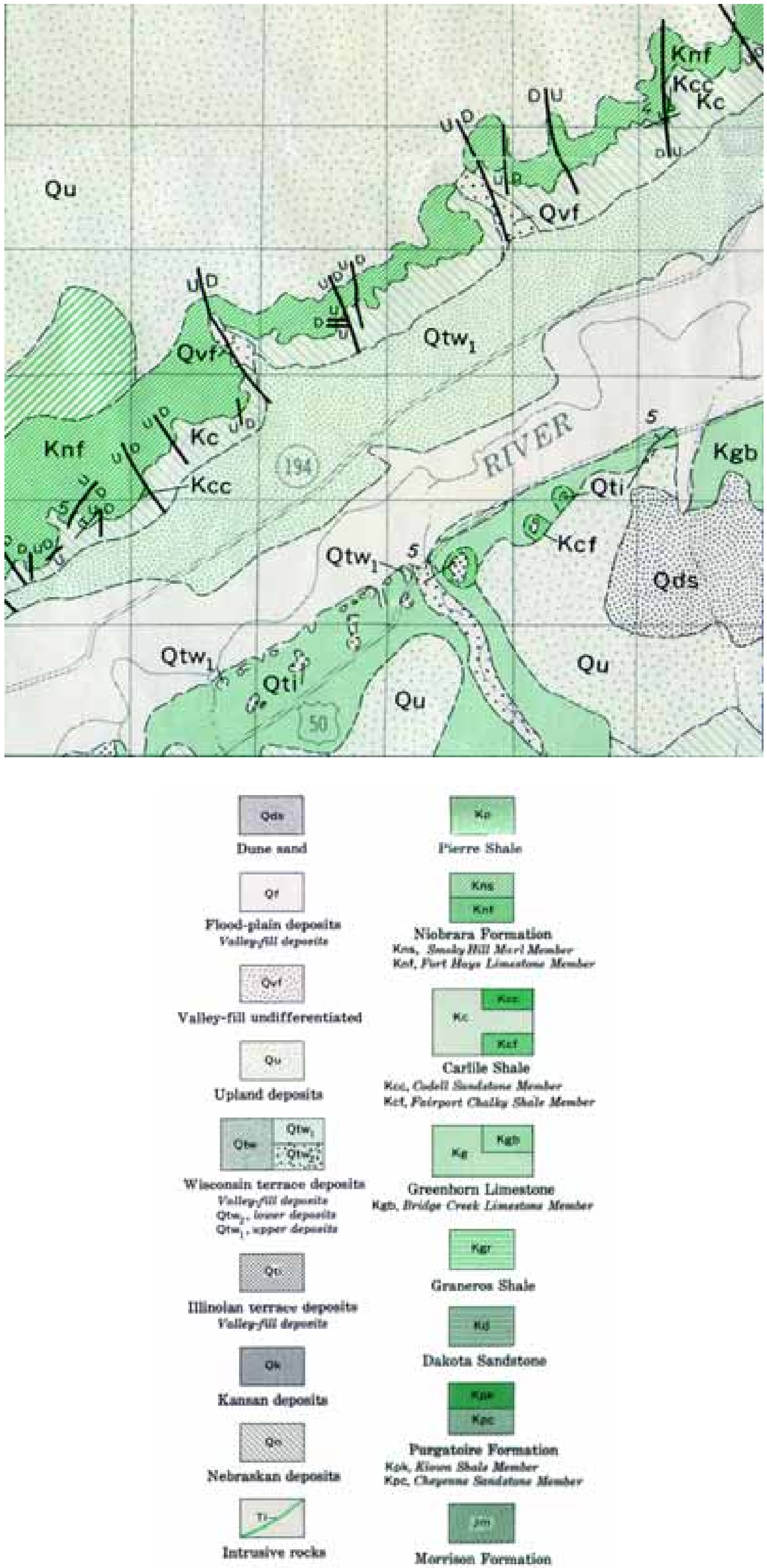

Figure 5: Rock Units in the Vicinity of Bent's Old Fort. Bent's Old Fort National Historic Site (Otero County, Colorado) is in T23S, R54 W (area shown in figure). During a water-supply survey, Weist and others mapped the rocks in the vicinity of Bent's Old Fort. These rocks are discussed in the rock units table of this section. *Source*: Weist and others (1965).

