National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Scotts Bluff National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/085

THIS PAGE:
Chimney Rock National Historic Site can be seen from Scotts Bluff on a clear day.

ON THE COVER:
Dome Rock

NPS Photos

Scotts Bluff National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/085

Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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U.S. Department of the Interior
National Park Service
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Denver, Colorado

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Executive Summary

This report accompanies the digital geologic map for Scotts Bluff National Monument in Nebraska, 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.

Scotts Bluff National Monument is located in the panhandle region of western Nebraska. The impressive 244 m (800 ft) high promontory of Scotts Bluff was an important landmark for emigrants and frontiersmen along the Emigrant Trails. The historical importance of Scotts Bluff National Monument was recognized by presidential proclamation in 1919. The proclamation not only established the Monument but also recognized the unusual geologic features of the bluff and surrounding terrain. These features include steep bluffs, ridges extending from the bluffs, rock formations, and areas of badlands topography.

The two most important geologic issues facing resource management at Scotts Bluff National Monument are rockslides and fossil preservation. Steep cliffs border the road and hiking trails to the summit of Scotts Bluff. Numerous rockslides, which pose a safety hazard to visitors, occur along both the road and trails. The Monument's roads and primary trails are historic resources from the Civilian Conservation Corps (CCC)-era. Historic preservation laws and policies mandate their protection and preservation.

Paleontological resources are found in the badlands area of the Monument in the Oligocene Brule Formation. Oligocene age strata contain a wide variety of vertebrate fossils including horses, oreodonts (extinct, sheep-sized, four-toed mammals), prairie dogs, foxes, turtles, rodents, beaver, and cats. Deformation structures in the strata and cylindrical, tubelike features record tracks and burrows of Oligocene animals. Some of the fossils serve as type, or indicator, fossils for the Oligocene Epoch of the Cenozoic Era.

Both fossil theft and erosion are threats to the paleontological resources. In July 2007, the Monument convened a special workshop to address the issues of fossil preservation including erosion problems, preserving research values, fossil theft, and curation of collected specimens.

Scotts Bluff and South Bluff are the most prominent features at Scotts Bluff National Monument. The bluffs rise from the relatively flat prairie and have remained essentially unchanged from the time when the early pioneers saw them. Wind and water erosion have carved other distinctive landforms, such as Eagle Rock and Saddle Rock.

The stratigraphic units in Scotts Bluff National Monument contain sedimentary features that represent both fluvial and eolian depositional environments. Cross-stratification, irregular bedding, ripple marks, pseudomorphs of gypsum, and concretions provide evidence not only of depositional processes but also of the prevailing climate at the time of deposition. Layers of volcanic ash record explosive volcanic activity in the western United States during the Oligocene. Distinctive pockets of pink ash often have a high correlation with fossil remains.

The Monument contains more geologic history than any other location in Nebraska. The exposed strata at Scotts Bluff National Monument span a time period extending from 33–22 million years before present. The fossils and sedimentary features at Scotts Bluff National Monument add significant data with regards to the global climate change occurring in the Tertiary Period.

The Tertiary history of the Scotts Bluff region began with an episode of erosion that cut drainage systems in the underlying sediments. These paleovalleys filled with fluvial and eolian pyroclastic material generated from the rising Rocky Mountains and volcanic centers to the west. In contrast to the tropical and subtropical environments of the early Tertiary, savannas and grasslands formed low-relief topography after the paleovalleys filled. With renewed uplift, erosional downcutting increased and produced more paleovalleys.

Accelerated rates of wind and water erosion during Pliocene and Pleistocene time shaped the present landscape. Geomorphic processes eroded and transported less resistant rock, leaving the topographic landmarks of Scotts Bluff, Wildcat Ridge, and South Bluff in this region of the Nebraska panhandle.

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Scotts Bluff National Monument.

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 innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting 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 current GRI contact information please refer to the Geologic Resources Inventory Web site (http://www.nature.nps.gov/geology/inventory/).

Scotts Bluff National Monument

Located in the panhandle region of western Nebraska, Scotts Bluff National Monument contains 1,215.33 ha (3,003.03 ac) of prairie and bluff habitat (fig. 1). Scotts Bluff is a massive promontory that served as an important landmark along the historic Oregon, California, Mormon Pioneer, and Pony Express trails (collectively known as the Emigrant Trails) (fig. 2).

About 10 million years ago, regional uplift caused streams to cut into the landscape and remove much of the previously deposited sediment. While streams eroded the softer sedimentary rock surrounding Scotts Bluff, a dense layer of limestone concretions, called "capstone," or "caprock," protected these softer units slowing erosion on the bluff itself (fig. 2). The capstone is responsible for the exposure of sedimentary layers at Scotts Bluff.

Alluvial fans, gently sloping masses of loose rock material, spread out from the base of Scotts Bluff (fig. 2). Between Scotts Bluff and the North Platte River there is an area known as "the badlands," which supports little vegetation. The loose material of the alluvial fans and the soft sediment in the badlands offer little resistance to the eroding power of water.

The 1919 presidential proclamation that established Scotts Bluff National Monument defined the significance of Scotts Bluff as a landmark to emigrants and frontiersmen on their journey west and recognized the unusual geologic features of the bluff and surrounding terrain (National Park Service 1998; www.nps.gov/scbl). The geologic features include steep, rocky, siltstone and sandstone bluffs, ridges that extend from the bluffs, and areas of badlands formations.

Regional Geology

Scotts Bluff National Monument lies within the western Great Plains in a region that was once almost continuous mixed-grass and shortgrass prairie but now is largely agricultural (i.e., farming and ranching). The Monument encompasses two large, cliff-rimmed bluffs—Scotts Bluff and South Bluff. Scotts Bluff rises 1,420 m (4,659 ft) above sea level and 244 m (800 ft) above the North Platte River. The north face of Scotts Bluff exposes more geologic history than any other location in the state of Nebraska. The strata are Tertiary in age and span a time period extending from 33 to 22 million years before present.

The steep elevation, ridges, and broad alluvial fans at the base of Scotts Bluff are composed of layers of sandstone, siltstone, volcanic ash, and limestone that record a history of wind and stream depositions as well as groundwater supersaturated with calcium carbonate (lime). The strata are part of the Oligocene White River Group and the Oligocene–Miocene Arikaree Group (fig. 3) (Swinehart and Loope 1987; Swinehart and

Diffendal 1997). Badlands topography is located between the north base of Scotts Bluff and the North Platte River, where deeply incised arroyos support little or no vegetation (National Park Service 1998).

The North Platte River and its floodplain form a portion of the Monument's northern boundary. No free-flowing streams are located within the Monument although several small drainages, consisting of gullies and ravines, have eroded into the bluffs.

Park History

As many as 55 archeological sites have been located and identified in Scotts Bluff National Monument (National Park Service 1998). Of these sites, 49 are prehistoric, representing the time from circa 10,000 B.C. to circa A.D. 1750. Humans occupied the Scotts Bluff region as early as 10,000 years ago during a period known as the Paleo-Indian State, which lasted from 10,000 to 6,000 B.C.

Since A.D. 1750, Cheyenne, Arapaho, Lakota, and Euro-Americans have occupied the region. Historic features significant to Scotts Bluff National Monument include the following:

- Remnants of the Oregon Trail roadbed in Mitchell Pass,
- An 1866 campsite of the famous frontier photographer and artist William Henry Jackson,
- Ruins of the brick Trailhead Arch constructed in 1930 that once stood at the base of the now-abandoned "Zig-Zag Trail,"
- The Oregon Trail Museum that was dedicated in 1936 and was once the only museum committed to telling the story of America's westward migration,
- The Summit Road that was built by the Works Progress Administration (WPA) and the Civilian Conservation Corps (CCC),
- The Summit Hiking Trail system that includes the first substantive development at the Monument in the form of the "Scout Trail" (also called the "Zig-Zag Trail") constructed in 1927 to replace an informal foot trail that had been worn into the bluff and had relied on a rickety ladder to finally reach the summit.

Details about the life of Hiram Scott, for whom the bluff was named, are scant. What is known includes the following: Scott was born around 1805 in St. Charles County, Missouri. As an employee of William Ashley's Rocky Mountain Fur Company, he attended the first fur trader rendezvous held near the Great Salt Lake in 1826. Historians believe that Scott died near the bluff when he was returning to St. Louis, Missouri, from the 1828 rendezvous.

In 1830, the first wagons made the overland trip west on the same route used by the fur traders. Scotts Bluff served as a landmark for these early travelers. Emigrants along the Oregon–California trail typically traveled on the south side of the Platte River until they reached Scotts Bluff, where the geology of the badlands forced them out of the valley. The badlands which stretched from the base of the bluff to the river formed a barrier to travel. Once out of the valley, the bluff formations forced the emigrants to the two closest passes through the bluffs: Robidoux Pass and Mitchell Pass.

At the time, Mitchell Pass, which lies within the Monument, could not accommodate covered wagons. In 1834, travelers described Mitchell Pass as "a large and deep ravine…very uneven and difficult, winding from amongst innumerable mounds 6–8 feet in height, the space between them frequently so narrow as scarcely to admit our horses." (National Park Service 1998, p. 33). Because Mitchell Pass was impassable, travelers used Robidoux Pass, which lies south of Scotts Bluff National Monument and is a national historic landmark.

