National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Hagerman Fossil Beds National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/162

ON THE COVER:
Paleontologist John White excavates *Equus simplicidens* ("Hagerman Horse") fossils from the Hagerman Horse Quarry in the mid 1960s. The Hagerman Horse is the oldest species in the modern horse genus *Equus.* Photo courtesy Phil Gensler (NPS HAFO)

THIS PAGE:
***TOP*: Aerial view of the Hagerman Horse Quarry.**
***BOTTOM*: Skull of Hagerman Horse. Specimens such as this illustrate the well-preserved nature of the fossils from the park. The Hagerman Horse is just one of more than 220 fossil species from the park; the most diverse Pliocene-aged fossil assemblage in the world. NPS photos courtesy Phil Gensler (NPS HAFO).**

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

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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Denver, Colorado

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

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

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

Printed copies of this report are produced in a limited quantity and they are only available as long as the supply lasts. This report is available from the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

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Executive Summary

This report accompanies the digital geologic map for Hagerman Fossil Beds National Monument in Idaho, 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.

World renowned for its exceptional abundance and diversity of Pliocene fossils, Hagerman Fossil Beds National Monument protects more than 220 fossilized plant and animal species, including the "Hagerman Horse" (*Equus simplicidens*), Idaho's state fossil. Authorized in 1988, Hagerman Fossil Beds National Monument represents the first Idaho unit to be added to the National Park System since 1924. The monument's 1,760.91 ha (4,351.15 ac) are located in south-central Idaho along the west bank of the Snake River, near the town of Hagerman, Idaho. Over 550 fossil localities lie on the arid slopes between the west bank of the Snake River and the Bruneau Plateau.

The monument lies within the Snake River Plain, a crescent-shaped physiographic province formed by both tectonic and volcanic activity. Sediment-filled, fault-bounded basins dominate the western Snake River Plain, while lava fields that document the northeastern migration of the Yellowstone-Snake River Plain hot spot characterize the eastern Snake River Plain. The monument is situated at the convergence of the western Snake River Plain and eastern Snake River Plain.

Layers of sedimentary and volcanic rock compose the bluffs in Hagerman Fossil Beds National Monument. Arroyos deeply incise the rock layers and steepen the slopes. Weakly-consolidated sediments and steep slopes promote hazardous landslide activity, which is a primary geologic issue affecting Hagerman Fossil Beds National Monument. Slope failure impacts the occurrence and recovery of fossils, destroys fossil localities, and poses safety hazards to field personnel. About 24 to 30 ha (60 to 75 ac) of fossil beds have been lost to landslides. Quarries, including the famous Horse Quarry, may become endangered in the future.

In September 2003, participants at a NPS sponsored workshop generated a list of geologic issues specific to Hagerman Fossil Beds National Monument. The issues include (in order of importance):

- Protection and preservation of paleontological resources and localities
- Landslide activity
- Wind transport and erosion
- Radioactivity associated with fossil material
- Geothermal activity
- Minerals and abandoned mineral lands
- Visitor Center siting
- Human industrial activity in Hagerman Valley

Deposited during the Pliocene epoch of the Neogene period, between about 4 to 3 million years ago, the Glenns Ferry Formation contains the fossils at Hagerman Fossil Beds National Monument. The Glenns Ferry strata record a variety of paleo-environments, including wetland, riparian, lacustrine, and grassland savanna ecosystems.

The quantity, quality, and species diversity found in the fossil sites at the monument provide an excellent record of the evolutionary changes in plants and animals. The fossils also record the ecological response of various species and their environments to climate change in the Pliocene.

The geologic features in the Glenns Ferry Formation, the overlying Tuana Gravel, and the late Pleistocene Yahoo Clay supply clues to the Pliocene-Pleistocene geologic history in the Hagerman area. Large blocks of Earth's crust, downdropped along faults to form basins, characterize the western Snake River Plain. Lakes formed in these catchment basins from runoff of the local tributaries to the ancestral middle section of the Snake River. Hagerman horses, camels, pronghorn, mastodon, peccary, saber-toothed cats, and many other animals roamed the grassland and patches of trees that grew on the ancestral Snake River Plain.

When the Snake River cut new canyons, it scoured the sediments of the Glenns Ferry Formation and deposited the coarse clastics of the Tuana Gravel. The late Pleistocene Bonneville Flood discharged an extraordinary volume of water through the Snake River Plain and eroded the bluffs on the western side of Hagerman Valley, exposing the fossiliferous Glenns Ferry Formation. [Note: see Glossary on page 35 for explanations of many technical terms used in this report, including terms used in the Map Unit Properties Table.]

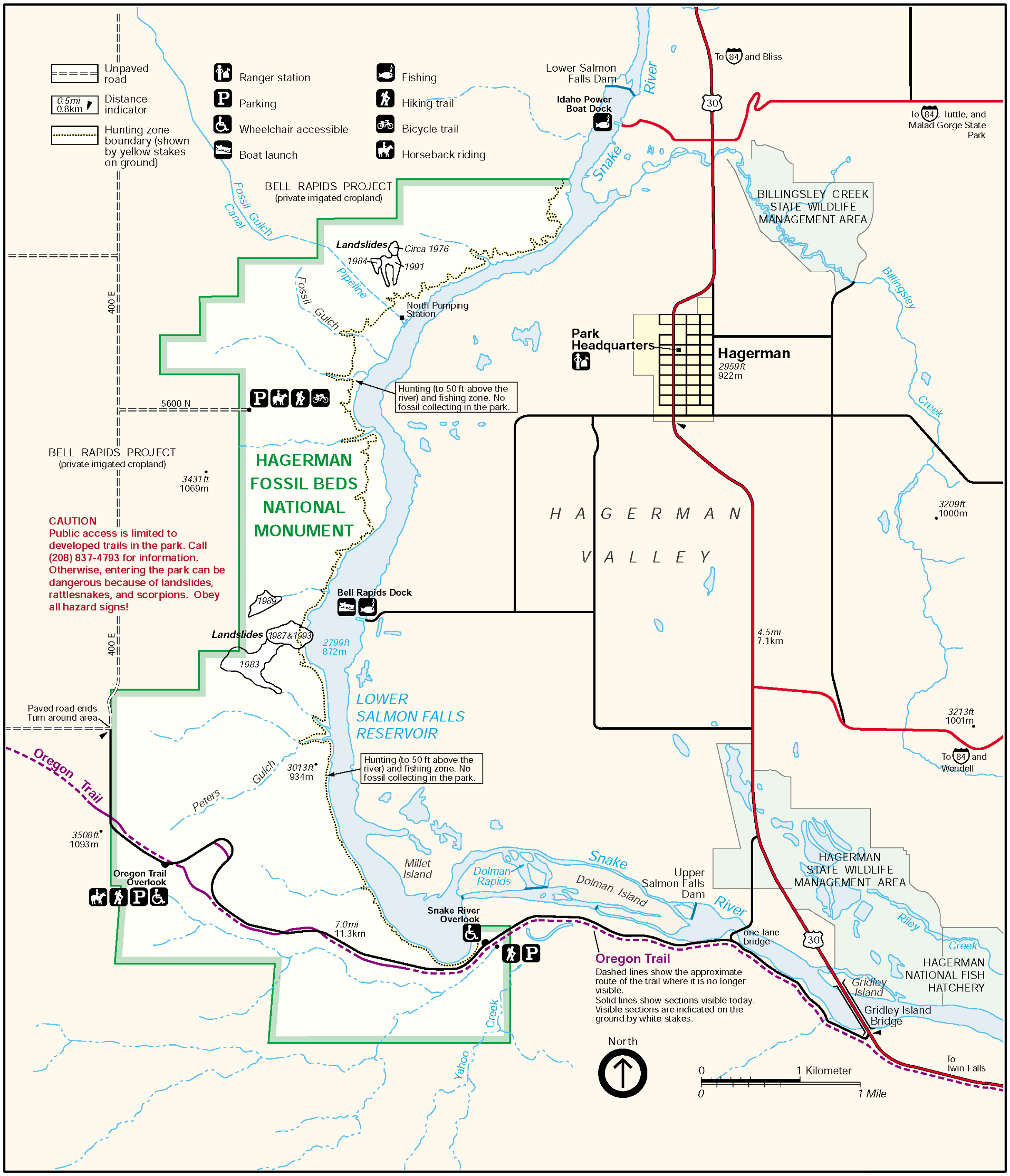


Figure 1. Location map of Hagerman Fossil Beds National Monument in south-central Idaho. Note locations of landslides indicated on map. NPS map.

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Hagerman Fossil Beds National Monument.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. 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 working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non-geoscientists. During scoping meetings the GRI team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

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

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

Regional Location and Significance

Authorized in 1988, Hagerman Fossil Beds National Monument was the first Idaho unit to be added to the National Park System since 1924. The monument's 1,760.91 ha (4,351.15 ac) are located in south-central Idaho along the west bank of the Snake River, near the town of Hagerman, Idaho (fig. 1). The Visitor Center is located on Route 30 in Hagerman across from the high school.

Hagerman Fossil Beds National Monument protects the world's best record of terrestrial lifeforms that existed during a portion of the Pliocene epoch called the Blancan land mammal age, roughly 4.0 to 3.2 million years ago (mya) (McDonald et al. 1996). The monument claims the largest concentration of Hagerman Horse (*Equus simplicidens*) fossils in North America (McDonald 1996). Over 150 individuals of the extinct *Equus simplicidens* have been recovered from the Hagerman Horse Quarry. In 1988, following a 1987 landslide that endangered Hagerman Horse fossils, the governor responded to citizens' requests and designated the Hagerman Horse as the state fossil of Idaho.

More than 220 fossilized plant and animal species in over 550 known individual fossil sites have been documented in the monument's bluffs that overlook the Snake River. This high concentration of paleontological resources from a relatively short geological time span provides an extraordinary amount of information regarding geological events, environmental changes, and biodiversity during the Pliocene. Such comprehensive data are extremely rare.

Regional Geology

Hagerman Fossil Beds National Monument lies within the Snake River Plain, a crescent-shaped feature that measures 64 km (40 mi) wide and extends across southern Idaho for about 480 km (300 mi) (fig. 2). Most of the monument is located on the arid slopes of the Snake River Plain between the west bank of the Snake River and the Bruneau Plateau (fig. 3). The monument's western boundary generally follows the top edge of the bluffs that rise 180 m (600 ft) above the Snake River. Just north of the monument, the Lower Salmon Falls hydroelectric dam maintains the river at a nearly constant elevation of 853 m (2,800 ft) (Farmer and Riedel 2003).

Layers of sedimentary deposits and volcanic rock compose the slopes in Hagerman Fossil Beds National Monument (fig. 4). Arroyos (water-carved gullies) that range from 0.8 to 1.6 km (0.5 to 1.0 mi) in length deeply incise the sedimentary and volcanic layers of the bluffs. Slope angles between the gullies commonly exceed 35 degrees, and some of the slopes are as steep as 70 degrees.

The sedimentary strata and solidified lava flows exposed in Hagerman Fossil Beds National Monument fall into either the Idaho Group or the Snake River Group (fig. 4). Strata in the Idaho Group unconformably overly the Miocene Idavada Volcanics and are divided into the following seven formations (in ascending order): Poison Creek Formation; Banbury Basalt; Chalk Hills Formation; Glenns Ferry Formation; Tuana Gravel; Bruneau Formation; and Black Mesa Gravel (Malde and Powers 1962). Of the seven formations, only two are exposed in Hagerman Fossil Beds National Monument: the Pleistocene Tuana Gravel and Pliocene Glenns Ferry Formation (Othberg et al. 2005). A continuous sequence of the seven Idaho Group formations is not exposed in the region, but a complete section would be nearly 1,500 m (5,000 ft) thick (Malde and Powers 1962).

Fourteen unnamed basalt units, which are younger than the Pliocene Glenns Ferry Formation but older than the Pleistocene Madson Basalt, have been mapped along the Snake River in Twin Falls County and Jerome County and assigned to the Idaho Group (Covington and Weaver 1991). Although the stratigraphic relationships of the basalts to other units in the Idaho Group are uncertain, they have been assigned to the Idaho Group because they are not faulted and fractured as are the basalt flows in the overlying Snake River Group. The basalt filled tributary canyons entering the ancestral Snake River from the south.

The Snake River Group comprises nine Pleistocene formations (from oldest to youngest): Madson Basalt; Sugar Bowl Gravel; Thousand Springs Basalt; Sand Springs Basalt; Wendell Grade Basalt; McKinney Basalt; Yahoo Clay; Crowsnest Gravel; and Melon Gravel (Malde 1982). The lake deposits of the Yahoo Clay are the only Snake River Group unit mapped in the monument although the Crowsnest Gravel outcrops in association with the Yahoo Clay near the monument's southern boundary (Othberg et al. 2005). The Snake River Group primarily occupies the eastern Snake River Plain. Approximately 160 km (100 mi) northeast of Hagerman, drillers encountered 270 m (900 ft) of the Snake River Group in a drill hole near Arco, Idaho (Malde and Powers 1962). At Craters of the Moon National Monument and Preserve (fig. 2), the Snake River Group has been divided into eight eruptive periods that span Pleistocene to Holocene time (Kuntz et al. 1989).

In Hagerman Fossil Beds National Monument, the main units include the Pliocene stream and lake sediments of the fossiliferous Glenns Ferry Formation, the early Pleistocene (late Pliocene?) Tuana Gravel, the late Pleistocene Yahoo Clay, and Quaternary landslide deposits (Malde and Powers 1972; Malde 1982; Kiver and Harris 1999; Farmer and Riedel 2003; McNerney 2005; Othberg et al. 2005). The poorly consolidated sediments of the Glenns Ferry Formation form the slopes of the monument. The age of the fossil-rich Glenns Ferry Formation ranges from approximately 4 to 3 million years ago (mya) (McDonald et al. 1996; Greg McDonald, NPS paleontologist, written communication, October 27, 2008), although some geologists suggest a time span from approximately 3.7 to 3.3 mya (Hutchison 1987; Dennison-Budak et al. 2008). Hart and Brueseke (1999) suggest that the lowest layers of the Glenns Ferry Formation in the Hagerman area may reach back to 4.5 mya. The Hagerman Horse Quarry dates to approximately 3.2 mya (Hart and Brueseke 1999). Within the monument, the Glenns Ferry Formation rests unconformably above the Miocene-aged Idavada Volcanics, but in other parts of Idaho, the formation rests above the late Miocene Chalk Hills Formation (McDonald et al. 1996).

A very dense, erosion-resistant, relatively thick carbonate layer in the Tuana Gravel forms a caprock above the more easily erodible sediments of the Glenns Ferry Formation. Any younger strata that were deposited above the Tuana Gravel have been eroded so that the Tuana Gravel now forms the surface of the Bruneau Plateau above the steep bluffs west of the Snake River (fig. 3). Deposited by the ancestral Salmon Falls Creek, Tuana Gravel represents braided stream sediments deposited across a nearly flat plain formed on an eroded Glenns Ferry Formation (Othberg et al. 2005).

Although the age of the Tuana Gravel is poorly constrained, the unit may represent a period of time that extends from the late Pliocene to the early Pleistocene (Malde 1991; Othberg et al. 2005). Malde (1991) placed a minimum late Pliocene age of 1.92±0.16 million years on Tuana Gravel mapped to the northwest of the monument. However, Tuana Gravel at Hagerman Fossil Beds National Monument may be equivalent to Tenmile Gravel mapped near Boise, which has a minimum early Pleistocene age of 1.58±0.085 million years (Malde 1991; Othberg 1994). To be consistent with the reference map used for Appendix A and GEOLEX, the U.S. Geological Survey's Geologic Names Lexicon, an early Pleistocene age has been assigned to the Tuana Gravel in this report (fig. 4) (Malde and Powers 1972; http://ngmdb.usgs.gov/Geolex/NewUnits/unit_10969.html, accessed September 2009).

Originally mapped as the Bruneau Formation, the Yahoo Clay consists of laminated to thin-bedded clay and silty clay (fig. 4). The Bruneau Formation is now restricted to an area downstream and west of Bliss, Idaho (Armstrong et al. 1975; Malde 1982). Fine-grained, Yahoo Clay sediments settled in McKinney Lake, a temporary lake created when the basalt of McKinney Butte dammed the Snake River (Othberg et al. 2005). River channel deposits of the Crowsnest Gravel buried the Yahoo Clay as McKinney Lake drained. In the southern part of the monument, exposures mapped as Crowsnest Gravel by Malde and Powers (1972) have been mapped as Yahoo Clay and Glenns Ferry Formation by Othberg and others

(2005), possibly because erosion and mass wasting removed much of the Crowsnest Gravel from this area since 1972.

Unsorted and unstratified landslide deposits form complex slumps, slides, and debris flows along the steep bluffs of the monument. The landslide deposits originate in Glenns Ferry Formation, Yahoo Clay, or older landslide deposits (Malde and Powers 1972; Othberg et al. 2005). The oldest landslides may have developed during or just after the Bonneville Flood, about 14,500 years ago. Landslides continue to impact fossil deposits and raise safety issues in the monument.

The crescent-shaped Snake River Plain developed at the northern end of the Basin and Range physiographic province during the late Cenozoic (fig. 5). The monument lies near the geomorphic and structural boundary between the northwest-trending western Snake River Plain and the northeast-trending eastern Snake River Plain. Whereas the monument is located in the western plain, the town of Hagerman, just across the river, is located on the eastern plain (Kiver and Harris 1999; Farmer and Riedel 2003).

While the topography is similar in the two areas, their geologic origins are quite different (Mabey 1982; Malde 1991). Extensional (pull-apart) forces associated with the origin of the Basin-and-Range Province in the Miocene epoch acted to shape the western Snake River Plain. The western basin filled with lava flows, fluvial deposits, and lake sediments. Part of this western stratigraphic sequence includes the Glenns Ferry Formation.

In contrast, the eastern Snake River Plain formed in response to the northeastward "migration" of the Yellowstone-Snake River Plain hot spot (Mabey 1982; Kiver and Harris 1999). Thought to be the surface expression of a persistent, stationary rising plume of hot mantle material, a hot spot does not actually migrate. Rather, as the lithospheric plate travels over the mantle hot spot, the hot spot appears to migrate. The Hawaiian hot spot is the largest, and perhaps the most famous, hot spot. Volcanic material from the Yellowstone-Snake River Plain hot spot initially erupted in northern Nevada and southeast Oregon 16.5 mya, entered the eastern Snake River Plain about 12.5 mya, and reached what is now Yellowstone National Park 2 mya (fig. 6).

Rhyolitic (high-silica) volcanic rocks covered by basaltic (low-silica) lava flows that are about 1 km (0.6 mi) thick characterize the eastern Snake River Plain (fig. 2) (Malde 1991). The rhyolite extends to depths of at least 3 km (2 mi). North and east of the Snake River, sand and gravel deposits and thin, poorly developed soils cover basalt flows in a broad flat agricultural area known as the Hagerman Valley (Malde and Powers 1972; Farmer and Riedel 2003). Further discussion of the origins of the western and eastern segments of the Snake River Plain continues in the Geologic History section of the report.

The geologic and geomorphic features within the Hagerman Valley reflect the influence of the Bonneville Flood, the catastrophic late Pleistocene flood that discharged an immense volume of water about 14,500 years ago. The force of the flood rounded basalt into boulders that range up to 3 m (10 ft) in diameter (fig. 7). These boulders are called "Melon Gravel," a name inspired by a roadside sign that read "petrified watermelons." Composed almost entirely of basalt broken from nearby basalt flows, the boulders came to rest on the east side of the valley in extraordinary deposits up to 90 m (300 ft) thick. Receding floodwaters left Melon Gravel bars that measure as much as 1.6 km (1 mi) wide by 2.4 km (1.5 mi) long (http://imnh.isu.edu/digitalatlas/hydr/lkbflood/lbf.htm, accessed September 2009).

