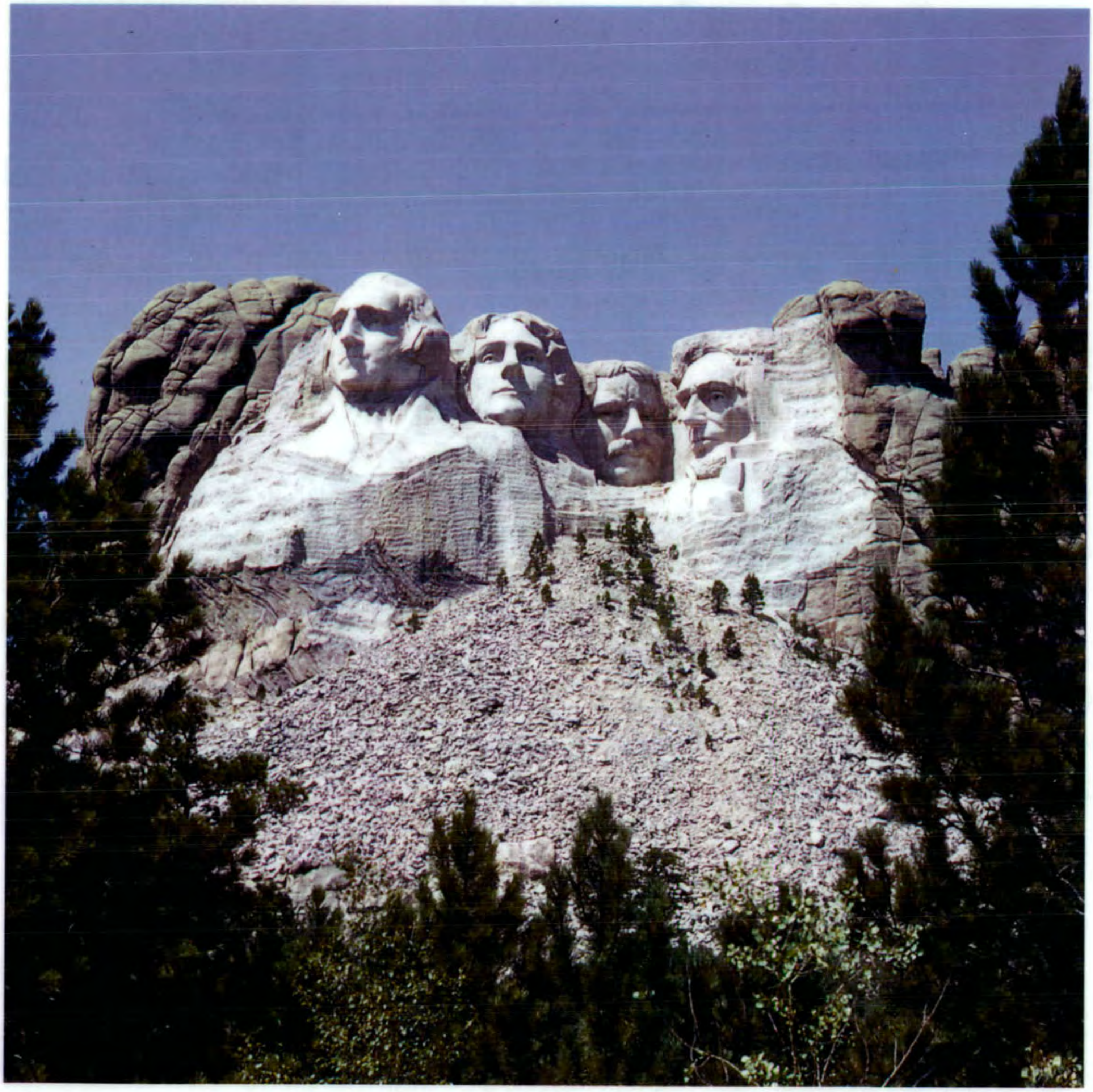
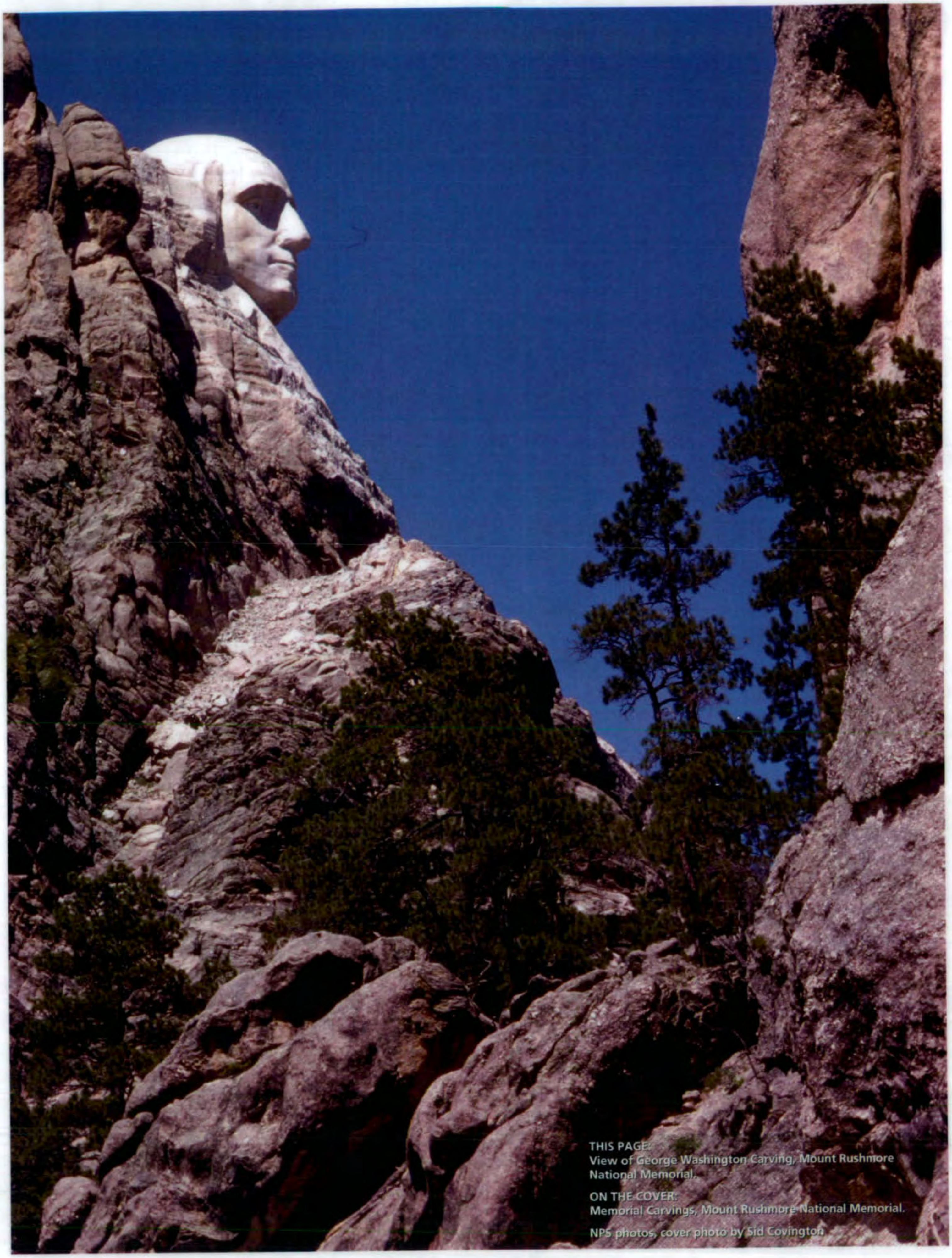
National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Mount Rushmore National Memorial
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/038





THIS PAGE:
View of George Washington Carving, Mount Rushmore National Memorial.

ON THE COVER:
Memorial Carvings, Mount Rushmore National Memorial.

NPS photos, cover photo by Sid Covington

United States Department of the Interior
NATIONAL PARK SERVICE
Geologic Resources Division
P.O. Box 25287
Denver, CO 80225

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IN REPLY REFER TO:

L2360

June 6, 2008

Memorandum

To: Superintendent
Mount Rushmore National Memorial

From: Carol McCoy
Chief–Planning, Evaluation, and Permits Branch

Subject: Geologic Resource Evaluation Report and Digital Geologic Map

The Geologic Resources Division of the Natural Resource Program Center is pleased to provide you with two copies of a summary report on Mount Rushmore National Memorial's geology and associated geologic resource management issues. A CD containing digital geologic map data of the park and an electronic copy of the report is also included. The geologic report reflects the contributions of park staff at a scoping meeting held on June 12-13, 2002 and their comments during the review process. These products have been designed to assist you and your staff in carrying out the resource stewardship mission of your park. Division staff and partners prepared these products as part of our Geologic Resource Evaluation Program.

