National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

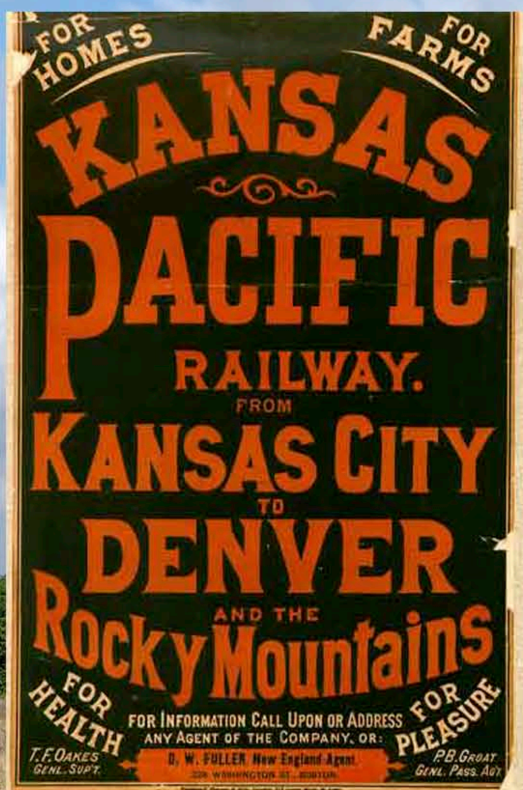
# Homestead National Monument of America

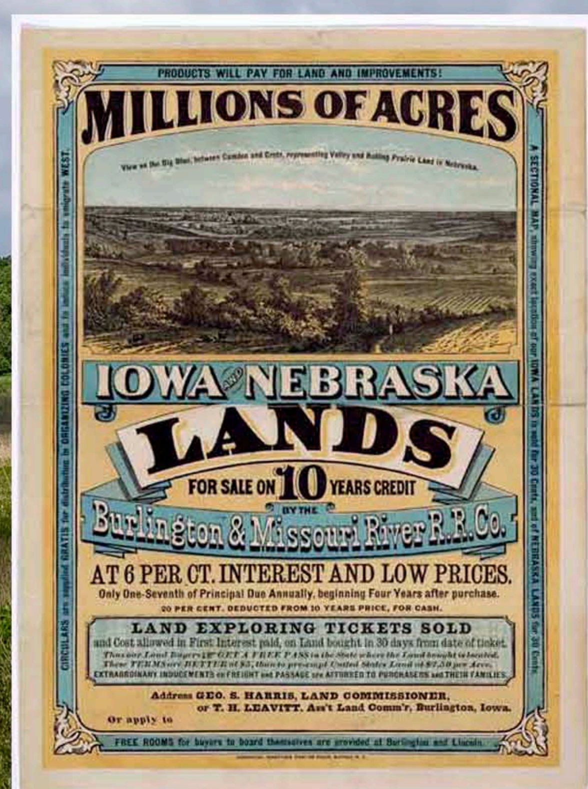
## *Geologic Resources Inventory Report*

Natural Resource Report NPS/NRSS/GRD/NRR—2011/452

**ON THE COVER**
The Homestead Heritage Center overlooks a restored tallgrass prairie. The composition is similar to that experienced by homesteaders. Photograph by Mel Mann, courtesy Jesse Bolli (Homestead NM of America)

**THIS PAGE**
Historic advertisements such as these drew homesteaders to the promise of new opportunities on federal lands. A view of the Cub Creek woodlands provides the backdrop. Photograph by Mel Mann, courtesy Jesse Bolli (Homestead NM of America). Advertisements available on the Homestead NM of America website: http://www.nps.gov/home/photosmultimedia/index.htm (accessed September 23, 2011).

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National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 80225

September 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics 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.

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



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Please cite this publication as:

Graham, J. 2011. Homestead National Monument of America: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/452. National Park Service, Fort Collins, Colorado.

NPS 368/110513, September 2011

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# Executive Summary

*This report accompanies the digital geologic map data for Homestead National Monument of America in Nebraska, produced by the Geologic Resources Division 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.*

Established as a memorial to pioneer life and the Homestead Act of 1862, Homestead National Monument of America preserves approximately 92 ha (228 ac) of terraced grassland and riparian, floodplain environments. Included in the monument are about 40 ha (100 ac) of restored tallgrass prairie and a rare, mesic bur oak (or burr oak) forest community. Cub Creek meanders through the western and northern sections of the monument past the homestead of Daniel Freeman, the first United States citizen to file for land under the Homestead Act of 1862.

Located within the Central Lowland physiographic province, Homestead National Monument of America encompasses a landscape carved by continental glaciation and subsequent erosion. River terraces, floodplain, and alluvial deposits in the monument and surrounding region not only provide clues to the post-ice age geologic history but also contribute archeological resources from both American Indian and Euro-American settlements.

Flooding and bank erosion along Cub Creek and surficial geologic mapping form the primary geologic issues that may affect resource management decisions at Homestead National Monument of America. Minor issues include potential seismic (earthquake) hazards and external activities such as quarrying operations and hydrocarbon exploration.

Flow in Cub Creek is controlled by upstream dams and water control structures. However, a major flood event could cause damage to historic buildings, septic systems in the monument, maintenance facilities, and other infrastructure. Museum collections, archives, and galleries in the monument have been moved to the new Homestead Heritage Center, located outside of the 100-year floodplain. Bank erosion caused by seasonal flooding may increase the sediment load in Cub Creek. Erosion may expose additional archeological sites, but it may also destroy existing sites.

Because bedrock is not exposed in the monument, a surficial geologic map would prove more beneficial to resource management than a bedrock map. Some of the features that could be identified on a surficial map include the specific lithology and age of unconsolidated surface deposits, geomorphic features, sampling sites along Cub Creek, and known and potential archaeological sites.

Although rare in Nebraska, earthquakes have been known to occur. The largest earthquake in Nebraska occurred in 1877 and split the walls of the Lincoln courthouse. In 2010, a 3.0 magnitude earthquake occurred in central Nebraska about 30 km (20 mi) north of Lexington. Seismic data indicate that active stress is still being applied to the Humboldt fault zone, east of Homestead National Monument of America, but also that the potential for significant ground shaking resulting from an earthquake in the area remains extremely low.

Quarrying operations and hydrocarbon exploration are also potentially minor, external issues for Homestead National Monument of America. Limestone, sand, and gravel have been quarried for cement, road material, riprap, and other purposes in southeastern Nebraska. A surficial map could identify potential areas where quarrying might occur. Oil is produced in the Forest City Basin, which intersects the southeastern corner of Nebraska approximately 113 km (70 mi) from the monument, but no hydrocarbons have been discovered in the vicinity of Homestead National Monument of America. Increased road traffic from hydrocarbon exploration in southeastern Nebraska may pose a minor external issue for the monument.

The surface geology at Homestead National Monument of America records a relatively young geologic history dating back to the end of the Pleistocene ice ages, about 10,000 to 12,000 years ago. Remnants of glacial and interglacial episodes lie between the surface deposits and the bedrock beneath the monument. Exposed in road cuts and along river banks, Pleistocene sediments include glacial till and interglacial deposits such as loess (windblown silt) and outwash sand.

Processes such as wind and water erosion, transportation, and deposition create and shape a rich variety of depositional environments. For example, beneath Homestead National Monument of America, coastal plain and estuary deposits form the Cretaceous Dakota Formation (Dakota Sandstone in the digital geologic data). Incursions of shallow seas into Nebraska during the Pennsylvanian and Permian resulted in a variety of marine and terrestrial depositional environments, several of which can be seen in exposures along the Missouri River.

Knowledge of the physical properties of the different geologic units mapped in the subsurface provides an additional interpretive dimension to the story of

Homestead National Monument of America. This report includes a Map Unit Properties Table that describes characteristics such as erosion resistance, suitability for infrastructure development, geologic significance, recreation potential, and associated cultural and mineral resources for each mapped geologic unit in the vicinity of the monument. A surficial geologic map would add significant data to this table.

This report also provides a glossary, which contains explanations of technical, geologic terms, including terms on the map unit properties table. Additionally, a geologic timescale shows the chronologic arrangement of major geologic events, with the oldest events and time units at the bottom and the youngest at the top. The timescale is organized using formally accepted geologic-time subdivisions and ages (fig. 15).

# Acknowledgements

*The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The GRI is administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate.*

The Geologic Resources Division relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

Special thanks to: Jesse Bolli (Homestead National Monument of America) who provided information and images used within the report.

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# Introduction

*The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Homestead National Monument of America.*

### Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The GRI, administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate, is designed to provide and enhance baseline information available to park managers. The GRI team relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. 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 these goals, the GRI team is systematically conducting a scoping meeting for each of the 270 identified natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

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

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

### Regional Information

Homestead National Monument of America is located in southeastern Nebraska's Gage County approximately 80 km (50 mi) south of Lincoln, and contains 92.23 ha (227.9 ac) of terraced grassland and floodplain (fig. 1). The monument includes woodland and riparian areas along Cub Creek, a log cabin similar to the original cabin built by the first homesteader, Daniel Freeman, the Freeman School, and about 40 ha (100 ac) of restored tallgrass prairie (fig. 2). The park lies 6 km (4 mi) west of Beatrice, on State Highway 4.

The lower reaches of Cub Creek meander through the western and northern portions of the monument before emptying into the Big Blue River less than 3 km (2 mi) to the east. The Big Blue River begins near Grand Island, Nebraska, and flows past Beatrice on its way to Turtle Creek Lake in northeastern Kansas. A mesic bur oak (or burr oak) forest, a rare vegetative community in Nebraska, follows Cub Creek through Homestead National Monument of America (fig. 2) (National Park Service 2006A). Elevations in the monument range from about 386 m (1265 ft) along Cub Creek's valley floor to 405 m (1330 ft) along the southeastern margin of the monument.

### Geologic Setting

Homestead National Monument of America lies within the Central Lowland province, which includes the eastern fifth of Nebraska. The broad Great Plains province encompasses the rest of Nebraska and extends to the foothills of the Rocky Mountains.

The Dissected Till Plains of the Central Lowland parallel the Missouri River and average about 110–130 km (70–80 mi) in width. This level-to-gently rolling landscape consists of glacial till left behind by continental ice sheets and loess (wind-blown silt) that have been dissected by several hundred thousand years of river erosion. 'Till' refers to any unsorted and unstratified (not layered) sediments deposited by a glacier.

Quaternary (2.6 million years ago to present) deposits in Nebraska consist primarily of loess, dune sand, and glacial till associated with the Pleistocene (2.6 million years to 11,700 years ago) Ice Age (fig. 3). The age of the base of the Pleistocene recently changed. In 2009, the International Commission on Stratigraphy voted to move the Pleistocene boundary from 1.8 to 2.6 million years ago. Therefore, publications prior to 2009 may refer to the previous time of the beginning of the Pleistocene.

In the area of Homestead National Monument of America, a thin band of Pleistocene loess and fluvial sand and gravel overlies thicker deposits of glacial till deposited during multiple advances of the Laurentide continental ice sheet that occurred from approximately 2.7 million years to 640,000 years ago (Burchett and Reed 1967; Roy et al. 2004; Balco et al. 2005). Ice advances during this time are referred to as 'pre-Illinoian' because they pre-date the Illinoian Glaciation that occurred from 310,000 to 128,000 years ago (Burchett and Reed 1967; Boellstorff 1978a, 1978b; Roy et al. 2004).

Holocene (11,700 years ago to present) sediments primarily include floodplain and river terrace deposits. Major changes to the climate and environmental conditions occurred in the region since the end of the Pleistocene. When the glaciers melted, the region became cool and dry and supported boreal forest habitats. Humans began to colonize the plains. The forests retreated to the north about 10,000 years ago and grasses became the dominant flora.

Sand hills developed in west-central Nebraska, and in eastern Nebraska, southeastward-flowing rivers developed a landscape of floodplains and terraces that were mantled with loess. Grasslands expanded with increased warm, dry conditions, and floodplain deposits promoted soil development (Mandel and Bettis 2000; Maher et al. 2003). When the climate became cooler and wetter between 5,000 and 3,000 years ago, lakes formed and human occupation increased (Bozell 2005). Additional information on the Holocene and Pleistocene history may be found in the Geologic History section of this report.

The bedrock mapped beneath the mantle of unconsolidated Quaternary deposits at Homestead National Monument of America consists of Mesozoic and Paleozoic sedimentary rock strata, or layers (fig. 4). The Cretaceous Dakota Formation represents a complex history of fluvial and estuarine deposition associated with the eastern margin of an extensive inland seaway (an epeiric sea) that divided the continent from the Gulf of Mexico to the Arctic Ocean. Approximately 100-95 million years ago, coarse sandstones and conglomerates filled broad paleovalleys that had eroded into Pennsylvanian bedrock. Relief on these paleovalleys was as much as 115 m (380 ft) (Joeckel et al. 2005). As the seaway advanced (transgressed) into Nebraska, the mouths of the paleovalleys became estuaries. The finer-grained sandstones, siltstone, and shale in the upper Dakota reflect this transition from dominantly fluvial deposits to deposition under marine tidal influences (Brenner et al. 2000; Brenner et al. 2003; Joeckel et al. 2005).

Rocks representing the time between the Lower Cretaceous and the Lower Permian are absent in this area of southeastern Nebraska. Such a gap in the stratigraphic succession is called an unconformity. Approximately 307 million years ago, an incursion of a shallow sea into the Homestead region resulted in the limestone and shale of the Chase and Council Grove Groups (fig. 4). On the GIS map, both the Chase Group and Council Grove Group are labeled as Permian, but recent research has shown that the Council Grove Group straddles the Permian-Pennsylvanian boundary (Sawin et al. 2006).

Exposures of Pennsylvanian rocks can be found along the Missouri River approximately 113 km (70 mi) east of the monument. Hydrocarbon exploration wells drilled within 10 km (6 mi) of Beatrice indicate that Devonian, Silurian, and Ordovician strata also underlie the monument, and these Paleozoic rocks overlie Precambrian rocks that are over 542 million years old. All the subdivisions of geologic time may be found on the geologic time scale (fig. 15). The bedrock strata in the subsurface dip gently westward.

### Park History

Occupation of the Great Plains began approximately 11,500 years ago when the Clovis people entered the region, and population increased dramatically in the Big Blue River valley from about 6,000 to 2,000 years ago. From 2,000 to 400 years ago, population increased with the addition of Woodland, Central Plains, and Oneota cultures. Horticulture was developed and semi-permanent villages were established. New technological innovations were implemented such as the bow and arrow and ceramic cooking and storage vessels (Bozell 2005).

Perhaps as a result of climatic deterioration, the Oneota people abandoned the region from about 1400 to 1600 C.E. When conditions improved around 1600, the Pawnee, who are descended from the Central Plains tradition, and the Oto, Ioway, Missouria, and Kansa (or Kaw) tribes, who are Siouan-speakers descended from the Oneota tradition, re-occupied the area (Bozell 2005).

About 300 years ago, Euro-American exploration expeditions entered the upper plains, and after 1820, American traders, military, and missionaries had created permanent establishments. Activity in the region increased with the opening of the Oregon Trail in the 1840s and Missouri and Iowa statehood. Although the main Oregon Trail did not extend through the monument area, the "Nebraska City Cut-Off" ran north of the area (Bozell 2005). In 1857, Beatrice was established and became the Gage County seat in 1859.

Settlement west of the Mississippi River sharply increased with the Homestead Act of 1862. For the price of a filing fee and on the condition that they would develop a farm within five years, any American citizen (male or female and including freed slaves), who was the head of a household, at least 21 years old, and who had not attacked the United States or befriended its enemies, was granted 65 ha (160 ac) of undeveloped federal land (U.S. Congress 1862). American Indians had occupied these lands for centuries but were not citizens and had little concept of land ownership. They were ineligible to participate in the Homestead Act of 1862 (National Park Service 1999).

On January 1, 1863, shortly after midnight, Daniel Freeman filed his claim. Thirty other citizens also filed on January 1. Freeman is described as a "colorful, self-promoter," who claimed for decades that he was the first homesteader. The symbolism of a person named Freeman being the first homesteader delighted national politicians (National Park Service 1999).

Nebraska citizens became interested in creating a national park on the Freeman property as early as 1909. In 1925, Nebraska's Senator George W. Norris, a powerful congressional leader, joined the effort to preserve the Freeman land, and in 1934, citizens of Beatrice formed the Homestead National Park Association in order to promote their cause.

Their efforts were rewarded in 1936 when President Franklin D. Roosevelt established the Homestead National Monument of America in order to "retain for posterity a proper memorial emblematical of the hardships and the pioneer life through which the early settlers passed in the settlement, cultivation and civilization of the Great West" (National Park Service 2010). That same year, the Department of Interior recognized Freeman as the first claimant (Potter and Schamel 1997; National Park Service 2010). The Freeman School, an original one-room prairie schoolhouse that was used until 1967, was added to the monument in 1971 (fig. 5).