Park History

From the Folsom paleo-Indian culture to the later Great Basin Archaic hunters and gatherers to the present, humans inhabited the area of the Hagerman Fossil Beds National Monument for at least the past 10,000 years. The area was also home to the Fremont peoples from about 2,000 to 700 years ago, as well as to the Shoshoni people. Wagons that rolled along the Oregon Trail from 1840 to 1870 left deep ruts that are still visible today in the southern end of the monument. Settlers moved into the region shortly thereafter.

In the 1920s, local rancher Elmer Cook led geologist H.T. Stearns to the bluffs above the Snake River containing the bone bed. Stearns and Smithsonian paleontologist J.W. Gidley returned the next summer and excavated three tons of bones, primarily from one species of an extinct zebra-like horse (*Equus simplicidens*) in one location that became known as the Horse Quarry, or Gidley Quarry (fig. 8 and inside front cover). Major digs continued through 1934, and were again conducted by universities during the 1950s and 1960s and by the National Park Service in 1997 and 1998. Research continues on the Hagerman fossils, and has thus far yielded over 200 scientific papers.

Congress authorized Hagerman Fossil Beds National Monument on November 18, 1988, to protect the world-renowned fossil deposits. The Horse Quarry was transferred from the state of Idaho to the U.S. Department of the Interior on October 6, 2004 (Phil Gensler, NPS Hagerman Fossil Beds geologist, written communication, November 30, 2009).

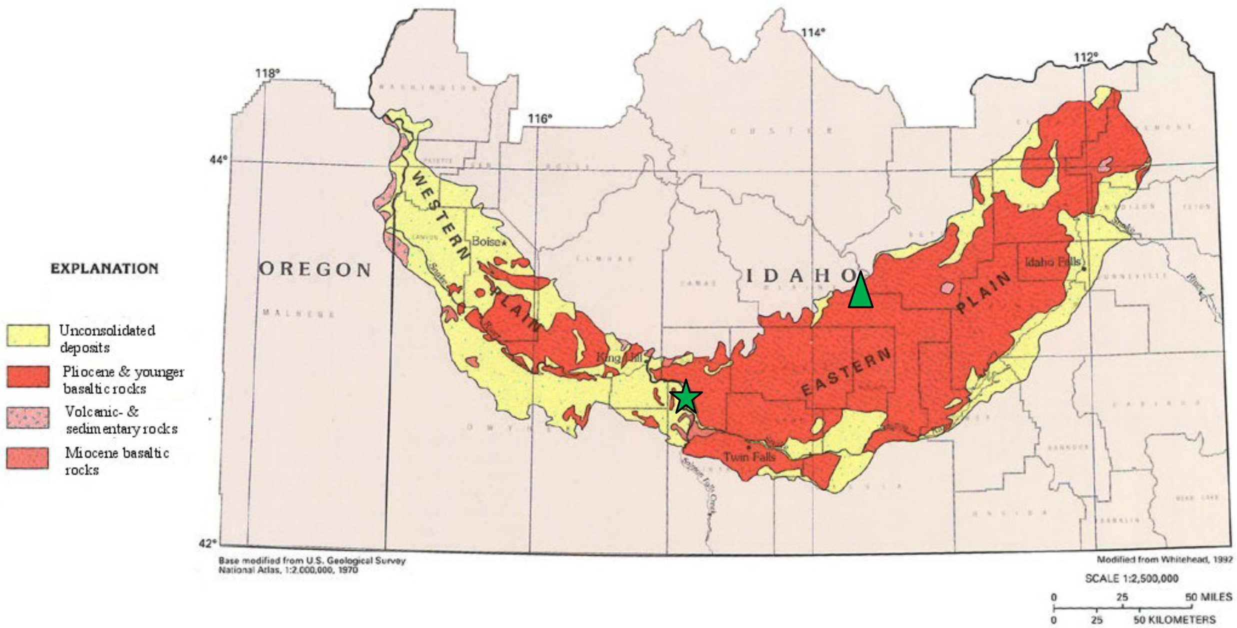


Figure 2. The Snake River Plain forms a crescent-shaped, physiographic feature across southern Idaho. Pliocene and younger basaltic-rocks (reds) fill the eastern plain while unconsolidated Quaternary deposits (yellow) characterize the western plain. The green star approximates the present location of Hagerman Fossil Beds National Monument. The green triangle marks the approximate location of Craters of the Moon National Monument and Preserve. Image modified from Whitehead (2008). Available online at: http://pubs.usgs.gov/ha/ha730/ch_h/jpeg/H053.jpeg. Accessed September 2009.

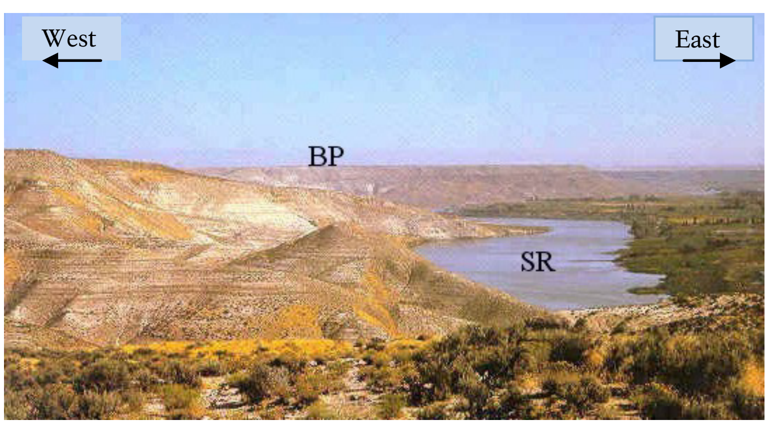


Figure 3. Overview of Hagerman Fossil Beds National Monument. View is to the north. Steep slopes rise from the Snake River (SR) to the Bruneau Plateau (BP). Photograph modified from the National Park Service website, http://www.nps.gov/archive/hafo/home.htm. Accessed September 2009.

Age		Group	Former Classification and Sequence (Map I-696)	Present Classification and Sequence (Malde 1982)	Depositional Environments of Units Exposed in the Monument
QUATERNARY	HOLOCENE		Stream alluvium Landslide debris	Stream alluvium Landslide deposits	Stream alluvium Active landslide deposits Alluvium of older streams Alluvial fan deposits
QUATERNARY	PLEISTOCENE				Older landslide deposits
QUATERNARY	PLEISTOCENE		Older alluvium		
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Melon Gravel	Melon Gravel	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	McKinney Basalt	Crowsnest Gravel	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Wendell Grade Basalt	Yahoo Clay	Lake deposits
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Sand Springs Basalt	McKinney Basalt	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Crowsnest Gravel	Wendell Grade Basalt	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Thousand Springs Basalt	Sand Springs Basalt	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP		Thousand Springs Basalt	
QUATERNARY	PLEISTOCENE	SNAKE RIVER GROUP	Madson Basalt	Madson Basalt	
QUATERNARY	PLEISTOCENE	IDAHO GROUP	Bruneau Formation		
QUATERNARY	PLEISTOCENE	IDAHO GROUP	Tuana Gravel	Tuana Gravel	Fluvial cycles of gravel, sand, and mud
NEOGENE	PLIOCENE	IDAHO GROUP	Glenns Ferry Formation	Glenns Ferry Formation	Lake and stream deposits Shoestring Road lava flow Clover Creek lava flow
NEOGENE	PLIOCENE	IDAHO GROUP	Banbury Basalt	Banbury Basalt	
NEOGENE	MIOCENE		Idavada Volcanics	Idavada Volcanics	

Figure 4. General stratigraphic column for rock units in the Hagerman Fossil Beds National Monument area. Note that the enclosed GIS map (Attachment 1 and Appendix A) reflects the former stratigraphic classification of Malde and Powers (1972). In 1982, Malde redefined the stratigraphic sequence as shown — most importantly, strata in the monument that was defined as Bruneau Formation in 1972 was determined to belong to the Upper Pleistocene, Yahoo Clay. "Depositional environments of units exposed in the monument" are those mapped by Othberg and others (2005).

Figure 5. Geologic provinces of the western United States. Hagerman Fossil Beds National Monument (green star) lies within the Snake River Plain (SRP), the crescent-shaped feature located at the northern end of the Basin and Range province. Other provinces include the Rocky Mountain System (RMS), Colorado Plateau, Columbia Plateau (CP), Cascade-Sierra Mountains (CSM), and the Pacific Border Province (PBP). The red circle east of Hagerman Fossil Beds National Monument represents the general location of the Yellowstone hot spot in Yellowstone National Park. SAF marks the trace of the San Andreas Fault. Modified from a NASA shaded relief map available online at: http://rst.gsfc.nasa.gov/Sect6/basin_range.gif. Accessed September 2009.

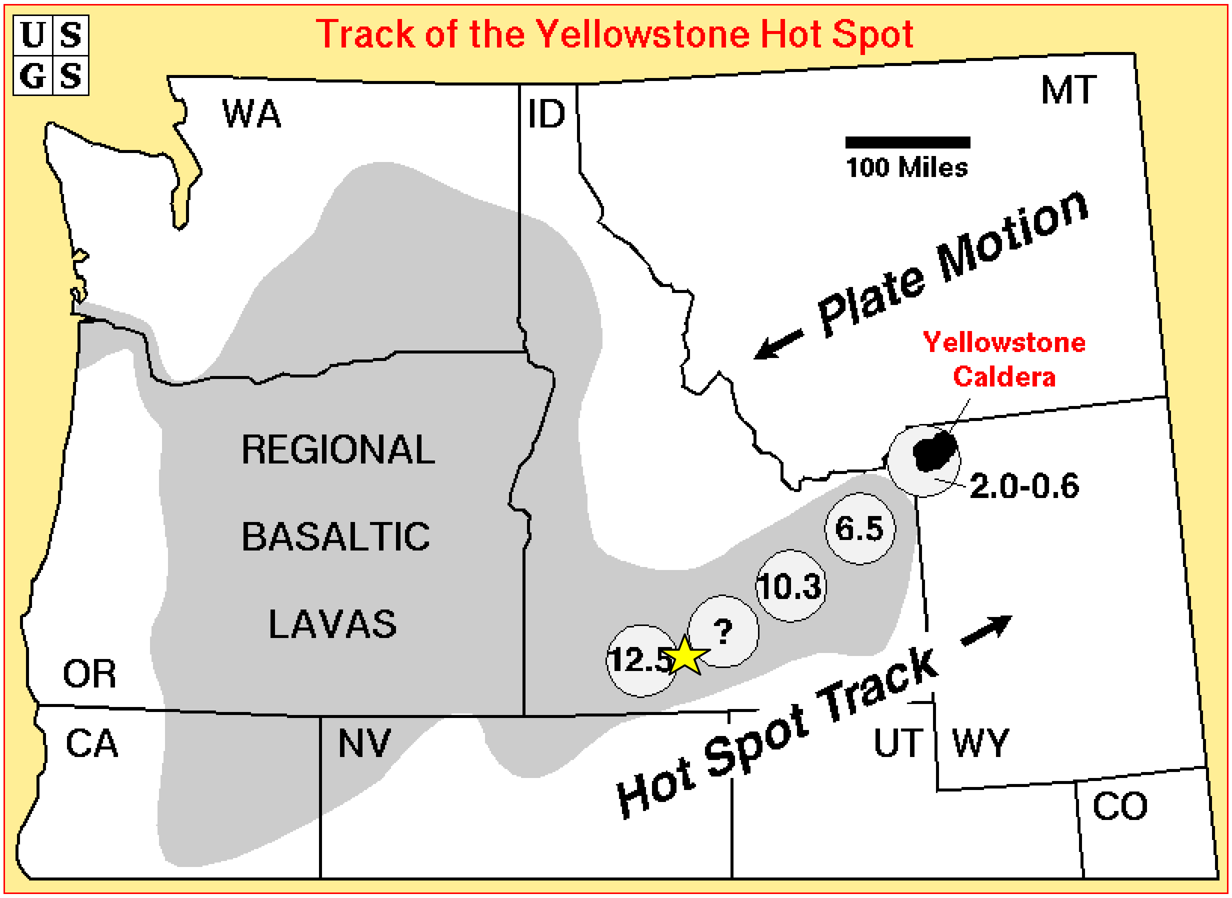


Figure 6. Migration of the Yellowstone-Snake River Plain Hot Spot relative to Hagerman Fossil Beds National Monument and the Eastern Snake River Plain. The yellow star approximates the present location of Hagerman Fossil Beds National Monument. As North America migrated southwest over the hot spot, the volcanism progressed northeast to its present position in Wyoming (black arrows). Ages in the circles are in millions of years before present. Figure modified from the U.S. Geological Survey website at: http://vulcan.wr.usgs.gov/Imgs/Gif/Yellowstone/OFR95-59/figure1.gif. Accessed September 2009.

Figure 7. Large "Melon Gravel" boulders, more than 1 m (3 ft) across are littered across Hagerman Valley east of the fossil beds and the Snake River. Elsewhere, Melon Gravels can be up to 3 m (10 ft) across. They were ripped out of basalt flows in the area, transported, and redeposited in the Hagerman Valley during the outburst flood from Lake Bonneville about 14,500 years ago. The same flood eroded and steepened the fossil-bearing bluffs within the monument. NPS photo.

Figure 8. Excavation at the Hagerman Horse Quarry during the 1930s. Smithsonian Institution photo by James Gidley, courtesy Phil Gensler (NPS HAFO).

Geologic Issues

The National Park Service held a Geologic Resources Inventory scoping session for Hagerman Fossil Beds National Monument on September 18, 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.

At the September 18, 2003, scoping session, the following significant geologic resource management issues were identified for Hagerman Fossil Beds National Monument:

- Protection and preservation of paleontological resources and localities
- Landslide activity
- Wind transport and erosion
- Radioactivity
- Geothermal activity
- Minerals and abandoned mineral lands
- Visitor Center siting
- Local industrial activity

Suggestions for continued research and monitoring of many of the above issues are listed in the Research and Monitoring Opportunities section. Contact the Geologic Resources Division for technical assistance.

Protection and Preservation of Paleontological Resources and Localities

Landsliding, slumping, erosion, weathering, wind action, and theft negatively impact the world-renowned Pliocene fossil sites in Hagerman Fossil Beds National Monument, the park's primary resource. Scoping meeting participants expressed interest in relocating previously known fossil sites and documenting and preserving new sites using GPS and photodocumentation. However, because of the unstable slopes, monitoring and research activities at the fossil sites are hazardous. Photographic monitoring captures changes in vegetation due to grazing, irrigation, and/or the introduction of exotic species. Any future actions with regard to paleontological resources should be supervised by the monument's paleontologist so that new data can be seamlessly integrated into the existing fossil resource management program.

As described in the Research and Monitoring Opportunities section, below, continued monitoring of paleontological resource localities within the park is critical for their protection and preservation. The public cannot currently access the fossil sites.

The Paleontological Resources Preservation Act (March 2009) mandates science-based paleontological resource management throughout the National Park Service. The Act also calls for developing plans for paleontological resource inventories and monitoring, emphasizing coordination with non-federal partners, scientists, and the public, as well as establishing a program to increase public awareness about the significance of fossil resources while protecting information about the specific fossil localities. The Act includes criminal and civil enforcement, penalty, reward, and forfeiture provisions. Specific regulations associated with the Act are being developed by the Departments of Interior and Agriculture.

Landslide Activity

Because landslide activity may occur more often and to a greater intensity at Hagerman Fossil Beds National Monument than at any other unit in the National Park System, landslides present a major geologic issue for resource managers (figs. 9–11) (Farmer and Riedel 2003). Active landsliding destroys the original depositional context of the fossils and reduces their scientific value. Landslides also impact the safety of field personnel and visitors. Roughly 24 to 30 ha (60 to 75 ac) of fossil beds have been lost so far, and strata where beds are rich with fossils may become endangered in the future (Kiver and Harris 1999; Farmer and Riedel 2003). At the scoping session, concern was raised over the frequency and order of magnitude of landsliding, which appears to be increasing. Landslides along the Snake River typically range in size from 90 to 240 m (300 to 800 ft) wide and up to 305 m (1,000 ft) long (Farmer 2004).

From 1979 to 2005, seven major slides occurred at Hagerman Fossil Beds National Monument, and two major landslides occurred on slopes adjacent to the monument on land managed by the Bureau of Land Management (Farmer 1998; Farmer and Riedel 2003; Farmer 2004). In 1987, a major slide destroyed a $1 million irrigation pumping station along the Snake River and nearly killed two workers (fig. 10). That slide was reactivated in 1993.

Another massive landslide that started to fail in 1983 continues to move and enlarge. Increased pumping to a leaky canal located behind the historic quarries triggered a slide in 1989 (fig. 11) (Kiver and Harris 1999).

Studies point to irrigation water from the Bell Rapids Irrigation Project as the main cause of the massive landslides that threaten large sections of the monument (Farmer and Riedel 2003). From about 1970 to the summer of 2005, water was pumped out of the Snake River and up to the Bruneau Plateau by the Bell Rapids Irrigation District (fig. 12) (Farmer 2004; Phil Gensler, NPS Hagerman Fossil Beds geologist, written communication, January 23, 2009). Unlined canal systems distributed the water to crops, and the irrigation water then percolated down through the unconsolidated sediments from leaking canals, ponds, and fields to form shallow perched groundwater systems. Perched groundwater aquifers are separated from a main body of groundwater by a confining bed, such as a bed of clay, which does not transmit significant quantities of groundwater (fig. 13). In this way, the aquifers are "perched" above the main aquifer.

Groundwater in these perched groundwater systems flows horizontally, emerging on the hillsides within the monument as springs and seeps (Michaels et al. 1996). The irrigation canals also penetrated the relatively impermeable carbonate layer in the Tuana Gravel that caps the slopes, allowing seepage from the canals to recharge the shallow perched aquifers in the Glenns Ferry Formation (National Park Service 1996).

When the 1987 landslide destroyed the Bell Rapids Canal, the Fossil Gulch Canal became the primary source of irrigation water to the perched aquifers. The Fossil Gulch Canal transported over 60 million m^3 (2.1 billion ft^3) of water during the five- to six- month irrigation season (Michaels et al. 1996). As much as 10 percent of this water was lost every irrigation season due to leakage. Immediately north and east of the Horse Quarry, about 617,000 m^3 (21.8 million ft^3) of seepage occurred annually from numerous locations. Compounding the problem, the Shoestring Road Basalt funneled groundwater from the leaking canal toward the cliffs containing the fossil beds (Michaels et al. 1996). Water also seeped in following application to the fields. Chemical analysis of groundwater indicated high levels of nitrates, consistent with fertilizers applied to the fields. This suggests that most of the groundwater came from field irrigation rather than pre-irrigation transport (Phil Gensler, NPS Hagerman Fossil Beds geologist, personal communication, November 2, 2009).

Increased groundwater meant increased pore pressure, which reduced shear strengths and increased slope stability problems. In addition, the slopes contain finely laminated, paper-thin shale layers with very low shear strengths and clays that expand with the addition of water (Farmer and Riedel 2003). The combination of increased pore pressure and expanding low-shear-strength clays created optimal conditions for slope failures.

Two perched aquifers were identified in the 1989 landslide, which was reactivated in 1998 (fig. 11). Further research has identified six hydrostratigraphic layers: three aquifers and three confining beds (Farmer 1998; Farmer 2004). Buried paleo-stream channels define the upper and lower aquifers, while the middle aquifer is primarily fractured basalt.

Since 2007, groundwater levels have not been measured in the monument's monitoring wells. Monitoring was discontinued primarily because irrigation ceased when irrigators sold a significant portion of their water rights to the state of Idaho. As of summer 2005, water has not been applied to the cultivated lands adjacent to Hagerman Fossil Beds National Monument. Several miles of underground metal irrigation pipe have been removed, although the majority of the piping has been left in the ground. The pump station remains, and irrigators retain a right-of-way through the monument so that irrigation can be resumed if it becomes economically feasible (Phil Gensler, NPS Hagerman Fossil Beds geologist, written communication, January 23, 2009).