Funded through the Natural Resource Challenge, the Geologic Resource Evaluation Program is in the process of providing each of the "natural area" parks with the above products which are designed to be user friendly to non-geoscientists. However, utilizing the digital geologic map requires some experience with Geographic Information Systems (GIS). Also enclosed are two copies of Meeting Challenges with Geologic Maps, an American Geologic Institute publication that underscores the value of geologic maps. Finally, we have included an informational brochure about the Geologic Resource Evaluation Program. We recommend that these products be shared with your staff in resource management, interpretation, maintenance, and safety.

The digital geologic map is the cornerstone product of the Geologic Resource Evaluation Program. In an interactive GIS format, the map displays geologic units (e.g., bedrock geology and surficial deposits) as well as the locations of faults and other geologic features in the park and surrounding area. The map is accompanied by a help file that provides explanatory geologic information. In addition, the Map Unit Properties Table in the report has been designed to help park staff interpret and use the geologic map. With basic GIS skills, or with the assistance of a

GIS specialist, park staff can use the map to assist them in a variety of contexts. Possible uses include locating areas with unstable terrain, reconstructing fire history, and identifying environments hospitable to endangered plant species. The electronic files that make up the digital geologic map, along with instructions for use, are contained in the GIS-Data folder on the CD. The CD also contains a printable "snapshot" version of the map.

We are committed to ever improving the quality and usability of our products and welcome your candid suggestions on them. We are available to walk you through the use of these products. Through this process we hope to help you apply these products while gathering feedback on measures we can adopt to further improve them. If you would like to set up an on-site meeting or have any questions regarding Geologic Resource Evaluation products, please contact Bruce Heise, Program Manager of the Geologic Resource Evaluation Program, at 303 969-2017.

cc:
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Mount Rushmore National Memorial

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/038

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

June 2008

U.S. Department of the Interior
Washington, D.C.

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer- reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly- published newsletters.

Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available from the Geologic Resource Evaluation Program website (http://www2.nature.nps.gov/geology/inventory/gre_publications) on the internet, or by sending a request to the address on the back cover.
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Executive Summary

This report accompanies the digital geologic map for Mount Rushmore National Memorial in South Dakota, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

The iconic presidential faces of Mount Rushmore National Memorial are 18 meters (60 ft) high and carved into the Harney Peak Granite (fig. 1). The Harney Peak Granite is the primary component of the Precambrian pluton exposed in the core of the Black Hills in South Dakota. The Black Hills, a prominent 200- by 105-kilometer (125- by 65- mi) elliptical dome, arched upward during the late Cretaceous to early Tertiary Laramide Orogeny. Precambrian mica schists, quartzites, and granite form the core of the Black Hills uplift while younger Paleozoic and Mesozoic sedimentary rocks rim the dome.

The Harney Peak Granite was selected as the medium for the memorial sculptures because it is a massive, uniform granite, relatively free of joints and fractures. The location of the sculptures allows a southeast- facing exposure with optimal lighting. Work began on the sculptures in 1927 and was finished in 1941. The four presidents represented in the memorial are George Washington, Thomas Jefferson, Abraham Lincoln, and Theodore Roosevelt. These men served as president during significant junctures in the development of our nation and remain an inspiration to those who visit Mount Rushmore National Memorial.

Geologic processes have played a significant role in developing the landscape of the Black Hills and in sustaining regional population growth. Tectonic upheaval deformed the rocks into a distinctive dome that drew Native Americans, trappers, and miners to the area from the surrounding plains. The discovery of gold led to a population boom in the late nineteenth century.

Weathering and erosion, coupled with human activities, have resulted in geologic issues that are significant with regard to the management of Mount Rushmore National Memorial. These issues include:

- structural stability and erosion,
- water resources and regional aquifers, and
- impacts from past mines and development in the park.

Joints and fractures in the Harney Peak Granite, together with the processes of weathering and erosion, pose a threat to the sculptures of Mount Rushmore. Cracks in the granite must be continually monitored and repaired to maintain the integrity of the memorial.

The complex geology of the Black Hills affects the hydrology of the region with regard to water quality and quantity. Currently, groundwater pumped from a well drilled into fractured mica schist and granite supplies water to the memorial.

Research from 2000- 2002 by the U.S. Geological Survey documented the hydrology of the region. Groundwater quality from the major aquifers is excellent. Recharge of the aquifers supplies abundant water for the region. The primary aquifers for the Black Hills region are found in the Paleozoic and Mesozoic sedimentary rocks, which surround the core of the Black Hills granitic rocks and are not present at Mount Rushmore National Memorial.

Although mining activity in the Black Hills has been high, mining impacts to the memorial from both historical and modern mining are slight. Nonetheless outstanding reclamation issues exist in the park. Three abandoned mines along with exploration pits are located within monument boundaries. In the past, pegmatite dikes were evaluated for potential sheet mica and potash feldspar. Mica was excavated from a small deposit called Mica Hill from 1943 to 1945. However, valuable mineral deposits were not identified in the memorial, which has been closed to mineral entry since its creation in 1925.

In addition to the sculptures, there are other prominent and distinctive geologic features worth emphasizing in the memorial. Igneous and metamorphic features are exposed throughout the memorial. Metamorphic features include schistosity, a type of foliation that occurs in coarse- grained metamorphic rocks. Large crystals of beryl, garnet, and other minerals associated with igneous and metamorphic rocks are also present throughout the memorial.

Geologic processes actively affect the landscape of the memorial. The fractures and joints present in the Harney Peak Granite are evidence that frost wedging, exfoliation, mineral expansion, and pressure release have weathered the rocks. These processes undermine the stability of the rock and of the memorial sculptures.

Prior to the Laramide uplift of the Black Hills, the Paleozoic and Mesozoic sedimentary strata that now rim the Black Hills covered Precambrian rocks to depths of up to 14 kilometers (9 mi). Intense heat and pressure metamorphosed the Precambrian sediments, and igneous plutons intruded the rock units. Today, this complex geology is exposed in Mount Rushmore National Memorial.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Mount Rushmore National Memorial

Purpose of the Geologic Resources Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

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

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non-geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

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

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www2.nature.nps.gov/geology/inventory/).

Geologic Setting

The 1,278.45-acre Mount Rushmore National Memorial is located in the Black Hills of South Dakota (fig.2). The Black Hills are the core of a prominent uplift associated with the Laramide Orogeny, a mountain-building episode that occurred about 65-45 million years ago (Ma). Topographically detached from the Rocky Mountains by about 193 kilometers (120 miles), the Black Hills are part of the Great Plains physiographic province. Harney Peak is the highest peak in the Black Hills at 2,207 meters (7,242 ft) above sea level. Mount Rushmore is 1,745 meters (5,725 ft) in elevation. The plains surrounding the Black Hills are about 915 to 1,070 meters (3,000-3,500 ft) above sea level (Kiver and Harris 1999). The 18-meter (60-ft) high presidential memorial sculptures at Mount Rushmore are carved in the Harney Peak Granite (fig. 1) (Powell et al. 1973).

The Black Hills form a 200- by 105-kilometer (125- by 65-mi) elliptical dome (also called a doubly plunging anticline) that is elongated in a north-south direction (fig.3) (Kiver and Harris 1999). The forested mountain range in southwest South Dakota and northern Wyoming covers approximately 2 million acres. Erosion has removed Paleozoic and Mesozoic sedimentary rock from the central axis of the dome, exposing the Precambrian rock that makes up the core of the uplift. This exposure extends from near the towns of Lead and Deadwood, SD to just south of Custer, SD.

Precambrian rocks buried to depths of approximately 4,572 meters (15,000 ft) form the crystalline basement in the northern Great Plains (Driscoll et al. 2002). The Precambrian igneous and metamorphic rocks exposed at Mount Rushmore are highly variable in composition and are the oldest geologic units in the region (fig.4). They are composed mostly of sedimentary rocks (graywackes) that have been metamorphosed to schists or of granite. When exposed at the surface, granite is a much denser, more stable rock mica schist, which can be very brittle and unsuitable for sculpting.

In the Black Hills, Paleozoic and Mesozoic sedimentary rocks appear as concentric rings around the Precambrian core (fig. 3). Although originally deposited over the Precambrian rocks as nearly horizontal beds throughout the area, the sedimentary rocks were tilted during the Laramide Orogeny and subsequently eroded from the core of the Black Hills. The remaining strata now dip steeply (≈ 15° to 20°) away from the core of the uplift and flatten out with distance from the Precambrian core to less than 1° (Carter et al. 2002).

Cambrian and Ordovician sandstone, shale, limestone, and dolomite unconformably overlie the Precambrian rocks. Another unconformity separates them from an overlying Devonian shale (fig.4). The Mississippian Madison Limestone is a major aquifer in the region and contains karst features in the Black Hills. The overlying Pennsylvanian and Permian Minnelusa Formation is also a major aquifer unit. Sandstone, shale, siltstone, and carbonate strata of Pennsylvanian and Permian age are overlain by red shale, siltstone, and evaporite deposits of Triassic age. Jurassic rocks are predominantly carbonate, shale, and calcareous shale. The Lower Cretaceous Inyan Kara Group forms another regional aquifer. Tertiary igneous and sedimentary rocks of the White River Group overlie the Cretaceous sandstones, shales, and minor carbonates. The youngest geologic units in the area are Quaternary alluvial deposits, which fill major drainages.