In 1850–1851, unknown persons significantly altered Mitchell Pass to allow for wagon traffic. One hypothesis suggests that the U.S. Army may have made the improvements by leveling and digging so that supplies to Fort Laramie could arrive more quickly. Another hypothesis suggests that a rival trading company may have done the work in Mitchell Pass in order to put the existing Antoine Robidoux trading post, located in Robidoux Pass, out of business. Unfortunately, there are no known written records of who did the work that dramatically changed Oregon–California travel in this area. Ruts from the wagon traffic on the Oregon Trail remain in the Monument today.

Nebraska citizens made inquiries about the possibility of establishing a national monument at Scotts Bluff as early as March 28, 1914. Interested citizens submitted a petition to the newly-formed National Park Service in 1916 urging it to establish a national monument to commemorate the Oregon Trail. In 1918, they submitted a second petition, and on December 12, 1919, Woodrow Wilson signed a presidential proclamation that officially established Scotts Bluff National Monument.

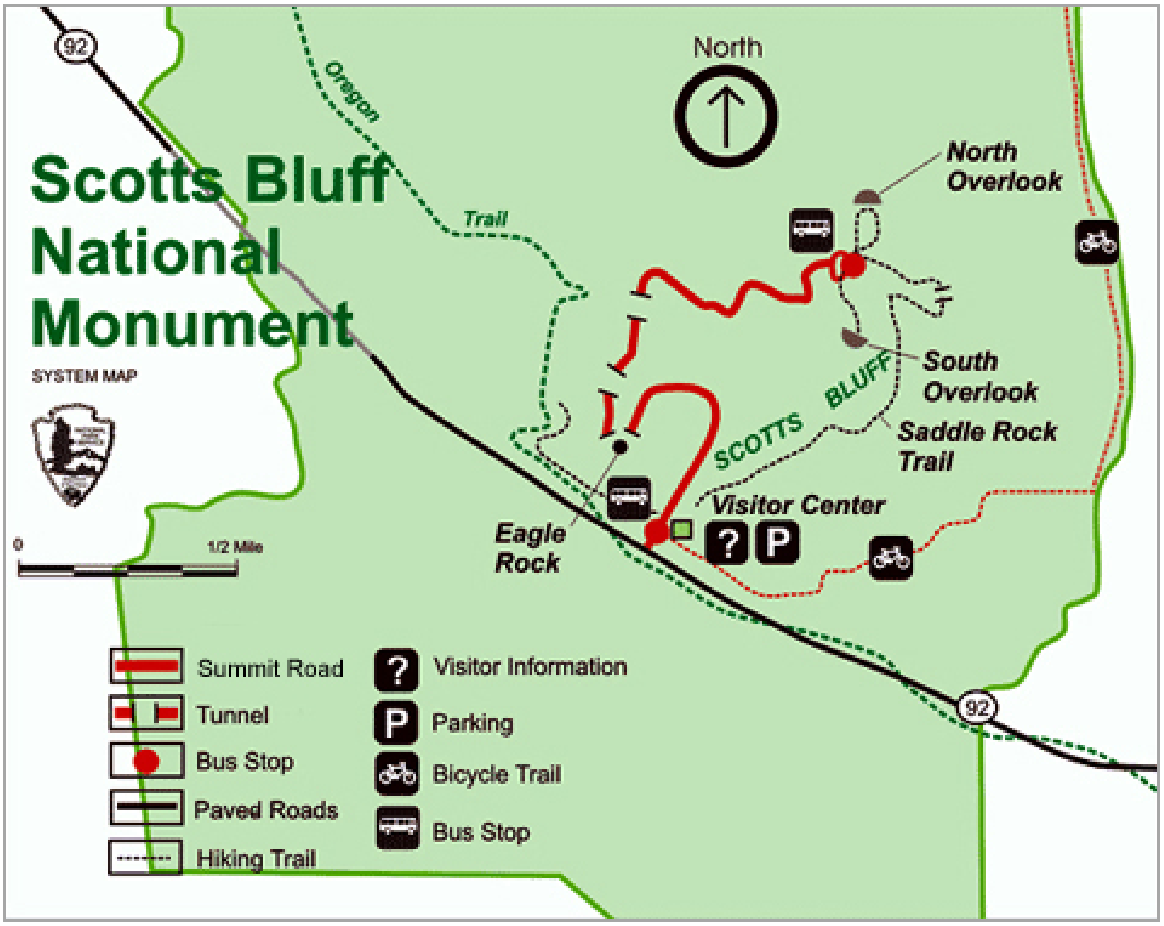

Figure 1. Location map for Scotts Bluff National Monument. NPS Graphic.

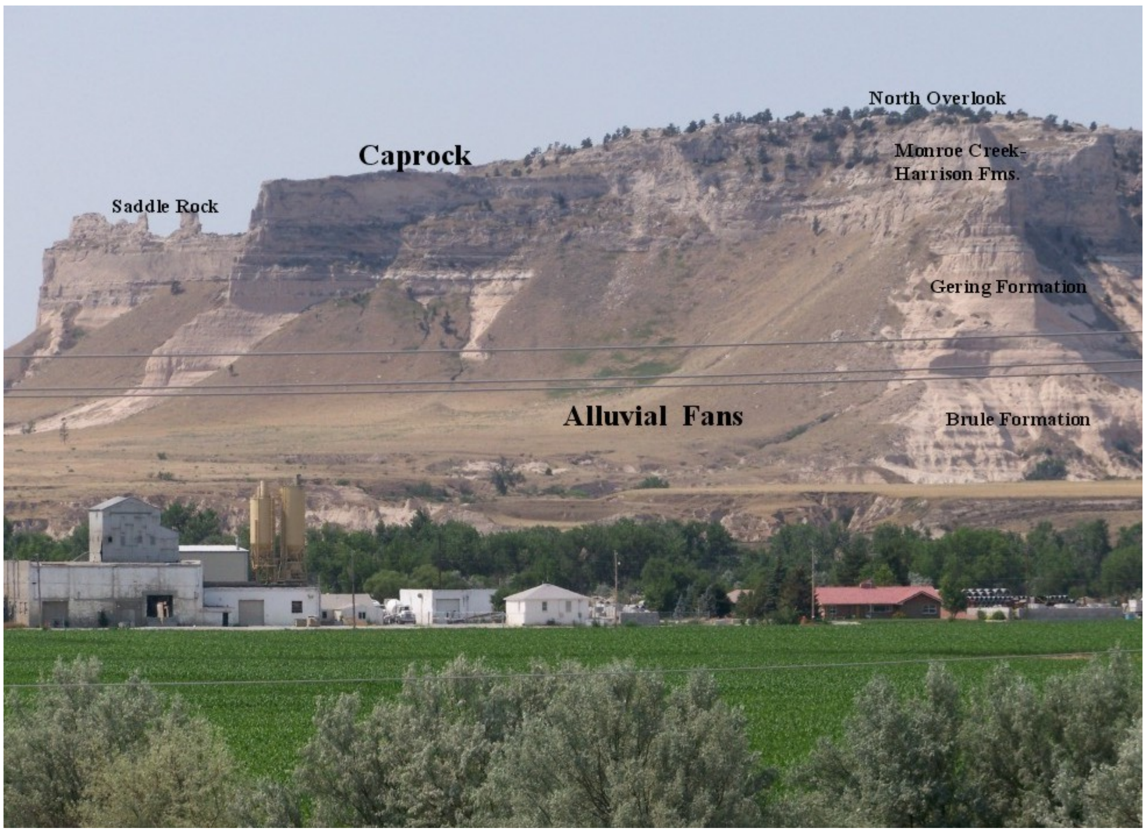

Figure 2. Scotts Bluff. View is to the south. Noted landscape features include the caprock that supports the bluff, alluvial fans spreading out from the base of the bluff, Saddle Rock, and the North Overlook. The bluff is composed of sedimentary rock of the Brule Formation, Gering Formation, and Monroe Creek–Harrison Formations. The trees behind the buildings are growing in the floodplain of the North Platte River. Photograph by John Graham (Colorado State University), July 7, 2007.

Era	Period	Epoch (Age in m.y.)	Group	Formation/Unit	Member
CENOZOIC	Quaternary	Holocene (0.01–present)		Unconsolidated alluvium and colluvium	
		Pleistocene (1.8–0.01)			
	Tertiary	Pliocene (5.3–1.8)		Broadwater Formation	
		Miocene (23.0–5.3)	Ogallala Group	Angora sand and gravel beds	
				Ash Hollow Formation	
				Duer Ranch beds	
			unconformity		
			Arikaree Group	Camp Clarke unit	
				Monroe Creek–Harrison Formations (undivided)	
		Oligocene (33.9–23.0)		Gering Formation	
			unconformity		
			White River Group	Brule Formation	brown siltstone unit (informal member)
					Whitney Member
					Orella Member
		Eocene (55.8-33.9)		Chadron Formation	
			unconformity		

Figure 3. General stratigraphic column for the region around Scotts Bluff National Monument. Units exposed in Scotts Bluff National Monument are highlighted in yellow and are described in detail in the Map Unit Properties Table. Most of the fossils found in the Monument are from the Orella Member of the Brule Formation. The Monroe Creek–Harrison Formations form the caprock on the top of Scotts Bluff. An "unconformity" represents a substantial break or gap in time between the lower rock unit and the overlying rock unit. Absolute age of epochs is given in millions of years. Data from Swinehart and Loope (1987) and Swinehart and Diffendal (1997).