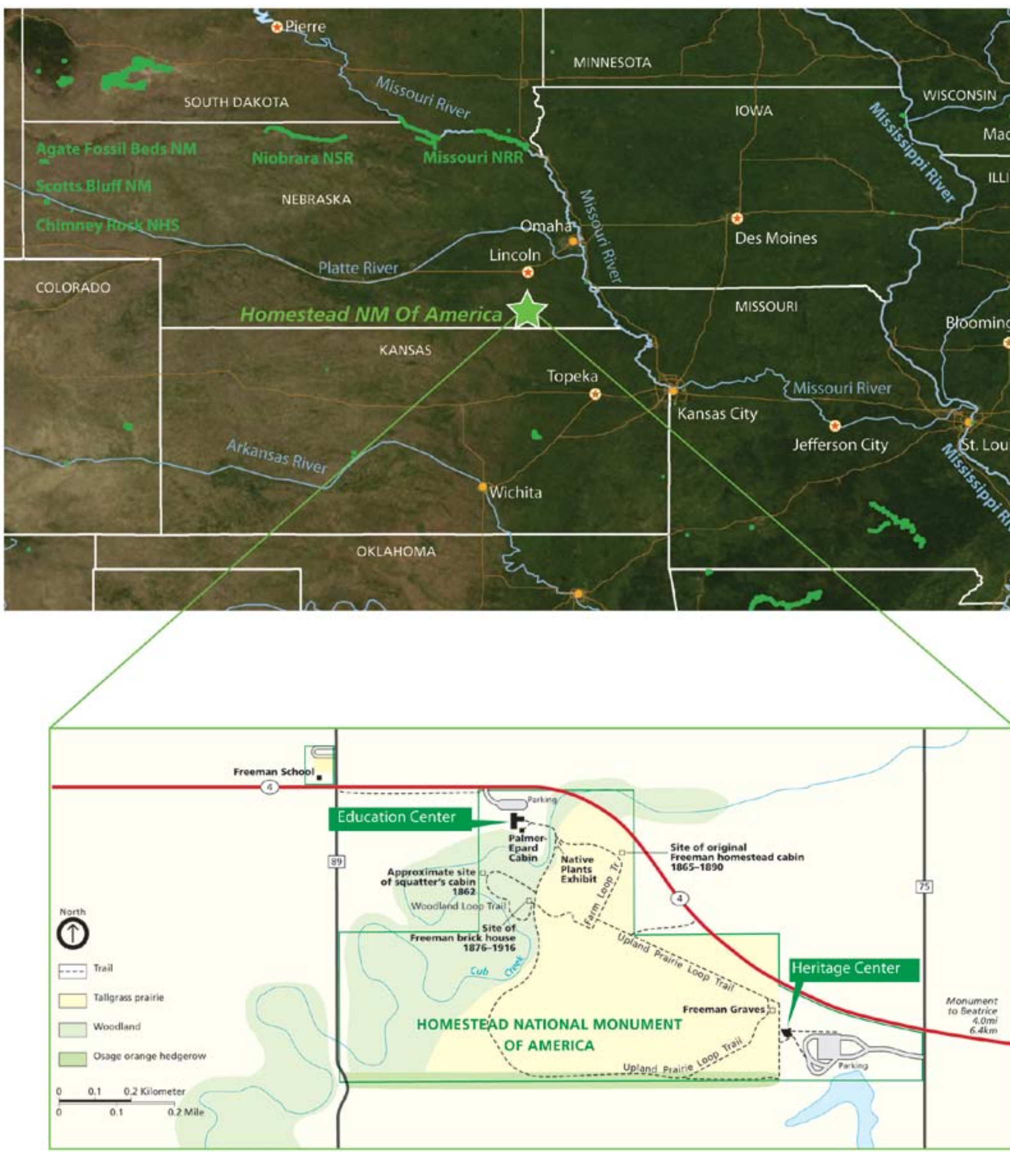



**Figure 1. Regional location and park map of Homestead National Monument of America, Nebraska. Other NPS areas appear as green on regional map; those in Nebraska are labeled. Interstate highways are shown in orange. Note the vegetation types indicated on the park map (see fig. 2). Regional map compiled by Jason Kenworthy (NPS Geologic Resources Division) from Arc Image Service, USA Prime Imagery and ESRI USA Base Map layers. Park map is a NPS graphic available online: http://home.nps.gov/applications/hafe/hfc/carto.cfm, accessed November 8, 2010.**

**Figure 2. Vegetation communities at Homestead National Monument of America. The park has restored approximately 40 ha (100 ac) of tallgrass prairie (upper picture; with bur oak woodland in the background). Less than 1% of the prairie remains in its native state—as the American Indians, and later explorers and homesteaders experienced it. The bur oak woodland along Cub Creek (lower picture) is a rare vegetation community in Nebraska. The osage orange hedgerow (mapped on fig. 1) was planted by the Freeman family and is not pictured here. Photographs by Mel Mann, courtesy Jesse Bolli (Homestead NM of America).**

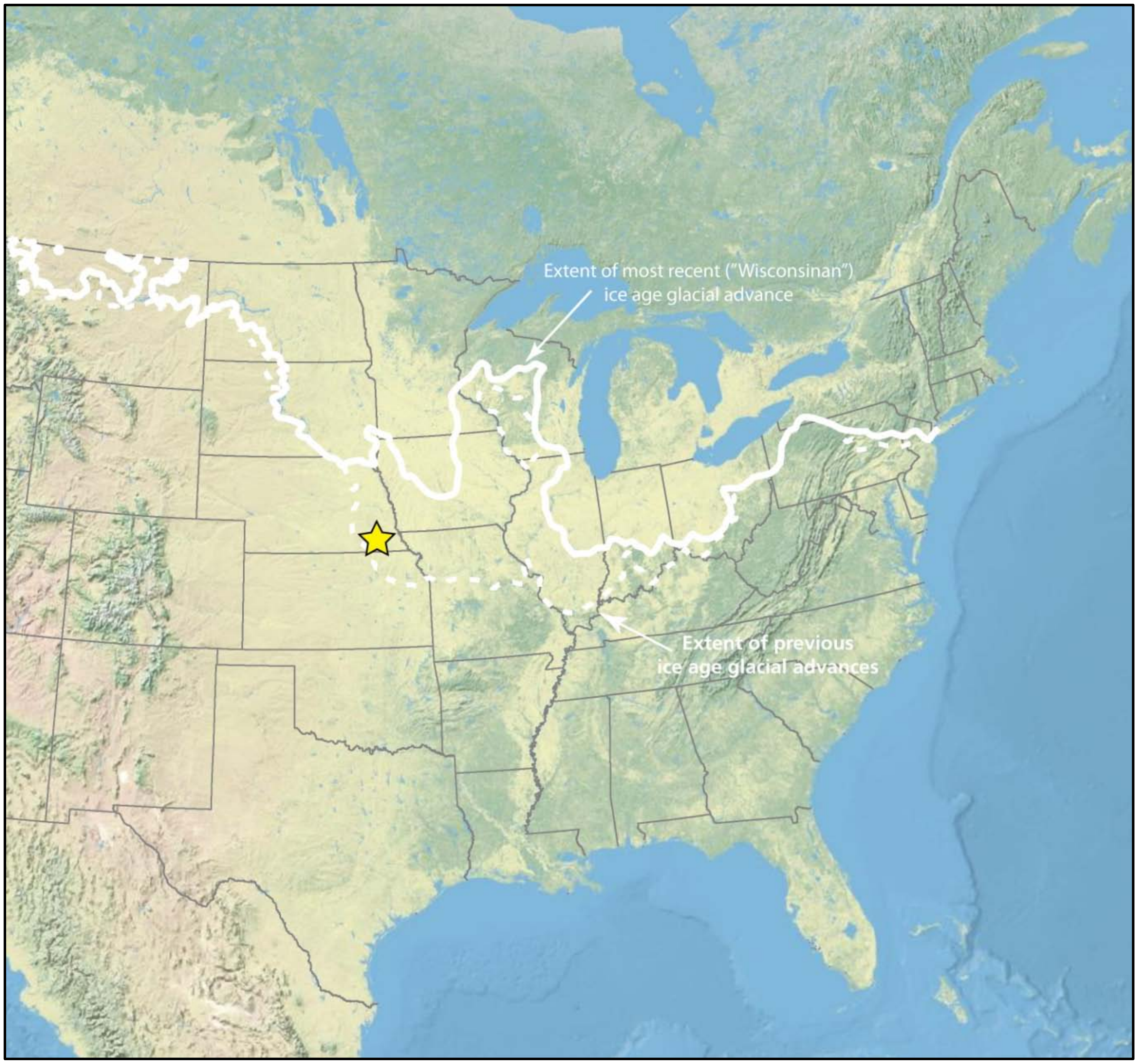



**Figure 3. Extent of Pleistocene glaciation in North America. Wisconsin, or Wisconsinan, glaciation (solid line) is the youngest glacial episode, occurring approximately 35,000—11,150 years ago. Homestead National Monument of America (yellow star) was covered by older glacial events (dashed line). Graphic compiled by Jason Kenworthy (NPS Geologic Resources Division) using USGS Digital Geologic Map of North America data (Garrity and Soller 2009) and ESRI Arc Image Service USA Topo imagery.**

| Era | Period | Epoch | Age* | Rock/Sediment Unit | Description |
|---|---|---|---|---|---|
| Cenozoic | Quaternary | Holocene | 0.01 - present | River alluvium and terrace deposits | Unconsolidated clay, silt, sand, and pebbles. |
| | | Pleistocene | 2.6 – 0.01 | Glacial till, fluvial sand and gravel, loess deposits | River sand and gravel and poorly-sorted clay, sand, pebbles, and cobbles in glacial till deposits. |
| | Tertiary – Neogene | Pliocene | 65.5 – 2.6 | Units of this age interval are absent in the Homestead National Monument of America area. | |
| | | Miocene | | | |
| | Tertiary – Paleogene | Oligocene | | | |
| | | Eocene | | | |
| | | Paleocene | | | |
| Mesozoic | Cretaceous | Upper | 100 – 65.5 | | |
| | | Lower | 145 – 100 | Dakota Formation (Kd) | Sandstone, shale, and mudstone, with basal pebbly conglomerate. |
| | Jurassic | Upper | 161 – 145 | Units of this age interval are absent in the Homestead National Monument of America area. | |
| | | Middle | 175 – 161 | | |
| | | Lower | 200 – 175 | | |
| | Triassic | Upper | 228 – 200 | | |
| | | Middle | 245 – 228 | | |
| | | Lower | 251 – 245 | | |
| Paleozoic | Permian | Lopingian (Upper) | 260 – 251 | | |
| | | Guadalupian (Middle) | 270 – 260 | | |
| | | Cisuralian (Lower) | 299 – 270 | Chase Group (Pc) | Cherty and fossiliferous limestone and carbonaceous, fossiliferous, fissile shale. |
| | Pennsyl-vanian | Upper | 307-299 | Council Grove Group (Pcg) | Shale and interbedded cherty, limestone. Fossiliferous. |
| | | | | Admire Group | Shale and limestone. |

**** Age is in millions of years before present and indicates the time spanned by associated epoch or period. Rock/sediment units associated with those epochs or periods may not encompass the entire age range.***

**Figure 4. General stratigraphic column for potential surficial and mapped bedrock units in the Homestead National Monument of America area. The Dakota Formation, Chase Group, and Council Grove Group are mapped in the subsurface of the park (map unit symbols in parentheses). Colors are standard colors approved by the U.S. Geological Survey to indicate different time periods on geologic maps; they also correspond to the colors on the Map Unit Properties Table. See the Map Unit Properties Table for more detail.**

**Figure 5. Freeman School, Homestead National Monument of America. National Park Service photograph courtesy of Jesse Bolli (Homestead NM of America).**

# Geologic Issues

*This section addresses geologic issues that may require attention from resource managers at Homestead National Monument of America. Contact the Geologic Resources Division for technical assistance.*

Geologic issues that may affect resource management decisions at Homestead National Monument of America include the following:

- flooding and bank erosion along Cub Creek
- surface water quality
- surficial geologic mapping

Additional potential issues include minor seismic hazards and issues that may originate from activities outside the park boundaries, such as hydrocarbon exploration and quarrying operations.

### Flooding and Bank Erosion along Cub Creek

Approximately 60% of Homestead National Monument of America lies within the 100-year floodplain of Cub Creek and the Big Blue River (National Park Service 1999). A 100-year flood describes a substantial flood event that has a 1 in 100 (1%) chance of happening in any given year. While a 100-year flood may happen two years in a row, for example, the chances are unlikely that such a rare event will take place with that frequency. Nevertheless, buildings, septic systems, and other infrastructure in Homestead National Monument of America may sustain significant damage should severe flooding occur.

To prevent potential damage to the historic and prehistoric collections, archives, and museum galleries, the monument moved these items to the new Homestead Heritage Center (fig. 1), which lies outside the designated 100-year floodplain. The old visitor center, two existing staff houses, and the maintenance facility remain within the 100-year floodplain. Solvents, fuels, oil, paint, and other potentially hazardous materials associated with maintenance activities are stored so that they will not be directly exposed to flood waters. The existing sewage system at the old visitor center undergoes routine monitoring and pumping. The system will be capped to protect it from floods and relocated when replacement becomes necessary (National Park Service 1999).

Although water control structures and dams control the flow of water in Cub Creek, seasonal floods may erode the creek's banks. Erosion forms deep cutbanks along Cub Creek and adds additional sediment to the stream (fig. 6). Summer flooding in 1993 caused significant bank erosion along Cub Creek (Jesse Bolli, Homestead NM of America, Resource Management Specialist, written communication, December 23, 2010). A portion of the Hedgerow Trail was re-routed to the east onto the adjacent prairie. Heavy rain and floods in the spring of 1999 eroded the bank behind the maintenance area and along the west side of the prairie. In 2007, the historic Palmer-Epard Cabin was almost flooded by rising waters that caused a portion of the trail near the ash thicket to collapse into the creek. This same section of trail collapsed during flooding in 2002 (Jesse Bolli, Homestead NM of America, Resource Management Specialist, written communication, December 23, 2010).

In an effort to control erosion near park infrastructure, shoreline armoring was installed beneath the footbridge over the creek (fig. 7). Shoreline armoring is not used elsewhere along Cub Creek.

A dam and pond along an unnamed creek spans the southern boundary of the park in the southeast corner. This feature was originally constructed by the Natural Resource Conservation Service (Soil Conservation Service) in the 1960s or 1970s for flood control. The feature was subsequently incorporated into the park when the land surrounding the Heritage Center was added in 2006. The park monitors water quality in the pond and does not anticipate removing or restoring the dam (Jesse Bolli, Homestead NM of America, Resource Management Specialist, written communication, November 9, 2010).

While bank erosion may expose additional archeological sites in Homestead National Monument of America, erosion may also destroy known archeological sites. Two archeological sites in the monument may be impacted by Cub Creek bank erosion. The Freeman Homestead site covers 12.0 ha (29.7 ac) and represents the most significant site with regards to the monument's interpretive mission. The site contains 7 spatially and temporally discrete areas including the Freeman and Suiter Cabins, the Squatter's Cabin, the brick house, the brick kiln, the Quackenbush house, the Agnes Suiter-Freeman Cabin, and a frame house. Located on a major segment of the Cub Creek terrace, the site may potentially be impacted by bank erosion (Bozell 2005). In order to stabilize stream banks and prevent flood damage to archeological sites, park management consulted with the NPS Water Resources Division in 2002 and is currently developing a management plan for Cub Creek (Jesse Bolli, Homestead NM of America, Resource Management Specialist, written communication, December 23, 2010).

A much smaller site, located in the southwestern margin of the monument, consists of a relatively recent garbage dump dating from the 1920s to the 1950s. The Cub Creek channel may be actively eroding this 0.05 ha (0.12 ac) site (Bozell 2005).

Lord and others (2009) suggest monitoring strategies and vital signs monitoring for stream systems as part of a geologic monitoring manual published by the Geological Society of America and the NPS. The monitoring strategies and vital signs include watershed landscape, hydrology, sediment transport, channel cross section, the form the channel takes in plan form, and the longitudinal profile of the channel. Contact the Geologic Resources Division for additional information.

Excessive erosion and runoff of sediment, nutrients, herbicides, and bacteria may cause surface water quality problems. The park administers a Cub Creek Water Quality Project in which local Beatrice Middle School Science classes collect water samples from two sites on Cub Creek (North Site and West Site) and monitor flow rate, pH, temperature, dissolved oxygen, conductivity, alkalinity, and concentrations of nitrates, phosphates, and sulfates (fig. 8) (National Park Service 2006A). Additional information regarding surface water quality is available from the NPS Water Resources Division ocated in Fort Collins, Colorado, and on the web at http://www.nature.nps.gov/water/ (accessed October 5, 2010).

#### Surficial Geologic Maps

Because no bedrock is exposed in Homestead National Monument of America, a detailed surficial geologic map will be more beneficial to management than a bedrock map. Permian bedrock (fig. 4) is buried by approximately 61 m (200 ft) of surficial deposits (Nebraska Oil and Gas Conservation Commission 2011). No surficial, Quaternary deposits are mapped on the 1:250,000 scale bedrock map that was used to create the digital map for Homestead National Monument of America (see Geologic Map Data section; Attachment 1) (Burchett et al. 1972). A surficial geologic map could identify specific geomorphic features, the lithology of these features, and the age of the sediments.

A soils map and detailed soils database was produced for the park by the NPS Soil Resources Inventory in cooperation with the Natural Resources Conservation Service (National Park Service 2006B). The database provides information about the 'parent material' from which each soil unit forms, and this information can be used to develop a general understanding of the underlying surficial geology. The parent material for the soils in the Cub Creek floodplain and valleys come from alluvial deposits, stream sediment that has been deposited within the last 10,000 years. Fine-silty colluvium, which is a generic term for any unconsolidated heterogeneous mixture of soil and rock material, provided the parent material for the soil on the hillslopes adjacent to the Cub Creek floodplain. In the southeast section of the monument, the parent material consists of glacial outwash, till, and loess deposited during the Pleistocene (Natural Resources Conservation Service 2003; National Park Service 2006B). The soils map can provide basic information about the underlying geology, but it cannot substitute for field-based surficial geologic mapping.

The NPS Soils Resources Inventory will be creating additional products for use at Homestead National Monument of America during fiscal year 2011 (Pete Biggam, NPS Geologic Resources Division, Soil Scientist, personal communication, November 10, 2010). Contact Pete Biggam of the NPS Soil Resources Inventory program for additional information.