Rivers flow radially from the Precambrian core across hogbacks and cuestas on the western slopes. Rivers also flow through the Red Valley, a scenic valley carved into soft Triassic shales and red sandstones of the Spearfish Formation (Kiver and Harris 1999). The Red Valley runs parallel to the adjacent hogbacks and rings the Black Hills dome (fig. 3). Most streams loose all or part of their flow becoming sinking streams as they cross exposures of the Madison Limestone and Minnelusa Formation. Dissolution of the limestone in these units has created underground conduits that funnel the stream flow.

About 75% of the memorial is occupied by three topographic basins: Starling basin, Lafferty Gulch basin, and East Boundary basin. While separated by drainage divides on the surface, the basins may be hydraulically connected in the subsurface (Powell et al. 1973). Starling basin drains the west and southwestern part of the memorial, Lafferty Gulch basin drains the central and northern part, and East Boundary basin drains the northeastern section of Mount Rushmore National Memorial.

Large, north–trending, granite sills, some of which are several hundred feet thick, form the more prominent hills and mountains in the memorial. About 1,700 Ma the large magma body that later crystallized into the Harney Peak Granite batholith squeezed and melted its way into the surrounding metamorphic rocks (Kiver and Harris 1999). An eastward extending sill composed of Harney Peak Granite was injected into the schists in the Mount Rushmore area. Very coarse- grained granitic pegmatite sills and dikes are also common in the memorial (Powell et al. 1973). Light- colored pegmatite dikes can be seen extending through the sculpture at Mount Rushmore. The dips of the foliation and remnant bedding in these rocks increase from about 30° near the west border of the memorial to about 65° near the east border (Powell et al. 1973).

Numerous smaller structures–folds, faults, domes, and monoclines–also occur in the Black Hills. The deformation and uplift associated with the Cretaceous-Tertiary Laramide Orogeny produced deep faults and fractures that acted as conduits for magma. Igneous intrusions were emplaced along those conduits on the northern flanks of the Black Hills uplift during the Tertiary Period. The intrusions formed sills, dikes, laccoliths, and small stocks of various compositions. These igneous features include the gray to greenish- gray phonolite of Devils Tower; tan to reddish- brown, iron-stained trachyte in the Bear Lodge Mountains; dark- gray to greenish- gray latite with large crystals of andesine, oligoclase, biotite, hornblende, and sphene, and light-tan to light- gray rhyolite that forms laccoliths and stocks near the towns of Deadwood, Lead, Sundance, Sturgis, and Galena (DeWitt et al. 1989).

The area around Mount Rushmore was not glaciated during the Pleistocene Ice Ages (Kiver and Harris 1999). The present rugged landscape in the core of the range is the result of differential weathering and erosion, mostly by running water.

The continental climate of the Black Hills is characterized by generally low precipitation, hot summers, and cold winters, but also by extreme variations in both precipitation and temperature (Driscoll et al. 2002). As a prominent landform amidst the surrounding plains, the geography and topography of the Black Hills uplift influences spatial patterns of precipitation in the area, especially in the high- altitude areas near Harney Peak. Areas of relatively low precipitation occur in the lower altitudes. However, in most areas exceeding 1,800 meters (6,000 ft) above sea level, average annual precipitation is in excess of 48 centimeters (19 in). Most of the precipitation occurs during May and June, with the smallest amounts November through February.

Park History

Native Americans did not live in the Black Hills, although the Lakota made frequent visits to the area (Powell et al 1973). They called the Black Hills "Paha Sapa" meaning hills that are black. Members of the Francis and Louis-Joseph Verendrye expedition in 1743 may have been the first Europeans to visit the Black Hills. Fur trappers and military expeditions traversed the area in later years, but the area was officially closed to settlers because the land was part of the Great Sioux Reservation established in the Fort Laramie Treaty of 1868.

In 1874, General G.A. Custer led a party into the Black Hills and confirmed the presence of gold. In violation of treaty and Federal law, miners flocked to the area by the thousands. The resulting conflict led to the Black Hills War in which Tatanka Iyotake (Sitting Bull), Tasunka Witko (Crazy Horse), and their people waged war against the intruders and the United States. The war ended with a new treaty in 1877 in which the Sioux were forced to relinquish a strip of land along the western border of Dakota Territory 80 kilometers (50 mi) wide, plus all land west of the Cheyenne and Belle Fourche Rivers, including all of the Black Hills in modern South Dakota.

The first railroad reached the area in 1885 and various communities began promoting tourism. Devils Tower in Wyoming, the nation's first National Monument, was established in the northwestern part of the Black Hills in 1906.

In 1924, Doane Robinson, then State Historian of South Dakota, had the idea of sculpting massive figures on some of the granite spires, or pinnacles, known as the Needles in the area south of Harney Peak. He contacted the well- known American artist, Gutzon Borglum, with the idea of creating a monument commemorating western heroes. Instead, Borglum urged that the figures be of nationally recognized historic individuals.

Legislation to permit the sculpting in the Black Hills National Forest was passed by Congress in 1925 with the help of United States Senator Peter Norbeck and Congressman William Williamson, both of South Dakota. Mount Rushmore, named in 1885 for Charles E. Rushmore, a New York lawyer, was selected because its southeast face had the proper lighting and the monolithic granite mass was relatively free of joints and fractures and was large enough for the planned sculpture (Powell et al. 1973; Kiver and Harris 1999).

Work began on August 10, 1927, the day President Calvin Coolidge dedicated the memorial. Due to a lack of dependable funding, sculpting continued intermittently for 14 years. After Borglum's death in 1941, work ceased for about 8 months. His son, Lincoln, then became sculptor- in- charge. Over 400,000 tons of rocks were excavated during construction. The cost to complete the memorial was slightly less than one million dollars, about thirteen million dollars today (http://www.measuringworth.com, accessed June 28, 2007).

Four presidents – George Washington, Thomas Jefferson, Abraham Lincoln, and Theodore Roosevelt – were selected for the memorial because of the important roles they played in the history of the United States. Washington's head was dedicated on July 4, 1930, by Doane Robinson. President Franklin D. Roosevelt dedicated the Jefferson head on August 30, 1936. The Lincoln head was dedicated by Senator Edward R. Burke of Nebraska on September 17, 1937. Roosevelt's head was dedicated on July 2, 1939, by Governor Harlan J. Bushfield of South Dakota and William S. Hart, the silent- screen star.

The original plan was to sculpt the figures from the waist up showing their hands and period clothing. This concept was abandoned during World War II and work on the memorial ended in October, 1941 (Powell et al. 1973; Kiver and Harris 1999).

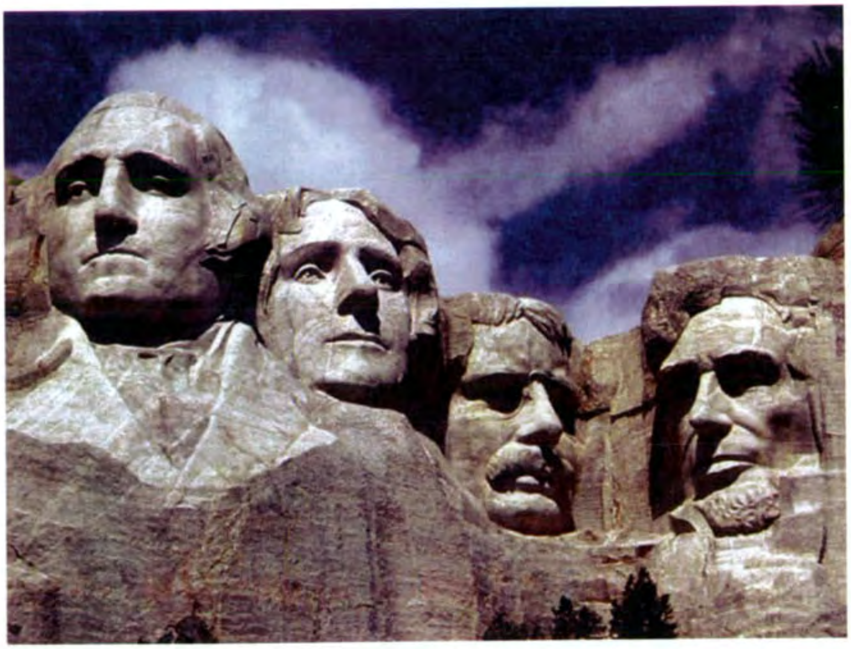

Figure 1. Presidential faces of Mount Rushmore National Memorial carved into Harney Peak granite. From http://bensguide.gpo.gov/ images /symbols/mountrushmore.jpg (accessed February 8, 2006).