Geologic Issues

The National Park Service held a Geologic Resources Inventory scoping session for Scotts Bluff National Monument on March 3–4, 2003, 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.

Rockslides

The single most important geologic issue for resource management at Scotts Bluff National Monument is rockslides (Appendix B). Rockslides affect park roads and trails and pose a hazard to park staff and visitors (figs. 4 and 5). Much of the erosion at Scotts Bluff results from rockslides; for instance, in October 1974 and October 2000 large rockslides impacted the Saddle Rock Trail (the old Summit to Museum Trail) (stop J in Swinehart and Loope 1987). Remains of the slides, including large blocks of talus, are still obvious today. Steep cliffs border the road and hiking trails that lead to the top of the Monument. The remnants of numerous rockslides are evident along the cliffs (fig. 4). In 2000, about 2.9 million kg (3,000 tons) of rock fell on the Summit Road (see Appendix B).

The Summit Road passes through three tunnels on its way to the top of Scotts Bluff (fig. 1). Interpretive exhibits and signs are located along the road. Between 1976 and 1985, during the peak visitor use months of June–August, 10 major rockslide events occurred, primarily between tunnels 2 and 3 (National Park Service 1989). A 1989 environmental assessment of the Summit Road found that excavation of rock material during road construction had left an exposed vertical cliff of several horizontally bedded rock units (National Park Service 1989). The lower rock units of the cliff are poorly cemented and easily erodable sandstones and siltstones. One critical boundary that easily erodes exists at the contact of a volcanic ash bed and the overlying, massive sandstone unit that forms the upper cliff area.

The reoccurrence of major rockslide activity initiates as erosion and slumping in the weak lower rock units. This erosion leads to undercutting and loss of support of the upper sandstone unit (National Park Service 1989). Exfoliation fractures develop in the upper cliff, and eventually these exfoliation sheets fail and fall onto the roadway. Following extensive rockslide activity, the upper cliff temporarily achieves some stability. Once the erosion of the lower units reaches a point that it begins to undercut the upper cliff, the cycle of major rockslide activity begins again. Since construction of the Summit Road, erosion, exfoliation development, and rock failure has taken place on an approximately 20-year cycle.

Following the 1989 environmental assessment, the Federal Highways Administration used shot-crete in an attempt to stabilize the area around the tunnels (fig. 6). A few minor cracks have developed in the shot-crete since its application in 1991. Compared to other areas of the Summit Road and Saddle Rock Trail, the slides in the area between tunnels 2 and 3 are now few and small in size (Robert Manasek, Resource Management Specialist, Scotts Bluff National Monument, written communication, February 13, 2007; author's observation, July 7, 2007).

In October 2000, a rockslide again impacted Saddle Rock Trail. After completion of *Environmental Assessment Saddle Rock Landslide Hazard Removal Scotts Bluff NM, March 2001*, the park made the decision to blast and remove large amounts of material in an effort to keep the trail open (see Appendix B). The history of rockslides and the geology that makes up the features are enough evidence to suggest that removal of rockslide debris will not make the Saddle Rock Tail safe for visitors, but only act as a temporary measure. While it is the park's desire to keep the trail open to visitors, it will still remain a high-risk area from future rockslides.

Preservation of Paleontological Resources

Fossils are non-renewable resources and have increased scientific value when they are preserved in-situ or excavated by professional paleontologists. The Nebraska badlands of Scotts Bluff National Monument host some of the richest fossil-bearing strata in the state (fig. 7). The majority of the fossils found here are in the Orella Member of the Brule Formation, the same fossiliferous Oligocene unit exposed in Badlands National Park in South Dakota. Specimens from the Monument serve as type, or indicator, fossils for the Oligocene Epoch (23.0–33.9 million years ago) of the Cenozoic Era (65.5 million years ago to present).

The ash and silt-rich claystones of the Orella Member compose the lower two-thirds of Scotts Bluff (fig. 2) (Foss and Naylor 2002). A 2002 paleontological survey found significant fossils in the lower units of the Orella Member. Some of these fossils include ancestors to the modern dry land tortoises (*Stylemys*), extinct oreodonts (*Merycoidodon*), "mouse deer" (*Leptomeryx*), and fossil mammal burrows.

Collectors and souvenir hunters removed a large number of vertebrate fossils from the Orella badlands prior to 1910 when this area was incorporated into the Monument and fossil collecting was prohibited (Swinehart and Loope 1987). Today, collecting, rockhounding, and gold panning of rocks, minerals, and paleontological specimens, for either recreational or educational purposes is generally prohibited in all units of the National Park System (36 C.F.R. § 2.1(a) and § 2.5(a)). Violators of this prohibition are subject to criminal penalties. Nevertheless, illegal collection of fossils, remains a threat to the paleontological resources of Scotts Bluff National Monument (Foss and Naylor 2002; http://www.nps. gov/scbl). For example, researchers discovered evidence of illegal fossil collecting in the Orella Member during a 2002 paleontological survey (Foss and Naylor 2002). On Labor Day, 2005, park staff discovered four people in the badlands illegally collecting fossil fragments and "sand crystals" (disk-shaped gypsum crystals that have been replaced by calcite) (Robert Manasek, Resource Management Specialist, Scotts Bluff National Monument, written communication, February 13, 2007).

In addition to fossil theft, the unintentional disturbance of fossil material is a threat to paleontological resources. Fossils are often quite fragile and on one occasion, a park ranger witnessed two teenagers pick up a turtle fossil while exploring the Monument's badlands. By the time the ranger reached them, the teenagers had nearly destroyed the fossil, not intentionally but simply from handling the fossil out of curiosity. Additionally, people playing paintball frequent the badlands, and at times inadvertently disturb fossil materials (Robert Manasek, Resource Management Specialist, Scotts Bluff National Monument, written communication, February 13, 2007).

The natural erosion of the mudstones, siltstones, and fine-grained sandstones of the Brule Formation and Arikaree Group continually exposes new fossils in the monument. Erosion can also destroy the fossils before they can be collected and catalogued.

On July 17, 2007 a workshop (the Eroding Fossils Workshop) at Scotts Bluff National Monument addressed erosion as well as issues involving locating, collecting, and cataloguing fossil specimens (Lake et al. 2007). Participants at the workshop included paleontologists and curators from the University of Nebraska, Chadron State College, Badlands National Park, Fossil Butte National Monument, and Agate Fossil Beds National Monument. Superintendent Ken Mabery, Chief of Resource Management Bob Manasek, and Chief Ranger Pete Swisher represented the Monument. Specialists from the Geologic Resource Division (GRD) of the National Park Service and a local fossil enthusiast were present, also.

The goals of the workshop included the following:

- Developing a pilot policy, or template, for parks with erosive matrix and fossils.
- Developing a "grave to cradle" management strategy to deal with occasional, accidental fossil discoveries outside of a research design or specific collection strategy.

At the conclusion of the workshop, participants had identified several action items: planning a training session in GPS data collection, developing a short-term (5–6 years) cooperative agreement with Chadron State College for curation and/or preparation of fossils from the Monument, developing a standard operating procedure for the short-term paleontological curation strategy, and preparing a long-term sustainable general management plan for paleontological resources at Scotts Bluff National Monument.

Participants decided to convene a second "Phase 2" meeting to develop a strategy for producing a more detailed geologic map of the Monument, which would include a paleontological site inventory. GRD staff suggested that park managers submit a proposal to the GRD's GeoScientist-in-the-Parks program for a geologist who could begin the paleontological resource inventory at the Monument, assess current park collections, and develop a field guide/identification tools for future graduate students, paraprofessionals, or professionals interested in the paleontological resources at Scotts Bluff National Monument.

Progress continues on Phase 2 of the Eroding Fossils Workshop (Ken Mabery, Superintendent, Scotts Bluff National Monument, written communication, March 31, 2008). Robert Manasek, Resource Management Specialist for Scotts Bluff National Monument, has written a draft of a fossil management plan for the Monument and is awaiting comments from National Park Service paleontologists (Robert Manasek, NPS Scotts Bluff National Monument, written communication, January 29, 2009).

Potential research projects include exploring fossils found in the Brule Formation at both Scotts Bluff National Monument and Badlands National Park, and comparing the resources and Oligocene paleoenvironment of each park. This project could dove tail with a paleontological survey identifying fossil taxa as well as existing and potential fossil sites.

Erosion of Scotts Bluff

Erosion impacts fossil preservation, promotes conditions that are conducive to rockslides, and is slowly wearing down Scotts Bluff (fig. 8). In 1933, a metal survey post installed at the summit of Scotts Bluff marked the highest elevation as 1,417 m (4,649 ft) above sea level. The persistent, grain-by-grain erosion by rain, ice, and wind has removed fine-grained sandstone from the summit of Scotts Bluff and exposed approximately 0.3 m (1 ft) of the metal survey post since 1933.