Overlaying a detailed surficial geologic map onto a soil map (National Park Service 2006B) and a vegetation map (Kindscher et al. 2011) may provide valuable information regarding the relationship between vegetation and surficial geologic units such as terrace deposits, alluvial sediments, a variety of floodplain units, and units associated with the glacial history of the area. A large scale surficial map could locate the Cub Creek Project's North and West sampling stations, as well as any active or abandoned quarries that might be in the area. Furthermore, known and potential archeological sites could be marked on the map and identified with regard to potential erosion hazards.

#### Seismic (Earthquake) Hazards

Although rare and of little concern for resource managers at Homestead National Monument of America, earthquakes do occur in Nebraska (fig. 9). The largest earthquake originating in Nebraska happened in 1877 when movement occurred along a buried, geologic structure called the Midcontinent Rift that formed about 1.1 billion years ago during the Precambrian (see Geologic Features and Process section). Columbus, Nebraska, located about 84 km (52 mi) northwest of Lincoln, had major damage from the 1877 earthquake. The courthouse walls split in nine places and the walls of the schoolhouse sustained damage. Two severe shocks cracked walls and overturned printing cases in North Platte, approximately 350 km (220 mi) west of Lincoln, and at Sioux City, Iowa, walls cracked in a high school.

Earthquakes are measured according to the seismic energy they release (derived from the Richter Magnitude Scale) and by the amount of damage they cause (using a modified Mercalli intensity scale). The Richter Magnitude Scale, developed in 1935 by Charles Richter and Beno Gutenberg of the California Institute of Technology, measures seismic energy on a base-10 logarithmic scale, which means each magnitude of energy is 10 times greater than the previous one. For example, a magnitude 5 earthquake has 10 times the energy as a magnitude 4 earthquake.

The Italian volcanologist Giuseppe Mercalli developed his scale in 1884 to relate ground shaking with subsequent damage. It has been modified over the years and now contains 12 intensity levels. Shaking is widely felt at level IV and significant damage to poorly built or badly designed structures begins at level VII. In a strict sense, the Richter Magnitude Scale and the Modified Mercalli Intensity Scale are not comparable, but rough correlations can be made for locations near the epicenter of an earthquake (Steeples and Brosius 1996). Damage caused by the 1877 earthquake suggests that it was an intensity VII earthquake with an estimated magnitude on the Richter Magnitude Scale of 5.1 (U.S. Geological Survey 2009).

Earthquake data indicate that active, tectonic stress is still being applied to the Nemaha Uplift, a northeast-trending uplifted block of Precambrian and Paleozoic basement rock located approximately 56 km (35 mi) east of the monument (Berendsen and Blair 1995; Joeckel et al. 2007). The Humboldt fault zone, a complex zone of interconnecting faults, forms the eastern boundary of the 650-km-long (400-mi) uplift, which is buried beneath the relatively flat topography of southeastern Nebraska. Because stress continues to be applied to the Nemaha Uplift, movement along the faults in the Humboldt fault zone remains a possibility (Carlson and Joeckel 2003).

As of September 2011, the last earthquake with an epicenter in Nebraska occurred November 18, 2010. Centered 25 km (15 mi) east of Columbus, the magnitude 3.3 earthquake was triggered at a depth of 5 km (3 mi) (U.S. Geological Survey 2011). According to the 2008 National Seismic Hazard Mapping Program, the chance of an earthquake causing any significant ground shaking in the Homestead National Monument of America area is extremely low (U.S. Geological Survey 2009).

### Potential External Issues

#### Industrial Minerals

Quarrying for industrial purposes may pose a minor external issue for park management. In southeastern Nebraska, Pennsylvanian limestones, which lie beneath the oldest rocks mapped at Homestead National Monument of America, are quarried for the manufacture of cement, aggregate in concrete, riprap, agricultural lime, and other purposes (Burchett and Reed 1967). At one time, Cretaceous limestones were mined for agricultural lime, or aglime, and used as a soil additive, but no Cretaceous limestones are currently being mined in Nebraska (Matt Joeckel, geologist, Nebraska Geological Survey, written communication, April 20, 2011). Quaternary sand and gravel in alluvial deposits may also be quarried for road material. In the past, American Indian groups quarried Permian-age flint about 32 km (20 mi) southeast of the monument in the Wymore/Blue Springs area (Bozell 2005).

An apparently abandoned aggregate quarry is located immediately northeast of the park across Nebraska Route 4, approximately 610 m (2,000 ft) from the easternmost border of the monument. The quarry has not been active for at least the past eight years (Jesse Bolli, Homestead NM of America, Resource Management Specialist, personal communication, November 9, 2010). Another quarry was located east of the park along Cub Creek. When the quarry was operating, the park was concerned that vibrations from heavy truck traffic associated with quarrying activities might impact park cultural resources (Jesse Bolli, personal communication, to Bruce Heise, Geologist, Geologic Resources Division, June 2003).

A surficial geology map could help identify potential areas where aggregate quarrying might occur in the Homestead National Monument of America region.

#### Oil and Gas

Hydrocarbon exploration poses no immediate, internal threat to Homestead National Monument of America. Approximately 97 km (60 mi) east of Homestead National Monument of America, a variety of Paleozoic sedimentary rock units have yielded oil in the Nebraska portion of the Forest City Basin, which lies east of the Nemaha Uplift (Burchett and Arrigo 1978; Charpentier 1995; Nebraska Oil and Gas Conservation Commission 2011). In addition to Nebraska's Richardson and Nemaha counties, the Forest City Basin includes parts of southwestern Iowa, northwestern Kansas, and central Missouri. The Nemaha Uplift acts as a barrier to westward migration of oil out of the Forest City Basin and reduces the potential for commercial amounts of hydrocarbons west of the uplift.

Current data suggest that the Paleozoic strata on the gently dipping western flank of the buried Nemaha Uplift do not contain commercial quantities of hydrocarbons. Exploration wells drilled in Gage County, have not discovered hydrocarbons (Burchett et al. 1983; Nebraska Oil and Gas Conservation Commission 2011). No oil and gas drilling permits were issued for Gage, Johnson, or Pawnee counties in 2009 or 2010 (Nebraska Oil and Gas Conservation Commission 2011). If exploration continues in Richardson County, the park may experience increased traffic on Route 4.

Figure 6. Erosion along Cub Creek has formed a large cutbank with eroded and exposed soil, exposed roots, and fallen trees. Stream erosion is a management concern within the park; note the high sediment load in the creek. This view is to the north. National Park Service photograph courtesy of Jesse Bolli (Homestead NM of America).


Figure 7. Shoreline armoring is utilized beneath the footbridge over Cub Creek within the park. Erosion along the creek has exposed soil along the banks of Cub Creek. Rip rap was brought into the park to armor the shoreline; a few boulders are visible in the view to east. Larger-scale armoring is in place along the west bank (arrows indicate rows of smaller sized rip rap encased in wire mesh bundles). The park's education center is visible to the west of the bridge. National Park Service photographs courtesy of Jesse Bolli (Homestead NM of America).

**Figure 8. Volunteers from Beatrice Middle School Science classes, supervised by a volunteer ranger, collect water samples from Cub Creek in Homestead National Monument of America. Notice that the bank has been undercut by erosion and trees are beginning to slide down the relatively steep, non-vegetated bank. Footbridge in figure 7 is visible in the background. National Park Service photograph courtesy of Jesse Bolli (Homestead NM of America).**

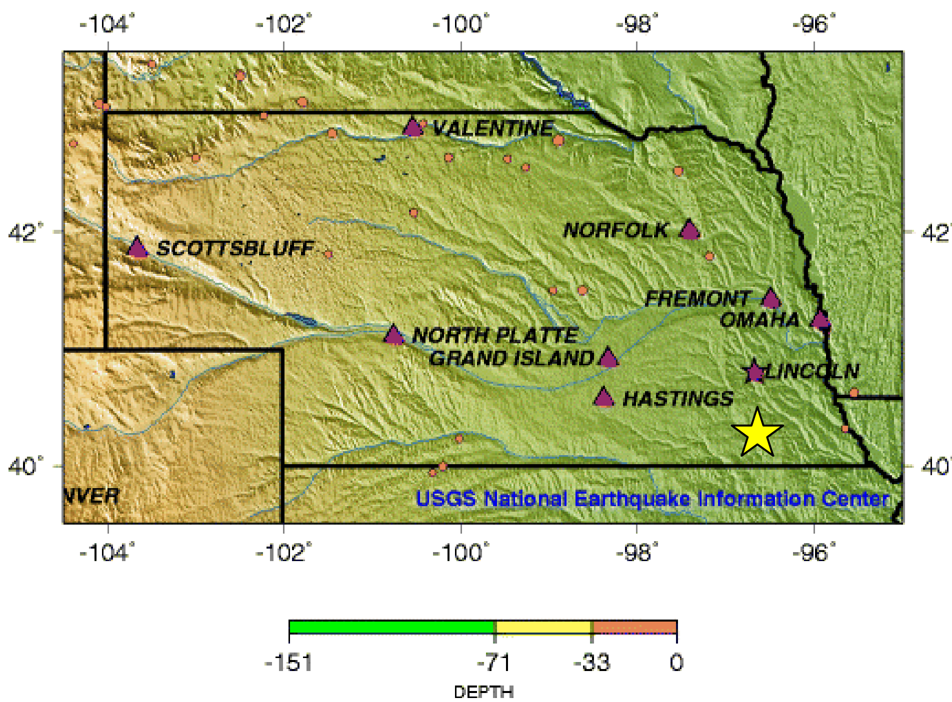



**Figure 9. Seismic activity (earthquakes) in Nebraska from 1990 to 2006. Depth is measured in kilometers. The purple triangles are cities, and the capital city of Lincoln is the purple star. Circles represent earthquakes, colored to indicate the depth range. Note that earthquakes in Nebraska (orange circles) are relatively shallow, occurring within 33 km (21 mi) of the surface. Seismic activity is rare in Nebraska and is not a major concern for resource managers at Homestead National Monument of America. The yellow star approximates the location of Homestead National Monument of America. U.S. Geological Survey map available online: http://earthquake.usgs.gov/earthquakes/states/nebraska/seismicity.php, accessed October 8, 2010.**

# Geologic Features and Processes

*This section describes the most prominent and distinctive geologic features and processes in Homestead National Monument of America.*

The landscape features at Homestead National Monument of America resulted from geologic processes occurring during the Quaternary (2.6 million years ago to present). However, these same processes, such as wind and water erosion, have shaped Earth's landscape for over 4 billion years. Homestead National Monument of America provides an excellent example of landscape evolution of the Central Lowland and Great Plains provinces. East of the monument, along the Missouri River, sedimentary structures in Cretaceous and Paleozoic rocks provide evidence of these timeless processes.

### Geomorphic Features

The only features exposed on the surface of Homestead National Monument of America are surficial, geomorphic features consisting of unconsolidated sediments. As identified in the "Geologic Issues" section, a map of the surface geology would help identify the features in the monument. In general, the topography is relatively flat with the highest area located in the southeast corner and the lower areas located along Cub Creek.

The restored tallgrass prairie in the monument grows on Holocene terrace deposits, which likely overlie older, Pleistocene glacial deposits. The Upland Prairie Loop Trail, Farm Loop Trial, and Freeman School Trail traverse river terraces in the monument. The Freeman School appears to rest on an older terrace.

The channel of Cub Creek forms a sinuous, meandering stream pattern as it crosses the monument. Typically, water flows faster on the outside of a curve in a meandering stream and tends to erode the bank (called a cutbank) (fig. 6). On the inside of the curve, the current slows and coarser sediment, such as sand and pebbles, settle out of the water column to form sandbars that usually build out from the bank (called a point bar).

Because Cub Creek is shallow, these features may not be as striking as in larger meandering rivers like the Mississippi, but a surficial geologic map may identify the point bars and cutbanks that exist in the monument. Some of these features may be seen along the Woodland Loop Trail that winds through Cub Creek's floodplain and passes the site of the Freeman brick house that existed from 1876 to 1916 and the approximate site of the squatter's cabin built in 1862.

### Pleistocene Features

Beneath the surface of Homestead National Monument of America lie remnants of the great Pleistocene Ice Ages. During the Pleistocene (2.6 million years ago to 11,700 years ago), vast continental ice sheets repeatedly flowed southward from Canada into Nebraska (fig. 3). During the early and middle Pleistocene (about 2.6 million years ago to 500,000 years ago), glaciers covered southeastern Nebraska and upon melting, left thick deposits of glacial till (fig. 10) (Burchett and Reed 1967; Boellstorff 1978a, 1978b; Balco et al. 2005; Lyle 2009).

Glaciers are massive flowing bodies of ice and extremely powerful erosional forces. They scour loose material from the landscape and pluck rock fragments from less resistant bedrock. Their passage leaves scrapes, grooves, and other marks on bedrock surfaces. Where the ice melts faster than it flows, the sediment carried by the glacier is simply dumped in a jumble of unsorted material, called glacial till (fig. 10). Glacial till deposited at the margin of a glacier forms a moraine. These may be terminal moraines, formed at the farthest extent of a glacier, lateral moraines, formed along the side of a glacier, or medial moraines formed between adjacent glaciers (fig. 11).

Occasionally, a boulder may be found on the Nebraska landscape that is not composed of any local bedrock. These are called glacial erratics because glaciers transported them into the area from some other place of origin. Many of the glacial erratics in southeastern Nebraska and northeastern Kansas consist of Sioux Quartzite, a hard pink Precambrian quartzite that occurs in the area where Iowa, South Dakota, and Minnesota meet (Lyle 2009). No glacial erratics are present in Homestead National Monument of America, however.

The glaciers advanced and retreated (melted) many times during the Pleistocene. When they advanced, the glaciers pulverized rocks and sediment into silt-size particles. When the glaciers melted, streams flowing from the ice sheet deposited silt onto floodplains. Temperature differences between the snow-covered northern regions and the bare ground to the south created significant atmospheric pressure differences that resulted in strong winds. Windstorms transported exceptional quantities of silt (loess) from west to east across the Nebraska plains (Kansas Geological Survey staff 1999; Mason et al. 2007). In eastern Nebraska, loess mantles glacial till (fig. 10). The Peoria Loess, the most recent loess unit to be deposited in the region, is approximately 1-5 m thick in southeastern Nebraska (fig. 12) (Mason et al. 2006; Lyle 2009). Although easily crumbled by hand, loess has the ability to maintain steep slopes if left undisturbed. Along the bluffs of the Missouri River, thick deposits of loess may be more than 30 m (100 ft) thick. In southeastern Nebraska and northeastern Kansas, loess provided the parent material for very productive soils.

## Regional Bedrock Features

### Dakota Formation

Approximately 61 m (200 ft) of surficial Quaternary deposits may overlie the bedrock beneath Homestead National Monument of America (Burchett et al. 1972; Nebraska Oil and Gas Conservation Commission 2011). The Cretaceous Dakota Formation (geologic map unit Kd) is the youngest bedrock in the region, being deposited from approximately 100 to 95 million years ago (fig. 4) (Brenner et al. 2000; Brenner et al. 2003; Joeckel et al. 2005; Ludvigson et al. 2010).

The fine- to coarse-grained sandstone layers in eastern Nebraska's Dakota Formation contain scattered chert pebbles, flecks of mica, iron oxide concretions, and fossils of plants, including logs whose woody tissue has been replaced by iron oxides. Crossbeds, inclined layers that form when sand is deposited by a current, record episodes of channel cutting and back-filling by sediment. Mottled mudstone layers exhibit evidence of ancient soil development (paleosols) (fig. 13). Oxygen isotope data from calcite cements in dinosaur tracks recently discovered in the Dakota Formation of southeastern Nebraska record mixing of brackish and fresh groundwater (Phillips et al. 2007). Analysis of Cretaceous pollen, oxygen isotopes, and stratigraphic data suggests that the Dakota Formation in eastern Nebraska was deposited in large fluvio-estuarine systems (Brenner et al. 2000; Brenner et al. 2003; Joeckel et al. 2005; Phillips et al. 2007; Ludvigson et al. 2010). When sea level lowered, westerly flowing rivers incised the relatively flat coastal plain, but when sea level rose, the mouth of the rivers became estuaries (fig. 14).

Exceptional concentrations of greenhouse gases existed in the Early Cretaceous atmosphere. Rapid sea-floor spreading resulted in submarine volcanic eruptions that elevated atmospheric carbon dioxide concentrations to over 1,000 parts per million (ppm), compared to 390 ppm (and continuing to rise) in September 2011 (Ludvigson 1999; Tans 2011). The climate was much warmer, and eastern Nebraska received about 250–410 cm (100–160 in) of rainfall, which is about three times more than today's annual rainfall of 76–81 cm (30–32 in) (White et al. 2001). Research into the Dakota Formation continues to provide insight into the Cretaceous greenhouse world and the effects of modern global climate change.

### Chase Group and Council Grove Group

Although not exposed in Homestead National Monument of America, the Paleozoic shale and limestone in the Chase Group (geologic map unit Pc) and Council Grove Group (geologic map unit Pcg) are exposed in Richardson County and along the Missouri River to the east.

In Pennsylvanian time, southeastern Nebraska was part of a low-relief, passively-subsiding epicontinental platform about 500 km (310 mi) wide (Heckel 1977, 1980; Fischbein et al. 2009). Fluctuations of relative sea level caused shallow marine environments to oscillate back and forth across this platform, producing cycles of marine sediments alternating with terrestrial deposits. These relatively short-interval stratigraphic cycles are called cyclothems. Cyclothems are recorded in Pennsylvanian strata throughout the world and provide significant information about worldwide sea-level fluctuations during the late Paleozoic Ice Age (Pabian and Boardman II 1995; Fischbein et al. 2009).