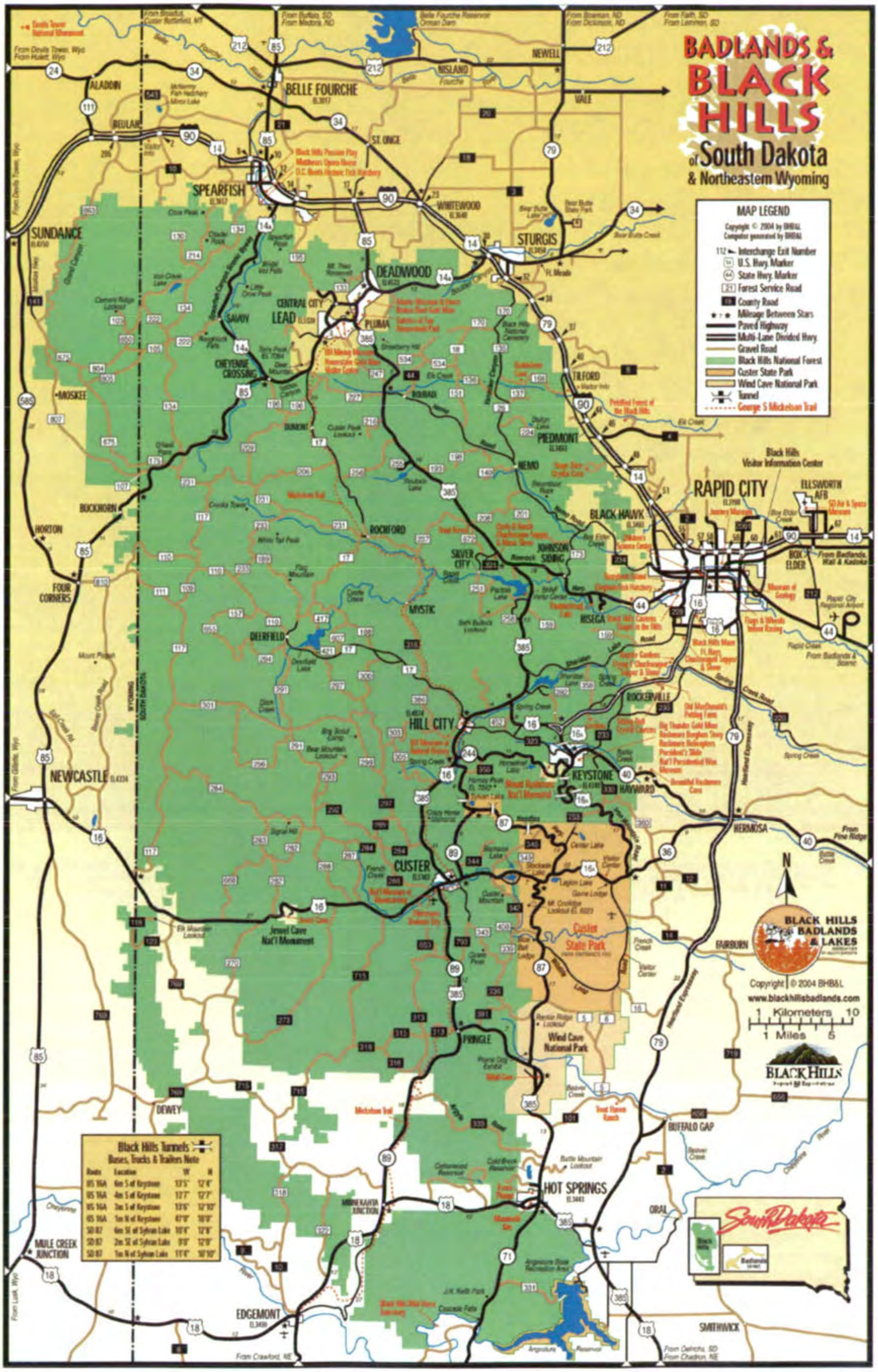

Figure 2. Regional location of Mount Rushmore National Memorial in the Black Hills area. From http://www.nps.gov/moru/planyourvisit/maps.htm (accessed June 26, 2007).

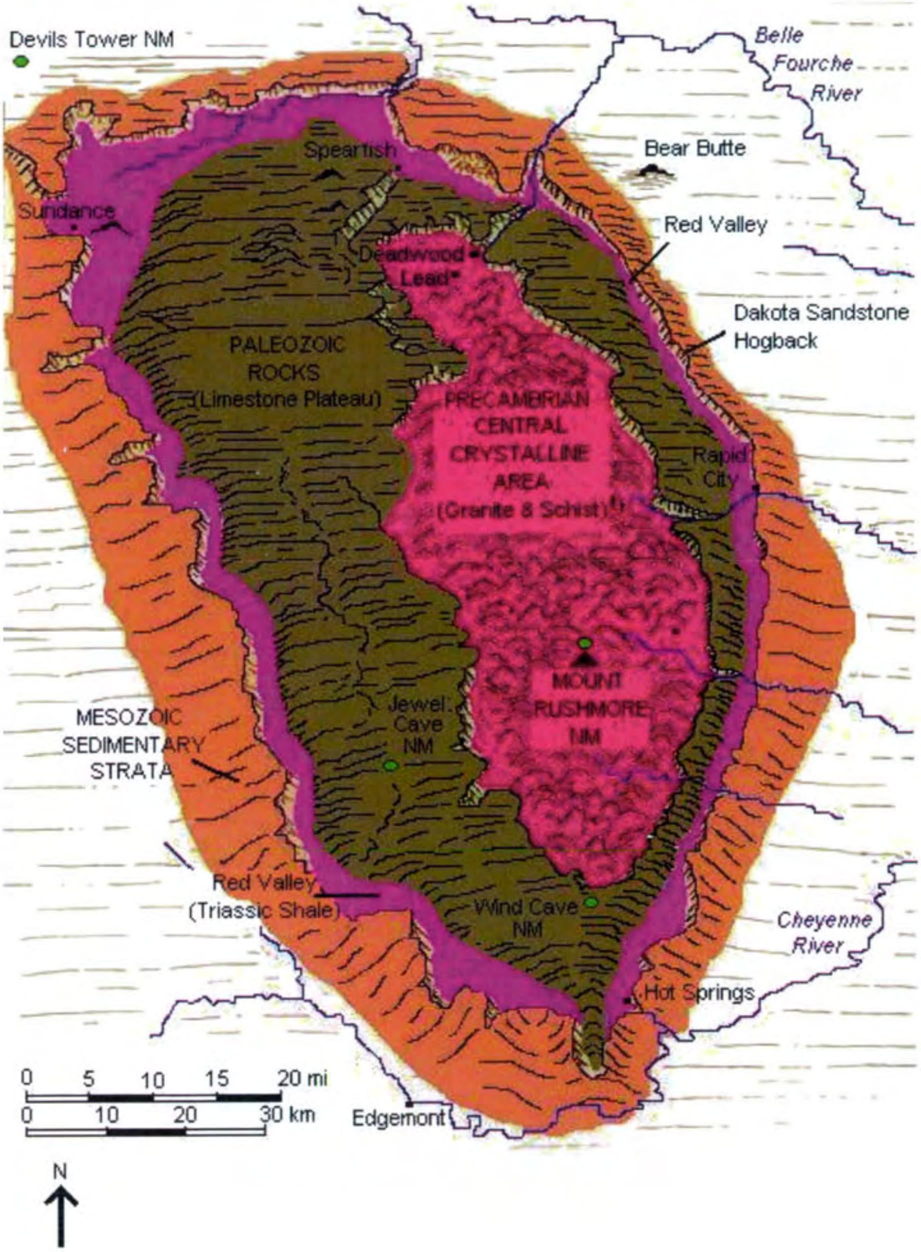

Figure 3. Diagram of the Black Hills dome showing progressively younger sedimentary rock layers ringing the central Precambrian core. Mount Rushmore National Memorial lies within the central crystalline core; Jewel Cave National Monument and Wind Cave National Monument lie within Paleozoic limestone; and Devils Tower is a Tertiary feature. Modified from Strahler, 1960.