Disturbed Lands

Two golf courses, cattle feedlots, a hog farm operation, irrigated and dry land fields, houses and other structures, and an open clay quarry pit have disturbed approximately 217 ha (535 ac) of Monument land. After purchasing these privately owned lands, the NPS demolished buildings, fenced the properties, and seeded the areas with varying amounts of native-grass seed in an effort to restore the native prairie environment. Prairie restoration continues to be a high priority for management.

Natural clay was quarried from a pit near the eastern boundary of Scotts Bluff during World War II (Appendix B). Because of other commitments, reclamation of the clay pit has not been identified as a primary resource management concern (Cockrell 1983; Robert Manasek, NPS Scotts Bluff National Monument, written communication, January 29, 2009).

Three irrigation canals, Nebraska State Highway 92, and a railroad track cross the Monument. The Mitchell-Gering Canal crosses the park just north of the bluffs, the Gering-Fort Laramie Lateral intersects the boundary on the east edge of the Monument, and the Central Canal impacts the northwest corner of the Monument (Cockrell 1983). The irrigation season is normally from May 1 to October 15. The canals are dry at other times of the year. These canals predate the establishment of the Monument, and the federal government recognizes an easement for each one.

Nebraska 92 crosses and overlaps the historic Oregon Trail route. The railroad track parallels the North Platte River in the northern portion of the Monument. The canals, highway, and railway tracks intrude upon the natural and historic scene at Scotts Bluff National Monument (Cockrell 1983). They all require maintenance by their respective agencies and may become the disturbed lands of the future.

Figure 4. Mass wasting has caused rockslides along the Summit Road to the North Overlook and South Overlook in Scotts Bluff National Monument. Photograph by John Graham (Colorado State University), July 7, 2007.

Figure 5. Rockslide is a potential geologic hazard along Saddle Rock Trail in Scotts Bluff National Monument. Steep cliffs and easily erodible strata promote hazardous conditions. Photograph by John Graham (Colorado State University), July 7, 2007.

Figure 6. Shot-crete (shock-crete) helps to stabilize the slope between tunnels 2 and 3 on Summit Road in Scotts Bluff National Monument. Photograph by John Graham (Colorado State University), July 7, 2007.

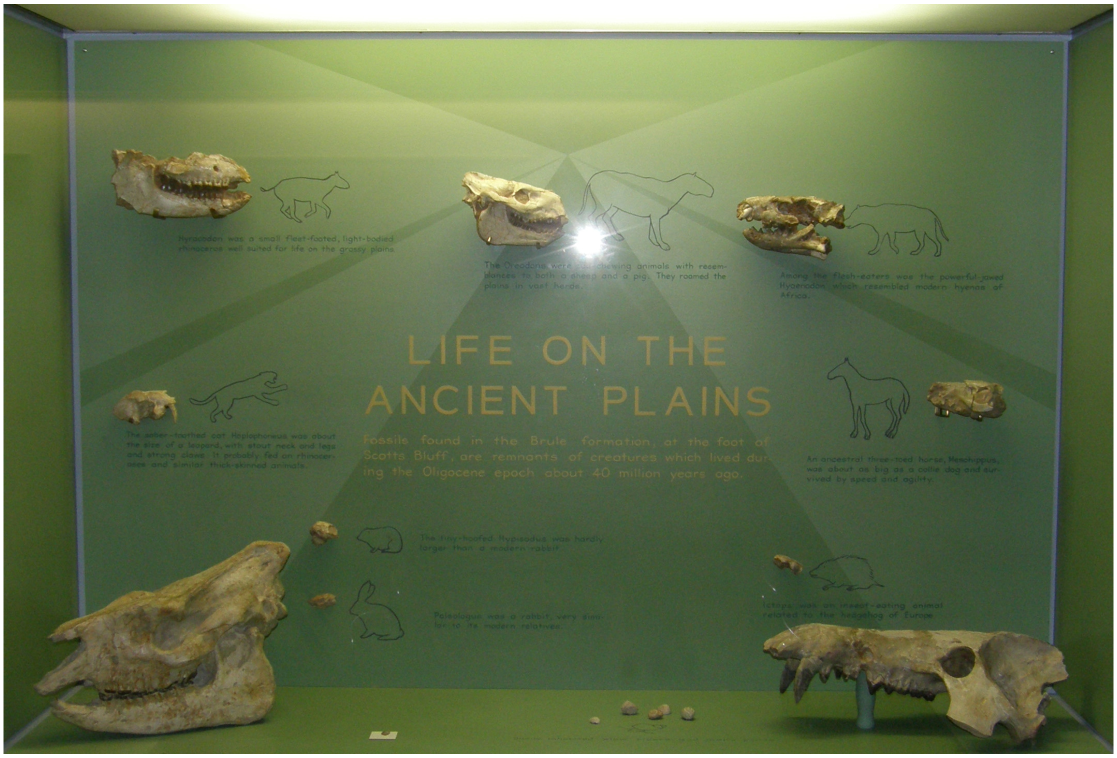

Figure 7. Fossil exhibit case in visitor center. The visitor center of Scotts Bluff National Monument exhibits fossils typical of those in the Brule Formation. Clockwise from top left, the large skulls in this case represent small rhino, oreodont, hyena-like carnivore, three-toed horse, pig-like omnivore (entelodont), rhino, and a saber-toothed-cat-like carnivore. Photograph by Jason Kenworthy (National Park Service), August 20, 2007.

Figure 8. Erosion on Scotts Bluff. Erosion has exposed about 0.3 m (1 ft) of this metal survey post, which was level with the surface when installed on the summit of Scotts Bluff in 1933. The survey marker shows the elevation of Scotts Bluff in 1933 to be 1,417 m (4,649 ft) above sea level. Photograph by John Graham (Colorado State University), July 7, 2007.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Scotts Bluff National Monument.

In the late 1890s, the U.S. Geological Survey made the first formal geologic investigation of the Scotts Bluff region. Geologists discovered about 226 m (740 ft) of continuous geologic strata that span a time period extending from 33–22 million years before present. Weathered into distinctive and unusual features, the strata contain fossils, diagenetic (changes following lithification) features, volcaniclastic deposits, and a wide variety of sedimentary structures useful for interpreting past depositional environments.

Fossils

Ancestors of modern horses, prairie dogs, foxes, turtles, rodents, beavers, and cats are preserved in the Orella strata at Scotts Bluff National Monument. Many of the same fauna are preserved in Badlands National Park in South Dakota.

Fossils of extinct oreodonts *(Merycoidodon)*, which resemble a cross between a sheep and a pig, have been found throughout the badlands of Nebraska, South Dakota, and Wyoming, including the badlands in the Monument. They have been found in Agate Fossil Beds National Monument, about 70 km (43 mi) north of Scotts Bluff and in Badlands National Park. Oreodonts were plant-eaters with a short face, tusk-like canine teeth, heavy body, long tail, short feet, and claws instead of hooves. They are more closely related to camelids than sheep. These woodland and grassland browsers roamed in large herds during the Oligocene and Miocene epochs.

In addition to oreodonts, the 2002 paleontological survey of the lower units of the Orella Member revealed many fossils of the dry land tortoise, *Stylemys*, and "mouse deer" (*Leptomeryx*) (Foss and Naylor 2002). *Stylemys* had the same neck structure as modern tortoises and did not possess teeth, but its forelimbs were unsuitable for burrowing, setting them apart from modern genera. *Leptomeryx* is in the Leptomerycid family, one of the earliest families of ruminants. The nearest living relatives of Leptomerycids are the mouse deer (tragulids) of equatorial Africa and southeast Asia. Attracted to wooded environments, *Leptomeryx* was a small, lightly-built mammal that fed on fruits, tender shoots, and occasional insects.

Topographic Features

Scotts Bluff was a towering landmark for the early travelers on the Emigrant Trails (fig. 2). The imposing Scotts Bluff and South Bluff rise from the plains essentially unchanged from the landscape that confronted the early pioneers. As a topographic feature, Scotts Bluff rises 1,417 m (4,649 ft) above sea level and 244 m (800 ft) above the North Platte River. The bluffs provide an excellent panoramic view of the North Platte River valley, especially from the North Overlook.

Rockfall and differential erosion have created other distinctive landforms such as Eagle Rock and Saddle Rock that rise from the relatively flat prairie of the Nebraska panhandle (figs. 9 and 10). Erosion has cut deep arroyos between the north base of Scotts Bluff and the North Platte River (fig. 11). The soft sedimentary rock erodes both vertically and headward, encroaching into the bluff.

The rate of erosion in the Scotts Bluff region increased about 5 million years ago during uplift of the Rocky Mountains. Eolian processes and stream erosion deposited silt, sand, mud, and volcanic ash over the area. These deposits lithified into layers of siltstone, sandstone, mudstone, and volcaniclastics. Supersaturated groundwater rich in calcium carbonate generated layers of limestone. The high plains that formed from the buildup of these deposits gradually eroded away. The finer grained layers of siltstone and mudstone that were not capped by a more resistant layer of sandstone and limestone eroded with relatively little resistance. More resistant sandstone and limestone formed a "roof" or caprock that protected other locations, which eroded more slowly. This differential erosion resulted in the unusual topographic features present in the Monument today.