Since irrigation ceased, two more landslides have occurred in Hagerman Fossil Beds National Monument, one in 2004 and one in 2005. These slides were large expansions of existing slides (Phil Gensler, NPS Hagerman Fossil Beds geologist, written communication, January 23, 2009). The bluffs contain wet areas that may produce landslides, but these areas may eventually dry because irrigation water is no longer being applied. The response time required for the artificial groundwater system to adapt to the drier conditions remains unknown.

Landslides may also occur closer to the level of the Snake River. Along the park boundary, the Snake River is impounded behind the Lower Salmon Falls Dam. Water from the reservoir saturates sediments at these lower elevations. Small landslides occur in these saturated sediments when the reservoir level is lowered (Phil Gensler, NPS Hagerman Fossil Beds geologist, personal communication, November 2, 2009). Idaho Power manages the reservoir levels for hydroelectric power generation.

Wind Transport and Erosion

Wind exposes new fossils, thus, allowing their collection. However, wind also exposes fossils to further erosion, exposure to sunlight, scattering, and theft. Wind may transport fossils downslope from their original position and cover fossil fragments with windblown sediment. Water dissolves the mineral cement holding particles together, and landslides loosen large areas of unconsolidated material. As a result, large quantities of sediment are available to be transported by wind.

Agricultural practices to the west create clouds of windblown material. This material is carried eastward over the monument, and brings in foreign material that includes not only topsoil and vegetation fragments but also animal wastes, agricultural chemicals, and pesticides.

Radioactivity

Both the sedimentary deposits and fossils at Hagerman Fossil Beds National Monument contain natural radioactivity from ^{238}U and ^{230}Th, which are naturally occurring radioactive isotopes of Uranium and Thorium, respectively (Williams et al. 2005). The radioactivity is variable. Some samples have no detectable radioactivity above background levels while others are highly radioactive. Fossils recovered from sandstone units are radioactive, while bones from clay layers are not radioactive (Greg McDonald, NPS paleontologist, written communication, October 27, 2008).

Fossil composition primarily consists of carbonate-fluorapatite with secondary calcite and quartz incorporated into the fossil matrix. The carbonate-fluorapatite contains a diverse assortment of trace elements. Scanning electron microscopy with x-ray microanalysis (SEM/EDS) reveals uranium and thorium concentrations up to 5,000 parts per million in the carbonate-fluorapatite. Radioactive emission levels in some fossil samples at Hagerman Fossil Beds National Monument have been measured at 21,000 counts per minute (cpm). Oxidized mineral deposits may record radioactivity at about 400 cpm (Williams et al. 2005). For comparison, background levels range from near 0 to 50 cpm.

The fossils are radioactive to the extent that precautions must be taken when handling and preparing the fossils (Covington 2004; Williams et al. 2005). For example, radon in the fossil/collection storage room has been detected at 25 picocuries per liter, which is six times the EPA recommended limit (Williams et al. 2005). The park has taken steps to mitigate the risk associated with radon by monitoring radon levels, providing staff training, installing an air handling system, and developing standard operating procedures for staff working in the storage room

Geothermal Activity

With the exception of Yellowstone National Park, southern Idaho has the largest known resources of geothermal water in the United States (Malde 1991). In operation since 1892, the Boise Warm Springs Water District remains the oldest geothermal heating company in the United States.

Active geothermal development occurs primarily at the south end of the monument and outside of its borders (Laney and Brizzee 2003). In this area of Idaho, aquaculture, greenhouses, and recreation sites utilize geothermal energy. For example, hot springs located approximately 10 km (6 mi) south of the monument have been commercially developed into resorts with swimming pools and hot tubs (fig. 14). Geothermal wells in Idaho deliver water with elevated temperatures that primarily range from 20° to 50° C (68° to 122° F), although some wells produce water with temperatures above 50° C (122° F) (Laney and Brizzee 2003).

Water wells drilled in the monument may have elevated temperatures. However, it is not known to what degree the surrounding geothermal wells are monitored in terms of temperature, flow rates, associated gases, and water quality. In addition, the method of disposal for the spent geothermal water is unknown (e.g., disposed of on the surface or in stream channels, re-injected into the subsurface, or managed by another method).

Minerals and Abandoned Mineral Lands

Mineral development in parks may occur under three circumstances: 1) where the unit is open by law to new federal mineral leasing; 2) where federal leases exist that pre-date the establishment or expansion of the park; and 3) where nonfederal (private or state-owned) mineral rights exist (including oil and gas) that would be economical to develop. No patented or unpatented mining claims exist for Hagerman Fossil Beds National Monument (National Park Service 2006).

In the past, gold placer mining occurred along the Snake River in the Hagerman area. Elemental mercury was used to amalgamate and extract the gold, a practice that leaves mercury in waste rock and soil. Prospect pits left from exploration and perhaps mining for uranium in the monument may have elevated radiation levels.

Visitor Center Siting

Tailings from prior mining activities remain on a 22-ha (54-ac) parcel, planned for a future park museum and research center on the east side of the Snake River. Contamination from hydrocarbon spills exist adjacent to the property. The level of significance of this soil contamination is unclear. Additional groundwater level and groundwater quality data are needed, as well as information on the potential effects of the contaminants on the new water supply well. The site is outside of the 100-year floodplain for the Snake River (Phil Gensler, NPS Hagerman Fossil Beds geologist, personal communication, November 2009).

Local Industrial Activity

Human activities in Hagerman Valley include agriculture, fisheries, electric power plants, wine production, meat by-product processing, livestock trucking, dairy farming, and tourism. Both state and federal fish hatcheries are major industries in the area. On the east side of the Snake River, between Dolman Rapids south of the monument and Lower Salmon Falls, north of the monument, five fish hatcheries operate in Pleistocene and Holocene alluvium. The Snake River contains four hydroelectric plants in the region, some of which are immediately north and south of the monument (Othberg et al. 2005). The impacts of these industries on water quality and water flow in Hagerman Fossil Beds National Monument are unknown. Impacts from the disposal of waste products from these industries are also unknown.

Research and Monitoring Opportunities

Paleo-ecological Research

The quantity, quality, and species diversity found in the fossil sites at Hagerman Fossil Beds National Monument, combined with the excellent collection of age dates provided by the stratigraphic record, offer outstanding opportunities for paleo-ecological research. Paleontological and sedimentological data may provide insight into the evolutionary changes in plants and animals and the ecological response of species and their environments to late Neogene global climatic change (National Park Service 1996). Work by Ruez (2006) presents an example of the high resolution paleo-ecological research opportunities available within the monument. High resolution geologic (facies) mapping and integration to the park GIS could facilitate detailed geologic investigations.

Paleontological Resource Monitoring

Continuation of the park's active paleontological resource monitoring program will continue to yield new information supporting the protection and preservation of fossils and fossil localities. In addition to assessing the condition of known fossil localities, new fossil localities may be discovered, or new discoveries made from previously identified localities. While new fossil material is found every season, a new fossil species is discovered within the park about every other year (Phil Gensler, NPS Hagerman Fossil Beds geologist, personal communication, November 2, 2009).

Santucci and others (2009) outline potential threats to in situ paleontological resources and suggest monitoring "vital signs" to qualitatively and quantitatively assess the potential impacts of these threats. Their five vital signs categories are:

Rates of Natural Erosion (Geologic Variables)

This vital sign assesses the geologic variables that contribute to increased erosion at a locality such as physical characteristics of a rock unit (rock type, how well cemented is the rock, etc.), bedding, degree of slope, and geochemistry. The unconsolidated nature of the Glenns Ferry Formation sediments in the monument contribute to rapid erosion.

Rates of Natural Erosion (Climatic Variables)

This vital sign assesses local climatic data on annual precipitation, rainfall intensity, relative humidity, wind speed, and freeze-thaw index (number of 24-hour periods per year when temperature fluctuates above and below 0°C [32°F]). All of these factors influence natural erosion rates. Wind exposes fossil material and also contributes to its erosion within the monument.

Catastrophic Geologic Processes or Geohazards

This vital sign assesses the potential for catastrophic geologic processes or geohazards that could impact a fossil locality. Such processes or geohazards include volcanism, geothermal activity, earthquakes, glacial activity, and mass-wasting events (landslides, slumps, rockfalls, etc.). Landslides are a major threat to paleontological resources and localities within the monument.

Hydrology and Bathymetry

This vital sign assesses potential impacts to fossils near water bodies, where changes in water level can affect the stability of paleontological resources. Such changes could be caused by natural fluctuations in water level or be related to storm events and flooding. Changing water levels in the reservoir behind the Lower Salmon Falls Dam can facilitate landslides near the water level.

Human Impacts

This vital sign assesses the potential for human impacts, both intentional or unintentional, on fossil resources. As noted above, there is limited visitor access to fossil localities within the monument, however potential exists for fossil vandalism and/or theft.

Landslides

At the 2003 scoping session, participants noted the need to distinguish the amount of water supplied to groundwater systems by precipitation from the amount of water supplied by irrigation. Even with the elimination of irrigation since 2005, the rates, frequency, duration, and direction of groundwater influx and movement require continued monitoring.

Monitoring water quality for sediment load, nutrients (phosphates, nitrates), temperature, discharge rates, water balance, and effects of water influx on fish hatcheries would also prove beneficial to management. Hydrogeologic research would help clarify the spatial distribution of perched aquifer discharge patterns on the hillsides and identify variable recharge areas to each groundwater system. Ultimately, hydrogeologic research could help design a mitigation plan to abate canal leakage, decrease the frequency of slope failures, and address the following questions raised at the scoping meeting:

- What changes are occurring in the groundwater flow regime?
- Are flow rates increasing and is groundwater quality decreasing?
- How are these changes affecting soils and carbonate layers, surface water quality, slope stability, human safety, property, and facilities?
- How much slump material has moved into the Snake River and subsequent siltation of downstream reservoirs?

Potential research projects include hydrologic modeling, dye tracer tests, paleo-landslide studies, flow rates of springs, and topographic mapping of the river bottom. Development of a landslide GIS layer would facilitate future monitoring and management. Funding for monitoring and mitigation of landslides, however, has not been a major priority for Hagerman Fossil Beds National Monument.

Geothermal Research

The temperature, flow rates, associated gases and water quality resulting from geothermal wells may be of interest to monument staff. Disposal of geothermal water and the effect on the surrounding ecosystem is another research opportunity.

Impacts from Wind Transport and Erosion

Potential questions to be answered by monitoring windblown material that enters the monument include:

- What is the nature of windblown material?
- How much herbicide, pesticide, and fertilizer is being suspended and transported?
- What are the incremental effects of wind on fossil sites?

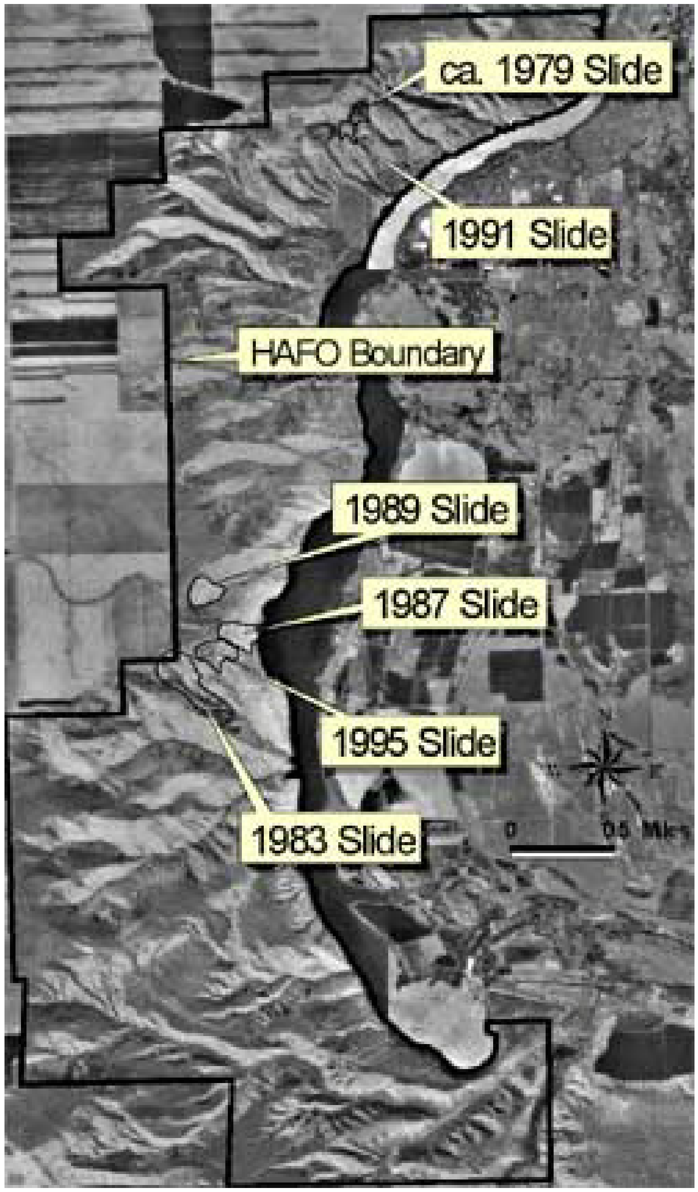


Figure 9. Relief map showing major landslides at Hagerman Fossil Beds National Monument prior to 2003. Arroyos dissect the bluffs in the monument. On the relatively flat Bruneau Plateau, dark and light, rectangular patterns outline agricultural fields. Map is from Farmer and Riedel (2003). Available online at: http://www.nps.gov/archive/hafo/watermgt/chap3.htm. Accessed September 2009.

Figure 10. 1987 landslide. This massive slide destroyed one of the water pumping stations for the Bruneau Plateau irrigation project. NPS photo (taken in November 2009) courtesy Phil Gensler (NPS HAFO).

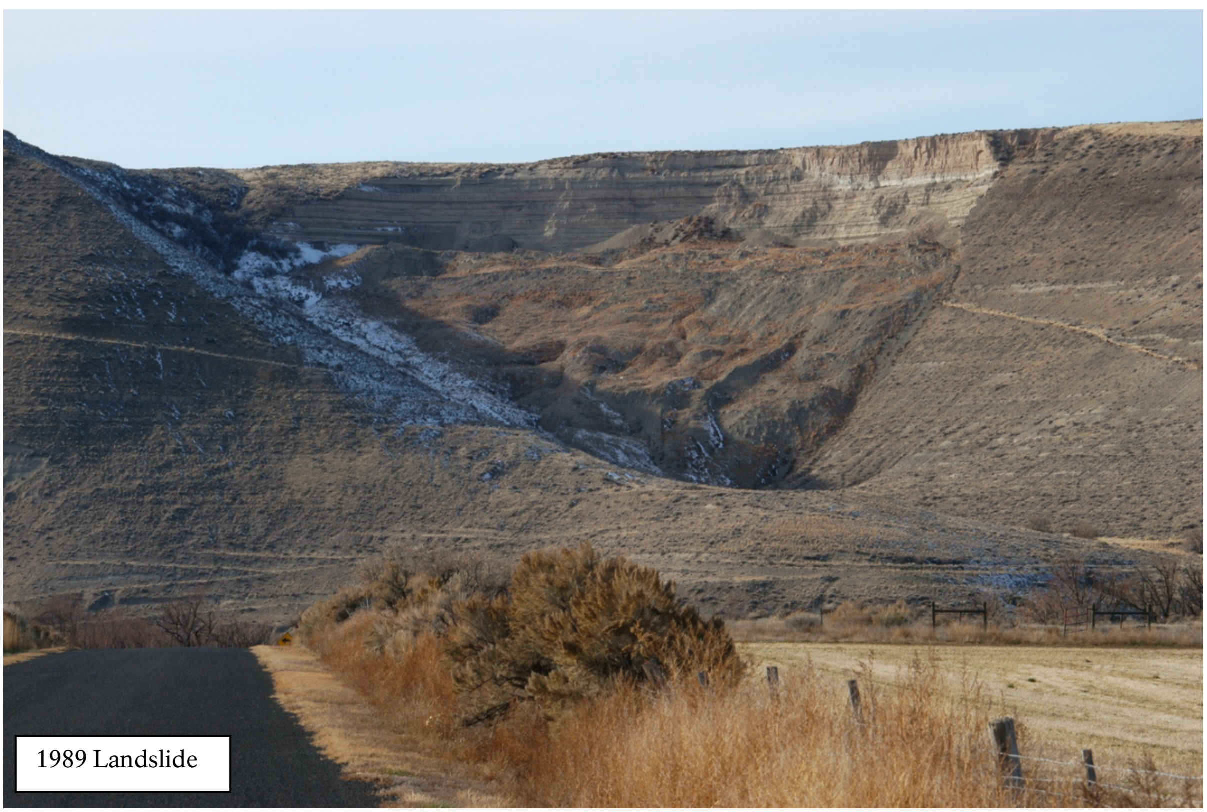


Figure 11. 1989 landslide. The original landslide occurred in 1989 (left two-thirds of slide scarp) and the slide reactivated in 2004 (right one-third). The "runout" of the 1989 slide reactivated in 1998. NPS photo (taken in November 2009) courtesy Phil Gensler (NPS HAFO).

Figure 12. Construction of pipeline transporting water from the Snake River to the Bruneau Plateau. The completed pipeline includes three pipes. The trench is now filled in. Interestingly, the vegetation on the slopes results from seepage of groundwater from irrigation activities. Naturally the slopes are unvegetated. NPS photo courtesy Phil Gensler (NPS HAFO).

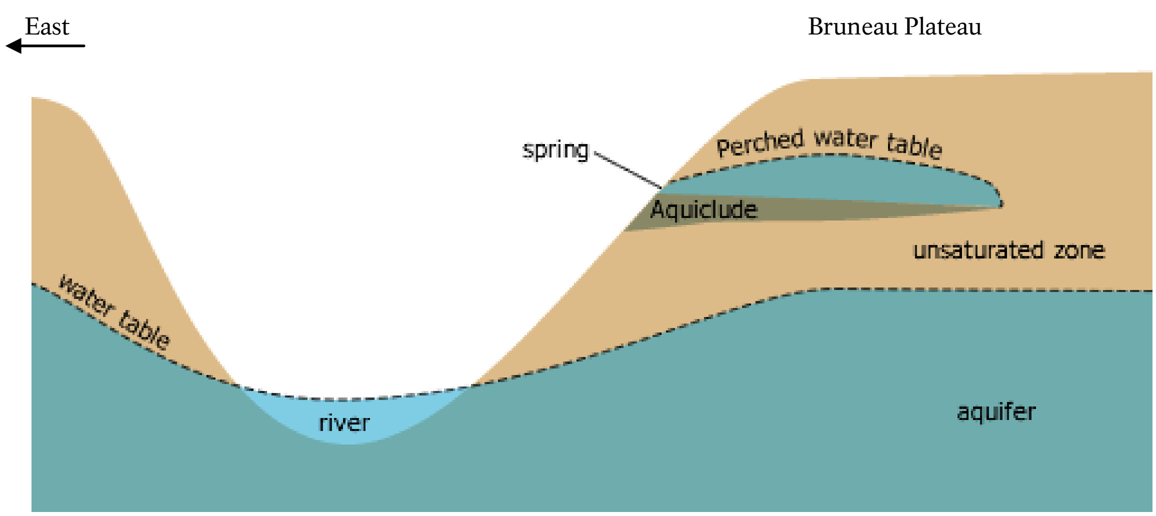


Figure 13. Diagram of a perched water table. An "aquiclude" is a confining bed through which significant groundwater does not easily flow. Groundwater above an aquiclude flows horizontally, rather than vertically, until it encounters the land surface and emerges as a spring or seep. Modified from a figure available online at: http://www.answers.com/topic/water-table. Accessed September 2009.