ERA	Period	Stratigraphic Unit	Thickness (feet)	Brief Description
CENOZOIC	Quaternary	Undifferentiated alluvium & colluvium	0-50	Sand, gravel, boulders, clay
	Tertiary	White River Group	0-300	Clay, channel sandstone
		Igneous Rocks		Rhyolite, latite, trachyte,
MESOZOIC	Cretaceous	Pierre Shale	1200-2700	Dark shale; limestone lenses
		Niobrara Formation	80-300	Impure chalk, calcareous shale
		Carlile Shale	350-750	Shale with sandstone layers
		Greenhorn Formation	225-380	Dark shale, impure limestone
		Belle Forche Shale	150-850	Gray shale, bentonite
		Mowry Shale	125-230	Siliceous shale, bentonite
		Muddy Sandstone/ Newcastle Sandstone	0-150	Brown, yellow, and white sandstone
		Skull Creek Shale	150-270	Dark siliceous shale
		Inyan Kara Group		
		Fall River Fm.	10-200	Sandstone
		Lakota Fm.	35-700	Sandstone, congl., siltst., coal
	Jurassic	Morrison Formation	0-220	Shale, thin sandstone
		Unkpapa Sandstone	0-225	Massive sandstone
		Sundance Formation	250-450	Shale, glauconitic ss, ls.
		Gypsum Spring Fm	0-45	Siltstone, gypsum, limestone
	Triassic	Spearfish Formation	375-800	Silty shale, red sandstone, siltstone with gypsum, thin limestone beds
PALEOZOIC	Permian	Minnekahta Limestone	25-65	Laminated limestone
		Opeche Shale	25-150	Red shale and sandstone
	Pennsylvanian	Minnelusa Formation	375-1175	Cross-bedded sandstone, limestone, anhydrite, shale
	Mississippian	Madison (Pahasapa) Limestone	<200-1000	Massive limestone, dolomite, caves in upper part
	Devonian	Englewood Formation	30-60	Limestone, local shale at base
	Ordovician	Whitewood (Red River) Formation	0-235	Buff dolomite and limestone
		Winnipeg Formation	0-150	Green shale with siltstone
	Cambrian	Deadwood Formation	0-500	Massive to thin-bedded sandstone, conglomerate, glauconitic shale
PRECAMBRIAN	Proterozoic	Harney Peak Granite		Layered granite, pegmatite granite, and pegmatite.
		Undifferentiated igneous & metamorphic rocks		Schist, slate, quartzite, iron-formation and arkosic grit; intruded by diorite, granite. pegmatite
PRECAMBRIAN	Archean			

Figure 4. Stratigraphic column for the Black Hills area. Units present in the Mount Rushmore area are shown in red. Modified from Driscoll and others, 2002.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Mount Rushmore National Memorial on June 12- 13, 2002. The following section synthesizes geologic issues identified during the scoping meeting, from discussions with scientists knowledgeable about the park, and from literature research. These issues may require attention from resource managers.

Structural stability and erosion, water resources, and mining impacts are geologic issues relevant to Mount Rushmore National Memorial. Construction projects have also led to increased erosion in some areas (Wenk 2000).

Structural Stability and Erosion

The Harney Peak Granite was deeply fractured during regional uplift associated with the Laramide Orogeny. The pinnacles and vertical slabs of rock that characterize the Needles area formed by weathering of the exposed, fractured, and weakened rock. However, the thick granite sill at Mount Rushmore has fewer joints and fractures than elsewhere.

Wind, precipitation (rain and snow), chemical weathering, and frost wedging are the primary erosive forces acting on the rocks in Mount Rushmore today. The granite in Mount Rushmore National Memorial is relatively resistant to weathering and erosion. Erosion of the granite faces has been estimated at a rate of only 0.1 inch per 1,000 years (Sever 2004; NPS 2006).

Frost wedging is a process wherein water that has percolated into minute cracks in the granite freezes, and as it freezes, the ice expands and further opens fractures in the rock. Frost wedging poses a substantial threat to Mount Rushmore (Sever 2004). To combat this threat, the cracks on the memorial are caulked with a silicon solution that prevents water from entering the cracks. Every year a maintenance crew inspects the memorial and repairs cracks found in the faces (Sever 2004).

Mount Rushmore National Memorial now has a "rock block monitoring" system that has been installed to detect temperature and any movement of the granite. A "rock block" is a distinct section of the Harney Peak granite defined by pegmatite intrusions and fractures in the granite. Twenty- one rock blocks have been identified on the sculpted faces with some rock blocks acting as "potential keyblocks." Potential keyblocks must move before any other rock block can move. Instruments attached directly to the sculpture measure displacements of less than 0.0001 inches. Four times each day measurements are transferred directly into a central data acquisition computer. Since the installation of the rock block monitoring system, only slight shifting has occurred due to temperature changes. Interpretation of the accumulated data suggests that no immediate danger exists to the sculpture (http://www.nps.gov/archive/moru/park_history/carving_hist/mem_maint.htm, accessed July 3, 2007).

Water Resources

The average annual precipitation in the Black Hills is about 46 cm (18 inches). For comparison, Death Valley National Park receives about 4.9 cm (1.92 inches) of precipitation annually and the Hoh Rainforest of Olympic National Park receives 338 cm (133 inches) annually (NPS 2006).

Groundwater is an important source of water in this region and the complex geologic history of the Black Hills is responsible for an equally complex hydrologic system. The Precambrian metamorphic and igneous rocks generally have low permeability, however local aquifers occur where the crystalline core has been extensively fractured and weathered.

Major aquifers occur in the permeable sedimentary rocks that ring the core of the Black Hills. These include the Deadwood Formation, Madison Limestone, Minnelusa Formation, Minnekahta Limestone, and Inyan Kara Group, with the Madison and Minnelusa Formations most heavily used (fig. 4). These strata serve as excellent aquifers and are tapped extensively for water in and beyond the Black Hills. Karst features such as sinkholes, water- loss zones in streams, collapse features, solution cavities, and caves develop in limestones such as the Madison. Additionally, local shallow aquifers are found in alluvial deposits along streams (Carter et al. 2002).

Layers of shale, siltstone, and gypsum act as barriers to the vertical flow of groundwater and separate the major aquifers in the region. The bedding of these confining layers and aquifers generally dips away from the flanks of the Black Hills, and thus in general, groundwater flows away from the central core of the Black Hills.

In the memorial groundwater is recharged by precipitation that infiltrates into the fractured mica schist. The extensive slope- stabilizing tree and plant cover helps control runoff and increases infiltration to the subsurface. Of the three main drainage basins in the memorial, groundwater is most prevalent in Lafferty Gulch basin (Powell et al. 1973).

Mica schist and granite are relatively impermeable and would yield little or no groundwater if they did not have extensive fractures and joints. Seeps and springs release groundwater from fractures in the rock. The water wells drilled in Mount Rushmore National Monument, including the present well, are located along joint trends (Nonnast 2002). Joint trends tend to be oriented to the northwest from about 25°- 55° and to the northeast from about 45°- 65°.

Until 1967, the total water supply for Mount Rushmore was obtained from springs. Increasing visitation required additional water sources so two wells were drilled in Lafferty Gulch basin and East Boundary basin. The well in Lafferty Gulch basin (well 3 of Powell and others, 1973) was drilled into fractured mica schist and granite and is 61 meters (200 ft) deep. The East Boundary basin well (well 4 of Powell and others, 1973), also in mica schist and granite, is 152 meters (500 ft) deep. In 1968, well 3 was connected to the water distribution system at Mount Rushmore National Memorial and became the primary water source for the memorial (NPS 2003; see Plate 1 of Powell et al. 1973 for well locations). Today recycled effluent helps to maintain the memorial's landscaping, is used to clean parking lots and vehicles, and may help with structural and wildfire suppression and mitigation.

In places, granite or pegmatite sills act as barriers to down gradient groundwater flow. The localized accumulation of groundwater in the vicinity of well 3 is probably due to a confining pegmatite or granite sill. Water from well 3 flows even when it is not being pumped. Each year about 7 million gallons of water are pumped from the well, with most water being pumped between April and September. Currently, the NPS holds three water rights that provide water for the memorial: well 3, Mount Rushmore springs, and Grizzly Bear spring (NPS 2003).

Population growth, resource development, and periodic droughts have the potential to adversely affect the quantity, quality, and availability of water within the Black Hills area and Mount Rushmore National Memorial (USGS 2002; Driscoll et al 2002). Water quality may also be degraded from mining activity outside the park, urbanization, irrigation, forest management practices, and recreational development.

To address the water resources of the Black Hills, a long-term investigation assessing the quantity, quality, and distribution of surface and groundwater resources of the Black Hills area was initiated in 1990 and completed in 2002. The study was a cooperative effort between the U.S. Geological Survey (USGS), the South Dakota Department of Environment and Natural Resources (DENR), and the West Dakota Water Development District. Detailed results of the study have been published in several reports for the Black Hills Hydrology Study, some of which are cited in this section. Additional information is available in two summary reports for the study by Carter and others (2002) and Driscoll and others (2002). These reports are available through the USGS or on- line at http://pubs. usgs.gov (accessed 9 Feb. 2006).

Some of the study's findings include:

- The Madison and Minnelusa aquifers have a large recharge capacity and dominate the groundwater budgets for the Black Hills area.
- Water levels do not decline from groundwater withdrawals in any of the bedrock aquifers.
- The Madison and Minnelusa aquifers are hydraulically connected at some locations.
- Artesian spring flow probably accounts for the largest percentage of groundwater leakage that occurs. Artesian spring flow is the single largest discharge component for the Madison and Minnelusa aquifers,. accounting for 38% of the total discharge from these aquifers.
- Large- scale development of the Madison and Minnelusa aquifers has the potential to impact the complex hydrologic system in the Black Hills area that controls interactions between groundwater levels and artesian flow.
- Streams provide an important source of recharge to the Madison and Minnelusa aquifers. Most streams generally loose all or part of their water when crossing outcrops of the Madison Limestone and Minnelusa Formation.
- Very few health- related limitations for substances associated with radioactive decay, such as radon and uranium, exist for Black Hills groundwater (Williamson and Carter, 2001). Arsenic was detected in a few samples from the Minnelusa aquifer.
- Most streams in the Black Hills area generally meet Environmental Protection Agency (EPA) water quality standards for designated beneficial uses. Exceptions are some streams in western South Dakota that are outside the Black Hills and which occasionally fail to meet EPA standards for temperature and dissolved oxygen during low- flow conditions.
- Human influences that may potentially degrade groundwater quality include development on and up-gradient of aquifer recharge areas and septic tanks.
- Human activities that may potentially degrade surface water quality include various land- use practices such as large- scale mining activities (increased sediment loading into surface streams and subsequent acid mine drainage), agricultural practices, and urban and suburban development.
- Of the average annual precipitation in the area, about 91.6% is returned to the atmosphere via evapotranspiration, about 3.5 % recharges aquifers, and about 4.9% is runoff from the land surface.
- Annual aquifer recharge rates were highly variable, ranging from about 62 cubic feet per second in 1936 to about 847 cubic feet per second in 1995.
- Total consumptive use from both groundwater and surface water was estimated as 218 cubic feet per second.