Sedimentary Structures

The strata within Scotts Bluff National Monument contain four units of Miocene and Oligocene age: Orella, Whitney, Gering, and Monroe Creek–Harrison (fig. 3). The Monroe Creek Formation and Harrison Formation are not differentiated in Scotts Bluff National Monument. Distinctive sedimentary features in the Monroe Creek–Harrison, Gering, and Whitney units are visible along the Saddle Rock Trail (Pabian and Swinehart 1979; Swinehart and Loope 1987). The badlands preserve sedimentary structures in the Orella Member of the Brule Formation.

The Monroe Creek–Harrison Formations form the caprock of Scotts Bluff and overlie the Gering Formation. Exposed north of the summit parking area, hard, lime-cemented ledges called "pipy" concretions formed when calcium carbonate (lime) precipitated from groundwater (Pabian and Swinehart 1979; Swinehart and Loope 1987). The pipy concretions are typical features found in the Arikaree Group. The concretions form a consistent northeast-southwest orientation over much of the southern Nebraska panhandle, suggesting that the concretions formed shortly after the deposition of the host sand. Small-diameter, vertical tubules characterize many of the concretions.

An 8 m (26 ft)-thick sequence of low angle (7°–15°), large-scale, cross-stratified sandstone crops out about 60 m (197 ft) down the trail from the summit parking area. Exposures at the south end of the summit parking area also display this sequence.

In the area of the first switchback from the summit of Scotts Bluff, the Monroe Creek–Harrison Formations contain knobby, potato-like concretions and crudely stratified sandstone.

Exposures of several sedimentary structures occur between the major bend and the concrete steps on the Saddle Rock Trail. The very fine to fine-grained sandstones contain compound cross-stratification as well as large-scale wedge planar sets up to 1.7 m (5 ft) thick. The wedge planar sets are cross-laminated, and the cross-laminations are laterally extensive, even, and distinct with small-scale foresets (up to 1 cm [0.25 in] in length) nearly perpendicular to the dip of the large-scale foresets.

The juxtaposition of dark, heavy minerals in the coarse silt against the overlying very fine sand readily illustrates the "inverse grading" and cross-laminations. Inverse grading is a sedimentary structure in which finer-grained material grades upward into coarser sediments. Ripple migration on eolian dunes probably caused these cross-laminations (Swinehart and Loope 1987). Other sedimentary structures that suggest cross-stratification resulting from wind erosion rather than fluvial processes include inversely graded, horizontally stratified sandstones, likely produced by migration of wind ripples across flat interdune surfaces; irregular bounding surfaces that suggest an original ridge and swale topography typical of modern dune fields; and laterally extensive lag deposits similar to lag deposits of modern eolian sediments.

About 23 m (75 ft) down the Saddle Rock Trail from the concrete steps, excellent exposures of a number of different types of invertebrate burrows are part of a laminated volcanic ash lens (≤50 cm [20 in] thick) and adjacent sandstone (Pabian and Swinehart 1979; Swinehart and Loope 1987). The cylindrical, smooth-walled burrows are massive and generally nonbranching. Geologists have interpreted the burrows as shelter burrows, deposit-feeding burrows, and vertical passageways made by insects, possibly beetles (Stanley and Fagerstrom 1974; Swinehart and Loope 1987).

At the major bend in the trail with the museum signpost, cross-stratified sandstone is interbedded with massive sandstone. The mineralogy and grain size of the two units are similar, and the lack of sedimentary structures in the massive sandstone may be attributed to either (1) a slower sedimentation rate and intense bioturbation that destroyed any bedding features, or (2) trapping of sediment by vegetation, which prohibited the formation of laminations (Swinehart and Loope 1987).

The contact between the horizontally stratified Gering Formation and the overlying massive and cross-stratified sandstone of the Monroe Creek–Harrison Formations is exposed at the second of three switchbacks along the northeast-facing bluff of the Saddle Rock Trail. "Sand crystals" up to 2.5 cm (1 in) in diameter developed at several horizons at this location. "Sand crystals" form in two stages. The discoidal shape of the crystals is from the growth of gypsum. The gypsum is then replaced by calcite (Swinehart and Loope 1987; http://www.nps.gov/scbl).

The first switchback north of the Saddle Rock Trail tunnel contains at least one horizon of "sand crystals". This location also highlights the uniform nature of the stratification in the Gering Formation.

At the entrance to the tunnel on the trail, abundant calcite pseudomorphs after lenticular gypsum crystals occur in an ash layer in the Gering Formation. Evaporite minerals, such as gypsum, indicate an arid climatic setting. The cone-like features projecting downward from the volcanic ash bed and into the underlying thin-bedded gray sandstone may represent vertical burrows or casts of roots that existed in the surficial sediments when the ash fell (Pabian and Swinehart 1979). Surrounding the ash are horizontally stratified and small-scale, cross-laminated, very fine-grained sands that have been interpreted as ephemeral stream deposits.

Concave-up deformation structures beginning at the level of the thin gray ash layer at the entrance to the tunnel may be inorganically induced deformation structures or tracks of vertebrates (Swinehart and Loope 1987; Santucci et al. 1998). The scale and bilobed nature of some structures suggests that the track-makers were large ungulates, possibly entelodonts. A variety of oreodonts, hyracodontid rhinos, tapirs, small horses, camels, and many carnivores also lived in the area during the Oligocene (fig. 7) (Swinehart and Loope 1987; http://www.nps. gov/scbl).

Volcaniclastic siltstones of the Whitney Member of the Brule Formation are exposed at the head-of-canyon switchback south of the tunnel. The unit's mineralogy, grain size, texture, and geographic distribution that seems to mantle the underlying topography suggests that the Whitney represents slow accumulation of airfall pyroclastic material (Pabian and Swinehart 1979; Swinehart and Loope 1987; http://www.nps.gov/scbl). The pyroclastic material originated from volcanic centers to the west.

The cliff face along the Saddle Rock Trail approximately 168 m (550 ft) north of Scotts Spring displays the irregular nature of the Whitney-Gering contact. Stratigraphic evidence indicates that this unconformable contact represents up to 4 million years of missing time at the Monument. Fractures in Whitney Member siltstones have provided conduits for groundwater, which resulted in Scotts Spring.

The Orella Member, the lowermost member of the Brule Formation and oldest exposed rocks (33 million years ago) in the Monument, forms the small badlands area in the northeast part of the Monument. A variety of sedimentary structures, similar to those found in the Gering and Monroe Creek–Harrison Formations are present in the Orella Member.

North Platte River and Scotts Spring

The North Platte River is the only flowing stream in the Monument. Because the North Platte River is a non-navigable river in this part of Nebraska, the Monument's north boundary extends to the center of the channel (http://www.nps.gov/scbl). Fluvial geomorphic features, the river's floodplain, and riparian habitat characterize the river's south bank. Historically, pioneers found the river to be much wider and more dangerous than it is today. Prior to the construction of upstream dams, the North Platte River flooded in the spring. Dams were constructed for flood control, the generation of electricity, and the diversion of water for irrigation (http://www.nps.gov/scbl).

Scotts Spring flows from fractures in the Whitney siltstone and is the only natural spring within Scotts Bluff National Monument. Pioneer diaries refer to Scotts Spring as a place to find clear drinking water as compared to the muddy water in the North Platte River. The spring is very small and easily missed by visitors. Today, animals use Scotts Spring, and their tracks can be seen in the mud or snow.

Figure 9. Eagle Rock. Rising from the relatively flat prairie, Eagle Rock is a distinctive feature at Scotts Bluff National Monument. Photograph by Karen Graham, July 7, 2007.

Figure 10. Saddle Rock. A product of mass wasting, Saddle Rock adds interest to the landscape at Scotts Bluff National Monument. Photograph by Jonathan S. Garcia (National Park Service), http://www.nps.gov/scbl.

Figure 11. Arroyos. Erosion cuts deep arroyos between the Monument and the North Platte River. View is to the west. Photograph by John Graham (Colorado State University), July 7, 2007.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Scotts Bluff National Monument. 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 Scotts Bluff National Monument informed 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. 12) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the 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 is source data for the GRI digital geologic map for Scotts Bluff National Monument:

Swinehart, J. B., and R.F. Diffendal, Jr. 1997. *Geologic map of the Scottsbluff 1 degree x 2 degree quadrangle, Nebraska and Colorado*. Scale 1:250,000. Geologic Investigations Series Map I-2545. 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, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file 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/).

Geologic History

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

Pre-Oligocene History

The sedimentary rock layers exposed at Scotts Bluff National Monument are only a fraction of the thick sediment package that was deposited in the high Great Plains physiographic region (fig. 12). These sedimentary rocks overlie an ancient Precambrian crust consisting of igneous and metamorphic rocks, similar to those exposed in the core of the Black Hills in South Dakota. A more detailed Precambrian, Paleozoic, and Mesozoic history of this region may be found in the GRI report for Mount Rushmore National Memorial (http://www.nature.nps.gov/geology/inventory/publications/reports/moru_gre_rpt_view.pdf).

At the end of the Cretaceous Period and beginning of the Tertiary Period, a vast seaway, called the Western Interior Seaway, covered this part of Nebraska (fig. 13). 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). During periods of maximum transgression, the width of the basin was 1,600 km (1,000 mi) (Kauffman 1977). After the seas withdrew in the early Tertiary, the region was close to sea level and a humid, subtropical climate prevailed (Swinehart et al. 1985; Hunt 1990).