A typical cycle might begin with richly-fossiliferous, marine limestone overlying terrestrial, near-shore deposits. Black shale, deposited in deeper marine environments, covers the limestone and indicates continued sea level rise (called a marine transgression). As sea level fell during a subsequent marine regression, shallow marine limestone capped the black shale, followed by gray shale deposited in near-shore depositional environments. A return to fossiliferous marine limestone signaled the beginning of the next (Heckel 1977; Heckel 1980; Bunker et al. 1988).

An example of at least three cyclothems in the Council Grove Group may be found in a roadcut on Four Mile Hill in Richardson County, east of the monument (stop 4 in Pabian and Boardman II 1995). The first cycle includes marine limestone overlain by terrestrial shale and capped by a paleosol. The second cycle begins with a transgressive sequence of marine limestone then is overlain by terrestrial shale deposited as sea level fell. The uppermost cyclothem involves a renewed transgression and deposition of marine limestone containing brachiopods, mollusks, and trilobites overlain by a thick sequence of shale containing root casts and freshwater fish fossils, indicating deposition following a regression of the shoreline from the area (Pabian and Boardman II 1995).

### Regional Geologic Structures

The Nemaha Uplift, Humboldt fault zone, and the southern extension of the Midcontinent Rift System dominate the structural features in southeastern Nebraska (see the Geologic History section). However, all of these features have little or no surface expression and are not exposed in the monument. Homestead National Monument of America lies approximately 56 km (35 mi) west of the buried axis of the north-trending Nemaha Uplift. The Nemaha Uplift separates Gage, Pawnee, and Johnson counties from the Forest City Basin, which lies east of the uplift.

Carlson and Joeckel call the Nemaha Uplift "the best-known and least understood feature of Midcontinent USA" (Carlson and Joeckel 2003). Discovered in 1915, its delineation in the subsurface has been based largely on exploratory drilling for hydrocarbons. The Nemaha Uplift framework geology originally developed during the Precambrian, from approximately 1.8 to 1.6 billion years ago, and is associated with the Midcontinent Rift System (Berendsen and Blair 1995; Joeckel et al. 2007).

The Midcontinent Rift developed in the Proterozoic when the continental core (craton) of North America began to pull apart (Van Schmus and Hinze 1985; Hoffman 1989). Extending for over 1,500 km (950 mi) from Lake Superior to Oklahoma, the Midcontinent Rift System forms one of North America's largest and most magnificent geologic features. Throughout most of its length, the Midcontinent Rift System lies buried deeply beneath the surface, in places as much as 1,600 m (5,500 ft) deep. Few wells have been drilled into the rift rocks. Definition of the rift has relied on geophysical methods including gravity, aeromagnetic, and seismic techniques (Van Schmus and Hinze 1985; Anderson 2010).

About 1.1 billion years ago, deformation along the Humboldt fault zone defined the trend of the Nemaha Uplift (Berendsen and Blair 1995). Adjacent to the uplift, rift-flanking basins filled with clastic sedimentary rocks (Berendsen and Blair 1995; Joeckel et al. 2007). These sedimentary rocks were eroded and re-deposited in structurally controlled basins along the Nemaha Uplift when the Midcontinent Rift was compressed later in the Proterozoic. High-angle faulting continued to occur along the Humboldt fault zone throughout much of the Paleozoic, establishing the Nemaha Uplift as a topographically-high feature during this time (Bunker et al. 1988; Berendsen and Blair 1995). In the Pennsylvanian and Permian, movement along the Humboldt fault zone created the current Forest City Basin (Bunker et al. 1988).

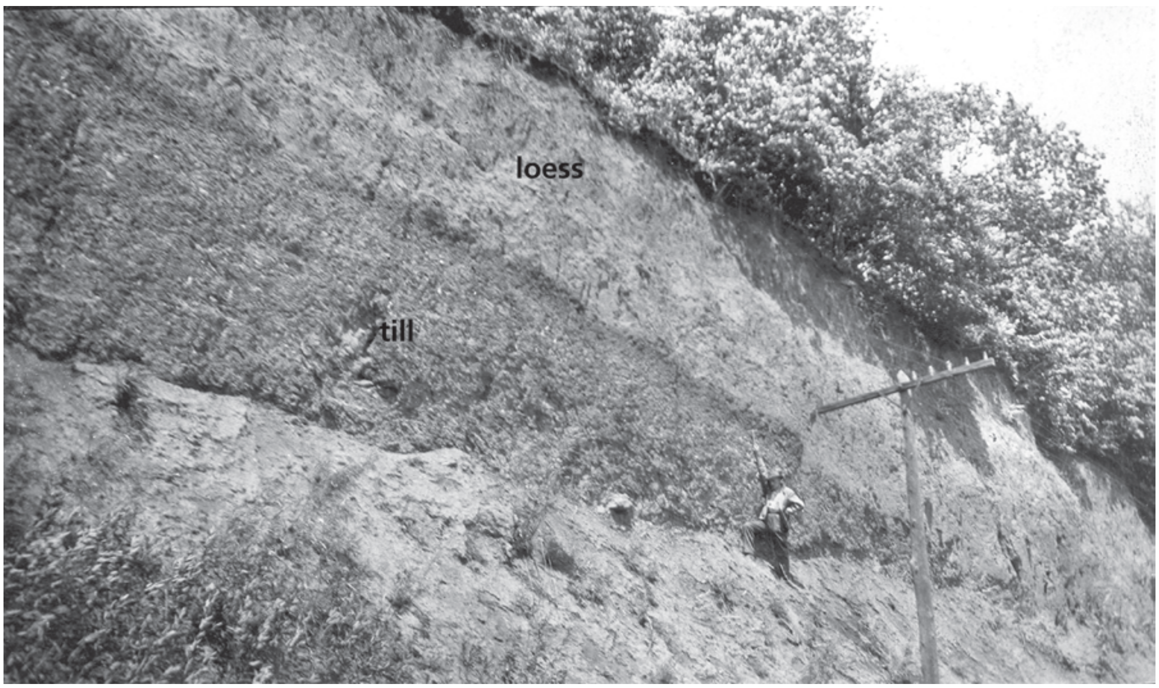
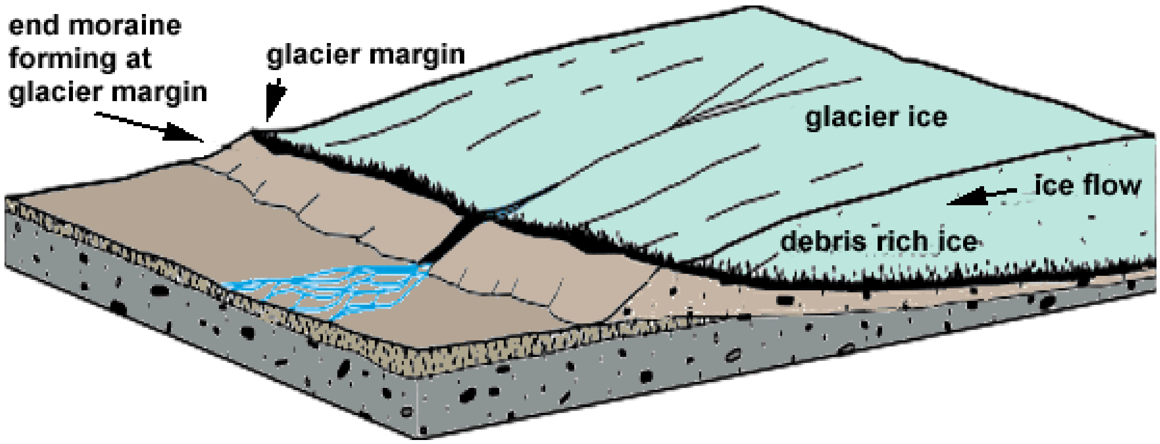



**Figure 10. Loess mantles a sequence of oxidized glacial till in this 1914 photograph of an outcrop in Douglas County, near Omaha, Nebraska. Note the geologist in the picture for scale. U.S. Geologic Survey photograph available online: http://libraryphoto.cr.usgs.gov/htmllib/btch477/btch477j/btch477z/btch477/awc00768.jpg, accessed October 12, 2010. Annotation by the author.**



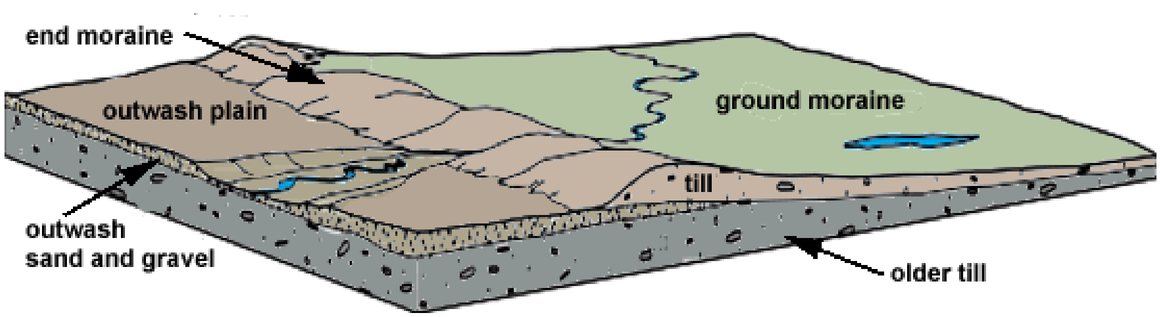




**Figure 11. An end moraine marks the farthest extent of an advancing glacier. In the upper diagram, debris (till) eroded by the flowing glacier gets deposited at the terminal margin of the glacier. In the lower diagram, a ridge of glacial till separates the ground moraine, which consists of till deposited at the base of the glacier, and the outwash plain. Illinois State Geological Survey graphics, available online: http://www.isgs.illinois.edu/maps-data-pub/publications/geobits/geobit2.shtml, accessed August 8, 2011.**

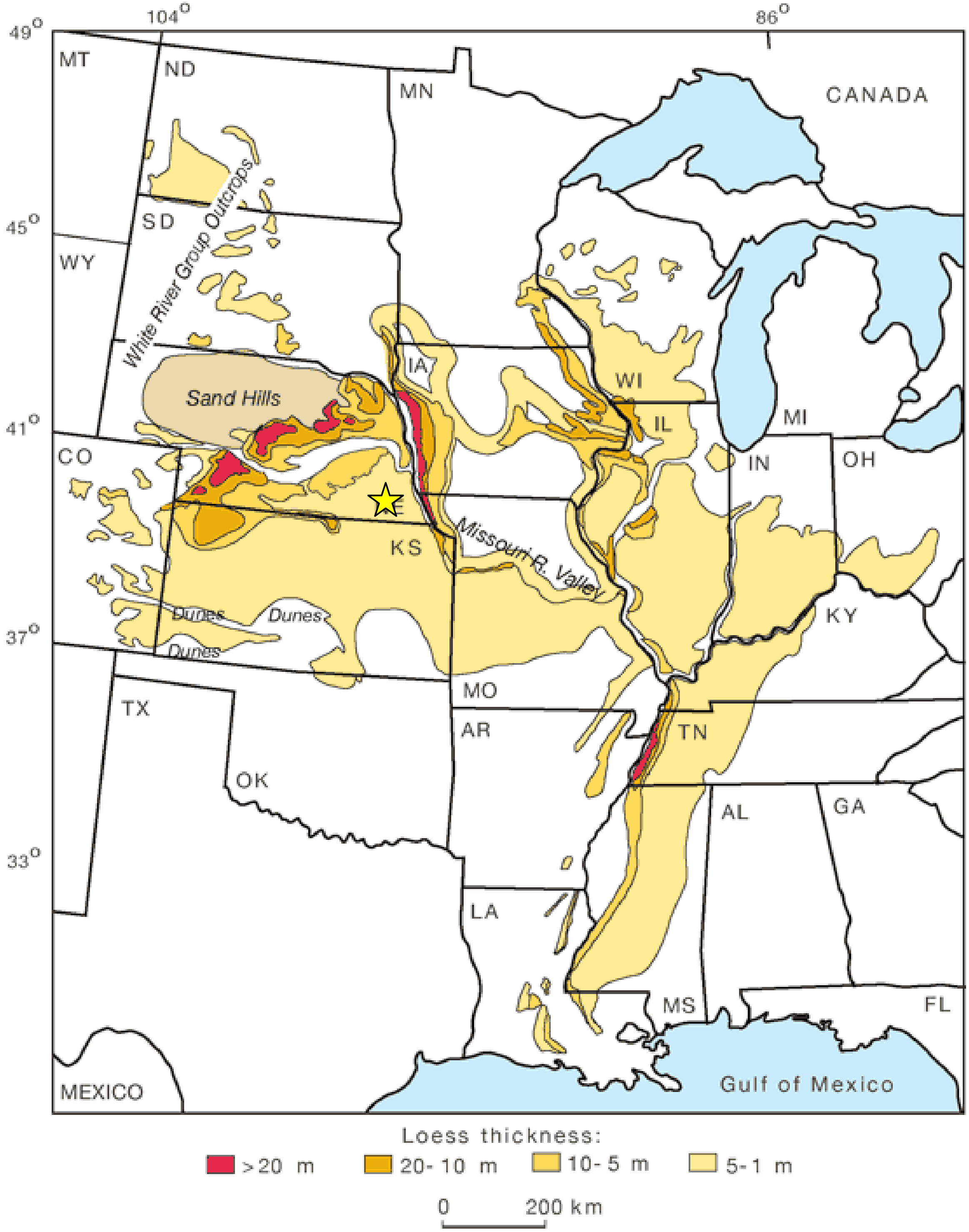



**Figure 12. Thickness of Peoria Loess in the central United States. Yellow star is the approximate location of Homestead National Monument of America. Diagram from Lyle (2009), available online: http://www.kgs.ku.edu, accessed August 8, 2011.**

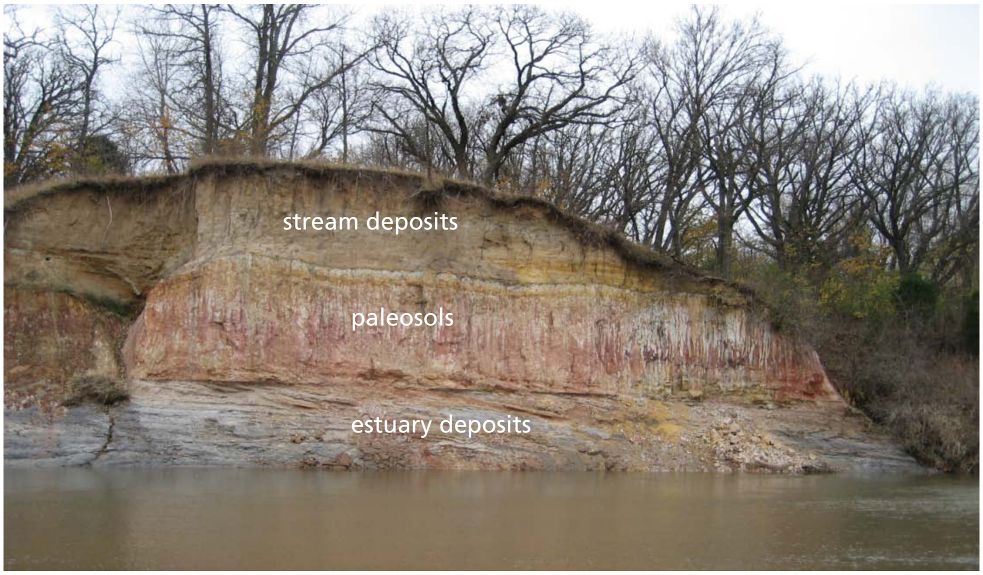



**Figure 13. The Dakota Formation near Fairbury, Nebraska, approximately 32 km (20 mi) southwest of Homestead National Monument of America. Estuary deposits form the inclined layers at the base of the outcrop. Above the estuary deposits, red and white mudstones record a series of ancient soils (paleosols). Coastal rivers flowing westward into the Western Interior Seaway during the Cretaceous deposited the brownish sandstone at the top of the exposure. University of Nebraska, Lincoln photograph available online: http://eas.unl.edu/~tfrank/History%20on%20the%20Rocks/Nebraska%20Geology/Cretaceous%20Webpage/Nebraska%20In%20Mesozoic/Nebraska%20in%20the%20Cretaceous.html, accessed 12 October 2010. Annotation by the author.**

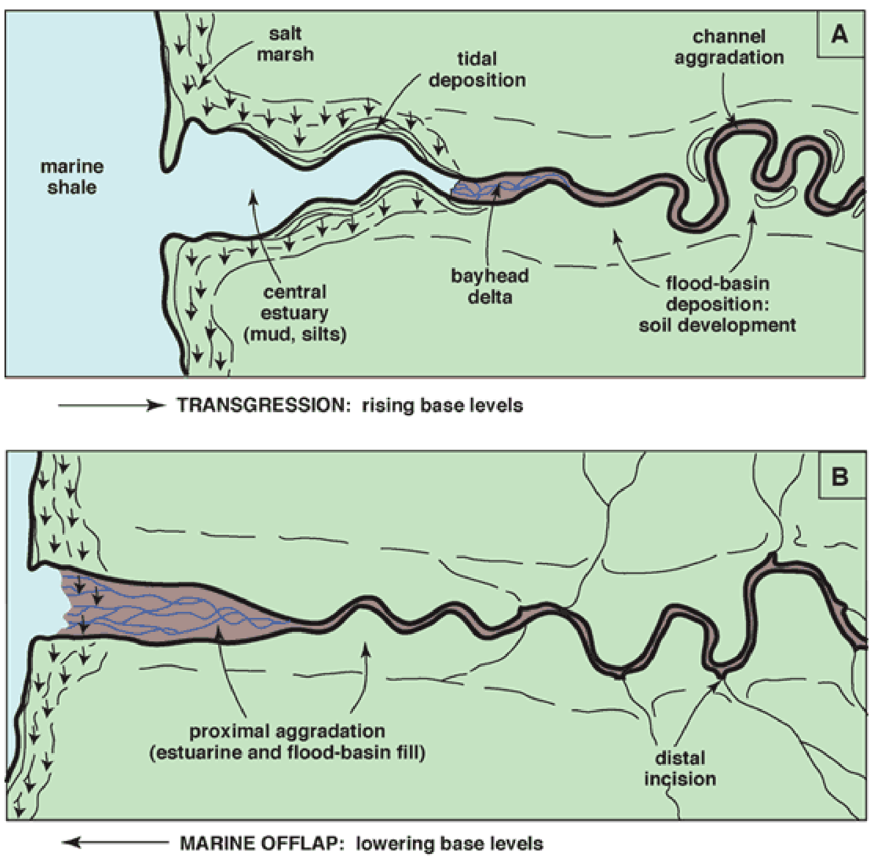



**Figure 14. Schematic diagrams illustrating the fluvial-estuarine system of the Dakota Formation of eastern Nebraska. During a sea level rise, or transgression, sea water floods the mouth of the river, forming an estuary (A). Today's Chesapeake Bay is an example of such an estuary. When sea level falls, the estuary becomes a fluvial-deltaic system in which sediment fills the previous estuary and upstream incision creates fluvial channels (B). Diagram from Ludvigson et al. (2010), available online: http://www.kgs.ku.edu/Current/2010/Ludvigson/index.html, accessed August 8, 2011.**

# Geologic History

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

Surface exposures at Homestead National Monument of America consist of geologically -young (less than 2.6 million years old) Quaternary deposits (fig. 6, fig. 8, fig. 15). Subsurface bedrock units that exist within the park but are not exposed at the surface were deposited during the Early Cretaceous, Lower Permian, and Upper Pennsylvanian (fig. 15). However, the geologic story of the monument begins in the Precambrian, almost 2 billion years ago.