Mining Impacts

Wilson and DeWitt (1995) mapped 1,084 mines and prospects in 85 metallic mineral districts in the Black Hills. Three mines mapped are in Mount Rushmore National Memorial: (1) the Big Shot mine in section 7, Township 2 South, Range 6 East; (2) an unnamed mine in the same section; and (3) the Mica mine, a small deposit at Mica Hill in section 18, Township 2 South, Range 6 East.

Mineral deposits in the Black Hills range in age from Early Proterozoic or Late Archean to Quaternary. Potassium feldspar was mined from the pegmatite at the Big Shot mine. Most of the feldspar crystals in the pegmatites are intergrown with other minerals making them uneconomical to produce (Powell et al. 1973). From 1943 to 1945, sheet mica was excavated from Early Proterozoic pegmatite at the Mica mine.

Small prospect pits scattered across the eastern half of Mount Rushmore National Memorial indicate a history of exploration and prospecting (DeWitt et al. 1988). Road construction material was removed from two pits in mica schist, and flagstone used in the early construction of the memorial was quarried from two other pits.

Prospect pits in pegmatite dikes were excavated primarily for sheet mica and potash feldspar (Powell et al. 1973; Wilson and DeWitt 1995). The other prospect pits in the area were probably excavated for gold (Powell et al. 1973; Wilson and DeWitt 1995), but all have proven uneconomic (Powell et al. 1973). All of the prospect pits are in the widest part of the Early Proterozoic metamorphosed iron- formation, which is unit Xif on the Map Unit Properties Table, and in hornblende schist where small aggregates of sulfide minerals were observed.

Disturbed Lands

Since 1925, development within the national memorial has occurred in order to provide for visitor access and services (Wenk 2000). These activities have led to increased erosion in some areas. Major road construction completed in 1990 on South Dakota Highway 244 generated several areas of erosion along the highway. Additional areas of disturbance resulted from major construction of visitor use and parking facilities completed in 1998.

A rehabilitation plan during the fiscal years 2001- 2005 was designed to include the following (Wenk 2000):

- Inventory and map disturbed sites,
- Replace lost top soil in areas worn to bedrock, and
- Revegetate with native plants.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Mount Rushmore National Memorial.

Igneous and Metamorphic Features

The presidential faces at Mount Rushmore are carved in an exposure of the Harney Peak Granite. The large granitic sills in the memorial are parallel or subparallel to the remnant bedding planes or metamorphic foliation of the surrounding rock. This is visible at Mount Rushmore where schist is exposed below the sculpture, and the granite contact is parallel to the foliation in the metamorphic rocks. Most of the sills are less than 91 meters (300 ft) thick, but the sill south of Doane Mountain may be as much as 300 meters (1,000 ft) thick. Smaller feeder sills and dikes connect all the large sills to each other and to the batholith. Sills are more abundant than dikes in Mount Rushmore except in the northeast part of the memorial where most of the pegmatites are northeast striking vertical dikes (Powell et al. 1973). A single pegmatite may appear as a dike in one place and a sill in another.

The foliation and remnant bedding in the metamorphic rocks are approximately parallel. In Mount Rushmore National Memorial, the strike is between N20°E and N20°W, and the dip is 35°- 55° east. From Mount Rushmore to the northwest corner of the memorial, most dips are between 20° and 45° east and northeast, and most strikes are between due north and N80°W (Powell et al. 1973). A few folds have been found along the contacts between mica schist units and quartzite, but exposures are so sparse that structural data are inconclusive.

Minerals

A variety of minerals are present in the metamorphic and igneous rocks exposed in Mount Rushmore National Memorial. Quartz, biotite mica, and muscovite mica are the primary minerals in the metamorphic rocks. Accessory minerals include plagioclase, garnet, tourmaline, sillimanite, staurolite, actinolite, and grunerite. The grain size of the minerals in the metamorphic rocks is quite small, ranging from 0.3- 1.0 millimeters (0.01 –0.04 in) in length, but there are exceptions. Grunerite, an amphibole found in the metamorphosed Early Proterozoic iron formations, occasionally forms rosettes that are 2 millimeters (0.08 in) in diameter. Red garnet crystals also may grow to 2 millimeters (0.08 in) in length and some hornblende crystals are up to 3 millimeters (0.12 in) in length (Powell et al. 1973).

Crystals are larger in the Harney Peak Granite and the many pegmatites present throughout the Black Hills. The granite is composed primarily of potassium feldspar, albite sodium feldspar, and quartz, with crystals that are approximately 3 mm (0.12 in) long. However, perthite crystals (K, Na feldspar that forms strings or laths) in the granite may be several centimeters to several meters long (Powell et al. 1973). The Mount Rushmore pegmatites are composed primarily of quartz, the feldspars albite and microcline, and muscovite mica. Some common accessory minerals in the pegmatite include tourmaline, biotite, garnet, and beryl. One bright- green beryl crystal measuring 33 centimeters (13 in) in length was discovered in a 0.6- 1.2 meter thick (2.3- 4.6- ft) perthite and quartz-filled fracture exposed on the sculpture between the figures of Lincoln and Roosevelt. A red- brown garnet crystal 7.6 centimeters (3 in) in diameter was found in the same fracture (Powell et al. 1973). However, federal mineral development is prohibited in the park along with the collection of mineral specimens with out a scientific permit.

Cave and Karst Features

No known caves exist in Mount Rushmore National Memorial, but cave and karst features are common in the Mississippian Madison Limestone elsewhere in the Black Hills. The Madison and other sedimentary strata, including other limestone formations, surround the metamorphic and igneous core of the Black Hills (fig. 3). Two of the largest caves in the area are National Park Service units - Wind Cave National Park and Jewel Cave National Monument. In addition to solution features such as caves, sinking streams, and dissolution holes, the Madison also commonly has collapse features and sinkholes.

Frost Wedging

Frost wedging, the freeze and thaw cycle, is a primary erosive force at the memorial. Over time, frost- wedging of small fractures and joints can exert intense pressure on the granite, wedging blocks of rock apart. Frost-wedging plays a significant role in weathering the rock that forms the sculptures, requiring that the fractures in the rock be monitored and stabilized.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Mount Rushmore National Memorial. The accompanying table is highly generalized and is provided for background purposes only. Ground- disturbing activities should not be permitted or denied on the basis of information in this table. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.

This section explains specific properties associated with different rock units that the park should be aware of when making resource management decisions. Geologic features and processes often occur in, or can be restricted to, a particular stratigraphic unit (group, formation, or member). The geologic units in the following table and their geologic features and properties correspond to the units found in the accompanying digital geologic data. Source data for the GRE digital geologic map are from:

DeWitt, Ed, 2004, Geologic map of the Mount Rushmore and Rapid City 60' x 60' Quadrangle, South Dakota, USGS unpublished mylar maps scale 1:100,000.

The following table presents a list of units exposed in Mount Rushmore National Memorial and features for each map unit. This table includes several properties specific to each unit present in the stratigraphic column including: age, map unit name and symbol, unit description, topographic expression, resistance to erosion, hazards, cultural resources, mineral occurrence, and suitability for development.