The oldest Tertiary rocks in the area are the upper Eocene Chadron Formation (fig. 3) (Swinehart and Diffendal 1997). In a complicated paleovalley system, streams deposited sediments that became the rocks of the Chadron Formation. These paleovalleys cut into Cretaceous strata (Swinehart et al. 1985). During the late Eocene and early Oligocene epochs, fluvial deposition of the Chadron Formation ceased and eolian processes dominated deposition of volcaniclastic sediments.

Oligocene–Miocene History

Strata at Scotts Bluff National Monument span approximately 10 million years of geologic time in the Oligocene and Miocene epochs (fig. 12). Along with the units at Agate Fossil Beds National Monument to the north, these rocks record a significant, although brief, snapshot of Tertiary environments during a time of global climate change (fig. 14).

In the Oligocene (fig. 15), eastward flowing rivers deposited vast sheets of sediment over the Great Plains, filling in structural basins that formed adjacent to the Rocky Mountains during the Cretaceous–Eocene Laramide Orogeny (Kiver and Harris 1999). The Eocene–Oligocene transition probably records the most dramatic climate change in the Tertiary. During Oligocene and Miocene time, vegetation changed from subtropical forests of early Tertiary time to savanna ecosystems with grasslands dotted with abundant patches of trees and shrubs. The principal large mammals living in western Nebraska during Oligocene time include oreodonts, deer, rhinoceros, and a variety of carnivores (Pabian and Swinehart 1979; Foss and Naylor 2002).

The oldest rocks at Scotts Bluff National Monument are the Oligocene siltstones and mudstones of the Orella Member of the Brule Formation deposited about 33 million years ago (Swinehart and Loope 1987; Swinehart and Diffendal 1997; http://www.nps.gov/scbl). Regional downcutting created a series of valleys prior to deposition of the upper part of the Orella, Whitney Member, and brown siltstone interval (Swinehart et al. 1985). The paleodrainages trended west to east and had a less complicated pattern than the Chadron paleovalleys.

The high percentage of volcanic glass and lithic pyroclastic detritus in the Orella and Whitney members of the Brule Formation represent volcanic ash derived from tremendous ignimbrite-style volcanic eruptions in the west, most likely Colorado (Swinehart and Loope 1987; Swinehart et al. 1985; Swinehart and Diffendal 1997). The Whitney Member appears to have formed under increasingly arid conditions compared to the Orella Member whose stream-deposited sediments indicate an abundance of moisture (Pabian and Swinehart 1979).

Widespread fluvial erosion impacted the region in the late Oligocene. The river-dominated system interrupted the succession of low-relief landscapes that had formed via accumulation of pyroclastic eolian material in western Nebraska (Swinehart et al. 1985). The erosion produced the unconformity that separates the Gering Formation (Arikaree Group) from the Brule Formation and other older Cenozoic units in western Nebraska (fig. 3). A narrow paleovalley formed as part of a major west-east drainage system. Maximum depths of downcutting were about 30 m (100 ft) (Swinehart et al. 1985).

The paleovalley followed the long axis of today's Wildcat Ridge. Fluvial sediments of the Gering Formation reflect multiple cuts and fills in the paleovalley. They are interlayered with eolian pyroclastic deposits. One of the volcanic ash beds in Scotts Bluff National Monument runs continuously for a minimum of 200 m (650 ft) (Swinehart and Loope 1987). The growth of gypsum, later replaced by calcite, formed the "sand crystals" in the Gering Formation. Gypsum, an evaporite mineral, suggests that the region had an arid climate during the late Oligocene.

Eolian volcaniclastic deposits comprise most of the overlying upper Oligocene and lower Miocene Arikaree Group (Monroe Creek–Harrison Formations and beds of the informal Camp Clarke unit). Direct air-fall and windblown pyroclastic detritus of the Monroe Creek and Harrison Formations succeeded the alluvial fill deposits of the Gering Formation and continued until Arikaree deposition ceased about 19 million years ago (Swinehart et al. 1985). Evidence for an eolian origin includes sedimentary features such as cross-stratification, lag deposits, wind ripple features, and irregular bounding surfaces in the Monroe Creek–Harrison Formations in Scotts Bluff National Monument. The Great Plains continued to aggrade, or build up, sediments until a low-relief landscape again dominated the western Nebraska landscape. The region looked similar to today's broad Serengeti savanna.

Like the savannas of east Africa today, the rich volcanic soils of western Nebraska during the Miocene supported grasses, which together with small trees and bushes growing along shallow streams, were a ready food source for the great herds of plant-eating mammals and their predators. Many of the animals (e.g., chalicotheres, rhinoceroses, entelodonts, beardogs, land beavers, camels, horses, and pocket gophers) thrived in this early Miocene climate and their numbers expanded to the capacity of the available food supply (http://www.nps.gov/agfo/index.htm; http://www.nps. gov/ geology /parks/agfo).

Perhaps because the rising Rocky Mountains blocked the flow of moisture-laden air from the west, the climate in western Nebraska became more arid. Research on grass species of the ancient savanna suggests that a major drought occurred in the Nebraska panhandle during the Early Miocene about 19–20 million years ago (Hunt 1990).

Landscape development in western Nebraska underwent a major change in the middle Miocene. A period of erosion separates the Arikaree Group from the overlying Ogallala Group. Widespread eolian deposition gave way to restricted alluvial deposition in paleovalleys. During the last two thirds of the Miocene, a wide variety of drainage systems and paleovalleys of different sizes developed, which sediment subsequently filled (Swinehart et al. 1985). Alluvial sediments filled a paleovalley about 24 km (15 mi) wide and up to 100 m (300 ft) deep in eastern Sioux, southern Dawes, and northern Box Butte counties.

In contrast to formations in the Arikaree Group, formations in the Ogallala Group contain much less pyroclastic debris. Erosion in the southern Rocky Mountains provided abundant alluvial material (Swinehart et al. 1985; Swinehart and Diffendal 1997).

Toward the end of the deposition of the Ogallala Group, a southeast-trending paleovalley eroded into the underlying sediments north of the present North Platte River valley. This paleovalley later filled with the sand and gravel beds of the informal Angora unit (fig. 3). Erosion of the Angora sand and gravel during the upper Miocene probably gave rise to the North Platte River system. Principal tributaries such as Pumpkin Creek, however, developed later, during or after the early Pleistocene (Swinehart and Diffendal 1997).

Pliocene–Holocene History

In the last 5 million years, erosion has greatly exceeded deposition in western Nebraska. The modern North Platte River follows a trend established near the end of the Miocene. A succession of valleys maintained this trend but shifted progressively to the southwest during the Pliocene, Pleistocene, and Holocene epochs. Pliocene fluvial sand and gravel filled a major paleovalley north of the present-day North Platte River. These sediments became the Broadwater Formation (fig. 3) (Swinehart et al. 1985; Swinehart and Loope 1997).

Uplift over the last 5 million years elevated the High Plains to their current elevation of about 1,340 m (4,400 ft) above mean sea level (Kiver and Harris 1999). Regional uplift, increased moisture, and accelerated rates of wind and water erosion during Pliocene and Pleistocene time shaped the present landscape. No continental ice sheets or alpine ice glaciers covered central or western Nebraska, but erosion increased as a result of abundant stream discharge coming from the glaciated areas to the north and west (fig. 16). Wind and water erosion removed tremendous amounts of rock from the North Platte and Pumpkin Creek valleys during the Pleistocene Ice Ages (Pabian and Swinehart 1979). Wildcat Ridge and other landmarks such as Scotts Bluff remain as proof that the Brule Formation and Arikaree Group were once continuous with equivalent rock units to the north and south of those valleys. The coarse gravels of Scotts Bluff County and the alluvium beneath the floodplains of the North Platte River and Pumpkin Creek reveal the robust nature of the streams that drained this area during Pliocene and Pleistocene times.