#### Precambrian (prior to 542 million years ago)

The Precambrian represents approximately 88% of Earth's history from the formation of Earth 4,600 million years ago until 542 million years ago (fig. 15). Precambrian rocks in North America generally occur in two types of settings: 1) either in areas where continental glaciation has removed the younger rocks, such as in Minnesota and Canada, or 2) in areas that have undergone extensive uplift and erosion, such as the Rocky Mountains.

No Precambrian rocks are exposed in Nebraska. However, through drill-hole data and geophysical techniques, geologists have learned quite a bit about the Precambrian of Nebraska. About 19,000 wells have penetrated the Precambrian basement in Nebraska, and rock fragments from these wells have provided information about the chemical and mineral composition and the radiometric age of the samples (Carlson, 1967; Maher et al. 2003). Furthermore, subtle changes in the surface magnetic field and gravitational field have allowed geologists to interpret rock types below the surface.

Approximately 2 billion years ago, the region of today's Homestead National Monument of America consisted of a series of islands that may have looked similar to the volcanic islands that lay off the southeast coast of Asia today. About 1.8 to 1.6 billion years ago, these islands were sutured onto the proto-North American craton by a mountain building event called the Central Plains Orogeny (Sims and Petermar 1986; Maher et al. 2003; Carlson 2007).

Metamorphic and igneous rocks from the Central Plains Orogeny form the oldest rocks under Nebraska and are similar to rocks exposed in the Rocky Mountains of Colorado and southeastern Wyoming (Sims and Petermar 1986). The Central Plains Orogeny was one of many events that attached smaller pieces of continental crust to the growing proto-North American continent (Carlson and Treves 2001; Carlson 2007). It also established the basic structural trend for the future Nemaha Uplift (Carlson and Joeckel 2003). The Nemaha Uplift is underlain by a variety of Proterozoic rocks that include 1.63–1.8 billion year old granitic rocks, 1.1 billion year old mafic rocks, and slightly younger clastic sedimentary rocks (Berendsen and Blair 1995)

Approximately 1.1 billion years ago, extension (rifting) began to pull apart the southeastern portion of the North American craton, eventually forming the Midcontinent Rift System. Movement along normal faults (fig. 16A) formed uplifted areas and adjacent, down-dropped basins. The Midcontinent Rift consists of a series of basins that extend from the Lake Superior region through western Iowa, eastern Nebraska, eastern Kansas, and possibly into Oklahoma (Van Schmus and Hinze 1985; Hoffman 1989; Maher et al. 2003; Anderson 2010). Movement associated with the Humboldt fault zone resulted in the Nemaha Uplift and adjacent basins that filled with clastic sedimentary rocks eroded from the uplift (Berendsen and Blair 1995).

Dark, dense, basaltic lavas rich in iron and magnesium erupted along fractures, filling the subsiding basins (grabens) with as much as 20 km (12 mi) of basalt (Hoffman 1989). With a decrease in volcanism, rivers flowed into the subsiding basins, impressive lakes formed in the rift valley, and thick sequences of coarse-grained and fine-grained sedimentary rocks were deposited in the Midcontinent Rift. Rifting did not succeed in forming a new ocean, but great thicknesses of sediments, eroded from the rift valley margin, filled the valley and eventually buried it. The first land plants did not appear until about 450 million years ago, during the Ordovician, thus, erosion rates during the Precambrian and early Paleozoic would have been much higher than they are today.

About 1 billion years ago, plate collision replaced the tensional (spreading or separating) regime with a compressional regime causing a cessation of rifting along the Midcontinent Rift. Rocks and sediments deposited during rifting were compressed under intense pressure. Normal faults were reactivated as high-angle reverse faults (fig. 16B). In some areas, displacement along the reverse faults was 5 km (3 mi) or more (Berendsen and Blair 1995). Locally, movement across the Humboldt fault zone has been as much as 790 m (2,600 ft) since its inception in the Proterozoic. Seismic data from northeastern Kansas indicate that the Humboldt fault is currently a high-angle reverse fault with over 460 m

(1,500 ft) of displacement (Steeples 1989; Berendsen and Blair 1995).

Erosion of the uplifted region deposited sediments above the older sedimentary rocks on the margins of the rift. By the beginning of the Paleozoic, the Proterozoic rift-related, primarily sedimentary rocks had been eroded from the Nemaha uplift.

#### Paleozoic Era (542 to 251 million years ago)

Although the Paleozoic Era accounts for only 6% of Earth's history, the abundance and variety of fossils and sedimentary features preserved from that era allows detailed interpretations of the various depositional environments and ecosystems (fig. 15). In contrast to the active margins of the Precambrian, passive margins surrounded proto-North America at the dawn of the Cambrian (542 million years ago). Cambrian landscapes were devoid of all vegetation. Blowing sand, silt, and clay blanketed the continent. During the Cambrian, the Nemaha Uplift remained a topographically high feature (Berendsen and Blair 1995). By the Late Cambrian, shallow seas flooded the relatively stable proto-North American continent, spreading as far inland as Nebraska (fig. 17).

Fluctuating sea level in the Cambrian, Ordovician, Devonian, and Silurian deposited near-shore, beach sediments that hardened into sandstones and carbonates (limestone and dolomite). One sandstone formation, the Ordovician St. Peter Sandstone, is composed almost exclusively of uniform-sized quartz grains that are loosely cemented together. Because it is porous and permeable, the sandstone forms a potential reservoir for oil and gas. In the Forest City Basin of southeastern Nebraska, oil has been produced from the St. Peter Sandstone and from overlying (younger), fractured carbonates of the Viola Formation (Maher et al. 2003). The Doyle #1 hydrocarbon exploration well drilled approximately 10 km (6 mi) south of Beatrice, Nebraska, drilled through 14 m (47 ft) of St. Peter Sandstone, but Viola Formation rocks were not present.

Parts of the Nemaha Uplift remained above sea level throughout much of the Ordovician, Silurian, and Devonian. Minor movement along the Humboldt fault zone occurred in the Silurian and again in the Early Devonian (Bunker et al. 1988).

Throughout the Paleozoic, convergence of proto-North America with other lithospheric plates initiated mountain-building (orogenic) episodes along the margins of the continent (fig. 15). Plate collisions along active tectonic margins produced subduction zones, volcanic island arcs, mountain ranges, and sea level rise (transgression). During times of tectonic quiescence, the seas slowly retreated (regressed) from the Midcontinent and exposed sediments to erosion, which stripped away rock and sediment. Subsequent deposition resulted in much younger rock units unconformably overlying much older strata.

During the Mississippian (359 to 318 million years ago) and into the Pennsylvanian (318 to 299 million years ago), tectonic plate collisions along the margins of the continent formed the Appalachian Mountains to the east, the Ouachita Mountains in Arkansas and Oklahoma, and the ancestral Rocky Mountains in Colorado. At the time, proto-North America lay near the equator, surrounded by tropical seas, which spread into the interior of the continent as orogenies took place near continental margins (fig. 18).

The Ouachita orogeny, which began in the latest Mississippian and extended into the Pennsylvanian, produced the most dramatic displacement along the Humboldt fault zone (Bunker et al. 1988; Berendsen and Blair 1995). In southeastern Nebraska, a reactivated Humboldt fault zone dropped the Forest City Basin approximately 900 m (3,000 ft) relative to the Nemaha Uplift (Bunker et al. 1988; Maher et al. 2003).

Erosion of the rising Appalachian Mountains generated sediments that rivers funneled into the sea and onto the broad continental shelf that included Nebraska. Because Nebraska lay some distance from the mountains, this part of the continental shelf received mostly fine mud with occasional sand.

In the later part of the Paleozoic, the global landmasses were coming together to form the supercontinent Pangaea. Pennsylvanian rocks currently exposed in southern Africa, South America, Antarctica, Australia, and India indicate that during the Pennsylvanian, a large portion of the growing supercontinent was centered on the south polar ice cap. The growth and shrinkage of glaciers on the polar ice cap caused world-wide fluctuation of sea levels. Sea-level fluctuations caused marine cyclothems to encroach into the area from the east while aprons of coarse, clastic sediments were deposited on the flanks of the Nemaha Uplift (Joeckel et al. 2007). By the middle of the Pennsylvanian, shallow, tropical seas covered Nebraska, producing marine sediments that buried the Precambrian core of the Nemaha Uplift.

Shallow seas oscillated back and forth across the interior of the continent, producing the cyclothems found in Pennsylvanian and Permian sedimentary strata. Invertebrate marine fossils in limestone interbedded with multicolored, terrestrial shales and well-developed paleosols in the Council Grove Group (map unit Pcg) indicate times when southeastern Nebraska was flooded by the sea and times when the land was exposed above sea level (fig. 19).

During times of regression in the Upper Pennsylvanian, rivers incised the pre-existing cyclothems, carving valleys as much as 2,000 m (7,000 ft) wide and 30 m (100 ft) deep (Fischbein et al. 2009). When sea-level rose, estuaries formed in the mouths of the river valleys.

In general, Lower Permian sedimentation in Nebraska followed the cyclic pattern set in the Pennsylvanian. Sea level was generally lower and covered less of the

Midcontinent (Peterson 1980). Pangaea drifted northward, through tropical and into subtropical climates. Cherty, fossiliferous limestone and multicolored shales in the Chase Group (map unit Pc) suggest cyclic sedimentation continued throughout the Early Permian (Burchett et al. 1972; West et al. 2010).

The stratigraphic succession that includes Middle and Late Permian, Triassic, and Jurassic strata is missing in southeastern Nebraska. The Cretaceous Dakota Sandstone rests unconformably on the Lower Permian Chase Group in the vicinity of Homestead National Monument of America.

The most severe mass extinction event known occurred at the close of the Permian (see fig. 15 for the other major mass extinction events that have occurred through geologic time). Up to 96% of marine species and 70% of terrestrial vertebrates perished (Raup 1991). The only known mass extinction of insects occurred at this time. The loss of biodiversity is recorded in the extinction of 57% of all families and 83% of all genera. Thousands of species of insects, reptiles, and amphibians died on land while in the oceans, rugose corals and the once prolific trilobites vanished, as did many species of snails, urchins, sea lilies (crinoids), and some fish. Five million years later, at the dawn of the Mesozoic Era, the oceans began to evolve the chemistry of the modern oceans, and on land, the first mammals and dinosaurs emerged.

### Mesozoic Era (251 to 65 million years ago)

Although Triassic (251 to 200 million years ago) and Jurassic (200 to 146 million years ago) units can be found in the subsurface of western Nebraska, they are missing from eastern Nebraska (fig. 4). By the Early Triassic, the major landmasses had come together to form a supercontinent called Pangaea, but Pangaea began to break apart later in the Triassic. An active tectonic margin and subduction zone formed along the western margin of North America in the Jurassic, producing abundant volcanic activity as plate convergence continued. The Nebraskan interior, however, lay above sea level, exposed to erosion.

In the Cretaceous (146 to 65 million years ago), oceanic-continental plate convergence along the western margin of North America caused sedimentary strata to be folded and thrust eastward over Precambrian basement rocks. The rising mountains in the developing fold-and-thrust belt extended from Canada to Mexico (fig. 20). Sediment eroded from the mountains was deposited in an adjacent, subsiding basin that formed to the east (called the Western Interior Basin).

Seawater encroached northward into the subsiding Western Interior Basin from the Gulf of Mexico, which began to rift open in the Triassic. Marine water also began to spill into the basin from the Arctic. The seas advanced and retreated many times during the Cretaceous until a seaway extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 5,000 km (3,000 mi) (Kauffman 1977). Nebraska formed part of the eastern border of this Western Interior Seaway, the most extensive interior seaway ever recorded in North America (fig. 20).

The crossbedded sandstone, siltstone, and carbonaceous shale of the Dakota Formation (map unit Kd) reflect deposition along the eastern margin of the Western Interior Seaway. Similar to the fluvial-estuarine depositional systems in the Pennsylvanian, Cretaceous rivers incised underlying strata that was deposited on a relatively flat coastal plain as sea level lowered (fig. 14). As sea level rose, sediment backfilled the channels and the mouth of the rivers became estuaries (Brenner et al. 2000; Brenner et al. 2003; Joeckel et al. 2005; Phillips et al. 2007; Ludvigson et al. 2010). In eastern Nebraska, the Dakota Formation may be 200 m (650 ft) thick.

Elsewhere in eastern Nebraska, the Dakota Formation is overlain by (in ascending order) the Late Cretaceous Greenhorn Limestone, Graneros Shale, Niobrara Formation (mostly chalk), and the Pierre Shale. These strata document episodes in which the margins of the Western Interior Seaway expanded and contracted. The Pierre Shale, the uppermost Cretaceous unit in eastern Nebraska, consists of as much as 600 m (1,970 ft) of black, organic-rich, deep-water marine shale that contains occasional fossiliferous horizons. Apparently, abundant life swam in the normal marine waters near the surface of the interior seaway, but upon death, their remains settled onto the muddy, oxygen-poor sea floor where, in the anoxic environment with few scavengers, they escaped biodegradation (Maher et al. 2003).

### Cenozoic Era (65.5 million years ago to present)

#### Paleogene and Neogene Periods (the "Tertiary"; 65.5 to 2.6 million years ago)

From the Late Cretaceous into the Eocene epoch of the Paleogene (ranging from about 75 to 35 million years ago), subduction of an oceanic plate along the western margin of North America created an intra-cratonic compressional regime. Micro-continent sized landmasses repeatedly collided with and accreted onto the western margin of North America. These landmasses rode the subducting oceanic plate (the Farallon plate) like a conveyer belt, but they were too buoyant to be dragged down the subduction zone. The mini continental collisions compressed and elevated the area of the Western Interior Seaway, resulting in a complete draining of the seaway and the rise of the Rocky Mountains. Erosion dominated the geologic processes in eastern Nebraska, and if any Tertiary sediments were deposited, they were subsequently eroded before the Pleistocene epoch or by the continental glaciers that scraped the surface down to bedrock during the Pleistocene.

#### Quaternary Period (2.6 million years ago to present)

*Pleistocene Epoch (2.6 million years ago to 11,700 years ago)*

The Pleistocene is known for its ice ages and continental ice sheets that expanded southward from Canada into the eastern and central United States (fig. 21). At one time, geologists thought that the ice ages consisted of four stages. The two youngest ice ages, the Wisconsin (or Wisconsinan; 35,000 to 11,150 years ago) and Illinoian (310,000 to 128,000 years ago), are still considered valid, but the older two, the Kansan and Nebraskan, are now thought to consist of several, more complex glacial advances (Burchett and Reed 1967; Maher et al. 2003; Roy et al. 2004). These glacial episodes are now referred to as "pre-Illinoian" (figs. 3 and 21). The continental record shows evidence of at least six, and possibly seven, pre-Illinoian glaciations (Mickelson and Colgan 2004; Roy et al. 2004).

Illinoian glaciers did not advance into Nebraska, and the southernmost margin of the Wisconsin ice sheet extended into Iowa, about as far south as Des Moines, and into the northeastern corner of Nebraska, but did not extend into the Homestead National Monument of America region (Mickelson and Colgan 2004; Roy et al. 2004). However, pre-Illinoian glacial ice sheets advanced from an ice dome in western Canada and extended into eastern Nebraska and northeastern Kansas (Roy et al. 2007).