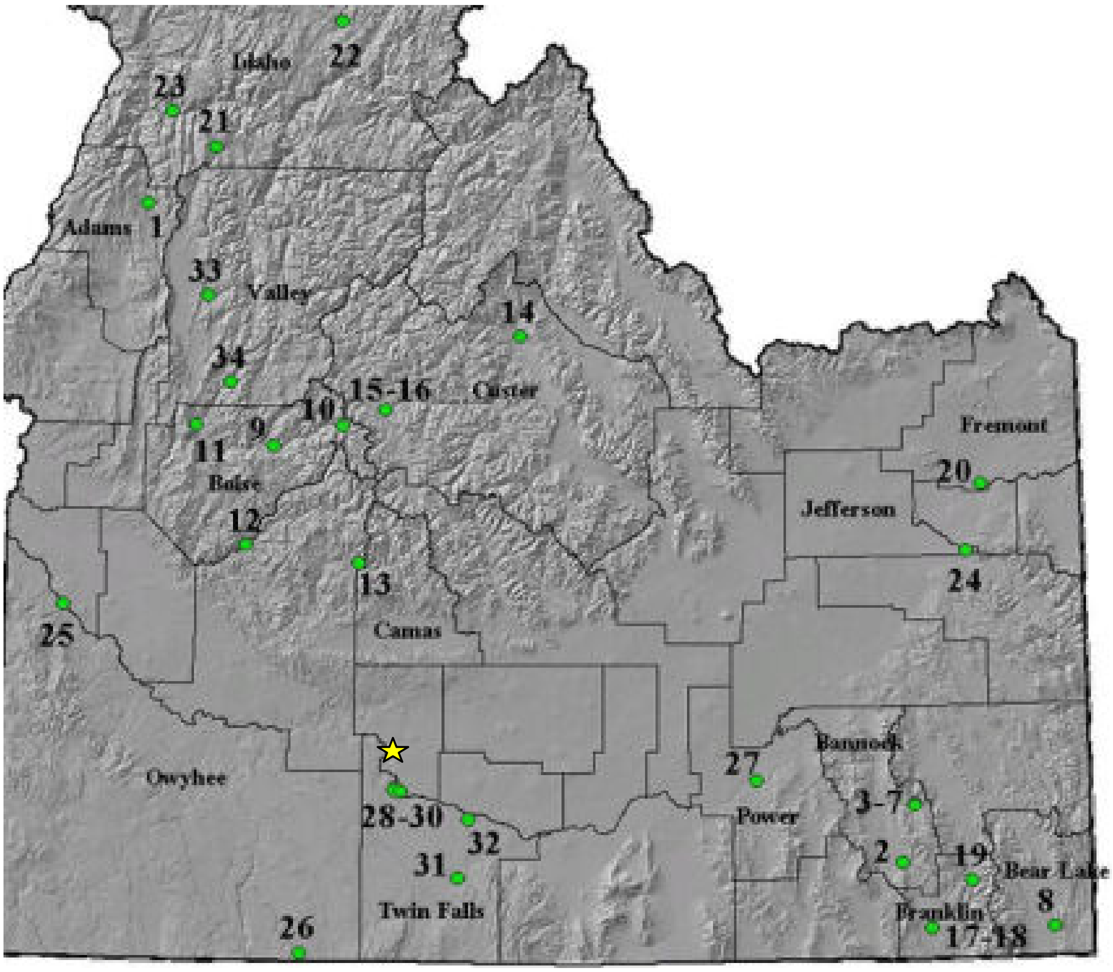


Figure 14. Commercially-developed geothermal springs in central and southern Idaho. The yellow star represents the approximate location of Hagerman Fossil Beds National Monument. Green circles are numbered and represent resorts that contain hot springs with water temperatures exceeding 29° C. (85° F.). Commercial development of hot springs #28-30 lies approximately 14 km (9 mi) south of Hagerman, Idaho. Modified from a figure available at: http://www.energy.idaho.gov/renewableenergy/recreation.shtml. A more detailed map identifying geothermal wells, springs, and commercial development of geothermal resources in Idaho is available at: http://geothermal.id.doe.gov/maps/id.pdf. Both maps accessed September 2009.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Hagerman Fossil Beds National Monument.

Paleontological Resources

Hagerman Fossil Beds National Monument contains the world's richest known fossil deposits from the late Pliocene epoch. Over an area of 15 km^2 (6 mi^2), more than 550 documented fossil sites from different horizons lie within the fluvial and floodplain sediments of the Glenns Ferry Formation (National Park Service 1996). The fossils at Hagerman Fossil Beds National Monument are not only numerous, but they are also found in a continuous undisturbed stratigraphic record spanning approximately one million years. Such a continuous record of geologic history is extremely rare.

Over 150 individuals of the extinct zebra-like Hagerman Horse, *Equus simplicidens*, have been recovered from the internationally famous Hagerman Horse Quarry (figs. 8 and 15) (McDonald 1996; McDonald et al. 1996). Five complete horse skeletons and more than 100 skulls, 48 lower jaws, and numerous isolated bones were removed from the quarry in the 1930s (McNerney 2005). The horse fossils range from yearlings to adults to older adults. Many of the specimens include partial skeletons with no evidence of predators disturbing the carcasses (McDonald 1996; Kiver and Harris 1999; National Park Service 2002).

Equus simplicidens is the earliest representative of the modern genus, *Equus*, which includes horses, donkeys, and zebras. The Hagerman Horse stood 1.1 to 1.5 m (3.6 to 4.9 ft) tall at the shoulder and weighed 110 to 385 kg (385 to 847 lbs). Its size, hooves, and teeth more closely resemble the living Grevy's zebra in Africa than the modern horse (McDonald 1993; Kiver and Harris 1999; National Park Service 2002; McNerney 2005).

The wide variety of carnivore fossils discovered in the Glenns Ferry Formation registers another remarkable aspect of the monument's fossil fauna. Over 100 different vertebrate species have been discovered at Hagerman Fossil Beds National Monument, 14 of which are carnivores. Vertebrates include 18 fish species, four amphibians, nine reptiles, and 50 mammals representative of the Blancan land mammal age (McDonald et al. 1996). Discoveries at Hagerman Fossil Beds in the 1930s revealed entirely new species, such as the saber-tooth cat (*Megantereon hesperus)*, lake cat (*Felis lacustris)*, peccary (*Platygonus pearcei)*, and mole (*Scapanus hagermanensis*) (http://www.nps.gov/archive/hafo/paleontology.htm, accessed September 2009).

Paleontologists also have identified 27 bird species from Hagerman Fossil Beds National Monument, including a new swan species, *Olor hibbardi*, and two species of cormorants, *Phalacrocorax idahensis* and *Phalacrocorax macer*. Ten bird species were first described from Hagerman specimens.

Table 1 lists some of the vertebrate types found at the monument, but more complete lists are available on the Map Unit Properties Table and in McDonald and others (1996). Some of the fossils and their significance are discussed at http://www.nps.gov/hafo/naturescience/animals.htm, and on Dr. Greg McDonald's "Critter Corner" at http://www.nps.gov/archive/hafo/paleontology.htm (accessed September 2009).

Table 1. Some vertebrate fossil fauna from Hagerman Fossil Beds

Common Name	Genus and Species
Bear	*Agriotherium* sp.
Beaver	*Castor californicus*
Camel	*Camelops* sp.
Catfish	*Ameiurus vespertinus*
Cormorant	*Phalacrocorax idahensis* *Plalacrocorax macer*
Giant marmot	*Paenemarmota barbouri*
Grison	*Trigonictis cooki*
Hagerman horse	*Equus simplicidens*
Hyena-like dog	*Borophagus direptor*
Lake cat	*Felis lacustris*
Mole	*Scapanus hagermanensis*
Muskrat	*Pliopotamys minor*
Otter	*Satherium piscinarium*
Peccary	*Platygonus pearcei*
Pronghorn	*Ceratomeryx prenticei*
Saber-tooth cat	*Megantereon hesperus*
Shrew	*Sorex* and *Paracryptotis*
Sloth	*Megalonyx leptostomus*
Snakes Garter snake Rattlesnake Racer Water snake Rat snake Milk snake	 *Thamnophis* *Crotalus* *Coluber* *Nerodius* *Elaphe* *Lampropeltis*
Swan	*Olor hibbardi*
Turtle	*Trachemys idahoensis* *Clemmys owyheensis*
(none)	*Ferinestrix vorax*

Fossil fauna from Hagerman Fossil Beds also illustrate a connection between North America and South America, two land masses once separated by an ocean. With the emergence of the Isthmus of Panama, a land bridge allowed animals to migrate from North America to South America. Pearce's peccary(*Platygonus pearcei*), the otter (*Satherium piscinarium*), the grison (*Trigonictic cooki*), and the spectacled bear (*Agriotherium* sp.) represent some of the animals at Hagerman Fossil Beds that made the journey to South America.

Invertebrate fossils are also abundant at the monument. Fluvial (river) and lacustrine (lake) layers of the Glenns Ferry Formation have produced about 40 invertebrate molluscan species (Taylor 1966). Invertebrates may be valuable for defining past paleoenvironments. For example, paleontologists defined three specific paleoenvironments in the Glenns Ferry Formation by using three distinct ostracode fauna. Ostracodes are microcrustaceans that have remained widely dispersed in freshwater and marine environments since the Cambrian period (542 million years ago) so their preferred environments are well known (Dennison-Budak et al. 2008). The lowest ostracode fauna represents a deep, permanent, cold, freshwater lake. The intermediate ostracode fauna identifies a change to an ephemeral system. The upper ostracode fauna, located in the Horse Quarry area, indicates a return to a more permanent freshwater system.

Pollen records show that an abundance of plant genera existed in the paleoenvironment of the Glenns Ferry Formation (Leopold and Wright 1985). In addition to pollen, petrified wood occasionally found in the monument suggests a lush Pliocene environment.

Currently, the fossil bed sites are unavailable to the public, whose access is limited to the developed trails at the monument. However, the Visitor Center contains many fossil exhibits. The Snake River Overlook, approximately 9 km (5.5 mi) south of the Visitor Center, provides an excellent view of the fossil-rich bluffs.

Paleogene - Neogene Ecosystem and Climate Change

Hagerman Fossil Beds National Monument is one of six fossil parks in the west that help piece together the story of ecosystem and mammalian evolution during the Paleogene and Neogene periods (fig. 16). The Cenozoic era is considered to be the "Age of Mammals." It was also a time of dramatic global climate change. Mammalian faunas from the Paleogene and Neogene periods reflect the division between the "hot house world" (or "greenhouse" world) of the earliest Paleogene (Paleocene and early Eocene), which was a continuation of the warm global temperatures and ice-free world of the Mesozoic, and the "ice house world" of the Oligocene to Recent with ice present at one or both poles (Janis 2001).

Isotopic age dates on the Peters Gulch and Fossil Gulch ash beds in the Glenns Ferry Formation and other geochronologic data suggest that the Glenns Ferry sediments span a period in the Pliocene epoch from approximately 3.7 to 3.2 million years (Hutchison 1987; McDonald et al. 1996; Dennison-Budak et al. 2008). The more than 220 vertebrate, invertebrate, and plant species preserved at Hagerman Fossil Beds National Monument represent the last vestiges of animals and plants that existed prior to the Pleistocene "ice ages" and the earliest appearances of modern flora and fauna. The Pliocene paleo-ecology at Hagerman Fossil Beds National Monument spans a variety of habitats, including wetland, riparian, and grassland savanna ecosystems.

Furthermore, the abundance and variety of animal and plant fossils in the Glenns Ferry Formation, as well as clues from the sediment, allow the paleo-ecology of the area to be reconstructed with a high degree of confidence. Plant pollen data suggest that annual precipitation measured about 51 cm (20 in) during the Pliocene, about twice the amount that falls today (Leopold and Wright 1985; McDonald et al. 1996).

A series of lake systems, collectively referred to as "Lake Idaho," formed in the western Snake River Plain. Streams and rivers flowed into Lake Idaho, and fish, ducks, geese, pelicans, cormorants, beaver, and an extinct variety of muskrat frequented the marshy environment. Horses, camels, pronghorn, mastodon, peccary, saber-toothed cats, and many other animals roamed across the grasslands and through the trees (McDonald 1993; Kiver and Harris 1999). The fauna and flora point to a floodplain environment within lush savanna grassland. Patches of trees grew on the eastern and southern margin of Lake Idaho (fig. 17).

The horse fossils at the Horse Quarry may represent an accumulation over many seasons, a single herd that clustered around a drying water hole during a drought, or perhaps an entire herd that drowned crossing a flooded river (Richmond and McDonald 1998). One hypothesis favors a drowning event during a spring flood in which the carcasses accumulated on a sandy point bar and were buried quickly by sediments, thus being preserved from scavengers and biodegradation (McDonald et al. 1996). Another suggests a mass mortality caused by a drought followed by a seasonal flash flood which buried the carcasses (Richmond and McDonald 1998).

The key to understanding mammalian evolution lies in understanding Paleogene and Neogene environmental changes. Differences between Paleogene and present-day mammals accompanied the change from equable, globally tropical conditions to a cooler, drier, more climatically zoned world. Hagerman Fossil Beds National Monument offers a snapshot, or window in time, into the semi-arid continental interior of North America during the Pliocene.

Stratigraphic Features

Glenns Ferry Formation

From 14 to 9 million years ago (middle Miocene), explosive rhyolitic volcanism associated with the Yellowstone-Snake River Plain hot spot deposited the Idavada Volcanics in southwestern and south-central Idaho. Beginning roughly 11 mya, sediments that would become the Idaho Group (fig. 4) settled over the Idavada Volcanics in lake, floodplain, and fluvial environments. In Hagerman Fossil Beds National Monument, the Glenns Ferry Formation overlies the Idavada Volcanics and contains features characteristic of these past environments.

The steep cliffs at Hagerman Fossil Beds National Monument expose about 183 m (600 ft) of the lower part of the Pliocene Glenns Ferry Formation (McDonald et al. 1996). Geologic features in the monument record the shallow, highly sinuous meandering stream and muddy floodplain depositional environment of the Glenns Ferry Formation. Floodplain strata consisting of calcareous silt, dark clay, sand, and minor shale lie marginal to and east of sediments deposited in a lake. The lake sediments consist of massive tan silt and fine-grained sand that form monotonous gray, diffusely banded outcrops from Glenns Ferry to Grandview, Idaho (McDonald et al. 1996).

The Glenns Ferry Formation can be divided into three members at Hagerman Fossil Beds National Monument (McDonald et al. 1996). The Lower Member, about 67 m (220 ft) thick, represents a floodplain environment that is capped by the Peters Gulch rhyolitic ash. Rhyolite is the volcanic (extrusive) equivalent to granite and, like granite, contains a mineral assemblage of primarily quartz, alkali feldspar, and plagioclase.

About 30 m (100 ft) of marshy floodplain sediments between the Peters Gulch ash and the overlying Fossil Gulch dacitic ash define the Middle Member of the Glenns Ferry Formation. Also an extrusive igneous rock, dacite registers a mineral assemblage of mostly potassium feldspar, biotite, and hornblende.

The 91 m (300 ft) Upper Member extends from the Fossil Gulch ash upward to the unconformable contact with Tuana Gravel. The Upper Member, another floodplain environment, includes the Horse Quarry.

The Glenns Ferry floodplain environments may also be subdivided into two units that can be mapped based on lithology. Units defined by lithology are called "lithofacies." The two lithofacies in the Glenns Ferry Formation include a muddy lithofacies and a sandy lithofacies. The muddy lithofacies contains cycles of silt and clay that become finer-grained toward the top of each cycle. The muddy lithofacies documents deposition on a wide, moist floodplain with abundant standing water (McDonald et al. 1996). Although found in all three members, the muddy lithofacies incorporates layers of organic (carbonaceous) paper-thin shale and diatomite only in the Middle Member. One of the most common types of phytoplankton, diatoms compose the soft, siliceous sedimentary rock called diatomite.

Sequences several meters thick of gravelly sand, trough cross-bedded sand, and rippled sand characterize the sandy lithofacies (fig. 18). These sequences also become finer-grained toward the top of each cycle. Overall, the sandy lithofacies contains coarser-grained clastics than the muddy lithofacies, and represents point bar deposits in a mixed-load, high-sinuosity meandering stream system. Cross-bed measurements indicate that the streams flowed to the north and northwest (McDonald et al. 1996).

Malde and Powers (1972) mapped two lava flows within the Glenns Ferry Formation in the monument: the Clover Creek lava flow and the Shoestring Road lava flow. The fine-grained Clover Creek lava flow consists of plagioclase-olivine basalt that exceeds 30 m (100 ft) thick near the mouth of Clover Creek. The source of this lava flow is unknown. Othberg and others (2005) did not map the Clover Creek lava flow.

The Shoestring Road lava flow (may actually correlate with the Deer Gulch basalt; Phil Gensler, NPS Hagerman Fossil Beds geologist, personal communication, November 2009; Hart and Brueseke 1999) originated from a vent about 5 km (3 mi) south of Bliss, Idaho. This gray to sooty brown lava flow is classified as a porphyritic plagioclase-olivine basalt. "Porphyritic" means that large crystals (phenocrysts) visibly project from within the fine-grained groundmass of the igneous rock. In the Shoestring Road basalt, phenocrysts of plagioclase grew up to 1 cm (0.4 in) in length. The 3- to 15-m (30- to 50-ft) thick layer extends northward from the Hagerman Horse Quarry (Othberg et al. 2005).

Tuana Gravel

Tuana Gravel unconformably overlies the Glenns Ferry Formation. About 61 m (200 ft) of Tuana Gravel outcrops at Indian Butte, south of Hagerman Fossil Beds. The unit thins to approximately 15 m (50 ft) near the northern boundary of the monument (Bjork 1968; Malde and Powers 1972). Tuana Gravel consists of upward-fining cycles of gravel to sand or mud deposited by a braided stream system inundating a relatively flat landscape. Stratigraphic evidence suggests that the braided stream channels periodically eroded into the underlying silts and clays of the Glenns Ferry Formation. The channels filled with trough cross-bedded sand, forming "cut-and-fill" structures (Sadler and Link 1996).

A well-cemented, massive carbonate layer forms a caprock in most of the monument and the surrounding area (Farmer and Riedel 2003; Othberg et al. 2005). The layer averages a few meters thick and is visible below overlying soil horizons in the bluffs. The carbonate records a climatic change believed to have developed during an interglacial dry cycle of the Pleistocene.

Yahoo Clay

About 50,000 years ago (Pleistocene epoch), basalt flowed from McKinney Butte and temporarily dammed the Snake River. McKinney Lake formed behind the dam and inundated Hagerman Valley. Exposures of Yahoo Clay in the monument represent fine-grained lake sediments that accumulated in McKinney Lake (Malde 1982; Othberg and Kauffman 2005). Typical of fine-grained lacustrine sediments, the clay is laminated to thinly-bedded. No vertebrate fossils have been recovered from the Yahoo Clay in the vicinity of Hagerman Fossil Beds National Monument.

Topographic Features

The Snake River is the primary perennial stream in the monument area. Yahoo Creek, along the southern edge of the park is also perennial. Fossil Gulch and Peters Gulch are two drainages that cut the bluffs, and both dissect important fossil beds. The steep terrain of Hagerman Fossil Beds National Monument creates badlands-type topography characterized by bluffs with little vegetation, landslide scarps, and hummocky deposits (fig. 3) (National Park Service 1996).

Figure 15. Mounted skeleton of the Hagerman Horse (*Equus simplicidens*), Idaho's State Fossil. Photograph courtesy of the National Park Service, Hagerman Fossil Beds National Monument. Available online at: http://www.nps.gov/hafo/planyourvisit/index.htm. Accessed September 2009.