Map Unit Properties Table

Age	**Unit Name (Map Symbol)** Linn (1999)	**Unit Name (Map Symbol)** Weist and others (1965)	**Unit Name (Map Symbol)** Tweto (1979)	**Description**	**Significant Features**
Quaternary		Dune sand (Qds)	Eolian deposits (Qe)	Very fine to coarse sub- rounded to well- rounded grains of clear quartz, contains some feldspar, includes dune sands and silt and Peoria Loess	Most dunes are stabilized by vegetation, serve as major catchments for recharging underlying aquifers
	Alluvium (Qal) Overbank fines (Qob) Saturated soil	Floodplain deposits (Qf)	Modern alluvium (Qa)	Unconsolidated clay, silt, sand and some lenses of gravel; cross- bedded; includes Piney Creek Alluvium and younger deposits	Bent's Old Fort National Historic Site is at the edge of this deposit
		Valley- fill deposits (Qvf)		All alluvial deposits outside of the Arkansas River	Yields moderate supplies of water for irrigation, stock, and domestic use
		Upland deposits (Qu)		All unconsolidated deposits not associated with streams (e.g., weathered shale, slope wash, and eolian deposits [loess])	May yield small quantities of water for stock and domestic use
	Terrace deposits (Qt)	Wisconsin terrace deposits (Qtw) Upper deposits (Qtw_1) Lower deposits (Qtw_2)	Gravel and alluviums (Qg)	Generally unconsolidated clay, silt, sand, gravel, cobbles, and boulders; spotty accumulations of caliche; includes Broadway and Louviers Alluviums	Bent's Old Fort National Historic Site lies on this deposit, younger terrace deposits form the most important unconsolidated aquifer in the area, Louviers Alluvium contains fossils (Scott, 1963), higher percentage of gravel than other Pleistocene deposits
		Illinoian terrace deposits (Qti) Kansan deposits (Qk) Nebraskan deposits (Qn)	Older gravels and alluviums (Qgo)	Clay, sand, gravel, and cobbles; includes Slocum, Verdos, Rocky Flats, and Nussbaum Alluviums Illinoian: generally unconsolidated poorly sorted, contains considerable caliche (although not as much as Kansan), commonly cross- bedded, most rock fragments are granite and pegmatite; Kansan: poorly sorted, contains large amounts of caliche coating and cementing, contains fragments of dark igneous rocks; Nebraskan: generally unconsolidated moderately well sorted, some well- rounded cobbles, 70% sand and finer materials, contains much caliche	Kansan: may represent the period during which the present drainage system was established, caps high buttes on both sides of the Arkansas River; Nebraskan: out of the valley proper and probably represent sheet- type deposits predating present Arkansas River drainage, important source of water for public supply
Unconformity—no Tertiary- age rocks in the immediate vicinity of Bent's Old Fort National Historic Site					
Cretaceous		Niobrara Formation Smoky Hill Marl Member (Kns) Fort Hays Limestone Member (Knf)	Niobrara Formation (Kn)	Calcareous shale and limestone Smoky Hill Marl Member: predominantly gray, tan, or yellow limy shale and marl, which weathers into a characteristic yellowish orange; bedding plains and joint surfaces often coated with gypsum or calcite crystals; numerous white flakes of calcite give beds a "salted" appearance; Fort Hays Limestone Member: strongly jointed and breaks into flakes parallel to bedding, contains pyrite crystals and limonite nodules	Both members contain layers of bentonite; Fort Hays Limestone Member: fossiliferous and quarried as building stone; Shale of Smoky Hills Marl Member easily erodes; Fort Hays Limestone Member is resistant (forms prominent cliffs)
		Carlile Shale (Kc) Codell Sandstone Member (Kcc) Fairport Chalky Shale Member (Kcf) Greenhorn Limestone Bridge Creek Limestone Member (Kgb) Graneros Shale (Kgr)	Carlile Shale, Greenhorn Limestone, Graneros Shale (Kcg)	Carlile Shale: chalky to calcareous shale, contains thin beds of limestone; Greenhorn Limestone: hard to distinguish from Carlile and Graneros because it contains so much shale, generally dark gray to black	Carlile Shale, Greenhorn Limestone, and Graneros Shale contain thin beds of bentonite; Greenhorn Limestone: quarried for building stone (e.g., original hearth in fort's kitchen is probably Greenhorn Limestone); contains numerous fossils, especially in upper section; resistant to erosion and forms a series of benches (some capped by Illionian and older Wisconsin terrace deposits); Carlile Shale: contains zone of large septarian concretions (as much as 6 ft [1.8 m] in diameter), Codell Sandstone Member is fossiliferous; Graneros Shale: contains thin stringers of gypsum crystals
		Dakota Sandstone (Kd) Purgatoire Formation Kiowa Shale Member (Kpk) Cheyenne Sandstone Member (Kpc)	Dakota Sandstone and Purgatoire Formation (Kdp)	Sandstone and shale Kiowa Shale Member: dark- gray to black shale, very sandy in places; Cheyenne Sandstone Member: lighter color and relatively easily erodible nature distinguish it from Dakota Sandstone; generally white, compared with yellowish- brown sandstone of the Kiowa Shale Member	Dakota Sandstone: commonly breaks into large angular blocks; quarried for building stone; weathered surfaces are coated with desert varnish, which Indians have chipped away to form pictographs in places; Purgatoire Formation contains marine Comanchean fossils (Weist and others, 1965); Dakota Sandstone and Cheyenne Sandstone Member: two major artesian aquifers in the area