Evidence from glacial till, interbedded volcanic ash layers, paleosols, and paleomagnetic data indicate at least three pre-Illinoian glacial advances covered the monument area (Roy et al. 2004). Glacial till from Elk Creek, Nebraska, approximately 60 km (37 mi) east of the monument, underlies an ash unit deposited 2 million years ago, indicating that an ice sheet entered southeastern Nebraska between the onset of North American glaciation (about 2.5 million years ago) and 2 million years ago (Boellstorff 1978a, 1978b; Roy et al. 2004). Evidence from tills in eastern Nebraska and northeastern Kansas indicate that the most recent glaciation of the Homestead National Monument of America region occurred between 780,000 and 640,000 years ago (Boellstorff 1978a, 1978b; Roy et al. 2004; Mason et al. 2007).

The deep-sea drilling program that began in the 1960s, as well as ice core data from Antarctica and Greenland, has provided an extraordinary amount of information about global climate history. Oxygen isotope data from deep-sea cores have helped define the warm and cool periods of the glacial and interglacial episodes. The detailed records indicate that global climate change is driven by changes in solar insolation (solar radiation), changing ocean currents, the internal dynamics of ice sheets, and changes in atmospheric composition (Mayewski et al. 1997; Mickelson and Colgan 2004; Intergovernmental Panel on Climate Change 2007). Ocean records indicate that every 5,000 to 7,000 years, exceptional numbers of icebergs broke away from the Wisconsinan continental ice sheet into the North Atlantic. Researchers have found that while the continental glaciers responded to a warming global climate, the subsequent discharge of meltwater and icebergs may have buffered the warming trend in the North Atlantic (Mickelson and Colgan 2004).

Warmer, interglacial periods separated the major glacial advances in the Pleistocene. Strong winds swept across the relatively flat terrain of the Great Plains, transporting and depositing large volumes of loess (windblown silt) into the Missouri River Basin. Some of these loess deposits form the bluffs along the Missouri River in eastern Nebraska and Iowa. Four distinct loess units have been identified in eastern Nebraska. These units include, in ascending chronological order: Kennard Formation, Loveland Loess, Gilman Canyon Formation, and Peoria Loess (Mason et al. 2007).

The Kennard Formation, first recognized in 2007, consists of thin layers of loess derived from nonglacial sources on the Great Plains. The loess began to accumulate after approximately 780,000 years ago and ended before 186,000 years ago, the beginning of Oxygen Isotope Stage 6 (Wright 2000; Mason et al. 2007).

The thicker Loveland Loess, which is up to 18 m (59 ft) thick, accumulated from approximately 165,000 to 125,000 years ago (Forman et al. 1992; Mason et al. 2007). The Loveland Loess is considered to be a single depositional unit because it does not contain any well-developed paleosols. The deposits may record the emergence of the Missouri River valley as a major source of glacially-derived loess.

The Sangamon Geosol, the most prominent paleosol in the loess succession, separates the Loveland Loess from the Gilman Canyon Formation. The paleosol spans the Midcontinent and developed during Oxygen Isotope Stage 5 (128,000–71,000 years ago) and much of Oxygen Isotope Stage 4 (71,000–59,000 years ago) (Curry and Pavich 1996; Wright 2000; Mason et al. 2007).

Loess accumulated slowly in the thin Gilman Canyon Formation, which is only 0.5–1 m (1.6–3.3 ft) thick in eastern Nebraska. Radiocarbon dates from organic matter indicate deposition occurred between 41,000 and 20,000 carbon-14 years before present, which correlates to approximately 45,000–25,000 calendar years before present (Mandel and Bettis 1995; Maat and Johnson 1996; Fairbanks et al. 2005; Mason et al. 2007).

Peoria Loess is the most recently deposited loess in eastern Nebraska and was deposited in the interval of 25,000–12,000 years ago (Oxygen Isotope State 2). This widespread loess can be traced from northeastern Colorado to Ohio and is over 30 m (100 ft) thick in southwestern Iowa near the Missouri River (fig. 12; Bettis 1990; Bettis et al. 2003). Both the Loveland Loess and Peoria Loess were transported southwestward from northwestward sources, but the thickness trends in the Peoria Loess indicate a significantly greater influx of nonglacial loess from the Great Plains (Mason et al. 2007). During this time, the Midcontinent may have been cooler and/or drier than in earlier glacial stages.

*Holocene Epoch (11,700 years to present)*

Since the end of the Pleistocene, several major climate and environmental changes have occurred in the Central

Lowland and Great Plains. With the retreat of the glaciers beginning about 18,000 years ago, the Plains became a cool, dry region, partially covered by boreal forest that provided habitat for a variety of herbivores, notably bison and mammoth. Melting of both mountain and continental glaciers opened an ice-free passage that allowed humans to colonize the Plains. By 10,000 years ago, most of the forests had retreated to the north, grasses became the dominant vegetation, and many ice age faunal species such as mammoth, sloth, horse, and camel would soon become extinct (Bozell 2005).

Dry conditions in west-central Nebraska resulted in a great expanse of sand dunes, known as the Sand Hills. Episodic aeolian activity throughout the Holocene produced the largest dunefield on the Great Plains of North America (Goble et al. 2003; Mason et al. 2004). The Nebraska Sand Hills form a distinct landscape of homogeneous (well-sorted) sand that has been shaped into dunes that may exceed 100 m (330 ft) in height. The youngest sand sheet was deposited between 950 and 650 calendar years before present (Mason et al. 2004). The extensive sand sheets suggest that deposition occurred during a drought in which groundwater flow systems that had maintained interdune wetlands were temporarily reduced or eliminated. Current research suggests that Holocene aeolian activity may provide a valuable record of climate change (Goble et al. 2003; Mason et al. 2004).

Evidence from cutbanks along the Big Nemaha River, approximately 80 km (50 mi) southeast of Homestead National Monument of America, suggests that an upland deciduous forest remained in the area until about 8,500 years ago (Bozell 2005). In eastern Nebraska, southeastward-flowing rivers developed a landscape of floodplains and loess-mantled terraces. Floodplain deposits began to cover bedrock exposures in the Nemaha River drainage basin, northeast of Homestead National Monument of America, about 10,200 years ago (Mandel and Bettis 2000; Maher et al. 2003).

Increased warming and drying expanded grasslands and brought drought to the Plains. The area became increasingly inhospitable for human occupation until about 5,800 years ago when cooler temperatures returned (Bozell 2005). The slow accumulation of floodplain deposits from roughly 7,000 to 4,800 years ago promoted soil development.

A cool, moist climate dominated the Central Lowland and Great Plains between 5,000 and 3,000 years ago. Many lakes formed and human occupation increased (Bozell 2005). Streams incised floodplain deposits about 4,800 years ago. Channel incision was followed by channel infilling at least three times over the past 4,000 years (Mandel and Bettis 2000; Maher et al. 2003).

The rich soil that developed over the past 7,000 years provided the foundation for the vast grasslands and variety of wildlife for which the Plains Indians' lifestyle was well-suited. The fertile soil also enticed settlers like Daniel Freeman to move west and stake a claim. In Homestead National Monument of America, remnants of the past are preserved in the prairie grasses that thrive on alluvial terraces and in the mesic burr oak forest that grows on the modern Cub Creek floodplain.

Today, the area of Gage County receives a moderate amount of precipitation from 76 to 81 cm (30 to 32 in) per year. Warm summers give way to snowy winters. Agriculture dominates the landscape.

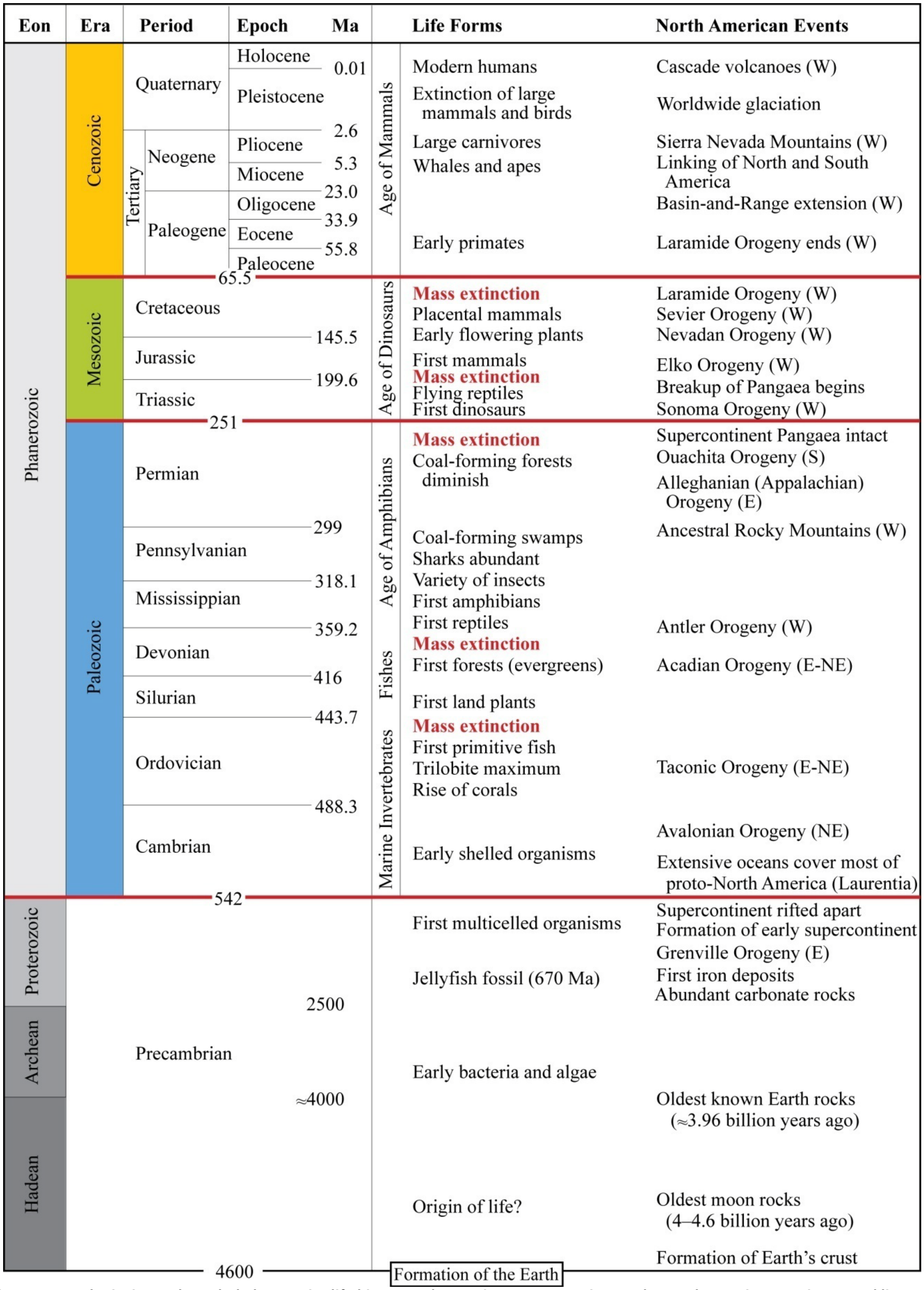



**Figure 15. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Radiometric ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location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

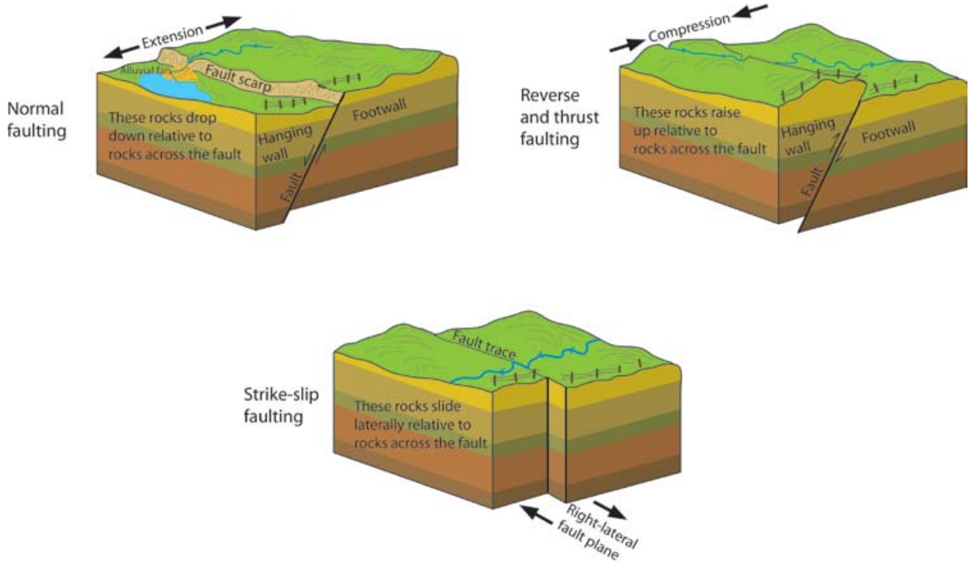



**Figure 16. Schematic illustrations of fault types. As a way of orientation, if you walked down a fault plane, your feet would be on the 'footwall,' and the rocks over your head would form the 'hanging wall.' In a normal fault the hanging wall moves down relative to the footwall. Normal faults result from extension (pulling apart) of the crust. In a reverse fault the hanging wall moves up relative to the foot wall. A thrust fault is similar to a reverse fault only the dip angle of a thrust fault is less than 45°. Reverse faults occur when the crust is compressed. In a strike-slip fault, the relative direction of movement of the opposing plate is lateral. If the movement across the fault is to the right, it is a right-lateral (dextral) fault, as illustrated above. If movement is to the left, it is a left-lateral (sinistral) fault. A strike-slip fault between two plate boundaries is called a transform fault. Graphic by Trista Thornberry-Ehrlich (Colorado State University.**

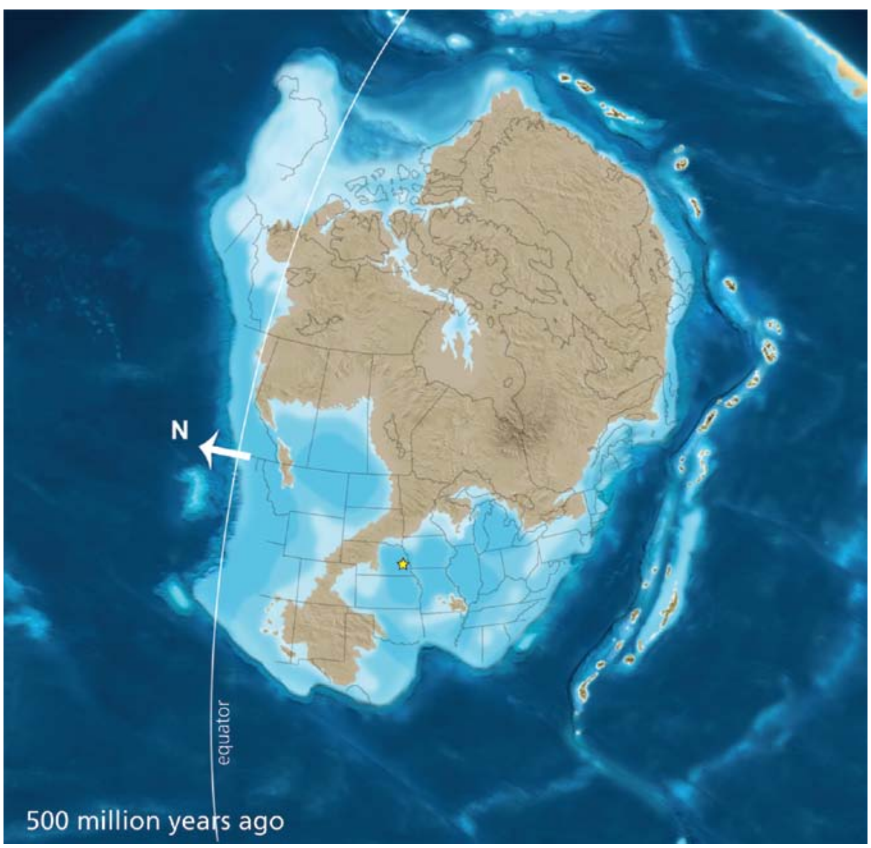



**Figure 17. Late Cambrian paleogeographic map of North America. Approximately 500 million years ago, southeastern Nebraska, which lay south of the Equator (white line) was covered by a shallow sea. Yellow star (not to scale) represents the general location of today's Homestead National Monument of America. Brown color is land surface. Relative depths of marine water are divided into shallow (light blue) and deep (dark blue). Paleogeographic map by Ron Blakey, Colorado Plateau Geosystems, Inc., http://cpgeosystems.com/namC500.jpg, accessed January 12, 2011. Annotation by the author.**