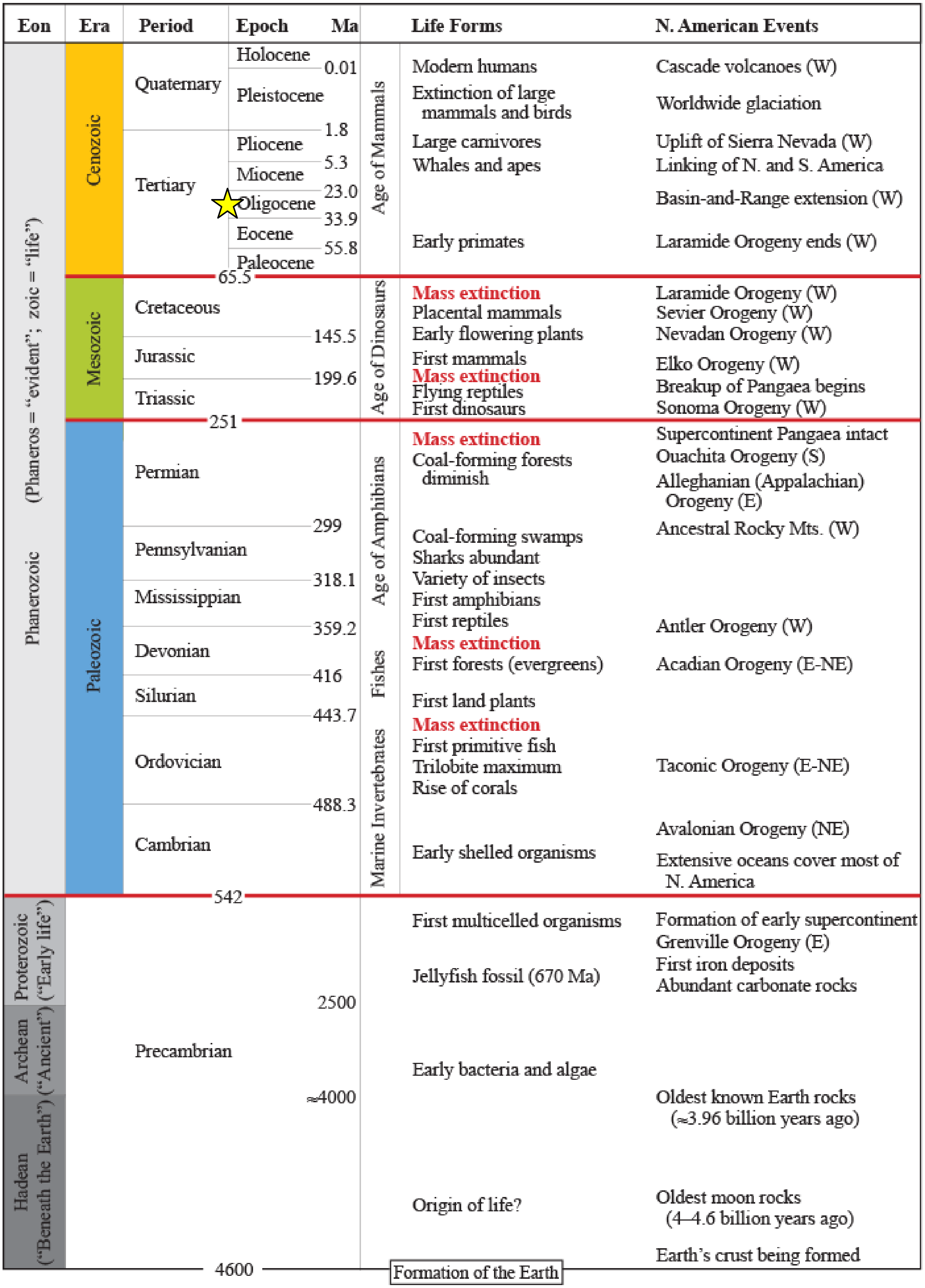

Figure 12. Geologic Timescale. Adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). Yellow star approximates the time recorded by the strata in Scotts Bluff National Monument. Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events.

Figure 13: Late Cretaceous paleogeographic map of North America. About 85 million years ago, the panhandle of Nebraska was part of the extensive Western Interior Seaway. SB marks the location of Scotts Bluff at the time. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/namK85.jpg.

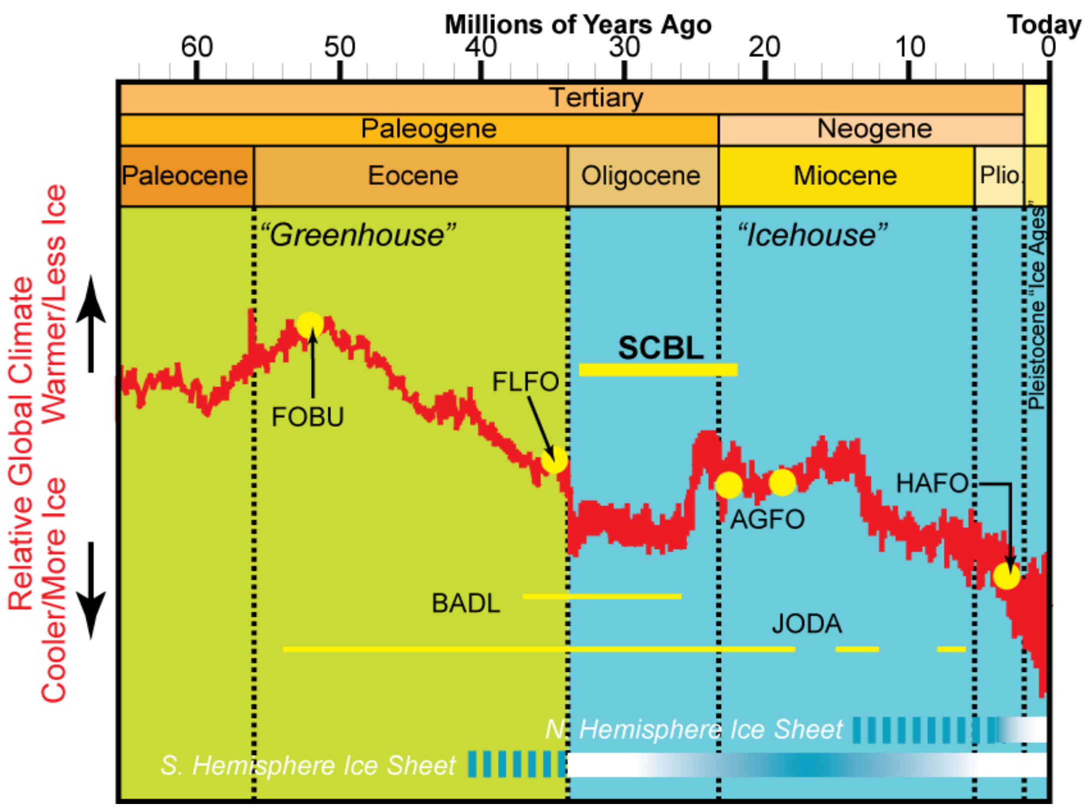

Figure 14. Relative global climate during the Tertiary Period. The red line is plotted with oxygen isotope data from Zachos and others (2001). The yellow dots and lines indicate the geologic age or range of ages of Scotts Bluff National Monument (SCBL) and six NPS units established to preserve scientifically significant Tertiary fossils and strata: Agate Fossil Beds National Monument in Nebraska (AGFO), Badlands National Park in South Dakota (BADL), Florissant Fossil Beds National Monument in Colorado (FLFO), Fossil Butte National Monument in Wyoming (FOBU), Hagerman Fossil Beds National Monument in Idaho (HAFO), and John Day Fossil Beds National Monument in Oregon (JODA). The transition from global "greenhouse" conditions with minimal polar ice sheets to "icehouse" conditions with ice sheets at one or both poles occurred near the Eocene-Oligocene boundary. Graphic adapted from a John Day Fossil Beds National Monument exhibit and modified from Kenworthy (2009). Original data from Zachos and others (2001).

Figure 15. Oligocene paleogeographic map of North America. About 25 million years ago, streams, wind, and evaporation were the depositional agents of the Gering Formation. SB marks the location of Scotts Bluff at the time. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/namPo25.jpg.