Regional Geologic Setting

Geographers have subdivided the United States into physiographic regions that, although they have great diversity within themselves, are distinctly different from one another.

From the Rocky Mountains on the west to the Appalachians on the east, the interior of our country is a vast lowland known as the Interior Plains. These plains are bounded on the south by a region of Interior Highlands, consisting of the Ozark Plateaus and the Ouachita province, and by the Coastal Plain. In the Great Lakes region, the Interior Plains lap onto the most ancient part of the continent, the Superior Upland. West of the Great Lakes it extends far to the north into Canada. The Rocky Mountains are distinctly different from the region to the east, which is the Great Plains. The Great Plains, then, is the western part of the great Interior Plains; the Rocky Mountains form its western margin and past glacial activity defines its eastern margin.

During the Pleistocene Epoch, huge glaciers formed in Canada and advanced southward into the great, central, low- lying Interior Plains of the United States. These glaciers and their deposits modified the surface of the land they covered, mostly between the Missouri and the Ohio Rivers; they smoothed the contours and gave the land a more subdued aspect. This glacially smoothed and modified land is called the Central Lowland. Although the ice sheets flowed into the northern part, the Great Plains is the largely unglaciated region that extends from the Gulf Coastal Plain in Texas northward into Canada between the Central Lowland and the foot of the Rocky Mountains. Its eastern margin in Texas and Oklahoma is marked by a prominent escarpment, the Caprock escarpment. Its southern margin, where it abuts the Coastal Plain in Texas, is at another abrupt rise or scarp along the Balcones fault zone (Trimble, 1980).

Within the Great Plains are many large areas that differ greatly from adjoining areas. The Black Hills stand out distinctively from the surrounding lower land; its dark, forested prominence can be seen for miles from any direction. At the southern end of the Great Plains is another, less imposing, forested prominence—the Central Texas uplift. Most impressive, perhaps, is the huge, nearly flat plateau known as the High Plains, which extends southward from the northern border of Nebraska through the panhandle of Texas and forms the central part of the Great Plains. The eastern and western rims of the southern High Plains are high, cliffed, erosional escarpments—the Caprock escarpment on the east and the Mescalero escarpment on the west. The north edge of the High Plains is defined by another escarpment, the Pine Ridge escarpment, which separates the High Plains from a region that has been greatly dissected by the Missouri River and its tributaries. There, several levels of rolling upland are surmounted by small mountainous masses and flat- topped buttes that are entrenched by streams. This region is the Missouri Plateau. The continental glacier covered the northeastern part of the Missouri Plateau and altered its surface (Trimble, 1980).

The South Platte and Arkansas Rivers and their tributaries have similarly dissected an area along the mountain front called the Colorado Piedmont. The Pecos River has excavated a broad valley trending southward from the Sangre de Cristo Range in New Mexico into Texas. The Mescalero escarpment separates the Pecos Valley from the southern High Plains. South and east of the Pecos Valley, extending to the Rio Grande and the Coastal Plain, is the broad plateau of bare, stripped, flat- lying limestone layers bearing little but cactus that is called the Edwards Plateau. Green, crop- filled valleys with gently sloping valley walls and rounded stream divides trend eastward from the High Plains of western Kansas and characterize a Plains Border section. And finally, between the Colorado Piedmont on the north and the Pecos Valley on the south, volcanic vents, cinder cones, and lava fields form another distinctive terrain in the part of the Great Plains called the Ration section (Trimble, 1980).