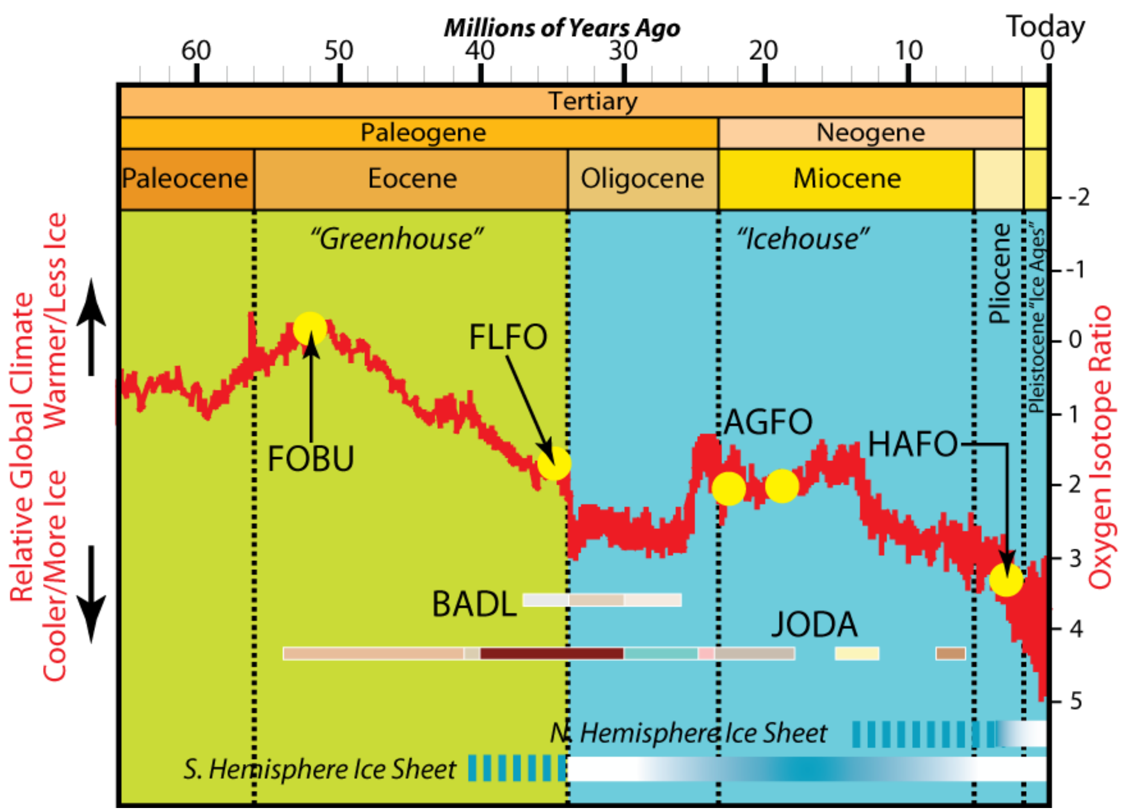


Figure 16. Relative global climate during the Paleogene and Neogene periods. The red line is plotted from deep water microorganism oxygen isotope data (a proxy for global climate) from Zachos and others (2001). The yellow dots and lines indicate the geologic age or range of ages of six NPS units established to preserve scientifically significant Paleogene and Neogene fossils and strata — including Hagerman Fossil Beds National Monument (HAFO); 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); 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 modified from Kenworthy (in prep). Original data from Zachos and others (2001).

Figure 17. Pliocene ecosystem in the area of today's Hagerman Fossil Beds. Layers of sand, silt, and clay at least 180 m (600 ft) thick were deposited in fluvial (river) and floodplain environments around the edge of ancient Lake Idaho. Mural by artist Jay Matternes. Copyright © Smithsonian Institution. Used with permission.

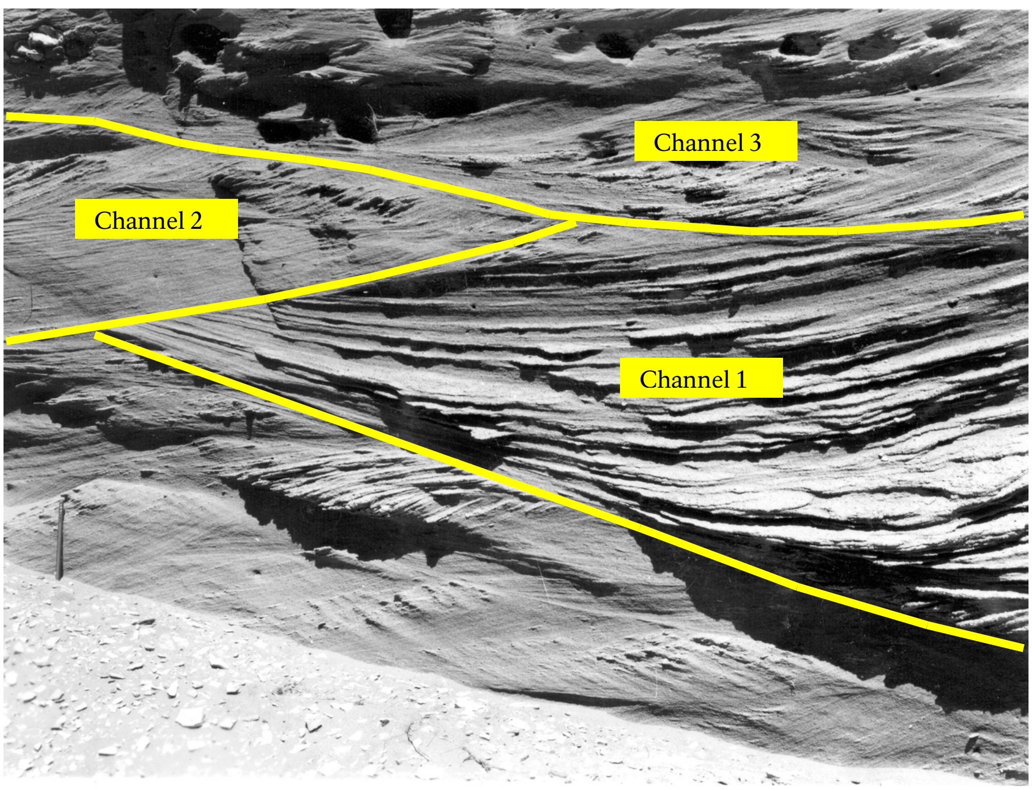


Figure 18. Cross-beds in the coarse-grained, sandy lithofacies of the Glenns Ferry Formation (late Pliocene). Larger grains consist of pea-sized pumice. For illustrative purposes, three channels that intersect each other have been outlined on the photograph. Channel 1 is the oldest channel deposit, and Channel 3 is the youngest set of cross-beds. The yellow lines mark the base of the channels. Each younger channel has eroded into the previous channel deposits. Just as they do in modern rivers, these Pliocene cross-beds formed as their channel migrated laterally across its floodplain. Pencil in the lower left for scale. The photograph captures an exposure near the top of a road cut of US 30 about 1.5 miles east of Hammett, which is west of Hagerman Fossil Beds National Monument. Modified from a photograph by H. E. Malde, September 11, 1960, available from the U.S. Geological Survey website at: http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Malde,%20H.E.%20%20271. Accessed September 2009.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Hagerman Fossil Beds 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 Hagerman Fossil Beds 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 represent rocks and unconsolidated deposits. Bold lines that cross and 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 utility of geologic maps and clarifies 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 correlations between geology and biology; for instance, geologic maps have served as tools for locating threatened and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where future earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps will 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 inhabited alcoves may occur at the contact between two rock units.

The features and properties of the geologic units in the following table correspond to the accompanying digital geologic data. Map units are those within or adjacent to the monument and are listed in ascending order from oldest to youngest. Please refer to the geologic time scale (fig. 19) 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, and mineral resources; and the suitability as habitat or for recreational use.

GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes and graphics, and report. The following map provided the source data for the GRI digital geologic map for Hagerman Fossil Beds National Monument:

Malde, H. E., and H. A. Powers. 1972. *Geologic map of the Glenns Ferry-Hagerman Area, west-central Snake River Plain, Idaho*. Scale 1:48,000. Miscellaneous Geologic Investigations Map I-696. 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 Hagerman Fossil Beds National Monument, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

This section provides a more detailed description of the structure, tectonics, depositional and erosional history, and general stratigraphy of Hagerman Fossil Beds National Monument and the surrounding area. The sedimentary and volcanic rocks exposed in the monument are only a fraction of the thick sediment package deposited in the western United States throughout geologic time.

Structural Overview

The Snake River Plain, which began forming in the Miocene epoch (fig. 19), consists of western and eastern segments with distinctive structural trends (fig. 2). The bluffs of Hagerman Fossil Beds National Monument lie in the western Snake River Plain, a northwest-trending structural basin bounded by basin-and-range style normal faults (fig. 20). Hagerman, Idaho lies in the eastern Snake River Plain, a northeast-trending volcanic plain that evolved with the southwest-to-northeast migration of the Yellowstone-Snake River Plain hot spot (fig. 6). Structurally, the western Snake River Plain also separates the Cretaceous-age Idaho Batholith of west-central Idaho from exposures of the batholith in southwestern Idaho.

During the Miocene epoch (23.03 to 5.33 million years ago [mya]), rising heat from the mantle began to thin the crust beneath the southwestern United States, causing the crust to bulge upward. The crust commenced to extend or pull apart, and as it stretched, steeply-dipping normal faults broke the crust into areally extensive blocks of rock. Some blocks were uplifted (relative to the downdropped blocks) and some dropped down along the surface of the faults to fill the space created by extension. Uplifted blocks of crust, called “horsts,” (German for ‘heap’) developed into the present fault-bounded north-south trending mountain ranges. Downdropped blocks filled with sediment to form relatively flat, fault-bounded valleys, or “grabens” (German for ‘ditch’) (fig. 20). The early explorer Major C. E. Dutton described the topography of the Basin and Range province “as an army of caterpillars crawling northward out of Mexico” (King 1977, p. 156).

Basin-and-range faulting extended into the western Snake River Plain where a long, fault-bounded structural graben formed 16 to 3 mya (Mabey 1982; Sadler and Link 1996). The graben eventually filled with volcanic deposits and lake sediments. During the past 9 million years, one or more lake systems, collectively known as Lake Idaho, filled the western Snake River Plain (McDonald et al. 1996). A prominent shoreline that sits at an elevation of 1,100 m (3,600 ft) represents Lake Idaho’s highest point (Wood 2000). A thick interval of stream sediments, including the Glenns Ferry Formation, accumulated in the western plain. In the western Snake River Plain, the Snake River incised to depths of 150 to 300 m (490 to 980 ft), forming steep-walled canyons in the basaltic rocks and strongly gullied badlands in the sediments (Malde 1991).

Although tectonic deformation created the western Snake River Plain, volcanic activity shaped the eastern Snake River Plain. The eastern segment traces the volcanic eruptions that progressed to the northeast as North America drifted southwestward over the Yellowstone-Snake River Plain hot spot (fig. 6). Initial volcanic activity began in the eastern Snake River Plain approximately 12.5 mya. Approximately 2 mya, the hot spot reached its current position beneath Yellowstone National Park in northwestern Wyoming.

The crescent-shaped Snake River Plain forms a distinct tectonic/volcanic landscape that interrupts the continuity of mountain ranges and valleys to the north and south (fig. 5). Cenozoic volcanic and sedimentary deposits, as much as 1.7 km (1.1 mi) thick, fill both the western and eastern sections of the Snake River Plain (Malde 1991).

Pre-Cenozoic Era (prior to 65.5 mya)

The Precambrian basement rocks buried beneath the monument are billions of years old and form part of the North American craton. The rock record of the Paleozoic Era (542 to 251 mya) is also buried beneath the monument. Shallow seas advanced and retreated many times onto the North American continent throughout the Paleozoic Era; thus, Paleozoic sedimentary rocks are dominated by limestone formed from calcareous sediments deposited in these shallow seas (fig. 21).

By the Early Triassic (251.0 to 245.9 mya), the process of plate tectonics had assembled all of the large land masses around the globe into one large supercontinent, Pangaea. Soon after forming, however, Pangaea began to split apart, and the lithospheric plates moved away from one another. On the west coast of North America, the Sierra Nevada cordillera developed, and ongoing volcanism and mountain building initiated a corresponding subsidence of the adjacent western interior region of North America. In the Cretaceous period (145.5 to 65.5 mya), a vast interior seaway connected the Arctic Ocean with the Gulf of Mexico (fig. 22).

Cenozoic Era (65.5 mya to present)

Paleogene Period (65.5 to 23.03 mya)

As the Cretaceous period neared an end, the seas gradually receded from the continent's interior. Plate tectonic activity along the western margin of North America produced the Laramide Orogeny, a mountain-building episode that occurred from 70 to 35 mya and resulted in the Rocky Mountains. In the Paleogene, lush subtropical jungles (with palm trees) existed throughout much of western North America. During Oligocene (33.9 to 23.03 mya) and Miocene epochs, vegetation changed from subtropical forests of the early Paleogene to savannas (scrubby trees and shrubs) or grasslands in the Neogene. By the Oligocene, climate was too cold and dry to support the jungle ecosystems.

Neogene Period (23.03 to 2.59 mya)

The Miocene saw an explosive diversification of mammal groups in response to a drying climate and the opening of forests into savannas. Growing aridity became a world-wide environmental factor, as evidenced by the desiccation of the Mediterranean Sea in the latest Miocene. Miocene global climate change has been associated with the major late Miocene extinctions of many mammal faunas (Janis 2001).

As mentioned above, volcanic activity related to the Yellowstone-Snake River Plain hot spot initiated the eastern Snake River Plain during the Miocene. Catastrophic volcanic eruptions of volatile rhyolitic magma removed great volumes of crustal material and left huge circular depressions or collapse features, called "calderas." Some of these calderas are up to 50 km (30 mi) in diameter. A second phase of eruptions produced fluid basaltic (low-silica) lava that flowed onto the surface and covered the rhyolite (high silica) lava.

Successively younger volcanic centers and volcanic tuff deposits track the hot spot's surface expression progressively northeast to its current position under Yellowstone National Park (fig. 6). For example, the Bruneau–Jarbridge caldera (near the Idaho–Nevada border) formed 12.5 to 10 mya, while the eruptions that created the Twin Falls caldera (northeast of the Bruneau–Jarbridge caldera) span 10 to 8.6 mya. Approximately 4.49- million year old volcanic tuffs outcrop in the eastern end of the Snake River Plain near the town of Heise, Idaho (http://www.ldeo.columbia.edu/~manders/SRP_erupt.html, accessed September 2009).

The first eruptions of the Columbia River Basalt Group from 17.5 to 14 mya mark the initial tectonic rifting of the extreme western Snake River Plain (Mabey 1982; Sadler and Link 1996). The Miocene Idavada Volcanics erupted during a time of regional uplift from 14 to 9 mya, which corresponded with the migration of the eastern Snake River Plain over the Yellowstone–Snake River Plain hot spot. Most of the relief of the Snake River structural graben likely formed between 11 and 8 mya, during the beginning of the late Miocene (Wood and Squires 1998).

In areas outside Hagerman Fossil Beds National Monument, interbedded coarse, arkosic fluvial sand (river sand with abundant feldspar minerals) and fine sediment deposits overlie the Idavada Volcanics. These deposits formed the Poison Creek Formation, the lowermost formation in the Idaho Group.

From approximately 9 to 2 mya, the western Snake River Plain subsided. Volcanic activity may have built lava dams across the ancestral Snake River near Hells Canyon, blocking the outlet of the western Snake River Plain (Kimmel 1982). Alternatively Beranek and others (2006) cite evidence the lake may have formed in a closed basin. Low-gradient streams flowed into the series of lakes known as Lake Idaho. Fish fossils in the Chalk Hills Formation (9.5 to 6.4 mya) record the filling of Lake Idaho (Wood 2000). The Chalk Hills Formation is younger than the Poison Creek Formation and forms the third formation from the base of seven formations of the Idaho Group. Like the Poison Creek Formation, the Chalk Hills Formation is not exposed in the monument or the surrounding area.

By the end of the Pliocene (5.33 to 2.59 mya), an Arctic ice sheet had formed and tundra and taiga vegetation became established (fig. 23). The emergence of the Isthmus of Panama produced a dramatic change in ocean currents, which then contributed to a profound cooling event 2.5 mya. The global climate became so cold that Earth began cycling in and out of ice ages.

Near the southeastern margin of Lake Idaho, stream and lake sediments accumulated to form the Glenns Ferry Formation (fig. 17). In the lush savanna grassland, a rich variety of animals flourished (as described in the "Geologic Features and Processes" section) including Hagerman horses, pronghorn, camels, and saber-toothed cats (McDonald 1993; Kiver and Harris 1999). The climate, twice as wet as today's semiarid conditions, supported a wide range of habitats and an ecosystem teeming with life.

Lake Idaho reached its highest elevation of about 1,100 m (3,600 ft) in the Pliocene (Wood 2000). Eventually, headward erosion of a north-flowing tributary of the Salmon River drainage system breached the natural dam containing Lake Idaho at Horseshoe Bend (Greg McDonald, NPS paleontologist, written communication, October 27, 2008). Timing of the breach and subsequent draining of Lake Idaho is poorly constrained, but may have occurred about 2.5 mya (Beranek et al. 2006). Downcutting rates measure approximately 120 m/million years (390 ft/million years) at the river's outlet (Wood 2000).

Basalt flows, silicic volcanic ash, and basaltic pyroclastic deposits in the Glenns Ferry Formation record volcanic activity within the monument from about 3.79 to 3.2 mya (Hart and Brueseke 1999). Seven volcanic ash beds in the Glenns Ferry Formation allow geologists to correlate the units in Idaho with those in Oregon (Swirydczuk et al. 1982).

Quaternary Period (2.59 mya to present)

Approximately 2 mya, spillover occurred at the outlet of the western Snake River Plain on the south end of Hell's Canyon, currently one of the deepest gorges in North America, and a drainage system developed that continues today with canyon cutting and terrace formation along the course of the Snake River (Malde 1991; Sadler and Link 1996; Wood 2000). As the base level lowered and Hells Canyon deepened, the Snake River beveled the Glenns Ferry Formation, downcut its channel through the soft sediments, and deposited the coarse-grained clastics of the Tuana Gravel. Tuana Gravel and Tenmile Gravel sediments are the first obvious signs in the geologic record of the energetic Snake River as it is seen today (Malde 1991).

Benches as much as 245 m (804 ft) above today's Snake River contain deposits of Tuana Gravel. Erosion of rock units near the Idaho–Nevada border provided the sediment that became the Tuana Gravel. Erosion and transportation processes rounded the rock fragments into gravel, sorted the gravel according to size, and distributed the sediment in alluvial fans.

By about 2 mya, what is now northwestern Wyoming was above the Yellowstone-Snake River Plain hot spot. Approximately 2.2 mya, 1.2 mya and 600,000 years ago catastrophic rhyolitic eruptions shook the area of Yellowstone National Park. About 2,000 years ago, the second stage of the eruptions covered the landscape with fluid basaltic lava, including the landscape at Craters of the Moon National Monument and Preserve. (http://volcano.oregonstate.edu/vwdocs/volc_images/north_america/yellowstone.html, accessed September 2009).

Downcutting by the Snake River followed deposition of the Tuana Gravel and reached a considerable depth prior to any deposition of the Bruneau Formation. For example, in the northern wall of the present Snake River canyon just north of Grand View, Idaho, the Snake River had cut into the Glenns Ferry Formation prior to deposition of the Bruneau Formation. Volcanic tuff in the lower part of the Bruneau lies at an elevation nearly 190 m (620 ft) lower than the nearest Tuana Gravel (Malde 1991).