Map Unit Properties Table

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Erosion Resistance	Hazards	Cultural Resources	Mineral Occurrence	Suitability for Development	Other
QUATERNARY	Alluvial deposits (Qal)	Holocene & Pleistocene. Stream- laid deposits of mud, silt, sand, & gravel; maximum thickness 10 m	Valley floodplains	Low	Flash flooding	Unknown	Potential placer deposits	Low. Located in floodplain	N/A
	Colluvium or talus (Qc)	Holocene & Pleistocene. Angular blocks & debris masking bedrock; many small deposits not shown; thickness as much as 10 m	Poorly sorted deposits at base of slopes	Variable	Unknown	None documented	None documented	Low. Unstable deposits	N/A
	Terrace gravel & alluvial fan deposits (Qt)	Pleistocene. Gravel, sand, silt soil; some higher elevation terrace deposits could be of Pliocene age; maximum thickness about 30 m	Relatively flat (terrace) or fan- shaped landforms	Variable. Some stabilization by plant roots	None documented	Unknown	Unknown	Limited exposures in memorial	Camel *Gigantocamelus* found S of Rapid City
TERTIARY	White River Group (Tw)	Oligocene & Upper Eocene. Silty claystone & poorly indurated sandstone, arkose, & conglomerate; gravel at higher elevations; thickness as much as 120 m	Not exposed in memorial	Moderate	Potential rockfall	Unknown	Unknown	Not exposed in memorial	N/A
MISSISSIPPIAN	Madison (Pahasapa) Limestone (Mp)	Lower Mississippian. Mainly thick- bedded dolomitic limestone; bluish limestone in uppermost part; includes Englewood Limestone in areas of steep terrane; thickness 80- 210 m	Not exposed in memorial	High	Rockfall	Unknown	Unknown	Not exposed in memorial	Cave (karst) features
ORDOVICIAN & CAMBRIAN	Deadwood Formation (OCd)	Lower Ordovician & Upper Cambrian. Glauconitic sandstone, shale, siltstone, & conglomerate; thickness 0- 200 m	Not exposed in memorial	Variable	Rockfall	Unknown	Unknown	Not exposed in memorial	N/A
PRECAMBRIANPROTEROZOIC (542-2500 Ma)	Harney Peak Granite (Xh)	Proterozoic. Layered granite, pegmatitic granite, & pegmatite. Leucocratic, peraluminous, plagioclase- microcline- quartz- muscovite granite. Tourmaline & biotite common, but biotite mainly in inner part of central mass. Central mass consists of hundreds of intrusions. More than 24,000 separate bodies of pegmatite & granite are known between the central mass & the line defining the outer limit of pegmatite & granite bodies. Several hundred zoned pegmatites in a peripheral zone contain deposits of feldspar, mica, beryl & other rare- element minerals. Emplacement age of 1,715±3 Ma for the main granite based on concordant U- Pb date for monazite, but the emplacement of some pegmatite bodies may have continued for ~10 Ma.	Pinnacles & near vertical, tabular rock bodies in Needles area; forms a thick sill at Mount Rushmore National Memorial	High	Potential rockfall	Rock into which presidents' faces are sculpted	Tourmaline, biotite, feldspar, mica, beryl and other rare- element minerals such as spodument; fractures contain groundwater	High but local areas may contain deep fractures	Famous for the 60- ft high faces of four important U.S. presidents
	Metagabbro (Xgby, Xgb)	Xgby: Early Proterozoic. Younger metagabbro. Alkalic gabbro; differentiated sill intruding quartzite & pelite; sills & dikes spatially distributed with or near shale, tuff, & volcaniclastic rock Xgb: Early Proterozoic. Amphibolite, actinolite schist, or greenstone; well foliated; sill- like bodies; at least 2 distinct types of probable different ages; not lithologically distinct.	Not exposed in memorial	High	Potential rockfall	None documented	None documented	Limited areal extent; not exposed in memorial.	Radiometric age: 1,880- 2,200 Ma
	Metagraywacke (Xgw2, Xgw1)	Early Proterozoic. Greenish- gray to grayish- tan siliceous schist. Minor chlorite, garnet, staurolite, or sillimanite in pelitic interbeds at various metamorphic grades. Originally deposited from a density, or turbidity, current (turbidite deposit) with recognizable coarse- to- fine grain graded bedding (Bouma cycle). Calc- silicate ellipsoidal structures develop from carbonate- rich concretions near the garnet metamorphic- grade boundary (isograd). Local discordances within units probably indicate penecontemporaneous slump, but a disconformity is inferred to exist in the lower part of the unit. Subunits pinch out NW of Pactola Lake. Includes part of the Precambrian Oreville Fm in Hill City 7½- minute quad. Thickness possibly as much as 2,200 m (7,200 ft). Xgw2: Metagraywacke unit 2: Middle part of unit Xgw. Pelitic parts may contain sillimanite near Harney Peak Granite. Underlies unit Xts in the Pactola Lake area; pinches out N of Hill City. Overlies unit Xqc to the SE in the Rockerville- Keystone area, where the unit may be as much as 2,000 m (6,500 ft) thick. Xgw1: Metagraywacke unit 1: Lower part of unit Xgw. Contains high metamorphic grade minerals such as sillimanite near the Harney Peak Granite. Disconformity inferred within or at the top of the unit. Maximum thickness probably about 1,500 m (4,900 ft), but pinches out or removed by erosion to the west.	Subdued topography compared to the more prominent hills and mountains of granite sills; generally vegetated with Ponderosa pine; exposed in the vicinity of the memorial's western border	Relatively high, but more easily eroded than Harney Peak Granite	None documented	Unknown	Sillimanite near the Harney Peak Granite; fractures contain groundwater resources	Schistosity and fractures may limit suitability in some sites	Fining upward sequences of sandstone to mudstone characteristic of turbidite deposition (Bouma cycles)

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Erosion Resistance	Hazards	Cultural Resources	Mineral Occurrence	Suitability for Development	Other
PRECAMBRIAN PROTEROZOIC (542-2500 Ma)	Metamorphosed younger alkalic basalt, tuff, & volcaniclastic rocks (Xby)	Early Proterozoic. Pillowed chloritic greenstone or amphibolite, layered amphibole schist & amphibole-bearing or biotite- rich schist; lenses of massive metachert & banded siderite- metachert or cummingtonite- rich beds; maximum thickness 1,000m (3,280 ft).	Not exposed in memorial	High	Unknown	Unknown	Sulfide minerals or graphite; cummingtonite-rich beds	Not exposed in memorial	U- Pb zircon age of 1,884±29 Ma
	Metamorphosed quartzite, debris flow conglomerate, pelite, & granite (Xqc)	Early Proterozoic. Heterogeneous metaconglomerate, & phyllite or schist; garnet- , staurolite- , andalusite- , & sillimanite- bearing at different metamorphic grades; matrix- supported metaconglomerate clasts range from quartzite to pelitic schist; lower contact unconformable or concordant with adjacent greywacke; contact inferred to be a disconformity; thickness 30- 700 m (98- 2,297 ft).	Narrow exposures near Grizzly Bear Creek & Stockade Lake, outside of memorial	High	Unknown	Unknown	Garnet. Staurolite, andalusite, sillimanite	Limited areal extent; not exposed in memorial	N/A
	Metamorphosed quartzite & pelite (Xqs)	Early Proterozoic. Interbedded quartzite, grayish- tan schist, & phyllite; massive, thick- bedded quartzite subunits; thin- bedded phyllite; sizable areas of predominantly phyllite are probable in larger fold noses; ripple- structured quartzite indicates shelf depositional environment; thickness 1,200 m (3,937 ft).	Not exposed in memorial	High	Unknown	Unknown	Unknown	Not exposed in memorial	N/A
	Metamorphosed tuff & shale (Xts)	Early Proterozoic. Phyllite & muscovite- biotite schist; andalusite, sillimanite, garnet, staurolite, or cordierite; manganese- rich garnet fine- grained metasedimentary rock, magnetite octahedra, & traces of chalcopyrite; included as part of Oreville Fm; includes increasing number of metagraywacke beds to the NE & loses distinctive identity; thickness as much as 700 m (2,297 ft).	Limited exposures in northern part of memorial	HIgh	None documented	None documented	Andalusite, garnet, sillimanite, staurolite, or cordierite; magnetite, & traces of chalcopyrite	Limited areal extent	U- Pb zircon age of 1,883±5 Ma
	Metamorphosed black shale (Xbs2, Xbs1)	Early Proterozoic. Dark- gray biotite schist & biotite- muscovite schist. Originally carbonaceous & iron-rich black shale (now pyrite- rich), tuffaceous shale, & siltstone. Locally contains massive chert beds. Includes part of Precambrian Loues Fm, part of Oreville Fm, & units E of Grand Junction fault in Berne quad. Thickness highly variable; original thickness estimated from 610- 1,200 m (2,000 to 4,000 ft). Xbs2: Thin- bedded dark phyllite, biotite schist, or garnet schist, depending on metamorphic grade. Resembles unit Xbs1 but contains thin units of metagraywacke. Equivalent to part of Oreville Fm. Stratigraphically higher than unit Xbs1 in central Black Hills but pinches out N of Pactola Lake. Thickness as much as 700 m (2,300 ft) in the Hill City 7.5 minute quad. Xbs1: Dark, thin- bedded slate, phyllite, or schist, & local thin beds of metachert. Generally biotite- rich & contains thin garnet- rich beds at higher metamorphic grade. Graphitic & sulfide- rich locally. Equivalent to Reausaw Slate and upper part of Poorman Fm in Lead area. Interlayered with individual metabasalt flows N- NW of Pactola Lake. Thickness estimated to range from about 30 m (100 ft) to possibly 1,000 m (3,300 ft).	Limited exposures	Relatively high, but more easily eroded than Harney Peak Granite	None documented	Unknown	Garnet; graphitic & sulfide- rich locally	Limited and isolated exposures in memorial area	N/A
	Metamorphosed carbonate facies iron-formation (Xif)	Early Proterozoic. Banded metachert with ankerite & siderite, & schist; contains cummingtonite-grunerite, & garnet at higher metamorphic grade; biotite- garnet schist & lense of massive metachert; locally sulfide- rich & graphitic; present at various stratigraphic levels including both younger & older Early Proterozoic units; poor exposures are typical in areas of low metamorphic grade, & unit mapped largely on metachert float; thickness variable, average 25m (82 ft).	Limited to thin, liner exposure SE of memorial	High	Unknown	Unknown	Ankerite, siderite, cummingtonite, grunerite, garnet locally sulfide- rich	None	N/A
	Quartzite (Xeq)	Early Proterozoic. Thick- bedded, light- tan quartzite & minor meta- arkose, both grading distally to quartzose phyllite; quartzite; 500- 3,300 m (1,640- 10,827 ft) thick	Extensive exposures S of memorial	High	Rockfall	Unknown	Unknown	Not exposed in memorial	N/A