Early geologic events and the later shaping processes determined the distinctive character of the landscape in each section. All parts of this region have a similar early history, and the differences are the results of local dominance of certain processes in the ultimate shaping of the landscape, mostly during the last few million years (Trimble, 1980). Precambrian mountains were reduced to low- relief by the time shallow Cambrian (early Paleozoic) (see Fig 6) seas began to creep across and cover much of the North American continent. Fluctuating shallow seaways and relatively thin layers of Paleozoic and Mesozoic strata characterize the history of the craton until Late Cretaceous time when the Laramide Orogeny began. Uplift of the Rockies produced a corresponding downwarp in the Great Plains where extensive shallow basins formed. In particular, the Williston Basin formed in the northern Great Plains in the Montana- Dakota area, the Denver- Julesburg Basin formed in eastern Colorado, and Midland Basin formed in Texas (Thornbury, 1965).

Alluvium from the eroding mountains filled these shallow basins to overflowing. Shifting stream channels, floodplains, swamps, and occasional volcanic ash (especially in Oligocene and Miocene time) mostly characterize the Tertiary- age Great Plains sediments. Some 6–8 million years ago, the landscape was quite monotonous as the vast fluviatile plain sloped gradually eastward from the mountains—with only the Black Hills and a few other local mountains rising about them. The depositional surface of the Great Plains ramped up to the mountain edges where erosional plains were cut across the hard Precambrian and younger rocks to form the high- level erosion surfaces found in Rocky Mountain National Park and other Rocky Mountain areas (Kiver and Harris, 1999).

Uplift of the Rocky Mountains and eastward tilting of the Great Plains during the Pliocene Epoch initiated a new regime of downcutting and removal of sedimentary debris. Tertiary sediments were completely removed from the Colorado Piedmont and certain other areas. However, the High Plains—from South Dakota to the Texas border—form an extensive area where the late Miocene- Pliocene surface has been little eroded. A narrow remnant of this old surface extends westward in southeastern Wyoming, north of the Colorado Piedmont; it is called the Gangplank. Modern- day Union Pacific tracks and Interstate 80 make use of this natural sedimentary rock ramp to cross the Laramie Mountains (Kiver and Harris, 1999).

Pleistocene ice sheets pushed southwestward out of Canada and covered the northern part of the Great Plains, the area north of the Missouri River. Prior to glaciation, the Missouri flowed northeastward into Hudson Bay. Blocked off by ice during the Wisconsin advance, the river followed a new course along the front of the glacier. Once established, the Missouri maintained essentially this course after the glacier retreated (Kiver and Harris, 1999).

The contrast in landforms on the two sides of the glacial boundary is striking. The glaciated section is noted for its hummocky topography made of irregular moraines in which kettles, kettle lakes, and morainal lakes are abundant. The streams wander aimlessly through the glacial deposits, into and out of lakes and swamps. In the areas south of the glacial boundary, streams have developed regular drainage patterns and typical fluvial landforms (Kiver and Harris, 1999).

Dry climatic episodes during the past 1,000 years have generated desert conditions—conditions that would make modern agriculture impossible (Kiver and Harris, 1999). This semiarid region hangs close to the threshold where windblown sediment will again move and convert thousands of square miles into dunes and desert (Muhs and others, 1993).

Eon	Era	Period		Epoch	Dates	Age of
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01	Mammals
				Pleistocene	1.81	
		Tertiary	Neogene	Pliocene	5.32	
				Miocene	23.8	
			Paleogene	Oligocene	33.7	
				Eocene	55.0	
				Paleocene	65.5	
	Mesozoic	Cretaceous			142.0	Reptiles
		Jurassic			205.1	
		Triassic			250	
	Paleozoic	Permian			292	Amphibians
		Carboniferous	Pennsylvanian		320	
			Mississippian		354	
		Devonian			417	Fishes
		Silurian			440	
		Ordovician			495	Invertebrates
		Cambrian			545	
Proterozoic	Also known as Precambrian				2,500	
Archean					2,500–3,800?	
Hadean					3,800–4,600?	

Figure 6: Geologic Time Scale*.* Dates (in millions of years) reflect the International Union of Geological Sciences International Stratigraphic Chart, except for the boundary between Archean and Hadean, which is not listed (http://www.stratigraphy.org/chus.pdf). The U.S. Geological Survey lists this boundary and the formation of Earth (at approximately 4,600 million years ago), which are used here.