The basalt and sediments of the Bruneau Formation define the evolution of four successive canyons that were cut by the Snake River and subsequently blocked by canyon-filling basalt flows from 1.9 to 1 mya. Once a canyon was cut, basaltic lava flows blocked the outlet. Lakes formed behind the basaltic lava dams. Lava flows solidified in upland areas (generally north of Hagerman Fossil Beds National Monument), and alluvial fans and pediment deposits formed marginal to the uplands (Malde 1991).

Bruneau basalts filled canyons that were commonly several hundreds of meters deep. When the canyons filled, the Snake River diverted to a new channel, which was usually south of the earlier canyon. After the fourth canyon was cut and filled with basalt that erupted from Big Foot Butte and Guffey Butte about 1 mya, the Snake River established its present canyon (the fifth). Downcutting of this canyon is considered to be younger than the Bruneau Formation (Malde 1991).

In late Pleistocene, about 50,000 years ago, basalt flows from McKinney Butte dammed the ancestral Snake River. A temporary but long-lasting lake, called McKinney Lake, formed behind the dam. Yahoo Clay as much as 180 m (600 ft) thick accumulated in this lake (Malde 1982). Yahoo Clay derives its name from the blocky silt and clay found near the mouth of Yahoo Creek southwest of Hagerman (Malde 1982).

McKinney Lake did not empty until Yahoo Clay sediments had accumulated nearly to the height of the McKinney lava dam (Malde 1982). As the Yahoo Clay accumulated, water was discharged from McKinney Lake, not by overflow but by leakage through the canyon-filling McKinney Basalt. Eventually, however, the lake overflowed and the lava dam was breached (Malde 1982). When downcutting reached a level of about 90 m (300 ft) above the present Snake River in Hagerman Valley, Crowsnest Gravel terrace deposits collected on the dissected Yahoo Clay surface.

Deposition of Crowsnest Gravel may have coincided with mountain glaciation (Malde 1982). If so, the glacial episode is younger than the McKinney Basalt. However, older gravel downstream from Bliss, Idaho, which had been mistakenly correlated with Crowsnest Gravel prior to 1982, may represent a glacial episode older than the McKinney Basalt (Malde 1982).

About 32,000 to 14,000 years ago, Lake Bonneville, the precursor of the Great Salt Lake, occupied about 52,000 km^2 (20,000 mi^2, or 12.8 million acres) of western Utah and smaller portions of eastern Nevada and southern Idaho (fig. 24). At its greatest extent, Lake Bonneville reached 523 km (325 mi) long, 217 km (135 mi) wide, and had a maximum depth of over 305 m (1,000 ft). The shorelines of Lake Bonneville can be found in the Wasatch Mountains, more than 300 m (984 ft) above the present level of the Great Salt Lake.

Lake Bonneville overtopped its rim at Red Rock Pass in southeastern Idaho about 14,500 years ago, and the Bonneville Flood swept through the Hagerman area, generally following the path of the present Snake River. Flood waters about 100 m (300 ft) deep discharged at a rate of 935,000 m^3/sec (33 million ft^3/s) (http://vulcan.wr.usgs.gov/Glossary/Glaciers/IceSheets/description_lake_bonneville.html, accessed October 2009). In comparison, the maximum historic discharge in the upper Snake River at Idaho Falls is 2,000 m^3/sec (72,000 ft^3/s), almost 470 times less than the Bonneville Flood (http://imnh.isu.edu/digitalatlas/parks/hagerman/hagerman.htm, accessed October 2009).

Pleistocene glacial outburst floods are known in other parts of the country as well. Within the Spokane Valley of Washington, a glacial outburst flood dwarfed the Lake Bonneville flood. Near the point of release, the catastrophic glacial Lake Missoula flood discharged at a peak estimated to be perhaps as high as 17 million m^3/sec (600 million ft^3/s), approximately 18 times more than the Bonneville Flood (O'Connor and Baker 1992).

The Snake River canyon had nearly eroded to its present width and depth when the catastrophic overflow of Lake Bonneville deposited flood debris in large boulder and gravel bars along the canyon floor. In places, these flood deposits reached heights of more than 61 m (200 ft) above the modern river (Malde 1982).

An estimated 4,700 km^3 (1,100 mi^3) of water filled Lake Bonneville. At a constant discharge of 935,000 m^3/sec (33 million ft^3/s), the Bonneville Flood would have lasted eight weeks, although attenuated flow through the canyons would have made the duration even longer (Malde 1991).

The flood deposited the Melon Gravel throughout the length of the Snake River Plain. Melon Gravel contains many basalt boulders that range from the size of a watermelon up to 3m (10 ft) in diameter (Malde and Powers 1962; Kiver and Harris 1999). Boulders near Hagerman Fossil Beds National Monument measure up to 1 m (3 ft) in diameter (fig. 7). The boulders accumulated only on the east side of the valley. On the west side, the flood eroded and steepened the bluffs, thereby exposing about one million years of Earth history in the upper layers of the Glenns Ferry Formation in Hagerman Fossil Beds National Monument (Greg McDonald, NPS paleontologist, written communication, October 27, 2008).

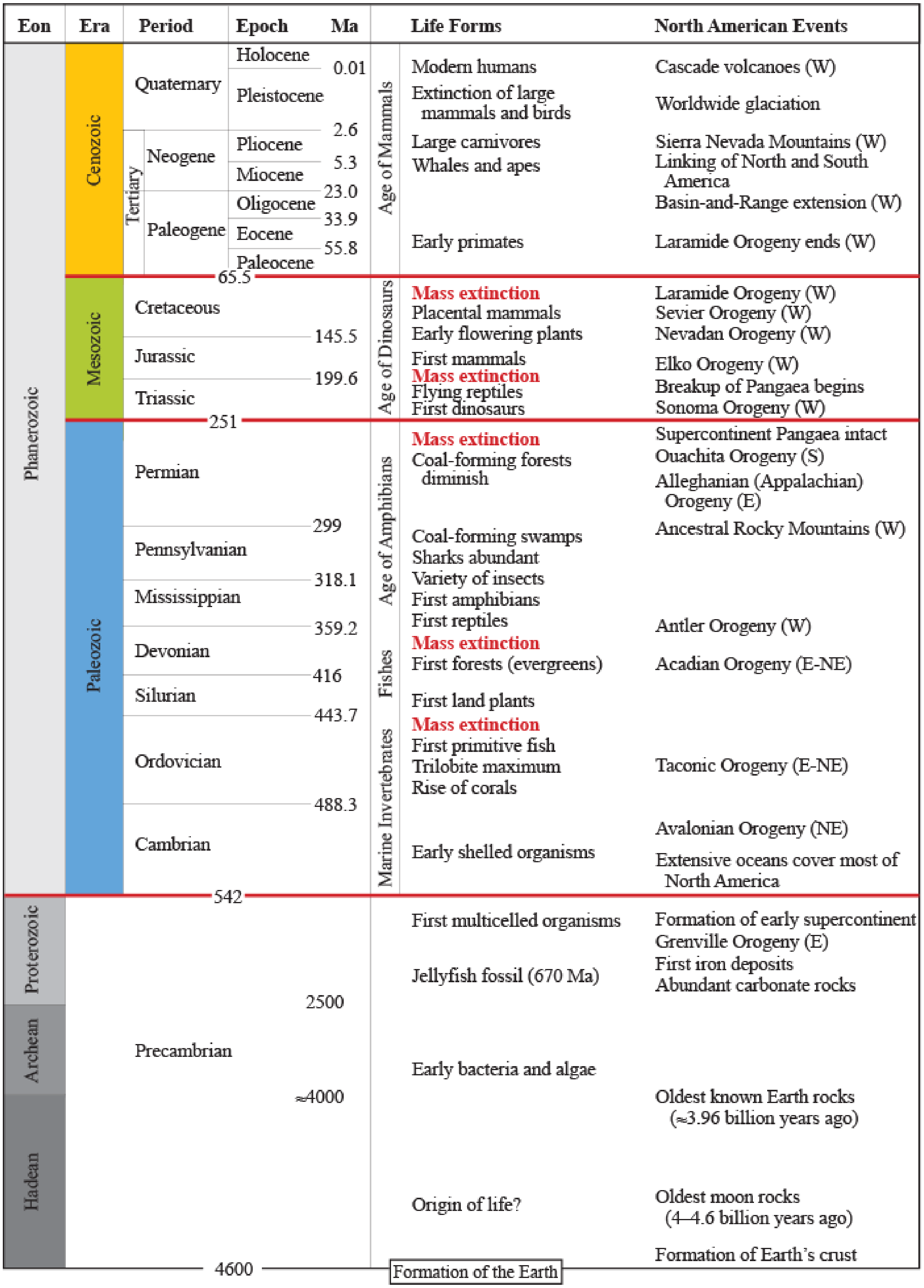
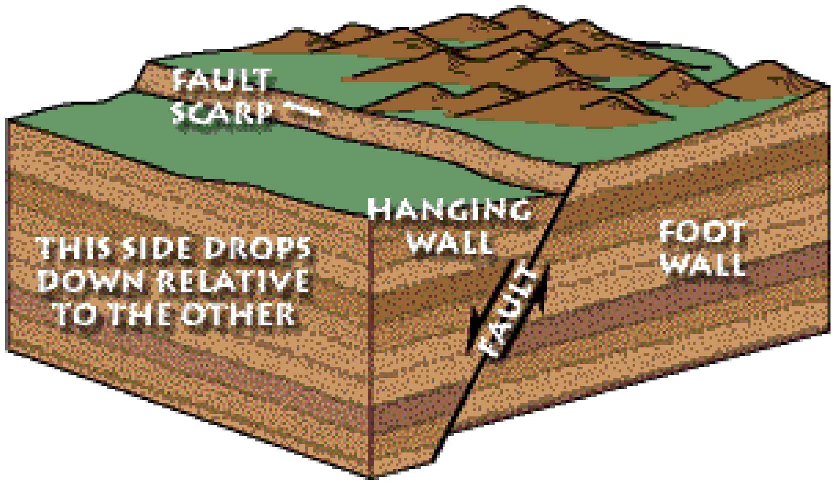
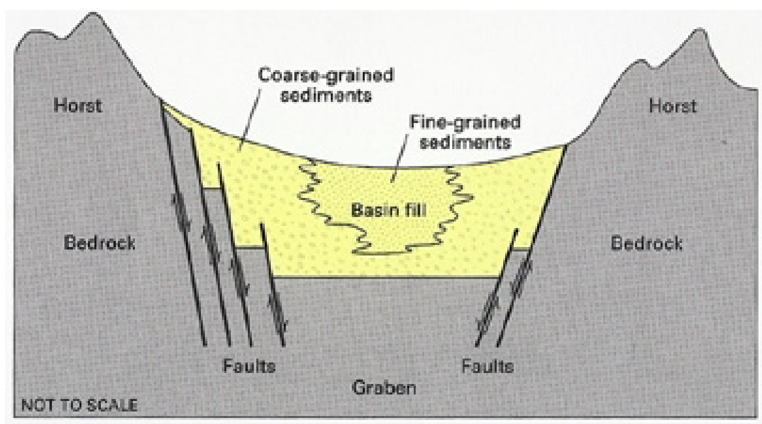


Figure 19. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, (http://pubs.usgs.gov/fs/2007/3015/) with additional information from the International Commission on Stratigraphy (http://www.stratigraphy.org/view.php?id=25). Note that this chart includes the August 2009 revision of the Pliocene-Pleistocene boundary to 2.59 Ma from 1.8 Ma.



Normal Fault



Horst and Graben topography

Figure 20. Diagram of a "normal" fault and basin-and-range topography. A) In a normal fault, rocks in the "hanging wall" above the fault plane move downward relative to rocks in the "footwall" below the fault plane. These terms developed as a result of early mining geology. Imagine walking down the fault plane into a mine. The rocks upon which you walk are in the "foot" wall while those that hang above your head are in the "hanging" wall. B) The western Snake River Plain is bounded by normal faults similar to the horst and graben topography of the Basin-and-Range Province. Sediments that fill the structural basin (graben) become progressively finer-grained toward the center of the basin. Normal fault diagram is from the U.S. Geological Survey, http://geomaps.wr.usgs.gov/parks/deform/gfaults.html and the graben-and-horst (basin-and-range) topography diagram is from the U.S. Geological Survey, http://pubs.usgs.gov/ha/ha730/ch_c/jpeg/C034.jpeg. Accessed September 2009.

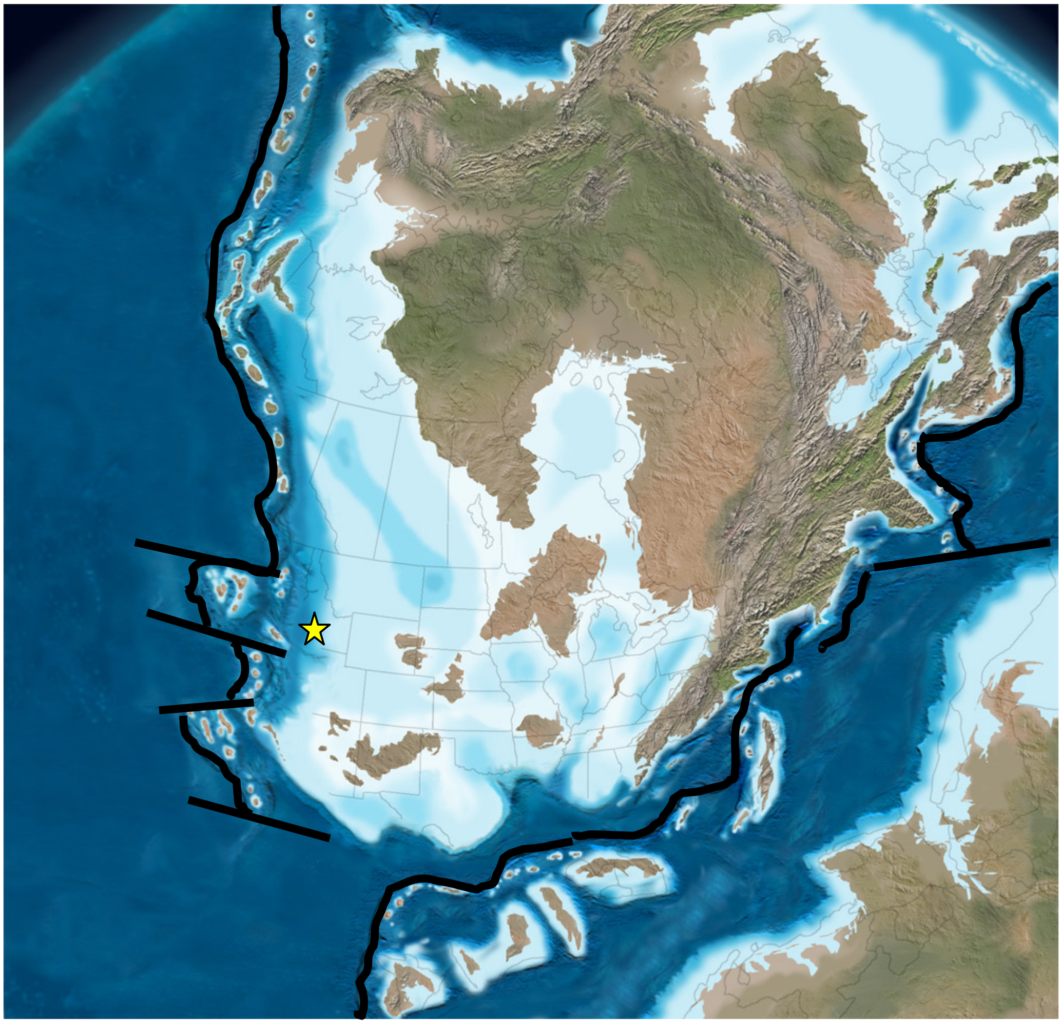


Figure 21. Late Devonian paleogeographic map of North America. Approximately 360 million years ago, marine environments inundated the western margin of North America. Throughout much of the Paleozoic, limestone accumulated in shallow seas that covered much of the North American continent. The yellow star marks the approximate location of today's Hagerman Fossil Beds National Monument. Black lines mark the approximate location of subduction zones associated with active plate boundaries. Both the western and eastern margins of North America were active tectonic margins at this time. Brown colors represent land areas, and blue colors represent water. Light blue areas signify shallower, near-shore environments, while deeper marine regions are colored dark blue. Map modified from Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namD360.jpg, **accessed September 2009.**

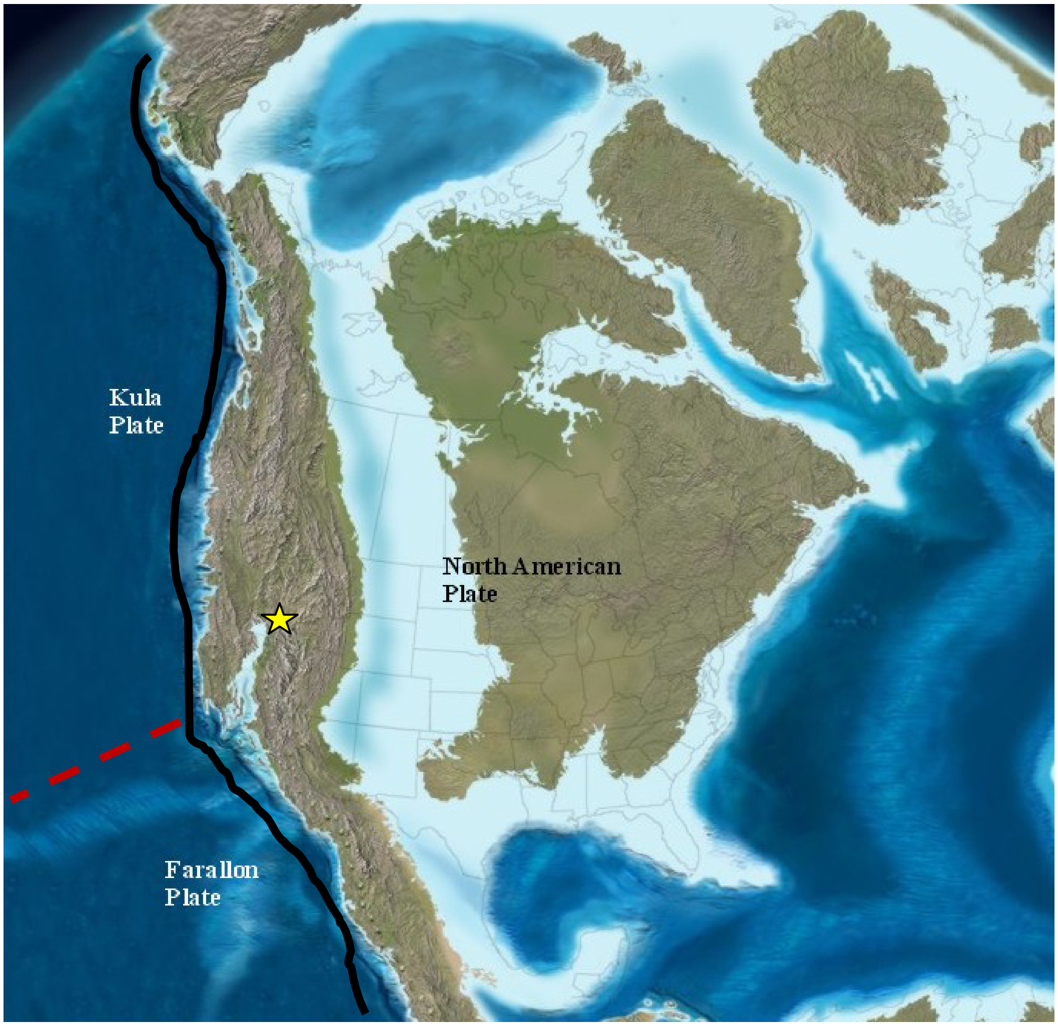


Figure 22. Late Cretaceous paleogeographic map of North America. Approximately 85 million years ago, an inland seaway (light blue) extended from the Gulf of Mexico to the Arctic Ocean. The yellow star is the approximate location of today's Hagerman Fossil Beds National Monument. Mountains formed from compression along the western margin of North America caused by the subduction of the Farallon Plate and Kula Plate beneath the North American Plate (thick black line). The dashed red line is the approximate location of the spreading center separating the Farallon and Kula plates. Map modified from the Late Cretaceous map of Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namK85.jpg. Accessed September 2009.