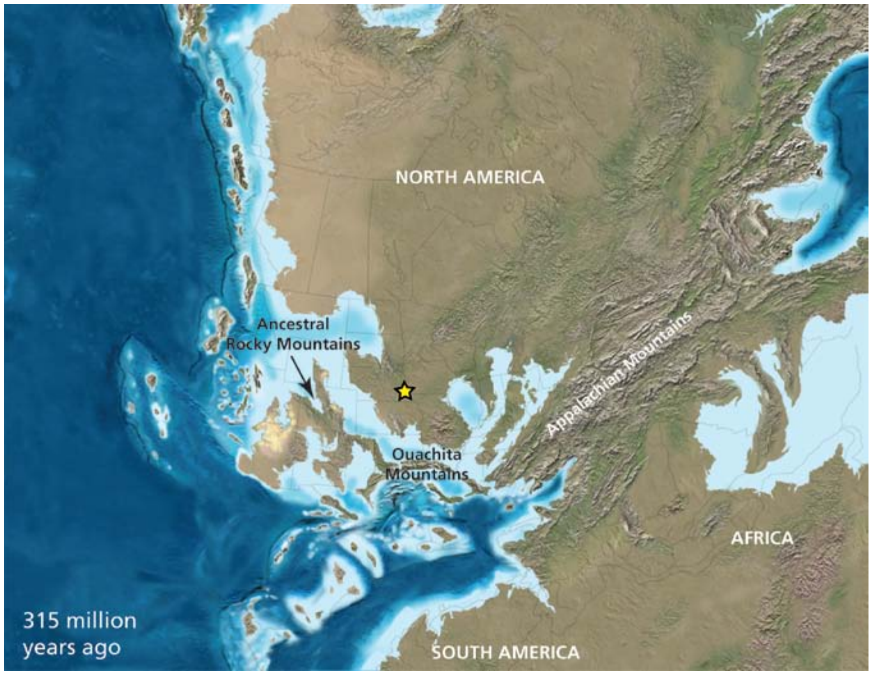



**Figure 18. Early Pennsylvanian paleogeographic map of North America. The Appalachian Mountains rise to the east of Homestead National Monument of America (yellow star) and the Ouachita Mountains to the south as Africa and South America collide with North America during the formation of the supercontinent, Pangaea. Major movement along the Humboldt fault zone occurred at this time. The collision caused the northwest-southeast trending Ancestral Rocky Mountains (dark brown) in Colorado. Brown color is land surface. Relative depths of marine water are divided into shallow (light blue) and deep (dark blue). Paleogeographic map by Ron Blakey, Colorado Plateau Geosystems, Inc., http://cpgeosystems.com/namPP315.jpg, accessed January 12, 2011. Annotation by the author.**

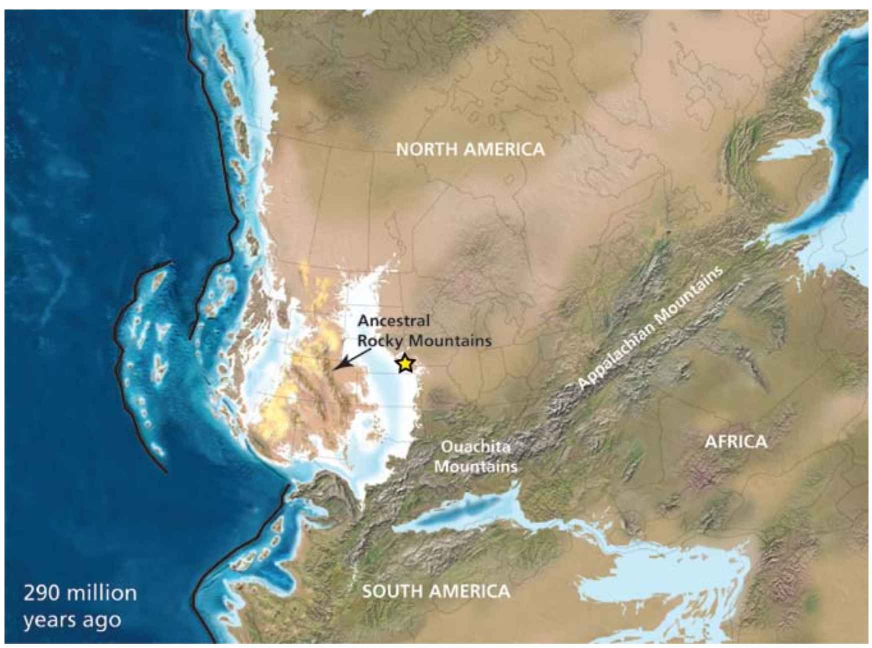



**Figure 19. Early Permian paleogeographic map of North America. Cycles of marine limestone and terrestrial shale in the Council Grove Group and Chase Group suggest that the region of Homestead National Monument of America (yellow star) was located near the margin of an inland sea and was impacted by periodic rise and fall of sea level. Remnants of the Ancestral Rocky Mountains (dark brown) can still be seen in Colorado. Brown color is land surface. Relative depths of marine water are divided into shallow (light blue) and deep (dark blue). Paleogeographic map by Ron Blakey, Colorado Plateau Geosystems, Inc., http://cpgeosystems.com/namP290.jpg, accessed January 12, 2011. Annotation by the author.**

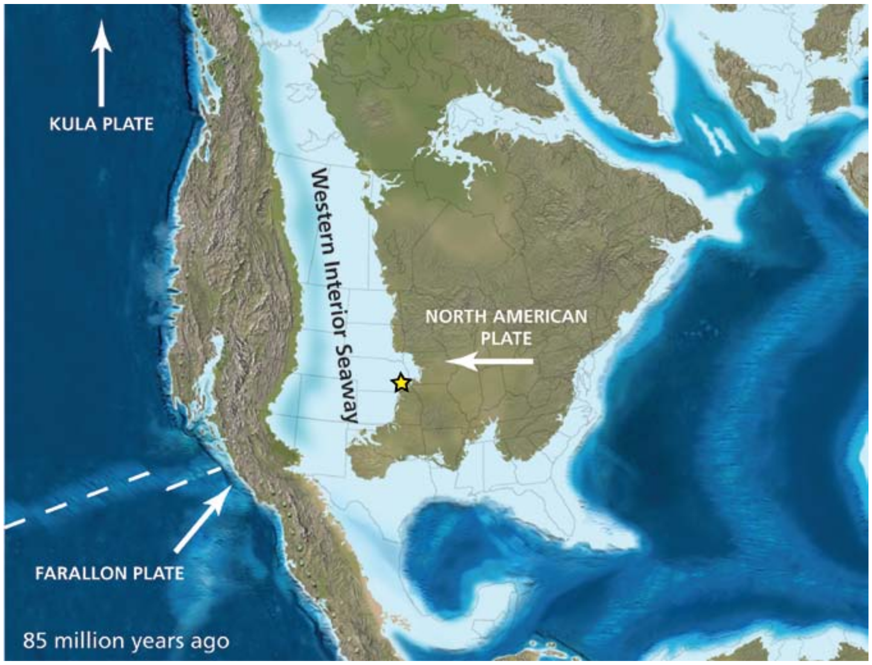



**Figure 20. Late Cretaceous paleogeographic map of North America. Approximately 85 million years ago, the Western Interior Seaway spread from the Gulf of Mexico to the Arctic Ocean. Nebraska lay on the eastern margin of the interior sea. In Nebraska, the Dakota Formation was deposited along the eastern margin of the seaway from 100 to 95 million years ago. Tectonic plate collisions produced mountains along the western continental margin. The yellow star marks the approximate location of today's Homestead National Monument of America. Arrows indicate the general direction of plate movement. The dashed line marks the approximate contact between the Farallon Plate and Kula Plate. Relative depths of marine water are divided into shallow (light blue) and deep (dark blue). Paleogeographic map by Ron Blakey, Colorado Plateau Geosystems, Inc., http://cpgeosystems.com/namK85.jpg, accessed January 12, 2011. Annotation by the author.**

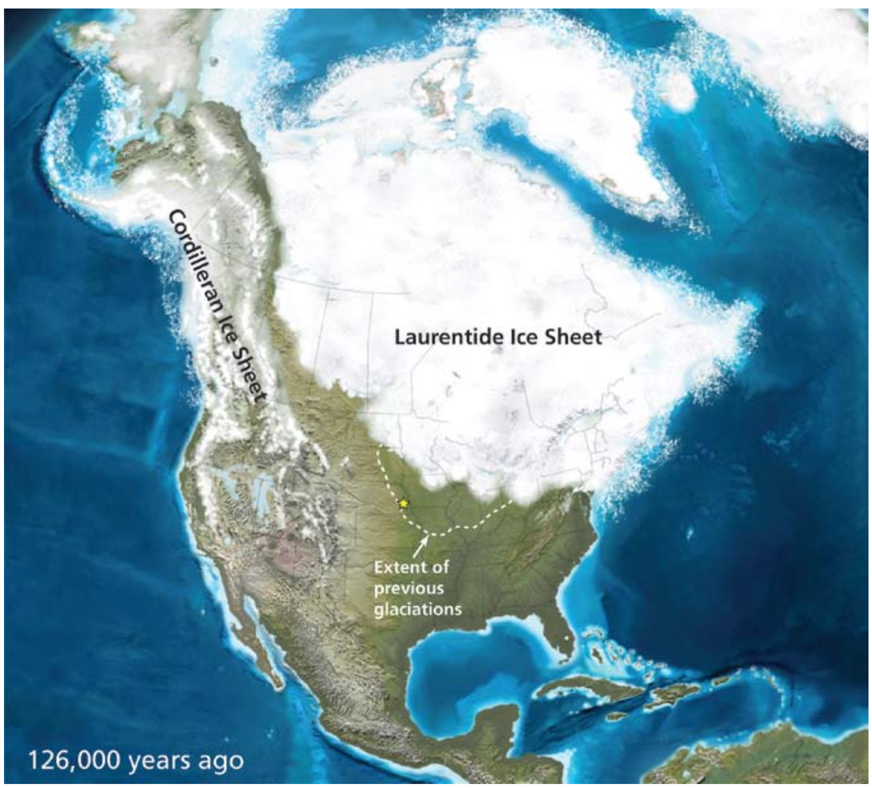



**Figure 21. Pleistocene paleogeographic map of North America approximately 126,000 years ago (Illinoian glaciation). The dashed line marks the approximate maximum extent of pre-Illinoian glaciations (prior to 310,000 years ago) (from Mickelson and Colgan 2004). The continental ice sheet advanced and retreated several times during the Pleistocene, covering the region of Homestead National Monument of America (yellow star) during the early and middle Pleistocene. In mountainous regions to the west, alpine glaciers formed. Paleogeographic map by Ron Blakey, Colorado Plateau Geosystems, Inc., http://cpgeosystems.com/namQ.jpg, accessed January 12, 2011. Annotation by the author.**

# Geologic Map Data

*This section summarizes the geologic map data available for Homestead National Monument of America. It includes a fold-out geologic map overview and a summary table that lists each map unit displayed on the digital geologic map for the park. Complete GIS data are included on the accompanying CD and are also available at the Geologic Resources Inventory (GRI) publications website: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm.*

### Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, geologic maps portray the spatial distribution and relationships of rocks and unconsolidated deposits. Geologic maps also may show geomorphic features, structural interpretations, and locations of past geologic hazards that may be prone to future activity. Additionally, anthropogenic features such as mines and quarries may be indicated on geologic maps.

### Source Maps

The Geologic Resources Inventory (GRI) team converts digital and/or paper source maps into the GIS formats that conform to the GRI GIS data model. The GRI digital geologic map product also includes essential elements of the source maps including unit descriptions, map legend, map notes, references, and figures. The GRI team used the following source maps to create the digital geologic data for Homestead National Monument of America:

Burchett, R.R., V.H. Dreeszen, E.C. Reed, and G.E. Prichard. 1972. Bedrock geologic map showing thickness of overlying Quaternary deposits, Lincoln Quadrangle and part of Nebraska City Quadrangle, Nebraska and Kansas. Miscellaneous Geologic Investigations Map I-729, U.S. Geological Survey, Washington, D.C., USA. (scale 1:250,000).

This source map provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report.

### Geologic GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available online (http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm). This data model dictates GIS data structure including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Homestead National Monument of America using data model version 1.3.1.

GRI digital geologic data for Homestead National Monument of America are included on the attached CD and are available through the NPS Integrated Resources Management Applications (IRMA; https://irma.nps.gov/App/Reference/Search?SearchType=Q). Enter "GRI" as the search text and select Homestead National Monument of America from the unit list. The following components and geology data layers are part of the data set:

- Data in ESRI geodatabase and shapefile GIS formats
- Layer files with feature symbology
- Federal Geographic Data Committee (FGDC)–compliant metadata
- A help file (.hlp) document that contains all of the ancillary map information and graphics, including geologic unit correlation tables and map unit descriptions, legends, and other information captured from source maps.
- An ESRI map document file (.mxd) that displays the digital geologic data

**Geology data layers in the Homestead National Monument of America GIS data.**

| Data Layer | Code | On Geologic Map Overview? |
|---|---|---|
| Quaternary Deposits Thickness | homecn1 | Yes |
| Geologic Contacts | homeglga | Yes |
| Geologic Units | homeglg | Yes |

### Geologic Map Overview

The fold-out geologic map overview displays the GRI digital geologic data draped over an aerial image of Homestead National Monument of America and includes basic geographic information. The aerial imagery and geographic information are not included with the GRI digital geologic GIS data for the park, but are available online from a variety of sources.

### Map Unit Properties Table

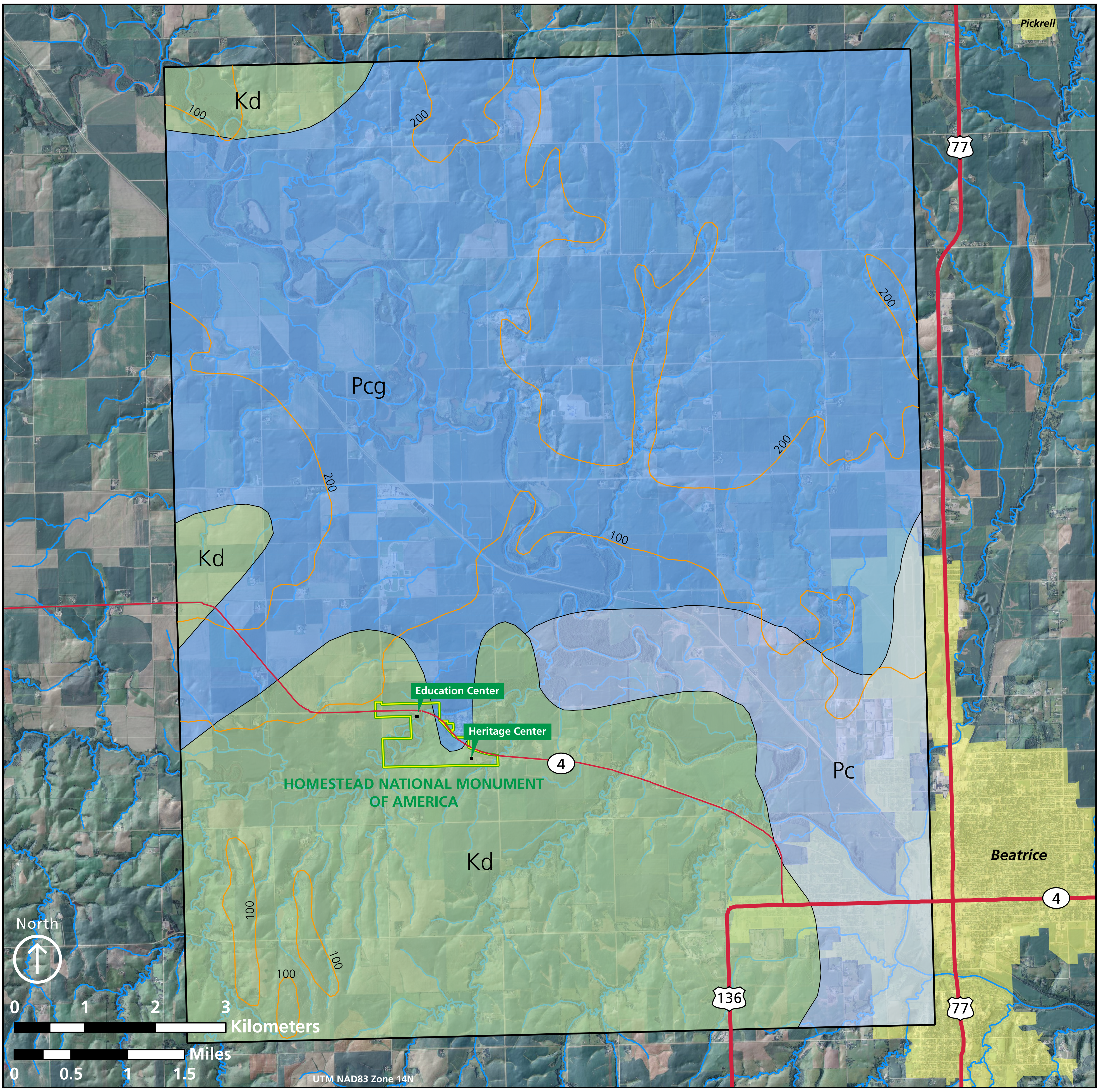
The geologic units listed in the fold-out map unit properties table correspond to the accompanying digital geologic data. Following overall structure of the report, the table highlights the geologic issues, features, and processes associated with each map unit. The units, their relationships, and the series of events the created them are highlighted in the "Geologic History" section. Please refer to the geologic timescale (fig. 20) for the geologic period and age associated with each unit.

### Use Constraints

Graphic and written information provided in this section is not a substitute for site-specific investigations, and ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the overview graphic. Based on the source map scale (1:250,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 127 meters /417 feet (horizontally) of their true location.

Please contact GRI with any questions.

# Overview of Digital Geologic Data for Homestead National Monument of America





**NPS Boundary**

**Quaternary Deposits Thickness**

100 Feet

200 Feet

**Geologic Contacts**

known or certain

map boundary

**Geologic Units**

Kd - Dakota Sandstone

Pc - Chase Group

Pcg - Council Grove Group

This figure is an overview of compiled digital geologic data. It is not a substitute for site-specific investigations. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the figure. Based on the source map scale (1:250,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 127 meters /417 feet (horizontally) of their true location.

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

Burchett, R.R., Dreeszen, V.H., Reed, E.C., and Prichard, G.E. 1972. Bedrock Geologic Map showing thickness of overlying Quaternary Deposits (scale 1:250,000). Miscellaneous Investigations Series Map I-729. U.S. Geological Survey.

Digital geologic data and cross sections for Homestead National Monument of America, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Natural Resource Information Portal: https://nrinfo.nps.gov/Reference.mvc/Search.(Enter "GRI" as the search text and select Homestead National Monument of America from the unit list.)