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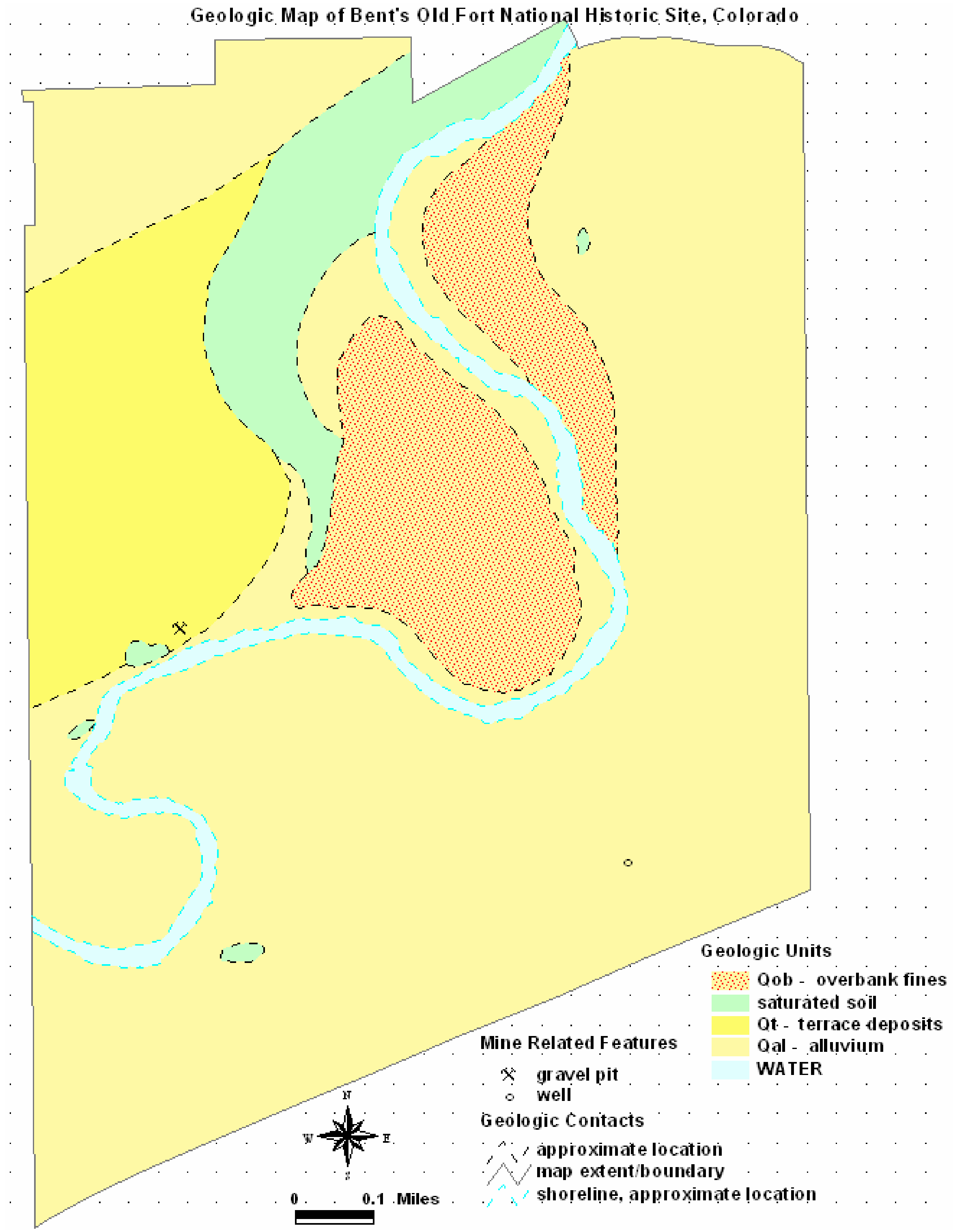
Appendix A: Geologic Map Graphic

This image provides a preview or "snapshot" of the geologic map for Bent's Old Fort National Historic Site. For the digital geologic map, see included CD.



The original map digitized by NPS staff to create this product was Linn, Sarah, 1999, Surficial geologic map of Bent's Old Fort NHS and Vicinity, Colorado, NPS, unpublished, 1:24000 scale. For a detailed digital geologic map and cross sections, see included CD.

Bent's Old Fort National Historic Site

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2005/005
NPS D-74, September 2005

National Park Service

Director • Fran P. Mainella

Natural Resource Stewardship and Science

Associate Director • Michael A. Soukup

Natural Resource Program Center

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