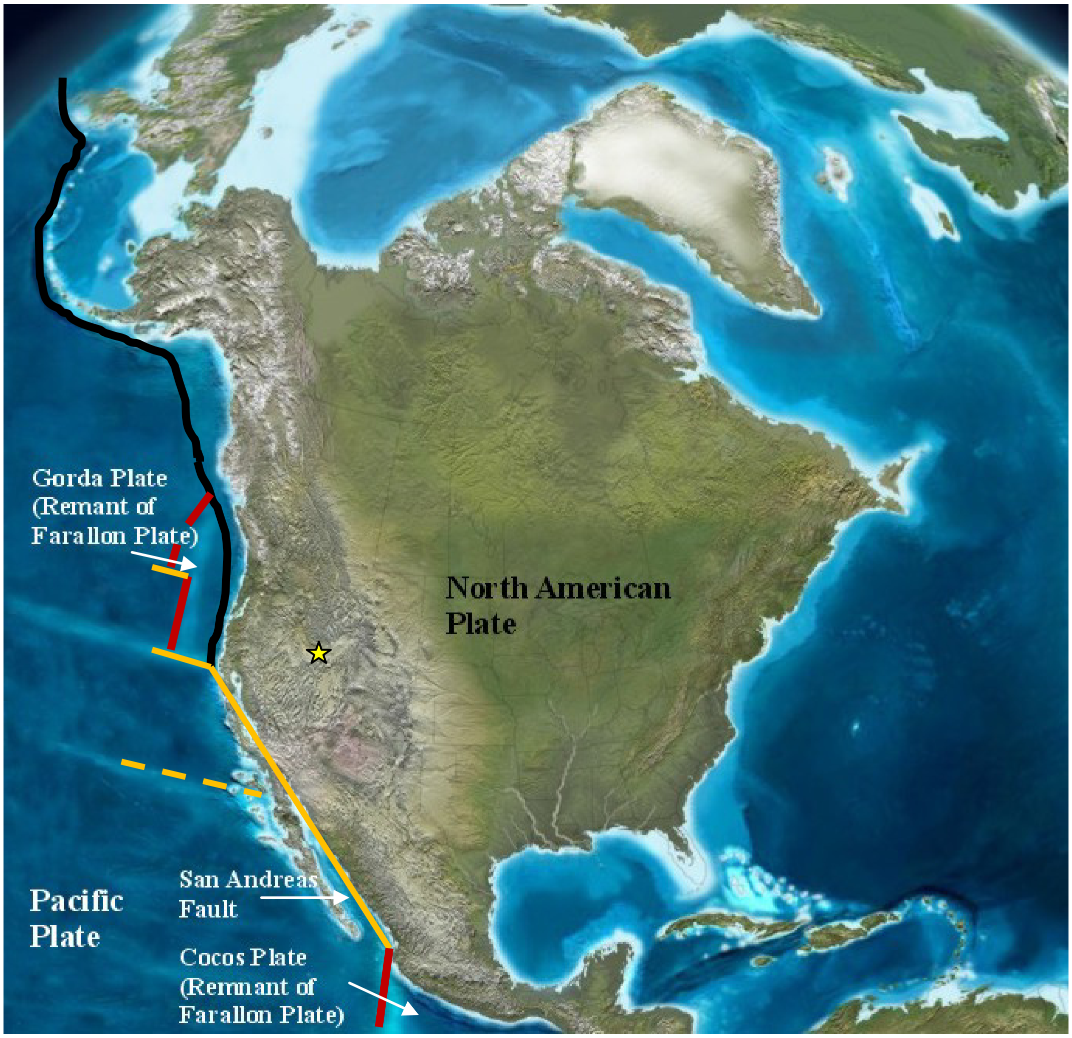


Figure 23. Pliocene paleogeographic map of North America. Approximately 3 million years ago, global climate cooled and ice sheets began to form in the northern latitudes. Alpine glaciers formed on mountain peaks. White-colored areas in northern latitudes and mountain ranges signify ice and snow. The tectonic regime along the western margin of North America also changed. By this time, North America had intersected the spreading center separating the Pacific Plate (to the west) from the Farallon Plate, giving rise to the San Andreas Fault system (orange). Other transform faults are also shown in orange. Red lines that separate the Pacific Plate from the Gorda Plate and the Cocos Plate indicate remnants of the spreading center between the Pacific and Farallon plates. The yellow star represents the approximate location of today's Hagerman Fossil Beds National Monument. Map modified from the Pliocene map of North America by Dr. Ron Blakey (Northern Arizona University). Available online at: http://jan.ucc.nau.edu/rcb7/namNp3.jpg. Accessed September 2009.

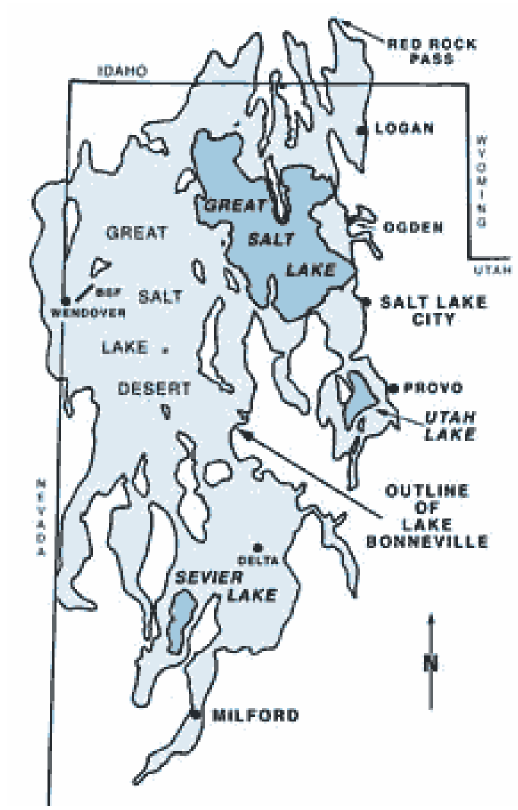


Figure 24. Extent map of Pleistocene Lake Bonneville and associated modern features ("BSF" near Wendover stands for "Bonneville Salt Flats"). About 14,500 years ago, Lake Bonneville overtopped its rim at Red Rock Pass, and flood waters inundated the Hagerman area. The Great Salt Lake and Sevier Lake are remnants of ancient Lake Bonneville. Figure available online at: http://geology.utah.gov/online_html/pi/pi-39/pi39pg01.htm. Accessed September 2009.

Glossary

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

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

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

alluvium. Stream-deposited sediment.

andesite. A dark-colored, fine-grained extrusive rock composed chiefly of sodic plagioclase and one or more of the mafic minerals (e.g. biotite, hornblende, pyroxene).

aquiclude. See "confining bed."

aquifer. A rock or sedimentary unit that is sufficiently porous that it has a capacity to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.

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

arroyo. A small, deep, flat-floored channel or gully of an ephemeral or intermittent stream in the arid and semiarid regions of the southwestern United States.

ash (volcanic). Fine pyroclastic material ejected from a volcano.

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

basalt. A dark-colored mafic igneous rock, commonly extrusive, composed chiefly of the minerals calcic plagioclase and clinopyroxene.

base level. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

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

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

batholith. A massive pluton, greater than 100 km^2, (39.6 mi^2) often formed from multiple intrusions.

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

bedding. Depositional layering or stratification of sediments.

block (fault). A crustal unit bounded by faults, either completely or in part.

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

calcareous. Describes rock or sediment that contains calcium carbonate.

caldera. A large bowl- or cone-shaped summit depression in a volcano formed by explosion or collapse.

carbonate. A mineral that has CO3-2 as its essential component (e.g., calcite and aragonite).

carbonaceous. Describes a rock or sediment with considerable carbon, especially organics, hydrocarbons, or coal.

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

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

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

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

confining bed. A body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers. Replaced the term "aquiclude."

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

cordillera. A Spanish term for an extensive mountain range; used in North America to refer to all of the western mountain ranges of the continent.

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

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

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

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

dacite. A fine-grained extrusive rock with the same general composition as andesite but having a less calcic plagioclase and more quartz.

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

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

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

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

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

extension. In structural geology, a strain term signifying increase in length. Opposite of compression. See "pull-apart basin."

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

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

feldspar. A group of abundant (more than 60% of Earth's crust), light-colored to translucent silicate minerals found in all types of rocks. Usually white and gray to pink. May contain potassium, sodium, calcium, barium, rubidium, and strontium along with aluminum, silica, and oxygen.

felsic. An igneous rock having abundant light-colored minerals such as quartz, feldspars, or muscovite. Compare to "mafic."

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

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

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

gabbro. A group of dark-colored, intrusive igneous rocks composed principally of calcic plagioclase and clinopyroxene. The coarse-grained equivalent of basalt.

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

graben. A down-dropped structural block bounded by steeply-dipping, normal faults (also see "horst").

granite. A plutonic, igneous rock in which quartz constitutes 10-50% of the felsic components and in which the feldspar ratio is generally in the range of 65-90%. Mica and amphibole minerals are also common.

groundmass. A term sometimes used for the matrix of a sedimentary rock or the finer grained and/or glassy material between the phenocrysts in a porphyritic igneous rock.

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

horst. Areas of relative up between grabens, representing the geologic surface left behind as grabens drop. The best example is the basin and range province of Nevada. The basins are grabens and the ranges are weathered horsts. Grabens become a locus for sedimentary deposition.

hot spot. A volcanic center, 100 to 200 km (62 to 124 mi) across and persistent for at least a few tens of millions of years, that is thought to be the surface expression of a persistent rising plume of hot mantle material.

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

intrusion. A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.

isthmus. A narrow strip or neck of land, bordered on both sides by water, connecting two larger land areas.

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

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lamination. Very thin, parallel layers.

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

lava. Still-molten or solidified magma that has been extruded onto Earth's surface though a volcano or fissure.

lithification. The conversion of sediment into solid rock.

lithofacies. A lateral, mappable subdivision of a designated stratigraphic unit, distinguished from adjacent subdivisions on the basis of lithology.

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

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

mafic. Describes dark-colored rock, magma, or minerals rich in magnesium and iron. Compare to "felsic."

magma. Molten rock beneath Earth's surface capable of intrusion and extrusion.

meandering stream. A stream having a pattern of successive meanders, or bends.

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.

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

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

olivine. An olive-green, grayish-green, or brown orthorhombic mineral common to low-silica igneous rocks, such as gabbro and basalt.

orogeny. A mountain-building event.

ostracode. Any aquatic crustacean belonging to the subclass Ostracoda, characterized by a two-valved (shelled), generally calcified carapace with a hinge along the dorsal margin. Most ostracodes are of microscopic size.

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

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

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

pediment. A gently sloping, erosional bedrock surface at the foot of mountains or plateau escarpments.

perched aquifer. An aquifer containing unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

phenocrysts. A coarse crystal in a porphyritic igneous rock.

placer. A surficial mineral deposit formed by mechanical concentration of mineral particles from weathered debris. The common types are beach placers and alluvial placers.

placer mining. The extraction and concentration of heavy metals or minerals from placer deposits by various methods, generally using running water.

plateau. A broad flat-topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).

pluton. A body of intrusive igneous rock.

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

porphyritic. An igneous rock characteristic wherein the rock contains conspicuously large crystals (phenocrysts) in a fine-grained groundmass.

pull-apart basin. A topographic depression created by an extensional bend or extensional overstep along a strike-slip fault.

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

recharge. Infiltration processes that replenish groundwater.

rhyolite. A group of igneous rocks, typically porphyritic and commonly exhibiting flow texture, with phenocrysts of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass. The fine-grained equivalent of granite.

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

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

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

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

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

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

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

shear strength. The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion.

silicic. Silica-rich igneous rocks or magma containing at least 65% silica. Granite and rhyolite are typical silicic rocks.

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

siltstone. A variably-lithified sedimentary rock with silt-sized grains.

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

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

spreading center. A divergent boundary where two lithospheric plates are spreading apart. It is a source of new crustal material.

spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

strata. Tabular or sheetlike masses or distinct layers (e.g., 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 and confined within a channel.

strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.

strike slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault. Said to be "sinistral" (left-lateral) if relative motion of the block opposite the observer appears to be to the left. "Dextral" (right-lateral) describes relative motion to the right.

subsidence. The gradual sinking or depression of part of Earth's surface.

taiga. A swampy area of coniferous forest sometimes occurring between tundra and steppe regions.

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

terraces (stream). Step-like benches surrounding the present floodplain of a stream due to dissection of previous floodplain(s), stream bed(s), and/or valley floor(s).

terrestrial. Relating to land, Earth, or its inhabitants.

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

transform fault. transform fault. A strike-slip fault that links two other faults or two other plate boundaries (e.g. two segments of a mid-ocean ridge). A type of plate boundary at which lithosphere is neither created nor destroyed, and plates slide past each other on a strike-slip fault.

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

unconfined groundwater. Groundwater that has a water table; i.e., water not confined under pressure beneath a confining bed.

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

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

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

water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.

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

References

This section lists references cited in this report. A more complete geologic bibliography is available from the National Park Service Geologic Resources Division.

Armstrong, R. L., W. P. Leeman, and H. E. Malde. 1975. K-Ar dating, Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho. *American Journal of Science* 275 (3): 225-251.

Beranek, L. P., P. K. Link, and C. M. Fanning. 2006. Miocene to Holocene landscape evolution of the western Snake River Plain region, Idaho: using the SHRIMP detrital zircon provenance record to track eastward migration of the Yellowstone hotspot. *GSA Bulletin* 118(9-10):1027-1050.

Bjork, P. R. 1968. The carnivora of the Hagerman local fauna (Late Pliocene) of southwestern Idaho. PhD diss., University of Michigan.

Chleborad, A. and P. Powers. 1996. *Slope map and locations of irrigation-induced landslides and seepage areas, Hagerman Fossil Beds National Monument, Idaho*. Scale 1:24,000. Openfile Report OF 96-0258. Reston, VA: U.S. Geological Survey.

Covington, H. R. and J. N. Weaver. 1991. *Geologic map and profile of the north wall of the Snake River Canyon, Edan, Murtaugh, Milner Butte, and Milner quadrangles, Idaho*. Scale 1:24,000. Miscellaneous Investigations Series Map I-1947-E. Reston, VA: U.S. Geological Survey.

Covington, S. 2004. Hagerman Fossil Beds National Monument geologic resources evaluation scoping meeting summary. Geological Resources Division. Lakewood, CO: National Park Service. <http://www.nature.nps.gov/geology/inventory/publications/s_summaries/HAFO_scoping_summary_20040315.pdf>

Dennison-Budak, C., A. J. Smith, D. F. Palmer, and P. Gensler. 2008. Ostracodes as indicators of the paleoenvironment in the Pliocene Glenns Ferry Formation, Lake Idaho, preliminary results. *Geological Society of America Abstracts with Programs* 40 (5): 85.

Farmer, N. 1998. A hydrostratigraphic model for the perched aquifer systems located near the Hagerman Fossil Beds National Monument, Idaho. MS thesis, University of Idaho.

Farmer, N. 2004. Landslides in the Lake Idaho Glenns Ferry Formation. *Geological Society of America Abstracts with Programs* 36: 26.

Farmer, N. and J. Riedel. 2003. *Water resources management plan, Hagerman Fossil Beds National Monument*. Geological Resources Division. Lakewood, CO: National Park Service. <http://www.nps.gov/hafo/watermgt/index.htm>

Hart, W. K. and M. E. Brueseke. 1999. Analysis and dating of volcanic horizons from Hagerman Fossil Beds National Monument and a revised interpretation of eastern Glenns Ferry Formation chronostratigraphy. Report submitted to Hagerman Fossil Beds National Monument. Oxford, OH: Miami University Department of Geology.

Hutchison, J. H. 1987. Late Pliocene (Blancan) *Scapanus* (*Scapanus*) (Talpidae: Mammalia) from the Glenns Ferry Formation of Idaho. *PaleoBios* 12 (45). <http://www.ucmp.berkeley.edu/science/paleobios/backissues/v12no45.pdf>

Janis, C. M. 2001. Radiation of Tertiary Mammals. In *Palaeobiology II*, ed. D. E. G. Griggs and P. R. Crowther, 109-112. Malden, MA: Blackwell Publishing.

Kenworthy, J. in prep. Changing fossils in a changing world: Interpreting long term climate change at Tertiary fossil parks of the NPS. MS thesis. Oregon State University.

Kimmel, P. G. 1982. Stratigraphy, age, and tectonic setting of the Miocene-Pliocene lacustrine sediments of the Western Snake River Plain, Oregon and Idaho. In *Cenozoic geology of Idaho*, ed. B. Bonnichsen and R. M. Breckenridge, 559-578. Bulletin 26. Moscow, ID: Idaho Geological Survey.

King, P. B. 1977. The evolution of North America. Princeton, NJ: Princeton University Press.

Kiver, E. P. and D. V. Harris. 1999. *Geology of U.S. parklands*. 5th ed. New York: John Wiley & Sons, Inc.

Kuntz, M. A., R. H. Lefebre, D. E. Champion, and B. Skipp. 1989. *Geologic map of the Inferno Cone quadrangle, Butte County, Idaho*. Scale 1:24,000. Geologic Quadrangle Map GQ-1632. Reston, VA: U.S. Geological Survey. <http://ngmdb.usgs.gov/Prodesc/proddesc_1155.htm>

Laney, P. and J. Brizzee. 2003. *Idaho Geothermal Resources Map*. Publication INEEL/MIS-2002-1618 Rev. 2. Idaho Falls, ID. Idaho National Laboratory. <http://geothermal.id.doe.gov/maps/id.pdf>

Leopold, E. B. and V. C. Wright. 1985. Pollen profiles of the Plio-Pleistocene transition in the Snake River Plain, Idaho. In *Late Cenozoic History of Pacific Northwest*, ed. C. J. Smiley, 323-348. American Association for the Advancement of Science.

Mabey, D. R. 1982. Geophysics and tectonics of the Snake River Plain, Idaho. In *Cenozoic geology of Idaho*, ed. B. Bonnichsen and R. M. Breckenridge, 139-153. Bulletin 26. Moscow, ID: Idaho Geological Survey.

Malde, H. E. 1982. The Yahoo Clay, a lacustrine unit impounded by the McKinney Basalt in the Snake River Canyon near Bliss, Idaho. In *Cenozoic geology of Idaho*, ed. B. Bonnichsen and R. M. Breckenridge, 717-728. Bulletin 26. Moscow, ID: Idaho Geological Survey.

Malde, H. E. 1991. Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon. In *Quaternary nonglacial geology: conterminous U.S.*, ed. R.B. Morrison, 251-283. Boulder, CO: Geological Society of America, The Geology of North America K—2.

Malde, H. E. and H. A. Powers. 1962. *Upper Cenozoic stratigraphy of western Snake River Plain, Idaho*. Bulletin 73 (10). Boulder, CO: Geological Society of America.

Malde, H. E. and H. A. Powers. 1972. *Geologic map of the Glenns Ferry-Hagerman area, west-central Snake River Plain, Idaho*. Scale 1:48,000. Miscellaneous Geologic Investigations Map I-696. Reston, VA: U.S. Geological Survey.

Maley, T. 1987. Exploring Idaho Geology. Boise, ID: Mineral Land Publications.

McDonald, H. G. 1993. Hagerman Fossil Beds, Hagerman, Idaho. *Rocks and Minerals* 68: 322-326.