Produced by the Geologic Resources Inventory

September 2011

# Map Unit Properties Table: Homestead National Monument of America

**The geologic map data for Homestead NM of America only includes three bedrock units: Dakota Formation, Chase Group, and Council Grove Group. Quaternary deposit descriptions were derived from information regarding regional surficial deposits.**

| Age | Unit Name (Symbol) | Features and Description | Erosion Resistance | Suitability for Infrastructure | Hazards | Paleontological Resources | Cultural Resources | Mineral and Potential Economic Resources | Caves and/or Karst | Habitat | Recreation | Geologic Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QUATERNARY (Holocene) | Modern stream alluvium | Clay, silt, and possibly minor sand and pebble deposits. Surficial mapping could provide a more detailed description. | Low. | Floodplain so suitable for trails but not for permanent structures. | Bank erosion along Cub Creek. | None. | Possible early settler and American Indian artifacts transported by streams. | Unknown. Possible sand and gravel. | None. | Riparian woodland: bur oak, silver maple, red elm, hackberry, cottonwood, boxelder. | Woodland Loop Trail. Freeman brick house. Squatter's cabin. | Typical landscape of Great Plains Province. |
| | Terrace and upland slope | Clay, silt, sand, and possibly pebble deposits. Surficial mapping could provide a more detailed description. | Variable. Erodes by lateral stream migration, but vegetation stabilizes the surface. | Good. Contains roads, parking lot, buildings, grave site. | Minor. May provide sediment to Cub Creek during spring flooding. | None. | Potential archeological sites: paleoIndian, American Indian, Euro-American. | Unknown. Possible sand and gravel. | None. | Native and restored tall-grass prairie: big and little bluestem, Indiangrass, switchgrass, goldenrod, fieldpussytoes, leadplant. | Farm Loop Trail; Upland Prairie Loop Trail; Freeman graves; Heritage Center; Education Center; native plants exhibit. | Typical landscape of Great Plains Province. |
| QUATERNARY (Pleistocene) | Loess and glacial outwash deposits | Loess: Light-tan silt. Windblown, homogeneous deposit. Weakly cemented but has the strength to maintain steep slopes. Provides parent material for modern soils.<br><br>Outwash: Sand and gravel deposited by streams flowing from the terminal margin of a glacier. | Loess: High unless disturbed. Outwash: depends on sediment size. | Loess: Low crushing strength requires deep supports for buildings. | May provide sediment to Cub Creek. | Potential for Pleistocene fossil sites. | Potential archeological sites where exposed. | Outwash: sand and gravel. | None. | Not exposed in the monument. | Not exposed in the monument. | Interglacial windblown loess and fluvial deposits from glacial outwash. |
| | Glacial till deposits | Unsorted deposits of clay, silt, sand, pebbles, cobbles, and boulders deposited because of glacial melting. Provides parent material for modern soils. | Variable depending on compaction and grain size. | High. | May provide sediment to Cub Creek. | Potential for Pleistocene fossil sites. | Potential archeological sites where exposed. | Unsorted nature of the deposits limits potential. | None. | Not exposed in the monument. | Not exposed in the monument. | Indicates glacial activity and may mark glacial boundaries. |
| | REGIONAL UNCONFORMITY<br>Approximately 100 million years of geologic history is missing from the stratigraphic record. | | | | | | | | | | | |
| CRETACEOUS (Upper)<br>CRETACEOUS (Lower) | Dakota Formation (Kd) | Light gray, yellowish gray, brownish gray, and reddish brown, fine to coarse grained micaceous sandstone and interbedded sandy carbonaceous shale, lenses of sand cemented by iron oxide and siltstone concretions; lenticular bedding, locally cross-bedded, with scattered chert pebbles. Equivalent to Dakota Group of the Nebraska Geological Survey, which includes (descending order): the Omadi Sandstone, Skull Creek Shale, Fall River Sandstone, Fuson Shale, and Lakota Sandstone. Present in the subsurface, but not exposed in the monument. | High. | Exposed along river banks away from monument boundaries. | None. | Potential for *inoceramus* (clam) shells and vertebrate fossils. Dinosaur tracks found in southeastern Nebraska. | Provided stone for tool manufacture by American Indian groups. | Some shale deposits were used to make brick and tile. | None. | Grasses, weeds, and woodland when exposed along river banks. | Not exposed in the monument. | Represents fluvial-estuarine deposition along the eastern margin of the Western Interior Seaway. |
| PERMIAN (Cisuralian "Lower") | REGIONAL UNCONFORMITY<br>Approximately 125 million years of geologic history is missing from the stratigraphic record. | | | | | | | | | | | |

**The geologic map data for Homestead NM of America only includes three bedrock units: Dakota Formation, Chase Group, and Council Grove Group. Quaternary deposit descriptions were derived from information regarding regional surficial deposits.**

| Age | Unit Name (Symbol) | Features and Description | Erosion Resistance | Suitability for Infrastructure | Hazards | Paleontological Resources | Cultural Resources | Mineral and Potential Economic Resources | Caves and/or Karst | Habitat | Recreation | Geologic Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PERMIAN (Cisuralian "Lower") | Chase Group (Pc) | Light gray to dark gray, yellowish gray to pale yellowish brown limestone and gray, green, red, reddish brown shale. Two thin-bedded to medium-bedded limestones in the upper part are argillaceous, cherty and fossiliferous; two medium-bedded to massive-bedded limestones in the lower part are very cherty, and fossiliferous. Shale is calcareous, arenaceous, fossiliferous, and locally fissile. Equivalent to upper part of Big Blue Series of the Nebraska Geological Survey, which includes (descending order): Nolans Limestone, Odell Shale, Winfield Limestone, Gage Shale, Towanda Limestone, Holmesville Shale, Barneston Limestone, Blue Springs Shale, Kinney Limestone, Wymore Shale, and Wreford Limestone. Present in the subsurface, but not exposed in the monument. | Variable. Limestone is more resistant than shale. | Exposures are typically limited to river-banks or road cuts in eastern Nebraska. | None. | Invertebrate marine fossils and trace fossils (trails, tracks, and burrows). | Chert (flint) was used by American Indian groups. Flint quarries occur southeast of the monument. | Limestone quarried for concrete aggregate, riprap, or agricultural lime. | Potential for dissolution caves and sinkholes in limestone units. | Grasses, weeds, and woodland when exposed along river banks. | Not exposed in the monument. | Overall regressive episode as the shallow sea retreated from the midconti-nent. |
| PERMIAN (Cisuralian "Lower") / PENNSYLVANIAN | Council Grove Group (Pcg) | Gray, green red, reddish brown, or maroon shale and interbedded dark- to light-gray, medium- to thick-bedded limestone. Shale is sandy, calcareous, fossiliferous; locally fissile; several fissile black shale beds are in the lower 23 m (75 ft). Limestone is cherty, argillaceous, very fossiliferous and locally contain shale partings. Equivalent to middle part of the Big Blue Series of Nebraska Geological Survey, which includes (descending order): Speiser Shale, Funston Limestone, Blue Rapids Shale, Crouse Limestone, Easly Creek Shale, Bader Limestone, Stearns Shale, Beattie Limestone, Eskridge Shale, Grenola Limestone, Roca Shale, Red Eagle Limestone, Johnson Shale, and Foraker Limestone. Present in the subsurface; not exposed in the park. | Variable. Limestone is more resistant than shale. | Exposures are typically limited to river-banks or road cuts in eastern Nebraska. | None. | Invertebrate marine fossils and trace fossils (trails, tracks, and burrows). | Chert (flint) was used by American Indian groups. Flint quarries occur southeast of the monument. | Limestone quarried for concrete aggregate, riprap, or agricultural lime. | Potential for dissolution caves and sinkholes in limestone units. | Grasses, weeds, and woodland when exposed along river banks. | Not exposed in the monument. | Cyclothems record sea level rise and fall due to glaciation. Fluvial-estuarine deposits resulting from sea level fluctuations. |

**Map reference: Burchett, R.R., V.H. Dreezen, and E.C. Reed. 1972. Bedrock geologic map showing thickness of overlying Quaternary deposits, Lincoln Quadrangle and part of Nebraska City Quadrangle, Nebraska and Kansas. Miscellaneous Geologic Investigations Map I-729, U.S. Geological Survey, Reston, Virginia, USA. (scale 1:250,000).**

# 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. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).*

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

**accretion.** The gradual addition of new land to old by the deposition of sediment or emplacement of landmasses onto the edge of a continent at a convergent margin.

**active margin.** A tectonically active margin where lithospheric plates come together (convergent boundary), pull apart (divergent boundary) or slide past one another (transform boundary). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism. Compare to "passive margin."

**alluvium.** Stream-deposited sediment.

**alpine glacier.** A glacier occurring in a mountainous region; also called a valley glacier.

**anticline.** A convex-upward ("A" shaped) fold. Older rocks are found in the center.

**arc.** See "volcanic arc" and "magmatic arc."

**arenaceous.** A sediment or sedimentary rock consisting wholly or in part of sand-size fragments, or having a sandy texture or the appearance of sand.

**argillaceous.** A sedimentary rock composed of a substantial amount of clay.

**asthenosphere.** Earth's relatively weak layer or shell below the rigid lithosphere.

**basalt.** A dark-colored, often low-viscosity, extrusive igneous rock.

**basement.** The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

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

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

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

**bedding.** Depositional layering or stratification of sediments.

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

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

**calcareous.** Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

**calcite.** A common rock-forming mineral: $CaCO_3$ (calcium carbonate).

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

**carbonate.** A mineral that has $CO_3^{-2}$ as its essential component (e.g., calcite and aragonite).

**carbonate rock.** A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).

**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).

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

**chert.** A extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz Also called "flint."

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

**clastic.** Describes rock or sediment made of fragments of pre-existing rocks (clasts).

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

**claystone.** Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

**colluvium.** Any heterogeneous mass of soil or rock material accumulated at the bottom of a slope through surface runoff, erosion, or downslope creep.

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

**continental rise.** Gently sloping region from the foot of the continental slope to the deep ocean abyssal plain; it generally has smooth topography but may have submarine canyons.

**continental shelf.** The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths less than 200 m (660 ft).

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

**continental slope.** The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

**convergent boundary.** A plate boundary where two tectonic plates are colliding.

**craton.** The relatively old and geologically stable interior of a continent (also see “continental shield”).
**crossbedding.** Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow 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”).
**cutbank.** A steep, bare slope formed by lateral erosion of a stream.
**deformation**. A general term for the processes of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).
**divergent boundary.** An active boundary where tectonic plates are moving apart (e.g., a spreading ridge or continental rift zone).
**dolomite.** A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).
**dolomitic.** Describes a dolomite-bearing rock, or a rock containing dolomite.
**drainage basin.** The total area from which a stream system receives or drains precipitation runoff.
**drift.** All rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier. Includes unstratified material (till) and stratified deposits (outwash plains and fluvial deposits).
**dune.** A low mound or ridge of sediment, usually sand, deposited by wind.
**eolian.** Describes materials formed, eroded, or deposited by or related to the action of the wind. Also spelled “Aeolian.”
**epicenter.** The point on Earth’s surface that is directly above the focus (location) of an earthquake.
**epicontinental.** Describes a geologic feature situated on the continental shelf or on the continental interior. An “epicontinental sea” is one example.
**estuary.** The seaward end or tidal mouth of a river where freshwater and seawater mix; many estuaries are drowned river valleys caused by sea-level rise (transgression) or coastal subsidence.
**extension.** A type of strain resulting from forces “pulling apart.” Opposite of compression.
**extrusive.** Describes molten (igneous) material that has erupted onto Earth’s surface.
**fault.** A break in rock along which relative movement has occurred between the two sides.
**floodplain.** The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.
**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; also any break in a rock (e.g., crack, joint, or fault).
**geology.** The study of Earth including its origin, history, physical processes, components, and morphology.
**glacial erratic.** Boulders transported by glaciers some distance from their point of origin.
**granite.** An intrusive igneous (plutonic) rock composed primarily of quartz and feldspar. Mica and amphibole minerals are also common. Intrusive equivalent of rhyolite.
**graben.** A down-dropped structural block bounded by steeply dipping, normal faults (also see “horst”).
**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 (also see “graben”).
**igneous.** Refers to a rock or mineral that originated from molten material; one of the three main classes of rocks—igneous, metamorphic, and sedimentary.
**incision.** The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.
**intercalated.** Layered material that exists or is introduced between layers of a different type.
**intrusion.** A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.
**island arc.** A line or arc of volcanic islands formed over and parallel to a subduction zone.
**karst topography.** Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.
**lacustrine.** Pertaining to, produced by, or inhabiting a lake or lakes.
**lava.** Still-molten or solidified magma that has been extruded onto Earth’s surface though a volcano or fissure.
**limestone.** A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.
**lithification.** The conversion of sediment into solid rock.
**lithify.** To change to stone or to petrify; especially to consolidate from a loose sediment to a solid rock through compaction and cementation.
**lithology.** The physical description or classification of a rock or rock unit based on characters such as its color, mineral composition, and grain size.
**loess.** Windblown silt-sized sediment, generally of glacial origin.
**magma.** Molten rock beneath Earth’s surface capable of intrusion and extrusion.
**magma reservoir.** A chamber in the shallow part of the lithosphere from which volcanic materials are derived; the magma has ascended from a deeper source.
**magmatic arc.** Zone of plutons or volcanic rocks formed at a convergent boundary.
**mantle.** The zone of Earth’s interior between the crust and core.

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

**meander.** Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

**mechanical weathering.** The physical breakup of rocks without change in composition. Synonymous with "physical weathering."

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

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

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

**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.

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

**orogeny.** A mountain-building event.

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

**outwash.** Glacial sediment transported and deposited by meltwater streams.

**overbank deposit.** Alluvium deposited outside a stream channel during flooding.

**overburden.** Rock and sediment, not of economic value, and often unconsolidated, that overlies an ore, fuel, or sedimentary deposit.

**oxbow.** A closely looping stream meander resembling the U-shaped frame embracing an ox's neck; having an extreme curvature such that only a neck of land is left between two parts of the stream.

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

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

**paleosol.** A ancient soil layer preserved in the geologic record.

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

**parent material.** Geologic material from which soils form.

**parent rock.** Rock from which soil, sediments, or other rocks are derived.

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

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

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

**pluton (plutonic).** A body of intrusive igneous rock that crystallized at some depth beneath Earth's surface.

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

**porosity.** The proportion of void space (e.g., pores or voids) in a volume of rock or sediment deposit.

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

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

**regolith.** General term for the layer of rock debris, organic matter, and soil that commonly forms the land surface and overlies most bedrock.

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

**relative dating.** Determining the chronological placement of rocks, events, or fossils with respect to the geologic time scale and without reference to their numerical age.

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

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

**rift.** A region of crust where extension results in formation of many related normal faults, often associated with volcanic activity.

**rift valley.** A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

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

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

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

**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.

**seafloor spreading.** The process by which tectonic plates pull apart and new lithosphere is created at oceanic ridges.

**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.

**shoreface.** The zone between the seaward limit of the shore and the more nearly horizontal surface of the offshore zone; typically extends seaward to storm wave depth or about 10 m (32 ft).

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

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

**sinkhole**. A circular depression in a karst area with subterranean drainage and is commonly funnel-shaped.

**slope.** The inclined surface of any geomorphic feature or 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.

**strata.** Tabular or sheet-like masses or distinct layers of rock.

**stratification.** The accumulation, or layering of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

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

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

**stream channel.** A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

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

**striations.** Parallel scratches or lines.

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

**structural geology.** The branch of geology that deals with the description, representation, and analysis of structures, chiefly on a moderate to small scale. The subject is similar to tectonics, but the latter is generally used for the broader regional or historical phases.

**structure.** The attitude and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusions.

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

**suture.** The linear zone where two continental landmasses become joined via obduction.

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

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

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

**terrane.** A large region or group of rocks with similar geology, age, or structural style.

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

**terrigenous.** Derived from the land or a continent.

**theory.** A hypothesis that has been rigorously tested against further observations or experiments to become a generally accepted tenet of science.

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

**till.** Unstratified (not layered) drift, deposited directly by a glacier without reworking by meltwater, and consisting of a mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

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

**trace (fault).** The exposed intersection of a fault with Earth's surface.

**trace fossil.** Tracks, trails, burrows, coprolites (dung), etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

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

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

**unconformity.** A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession.

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

**volcanic.** Describes anything related to volcanoes. Can refer to igneous rock crystallized at or near Earth's surface (e.g., lava).

**volcanic arc.** A commonly curved, linear, zone of volcanoes above a subduction zone.

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

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# Additional References

*This section lists additional references, resources, and web sites that may be of use to resource managers. Web addresses are current as of September 2011.*


#### Geology of National Park Service Areas

National Park Service Geologic Resources Division (Lakewood, Colorado). http://nature.nps.gov/geology/

NPS Geologic Resources Inventory. http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

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NPS Geoscientist-in-the-parks (GIP) internship and guest scientist program. http://www.nature.nps.gov/geology/gip/index.cfm

#### Resource Management/Legislation Documents

NPS 2006 Management Policies (Chapter 4; Natural Resource Management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

NPS-75: Natural Resource Inventory and Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/

Geologic Monitoring Manual
R. Young and L. Norby, editors. Geological Monitoring. Geological Society of America, Boulder, Colorado.
http://nature.nps.gov/geology/monitoring/index.cfm

NPS Technical Information Center (Denver, repository for technical (TIC) documents): http://etic.nps.gov/

#### Geological Survey and Society Websites

Nebraska Geological Survey: http://snr.unl.edu/csd/surveyareas/geology.asp.

U.S. Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geological Institute: http://www.agiweb.org/

Association of American State Geologists: http://www.stategeologists.org/

#### Other Geology/Resource Management Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator").

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.er.usgs.gov

U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

NPS 368/110513, September 2011

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