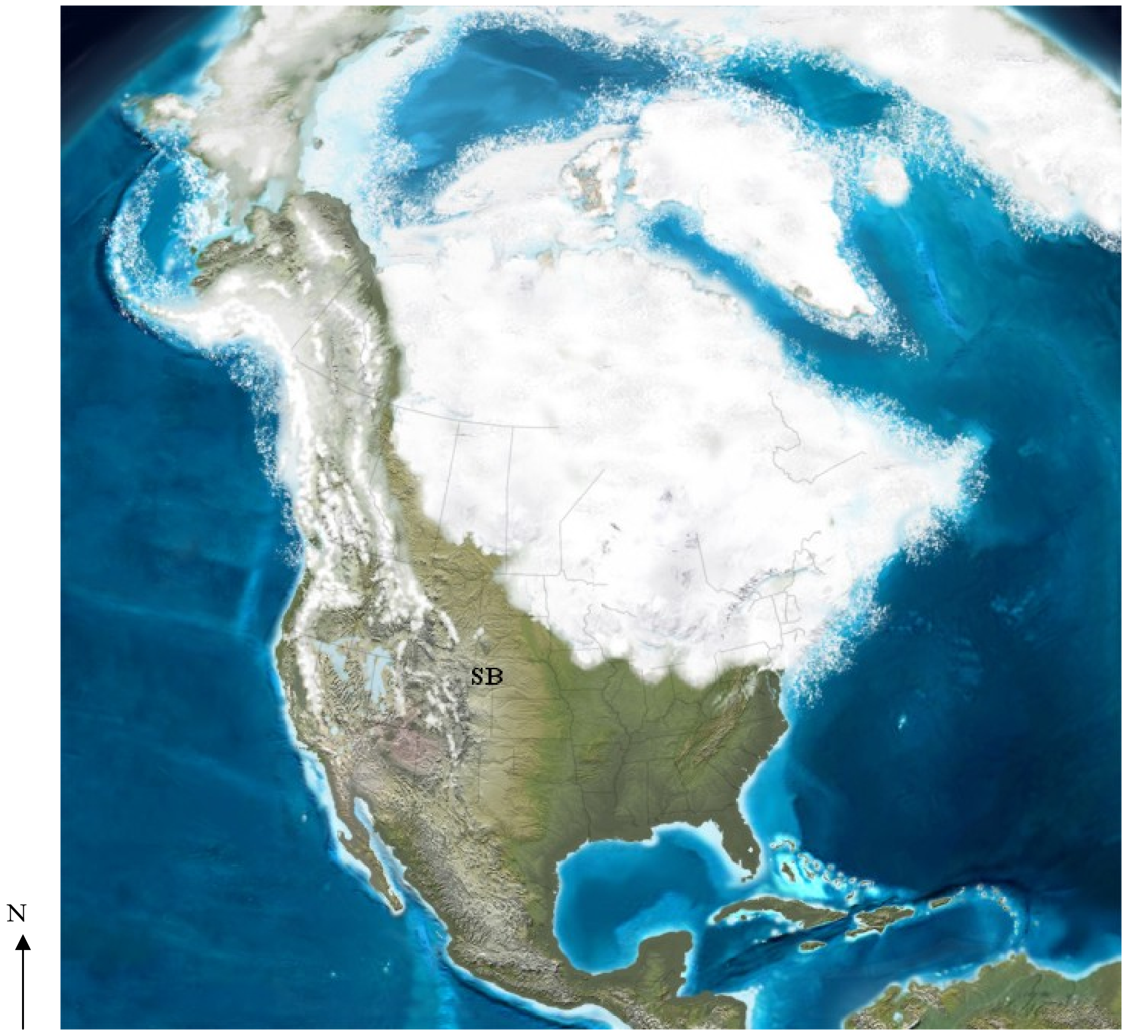

Figure 16. Pleistocene paleogeographic map of North America. About 12,600 years ago, continental-scale glaciers formed to the north of Scotts Bluff and alpine glaciers formed to the west. Scotts Bluff was not glaciated. SB marks the location of Scotts Bluff at the time. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/namQ.jpg.

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://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

absolute age. The geologic age of a fossil, rock, feature, or event in years; commonly refers to ages determined radiometrically.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a high-gradient stream flows out of a mountain front into an area of lesser gradient.

alluvium. Stream-deposited sediment that is generally rounded, sorted, and stratified.

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

authigenic. Formed or generated in place.

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

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

bedding. Depositional layering or stratification of sediments.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

bioturbation. The reworking of sediment by organisms.

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

breccia. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented angular clasts.

calcareous. Rock or sediment containing calcium carbonate.

cementation. The process by which clastic sediments are converted into rock by precipitation of mineral cement among the grains of the sediment.

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

chemical weathering. Chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances; commonly results in a change in chemical composition more stable in the current environment.

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

clastic. Said of rock or sediment made of fragments of preexisting rocks or minerals.

clay. Clay minerals or sedimentary fragments the size of clay minerals (<1/256 mm [0.00015 in]).

claystone. Lithified clay having the texture and composition of shale but lacking its fine lamination or fissility.

conglomerate. A coarse-grained sedimentary rock with clasts >2 mm (0.08 in) in a fine-grained matrix.

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).

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension.

deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

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

diagenesis. All the chemical, physical, and biologic changes undergone by a sediment after its initial deposition, and during and after its lithification, exclusive of surficial alteration (weathering) and metamorphism.

diagenetic. Pertaining to or caused by diagenesis.

diatom. A microscopic single-celled, freshwater and saltwater, aquatic plant related to algae; diatoms secrete siliceous frustules in a great variety of forms, which may accumulate in sediments in enormous numbers.

diatomaceous. Light-colored soft friable siliceous sedimentrary rock, consisting chiefly of opaline cell walls of diatoms.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

drainage basin. A region or area bounded by a divide and occupied by a drainage system (syn: watershed).

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

eolian. Formed, eroded, or deposited by or related to the action of the wind.

evaporite. Chemically precipitated mineral(s) formed by the evaporation of solute-rich water under restricted conditions.

exfoliation. The breakup, spalling, peeling, or flaking of layers or concentric sheets from an exposed rock mass caused by differential stresses due to thermal changes or pressure unloading.

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

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, or fault).

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

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

lamination. The finest stratification or bedding as in shale or siltstone; also the formation of laminae.

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

lithification. The conversion of sediment into solid rock.

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

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

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

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

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during subaerial dehydration.

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 geography from past geologic periods.

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

piping. Erosion or solution by percolating water in a layer of subsoil, resulting in caving and in for formation of narrow conduits, tunnels, or "pipes" through which soluble or granular soil material is removed. (Syn: tunnel erosion).

pipy concretions. Calcium carbonate-cemented concretions as much as tens of feet long.

pseudomorph. A mineral whose outward crystal form is that of another mineral species; it has developed by alteration, substitution, incrustation, or paramorphism.

ripple marks. The undulating, subparallel, usually small-scale ridge pattern formed on sediment by the flow of wind or water.

rock. A spolid, cohesive aggregate of one or more minerals or mineraloids.

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.

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

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

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a major sea level transgression-regression sediment package.

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 (1/256–1/16 mm [0.00015–0.002 in]).

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

slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).

slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.

spring. A site where water flows out at the surface due to the water table intersecting the ground surface.

strata. Tabular or sheet-like 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.

system (stratigraphy). The group of rocks formed during a period of geologic time.

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

tectonics. The geologic study of the broad structural architecture and deformational processes of the lithosphere and aesthenosphere.

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

trace fossils. Sedimentary structures such as tracks, trails, burrows, etc., that preserve evidence of an organism's life activities, rather than the organisms themselves.

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

type locality. The geographic location where a stratigraphic unit is well displayed, formally defined, and derives its name.

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

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

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

water table. The upper surface of the saturated (phreatic) zone.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Scotts Bluff National Monument. 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).

Appendix B: Scoping Summary

The following excerpts are from the GRI scoping summary for Scotts Bluff National Monument that was held on March 3–4, 2003. The contact information and Web addresses in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Participants at the 2003 scoping meeting included NPS staff members from Scotts Bluff National Monument (SCBL), Agate Fossil Beds National Monument (AGFO), Fort Laramie National Historic Site (FOLA), Fossil Butte National Monument (FOBU), and the Geologic Resources Division (GRD), and cooperators from the University of Nebraska-Lincoln (table 1).

The workshop 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.

Maps for Scotts Bluff National Monument

Currently, there are nine quadrangles of interest for SCBL: Lake Alice, Scottsbluff North, Mitchell, Minatare, Scottsbluff South, Roubadeau Pass, Wright Gap, Wildcat Mountain, and Murray Lake NE. Of these, none are known to have large-scale (1:24,000) mapping of the individual quadrangles. Bob Hunt (University of Nebraska-Lincoln) suggested contacting the Nebraska Conservation and Survey Division to see if these might be incorporated into the StateMap project, if they are not already mapped at suitable scale.

However, there are smaller scale maps for the area, but it is not known if any of these are digitized. A list follows.

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Specifically Mentioned Park Management Needs Related to the Geology at Scotts Bluff National Monument

Valerie Naylor and Robert Manassek (SCBL) weren't sure why the park had nine quadrangles of interest, but figured it was likely because of the viewshed around the park. They thought it most important to have digital datasets for the Scottsbluff South quadrangle at a large-scale, because of the potential for expansion to the west.

They also mentioned that the single most important issue pertaining to geology at the park involves rockslides on park roads and trails that represent potential dangers to park visitors and degradation of the natural resources (the cliffs) via erosion and mass wasting. The road to the top of the park is bounded by very steep cliffs that have numerous rock falls, as well as the walking trails that lead to the top. Phil Cloues (NPS-GRD) and Federal Highways have evaluated this problem in the park before. In 2000, approximately 3000 tons of rock fell on the park road. Also, the Saddle Rock Trail had similar problems in October 2000. An environmental assessment (*Environmental Assessment Saddle Rock Landslide Hazard Removal Scotts Bluff NM, March 2001*) was done, and subsequently large amounts of unstable material were blasted away to keep the trail open.

Near the man-made tunnels of the main park road, Federal Highways has used the latest geotechnical engineering methods to attempt to stop rock fall around the tunnels by applying shot-crete to blend in with the natural surroundings

It was suggested by Vince Santucci (FOBU) to have Hal Pranger (GRD) conduct a landslide assessment, much like the one he did for Fossil Butte NM.

Because Scotts Bluff NM has Oligocene fossils in the Brule Formation (the same unit that makes up most of the Badlands NP area in South Dakota), it might make for an interesting research project to compare/contrast the geological resources of each park, and perhaps recognize more paleontological resources. A paleontological survey would be useful for the park. The park has three irrigation canals that pass through the park. There are also FEMA designated floodplains, floodways, and wetlands. Additionally there is a natural spring (cistern) emanating within the park.

During World War II there was a clay pit that was excavated near the bluff along the eastern boundary. The commodity was simple clay.

The park has a geologic brochure entitled "The Rocks of Scotts Bluff;" it has a detailed stratigraphic column and the abridged version of the parks geologic story.

Geologic Reports

Ruthann Knudson (AGFO) says there is no encompassing geologic report for all three parks, so it would need to be written. However, on an individual basis, each park might have suitable reports. A few references are cited below.

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Table 1. Scoping meeting participants

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Scotts Bluff National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/085

National Park Service

Acting Director • Dan Wenk

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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 the 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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NPS D-61, June 2009

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