McDonald, H. G. 1996. Population structure of the late Pliocene (Blancan) zebra *Equus simplicidens* (Perissodactyla: Equidae) from the Hagerman Horse Quarry, Idaho. In *Palaeoecology and palaeoenvironments of Late Cenozoic Mammals*, ed. K. M. Stewart and K. L. Seymour, 134-155. Toronto: University of Toronto Press.

McDonald, H. G., P. K. Link, and D. E. Lee. 1996. An overview of the geology and paleontology of the Pliocene Glenns Ferry Formation, Hagerman Fossil Beds National Monument. In *Geology of the crook in the Snake River Plain, Twin Falls and vicinity, Idaho*, ed. R. C. Thomas, 16-45. Missoula, MT: Northwest Geology 26.

McNerney, M. 2005. Hagerman Fossil Beds National Monument. In *Paleontological resource inventory and monitoring: Upper Columbia Basin Network*, ed. J. P. Kenworthy, V. L. Santucci, M. McNerney, and K. Snell, 20-28. TIC #D-259. Lakewood, CO: National Park Service.

Michaels, P., L. Growney, and P. Donaldson. 1996. Use of geophysics to aid in mapping basalts relevant to ground water flow and a landslide hazard at Hagerman Fossil Beds National Monument. In *Case histories of geophysics applied to civil engineering and public policy*, ed. P. Michaels and R. Woods, 14-26. Geotechnical Special Publication 62. New York, NY: American Society of Civil Engineers.

National Park Service. 1996. *General management plan: Hagerman Fossil Beds National Monument, Idaho*. Lakewood, CO: U.S. National Park Service.

National Park Service. 2002. The Horse Quarry. Hagerman Fossil Beds National Monument website: <http://www.nps.gov/archive/hafo/quarry.htm>

National Park Service. 2006. *Management of mining claims, private sand and gravel, and coal development in the National Park System*. Briefing Statement. Lakewood, CO: National Park Service.

O'Connor, J. E., and V. R. Baker. 1992. Magnitudes and implications of peak discharges from glacial Lake Missoula. *GSA Bulletin* 104 (3): 267-279.

Othberg, K.L. 1994. Geology and geomorphology of the Boise Valley and adjoining areas, western Snake River Plain. *Idaho Geological Survey Bulletin* 29: 1-54.

Othberg, K. L. and J. D. Kauffman. 2005. *Geologic map of the Bliss quadrangle, Gooding, and Twin Falls Counties, Idaho*. Scale 1:24,000. Digital Web Map 53. Moscow, ID: Idaho Geological Survey. <http://www.idahogeology.org/PDF/Digital_Data_(D)/Digital_Web_Maps_(DWM)/bliss_DWM-53-m.pdf>

Othberg, K. L., V. S. Gillerman, and J. D. Kauffman. 2005. *Geologic map of the Hagerman quadrangle, Gooding and Twin Falls Counties, Idaho*. Scale 1:24,000. Digital Web Map 50. Moscow, ID: Idaho Geological Survey. <http://www.idahogeology.org/PDF/Digital_Data_(D)/Digital_Web_Maps_(DWM)/hagerman_DWM-50-M.pdf>

Richmond, D. R., and H. G. McDonald. 1998. The Hagerman Horse Quarry: Death and deposition. In *National Park Service Paleontological Research* Volume 3), ed. V. L. Santucci and L. McClelland, 103-104. Technical Report NPS/NRGRD/GRDTR-98/01. Geologic Resources Division. Lakewood, CO: National Park Service. <http://nature.nps.gov/geology/paleontology/pub/grd3_3/grd3pdf.pdf>

Ruez, D. R., Jr. 2006. Middle Pliocene paleoclimate in the Glenns Ferry Formation of Hagerman Fossil Beds National Monument, Idaho: A baseline for evaluating faunal change. *Journal of the Idaho Academy of Science* 42(2):1-16.

Sadler, J. L. and P. K. Link. 1996. The Tuana Gravel: early Pleistocene response to longitudinal drainage of a late-stage rift basin, western Snake River Plain, Idaho. In *Geology of the crook in the Snake River Plain, Twin Falls and vicinity, Idaho*, ed. R. C. Thomas, 16-45. Missoula, MT: Northwest Geology 26.

Santucci, V.L., J.P. Kenworthy, and A.L. Mims. 2009. Monitoring in situ paleontological resources. In *Geological Monitoring*, ed. R. Young and L. Norby, 189–204. Boulder, CO: Geological Society of America.

Swirydczuk, K., G. P. Larson, and G. R. Smith. 1982. Volcanic ash beds as stratigraphic markers in the Glenns Ferry and Chalk Hills Formations from Adrian, Oregon, to Bruneau, Idaho. In *Cenozoic geology of Idaho*, ed. B. Bonnichsen and R. M. Breckenridge, 543-558. Bulletin 26. Moscow, ID: Idaho Geological Survey.

Taylor, D. W. 1966. Summary of North American Blancan nonmarine mollusks. *Malacologia* 4: 1-172.

Whitehead, R. L. 2008. *Ground Water Atlas of the United States: Idaho, Oregon, Washington*. USGS Hydrologic Atlas HA 730-H. January 20, 2009. <http://pubs.usgs.gov/ha/ha730/ch_h/index.html>

Williams, T. J., M. Gunter, N. Farmer, and G. Philip. 2005. Natural radioactivity and the nature of vertebrate fossils at Hagerman Fossil Beds National Monument, Hagerman, ID. *Geological Society of America Abstracts with Programs* 37: 368.

Wood, S. H. 2000. Filling and spilling of Pliocene Lake Idaho: hot-spot tectonics, stream capture, climate? *Geological Society of America Abstracts with Programs* 32 (7): 470-471.

Wood, S. H. and E. Squires. 1998. History of Neogene Lake Idaho from geologic mapping of the NE margin and subsurface data of the western Snake River Plain. *American Association of Petroleum Geologists Expanded Abstracts* 1998.

Zachos, J., M. Pagani, L. Sloan, E. Thomas, and K. Billups. 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science* 292 (5517): 686-693.

Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Hagerman Fossil Beds 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 Hagerman Fossil Beds National Monument. The scoping meeting was on September 18, 2003; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Introduction

The National Park Service held a Geologic Resources Evaluation scoping meeting at the headquarters of Hagerman Fossil Beds National Monument (HAFO) on Thursday, September 18, 2003. The purpose of the meeting was to discuss the status of geologic mapping in the park, the associated bibliography, and the geologic issues in the park. The products to be derived from the scoping meeting are: (1) Digitized geologic maps covering the park; (2) An updated and verified bibliography; (3) Scoping summary (this report); and (4) A Geologic Resources Evaluation Report which brings together all of these products.

Hagerman Fossil Beds National Monument was established on November 18, 1988 by Title III of Public Law 100-696 (102 Stat. 4575). The monument was established to "preserve . . .the outstanding paleontological sites known as the Hagerman Valley fossil sites, to provide a center for continuing paleontological research, and to provide for the display and interpretation of the scientific specimens uncovered at such sites. . ." The monument has a total of 4,351 acres, almost entirely lying on the west side of the Snake River.

Hagerman Fossil Beds National Monument lies entirely within the Hagerman 7.5-minute topographic quadrangle. However, there are four additional quads of interest: Bliss, Indian Butte, Yahoo Creek and Tuttle. Malde and others (1963), produced a geologic map of the west-central Snake River Plain at a scale of 1:125,000. Malde and Powers (1972) published a geologic map of the Glenns Ferry-Hagerman area at a scale of 1:48,000. The Idaho Geological Survey (IGS) is in the process of converting this map to the most recent USGS topographic base at a scale of 1:24,000. The final product will be in CAD format but can be converted to ESRI formats. The map will include all data layers and metadata. The IGS is planning to update the stratigraphic nomenclature to currently acceptable unit names as well. Chleborad and Powers (1996) produced a slope map at a scale of 1:24,000. A soils map of the park has been digitized. There is a need expressed by the park for large scale maps of the landslide areas and of fossil sites.

Physiography

Hagerman Fossil Bed National Monument lies on the boundary between the eastern Snake River Plain and the western Snake River Plain. The Snake River Plain is an arc-shaped topographic basin extending about 640 km (400 mi) and trending generally east-west. Width of the plain varies from about 80 km (50 mi) to about 200 km (125 mi) toward the east. (Maley 1987). To the east, the plain ends in the Yellowstone Plateau, and on the west, it merges with the Columbia Plateau. The Western Snake River Plain is bound on the south by the Owhyee Plateau, composed of Cretaceous granitic rocks and Tertiary volcanic rock, and on the north by the Idaho Batholith. The eastern section cuts across Basin-and-Range topography. The Snake River Plain has little topographic relief and is topographically uniform. Elevations range from about 2,000 m (6,500 ft) on the extreme east end to about 670 m (2,200 ft) at the Oregon-Idaho border.

The monument lies almost entirely on the west side of the Snake River on arid, dissected slopes that are truncated by the Snake River, forming bluffs along the west bank. The bluffs rise about 200 m (650 ft) above the river from 850 m (2,800 ft) elevation at the water surface to about 1,100 m (3,450 ft) at the top of the slopes. To the west of the monument is the relatively flat Bruneau Plateau. On the east side of the river is the Hagerman Valley and the town of Hagerman.

Geology

Unlike the eastern Snake River Plain which is dominated by lava flows, the western portion, especially in the Hagerman area, is characterized by terrigenous sediments, mostly lake deposits, with a few thin basaltic stringers. The most of the sedimentary sequence is divided into the Idaho Group and the Snake River Group. The Idaho Group is underlain by the Idavada Volcanics, composed of silicic latite, forming thick layers of welded tuff and lava flows, and rhyolitic tuffs. This rhyolitic volcanism, associated with the Yellowstone-Snake River plain hot spot, deposited the volcanics in southwestern and south-central Idaho during the middle Miocene, about 14-9 MA (Malde and Powers 1962). The combined thickness of these layers may be over 610 m (2,000 ft). (Malde and Powers 1972). The Idavada Volcanics do not outcrop within the monument.

The Idaho Group has been divided into seven formations ranging in age from 11 million years to about 700,000 years old (Middle Miocene to Pleistocene). From oldest to youngest these formations are: Poison Creek Formation, interbedded with the Banbury Basalt; Chalk Hills Formation; Glenns Ferry Formation; Tuana Gravel; Bruneau Formation; and, Black Mesa Gravel. The Idaho Group are mostly lacustrine and associated deposits from Lake Idaho: lake, floodplain and alluvium; interbedded with lava flows. Only the Glenns Ferry Formation and younger deposits are exposed in the monument.

The Glenns Ferry Formation lies unconformably on the Chalk Hills Formation and the Banbury Basalt at some localities. The age of the Glenns Ferry Formation is generally from about 5-1.5 MA (Pliocene to early Pleistocene; Malde 1991). Malde and Powers (1972) describe the Glenns Ferry as "lake and stream deposits characterized by abrupt changes in facies." Some of these facies include massive silt, thick-bedded sands, thin bedded "dark clay, olive silt, and carbonaceous shale," sand and silt showing ripple marks, "granitic sand and fine pebble gravel. . .and quartzitic cobble gravel." Malde and Powers (1972) also show two lava flows exposed in the monument: Clover Creek lava flow (fine-grained plagioclase-olivine basalt), and Shoestring Road lava flow (coarse-grained porphyritic plagioclaseolivine basalt).

Tuana Gravel (Pleistocene) rests unconformably on the Glenns Ferry and is exposed mainly on the plateau to the west of the monument and east to the slope break inside the west boundary of HAFO. The Tuana is composed of pebble and cobble gravels with layers of massive brown to gray sand and silt (Malde and Powers 1972). Thickness ranges from about 61 m (200 ft) at Indian Butte, south of HAFO, to about 15 m (50 ft) at the north end (Bjork 1968; Malde and Powers 1972). A dense, hard carbonate layer has formed several feet below the surface on the tops of the bluffs. This layer forms a caprock in most of the monument and the surrounding area (Farmer and Riedel 2003).

The Bruneau Formation (Pleistocene) occurs in localized areas in the monument and more extensively immediately to the south. Malde and Powers (1972) describes the Bruneau as massive lake beds of fine silt, clay, and diatomite. Near the south end of HAFO, are exposures of the Pleistocene Crowsnest Gravel (Snake River Group), composed of silicic volcanic pebbles and terrace deposits. The Black Mesa Gravel is not exposed in the monument. They also map occurrences of alluvial pebble and cobble gravels, stream alluvium, and landslide debris (Pleistocene to Holocene). Landsliding continues to occur to the present.

Significant Geologic Resource Management Issues in Hagerman Fossil Beds National Monument

1. Landslide Activity

The two most significant geologic issues in Hagerman are the presence of fossils and active landsliding, which heavily impacts the occurrence and recovery of the fossils. Landsliding is a function of lack of consolidation of sediment, steep slopes, and the flow of groundwater. The first two are geological conditions beyond human control. However, the groundwater regime has been greatly modified by the influx of agricultural irrigation water from the plateau to the west of HAFO. Seven major slides related to irrigation have occurred in the last 25 years: ca. 1979, 1983, 1987, 1989, 1991, 1995, and 2004. Also, two other locations adjacent HAFO on property managed by the Bureau of Land Management (BLM) failed in 1993 and 1997. (Farmer and Riedel 2003).

The frequency and order of magnitude of landsliding appears to be increasing. There is a need to distinguish the contribution of water from precipitation versus that from agriculture. Continued monitoring needs to be done on groundwater influx and movement – rates, frequency, and duration -with direct supervision by the park hydrologist to ensure seamless integration into existing hydrologic program management. Monitoring water quality is needed including: sediment load, nutrients (phosphates, nitrates), temperature, discharge rates, water balance, and effects of water influx on fish hatcheries. How much slump material has moved into the Snake River? Is this resulting in the siltation of downstream dams? How much water is lost from ditches and canal and how does it impact the groundwater regime? Research needs include: hydrologic modeling, dye tracer tests, paleo-landslide studies, flow rates of springs, and topographic mapping of the river bottom.

2. Protection and Preservation of Paleontological Resources

HAFO was established, in part, to preserve and protect paleontological resources. It is one of the premier fossil sites in the National Park System and the richest Pliocene-aged fossil locality in the world. Yet, fossils are being destroyed and fossil sites are being obliterated by landsliding, slumping, erosion, weathering, wind action, and theft. There is a need to relocate previously known fossil sites and locate and preserve new sites using GPS and photographic documentation. Photographic monitoring is needed to document changes in vegetation due to grazing, irrigation, and the introduction of exotics. However, fossil researchers are at risk due to the instability of the bluffs, making inventory, monitoring, and research more difficult and dangerous. Future actions need to be closely supervised by the park paleontologist to ensure seamless integration into the existing fossil resource management program at the park.

3. Groundwater Use

The Bell Rapids Irrigation District has been pumping water out of the Snake River up to the Bruneau Plateau since about 1970. The increased influx of this water has not only precipitated increased landsliding (see above), but also has severely altered the groundwater regime in the park. Changes have occurred in groundwater quality and flow rates, which in turn have impacted vegetation, slope stability, soils, and water quality in the Snake River. Hydrologic models need to be updated based on on-going monitoring and research. Questions include: What changes are occurring in the groundwater flow regime? Are flow rates increasing and is groundwater quality decreasing? How are these changes affecting soils and carbonate layers, surface water quality, slope stability, human safety, property, and facilities?

4. Wind Transport and Erosion

Wind erosion is a primary replenisher of fossils as lag deposits. This has several impacts to fossil resources. While exposing new fossils and allowing their collection, wind also exposes fossils to further erosion, exposure to sunlight, scattering by wind and water, and to theft. Wind can also cover fossil fragments and move them downslope from their original deposition site. As water dissolves the cementing material holding particles together, and landsliding loosens large areas of material, the wind will pick up and transport larger quantities of material. Also, agricultural practice to the west create clouds of windblown material that is carried eastward over the park. This not only brings in more foreign material (e.g. topsoil, vegetation fragments), but also animal wastes, agricultural chemicals, pesticides, and exhaust emissions from equipment. Also, there may be radioactivity associated with some of the dust (see below). Monitoring question include: What is the nature of windblown material? How much herbicide, pesticide, and fertilizer is being suspended and transported? Are fossil sites being continuously monitored to determine the incremental effects of wind?

5. Minerals Issues/Abandoned Mineral Lands

Although there is no record of any outstanding unpatented mining claims in the monument, there is a history of gold placer mining along the Snake River in the Hagerman area. Miners used elemental mercury to amalgamate and extract the gold, often leaving mercury in waste rock and soil. There have been exploration and perhaps mining for uranium in the monument resulting in prospect pits that may have elevated radiation levels. Questions include: Is the park aware of the status of the mineral estate in the park? Are there private inholdings (surface estate), private minerals, split estates or patented mining claims. Are there state-owned lands or state submerged lands? Are there mineral leases? Is there potential for the development of mineral material (sand and gravel) extraction sites. Are there existing rights-of-way or easements (e.g. for the Bell Rapids Irrigation District) for pipelines, power lines, or roads that may present management issues. Are there any active, inactive, and/or abandoned mineral sites in the park? Does the park extract mineral materials for park maintenance or construction projects? Are all operations in compliance with all applicable laws, regulations, policies, and permits? How many AML sites are there within the park and have they been inventoried and plotted on a map?

6. Other Issues

Radioactivity: There is an occurrence of uranium and radium in the interbedded basalt flows. The uranium and radium has been preferentially taken up by fossil material, making them radioactive to the extent that precautions must be taken when handling and preparing fossils. Are there levels of radioactivity in the water? Is the radioactivity regional or local? What is the source of the radioactive elements? What process in the paleoenvironment deposited the minerals? Can the history of radioactivity help unlock the fossil 'story' at Hagerman?

Geothermal activity: Most of the active geothermal development is at the south end and mostly outside the park. There is a possibility that water wells drilled in the monument may have elevated temperatures. How much monitoring is there of geothermal wells, in terms of temperature, flow rates, associated gases and water quality? How and where is the spent geothermal water being disposed: on the surface, in stream channels, or is it being reinjected?

Visitors center siting: A museum and research center is planned for a 54-acre parcel on the east side of the Snake River. Tailings from prior mining activities remain on the site as well as contamination from hydrocarbon spills adjacent to the property. Questions requiring monitoring and research include: How has the soil been impacted by contamination? Is the site in a 100-year floodplain, and if so, what steps have been taken to protect the center from flooding? What is the groundwater level and quality? Will contaminants affect the new water supply well for staff and visitors?

Human industrial activity: The Hagerman Valley is the site of various activities including agriculture, forestry, fisheries, electric power plants, wine production, meat by-product processing, livestock trucking, dairy farming, and tourism. Both state and national fish hatcheries are major industries in the area. There are four hydroelectric plants in the area. What are the impacts of these industries on water quality and water flow? How are wastes products from these industries being disposed?

Scoping meeting participants

Participant	Occupation	Organization
Sid Covington	Geologist	NPS, Geologic Resources Division
Marsha Davis	Geologist	NPS, Pacific-West Region
Neal Farmer	Natural Resource Specialist	NPS, Hagerman Fossil Beds NM
Pat Ferrell	Geologist Researcher	University of Idaho
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Phil Gensler	Paleontologist	NPS, Hagerman Fossil Beds NM
Virginia Gillerman	Research Geologist	Idaho Geological Survey
Fran Gruchy	Chief of Operations	NPS, Hagerman Fossil Beds NM
Gary Johnson	Assoc. Professor of Geology	University of Idaho
Bob Lorkowski	Geologist	Volunteer
Greg McDonald	Paleontologist	NPS, Geologic Resources Division
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Mike Wissenbach	Natural Resource Specialist	NPS, Hagerman Fossil Beds NM
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Hagerman Fossil Beds National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/162

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Natural Resource Program Center
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