Geologic History

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

The Precambrian sediments and granitic rocks that are now exposed in Mount Rushmore National Memorial were once buried about 14 kilometers (9 mi) below the surface by younger sediments. Intense heat and pressure at these great depths changed the Precambrian sediments to metamorphic rocks such as schist. The metamorphic and igneous rock units arched upward during the Laramide Orogeny creating the Black Hills. The younger, overlying sediments were later eroded exposing the oval-shaped Precambrian core rimmed by Paleozoic and Mesozoic rocks (fig. 3).

Precambrian History of the Black Hills Region

The Precambrian rocks exposed in the Black Hills are predominantly Early Proterozoic (1,600-2,500 Ma) metasedimentary units (fig. 4). Exposures show both northwesterly and northeasterly structural trends and a locally dominant northwest-trending metamorphic foliation. In the southern Black Hills, the Harney Peak Granite forms a dome that disrupts and modifies the local structure of the Proterozoic metamorphic rocks.

The sheer number of Precambrian units mapped for the Black Hills region illustrates the complexity of the Precambrian depositional and tectonic history. Understanding the evolution of the Black Hills during the Precambrian is limited due to the complex geology, pervasive metamorphism, and deformation, as well as a lack of precise age control for metasedimentary rocks in the core of the Black Hills. However, some age control is possible due to radiometric age dates that are available for igneous rocks in the Black Hills.

The following interpretations of Precambrian history are based on stratigraphic, depositional, tectonic, and chronologic studies of the Black Hills (Redden et al. 1990). Correlation with units in surrounding areas is difficult because the Black Hills are more than 300 kilometers (190 mi) from correlative outcrops in southern Wyoming and more than 1,100 kilometers (680 mi) from similar age rocks in Manitoba and Saskatchewan.

2,500 (Ma)

Archean basement rocks underlie the Black Hills (fig. 5). These basement rocks consist of metamorphosed fine- to coarse-grained epicontinental clastic rocks and granite. During deposition of these ancient sediments, Wyoming formed the southern margin of the landmass that later became the core of the North American craton.

2,500 Ma to 2,170 Ma

An extensional tectonic setting developed along the passive southern margin of the craton. Coarse-grained clastic rocks with local anomalous concentrations of uranium and minor amounts of chromite were deposited on the continental Archean basement. Pronounced changes in lithology, remnant sedimentary features, and faults that formed as the sediments were deposited indicate an alluvial fan depositional setting. Sediments deposited in the alluvial fan were eroded from a western source. Sediments become finer-grained towards the top and may preserve progressive deposition into a marine basin that had originally formed to the east.

2,170 to 1,980 Ma Deformation Event

Gabbro sills intruded into the Early Proterozoic strata and Archean basement about 2,170 Ma (Redden et al. 1990). Folding occurred along north-northwest-trending axes with subsequent erosion. These events indicate a change from an extensional tectonic setting to one of compression along the cratonic plate margin. The deformation occurred between 2,170 Ma and 1,980 Ma and may record early activity associated with the 1.9 to 1.7 billion-year-old Trans-Hudson Orogeny that resulted in more land being accreted to the Wyoming province (fig. 6). Sediments derived from the east were deposited in alluvial fans that connected to a marine shelf and tidal flat to the west and south. Folding caused by tectonic compression and increased sedimentation resulted in subsidence and the creation of the main Black Hills basin. Quartz-rich and feldspathic sediments deposited into the Black Hills basin eventually were metamorphosed to quartzite and mica schist.

At about 2,000 Ma, black shale was deposited in a deepening Black Hills basin. This deposition was accompanied by the submarine eruption of basalt. Density currents (turbidites) transported sediment from more shallow, shelf environments into deeper water and deposited these sediments over the basalt.

Two depositional settings have been proposed for the Black Hills area during this time. One setting is an intracontinental basin. Intracontinental basins form within the interior of the continent and away from plate boundaries. The other is a back-arc basin. Back-arc basins are located landward of a volcanic arc that forms above a subduction zone. The general composition of the turbidites, however, favors the interpretation of an intracontinental basin depositional environment (Redden et al. 1990).

While a marine basin formed in the Black Hills region, the area to the east was undergoing tectonic uplift and deformation as well as volcanism. Water depths increased from east to west and north to south. Source areas to the east supplied the sands that later became quartzites and silts and muds that later would be metamorphosed to mica schist.

1,980 Ma to 1,900 Ma Depositional Break

A depositional hiatus lasting about 90 my separates the turbidite deposits and basalt flows of the initial basin development and deepening from younger overlying conglomerates, debris flows, and scattered volcanic rocks. In some areas, the older rocks were folded and overturned prior to deposition of conglomerate and debris flow deposits. This suggests that a tectonic event may have occurred prior to the depositional break. Any deformation during this time is poorly understood. Although speculative, the deformation may be attributed to east- west closure of the Black Hills basin along part of what would become the axis of the Trans- Hudson Orogeny (Redden et al. 1990).

1,900 to 1,710 Ma Deposition and Deformation Events

A thick, widespread shale unit in the central Black Hills was deposited between 1,880 and 1,710 Ma. The main Black Hills basin continued to evolve as an intracontinental or back- arc basin from about 1,900 Ma to 1,800 Ma.

The Archean basement and overlying Early Proterozoic strata were highly deformed during the Trans- Hudson Orogeny that occurred approximately 1.7 to 1.9 billion years ago (Hoffman 1989; Redden et al. 1990). This deformation event resulted from the collision of the Superior craton of eastern Canada with the Hearne craton in northern Saskatchewan and the Wyoming craton of the western United States. The stratified rocks and Archean basement were folded along north- northwest trending axes and regionally metamorphosed. The orogeny included extensive folding and thrust faulting, metamorphism, and granitic intrusion along a belt that extended from Hudson Bay west through Saskatchewan and then south through the western portions of the Dakotas and Nebraska.

Rubidium- strontium (Rb- Sr) age dates suggest that the metamorphism may have occurred about 1,840 Ma. Igneous activity associated with the Trans- Hudson Orogeny primarily occurred from about 1,910 Ma to 1,840 Ma.

1,710 Ma: Harney Peak Granite

The Harney Peak Granite was likely derived from melting of the Archean crust and minor amounts of Early Proterozoic rocks that overlie the Archean basement. The intrusion of magma that created granite plutonic domes also deformed the previously folded structures. The 1,710 million- year- old Harney Peak Granite seems too young to be related to the 1,910- 1,840 Ma main phase of igneous activity associated with the Trans- Hudson Orogeny (Redden et al. 1990). Tectonic activity in the Central Plains Orogeny to the south is the event more likely associated with the generation of the Harney Peak Granite.

During the Central Plains Orogeny, a series of island arcs were progressively added to the southern margin of North America from about 1,780 Ma to 1,610 Ma (Carlson and Treves 2001). The Central Plains Province (fig. 6) consists of metamorphic and granitic rocks in a belt more than 1000 kilometers (620 miles) long and at least 500 kilometers (310 miles) wide that truncates the rocks of the Trans- Hudson orogen (Sims and Peterman 1986).

Middle Proterozoic Uplift

Metamorphosed volcanic tuff (metatuff) and metamorphosed greywacke (metagreywacke) record a metamorphic event that occurred between 1,600 Ma and 1,400 Ma (Redden et al. 1990). A northeast- trending metamorphic foliation that is found in the rocks of the Black Hills developed during this time. This foliation may have been part of a much larger structural regime, but the regional extent of this Middle Proterozoic tectonic activity is unknown.

Paleozoic History of the Black Hills Region

The Paleozoic strata that rim the core of the Black Hills record several episodes of marine deposition followed by subaerial exposure and erosion. Evidence of shallow marine depositional environments of a transgressive sea is preserved by the Cambrian and Ordovician sandstone, glauconitic shale, limestone, and dolomite units (Driscoll et al. 2002). Sea level rose in the latest Cambrian and flooded almost the entire North American continent, leaving a strip of land or a series of islands exposed along what is known as the Transcontinental Arch (fig.7). This arch is an upland that stretched from northern Minnesota southwestward across South Dakota, northwestern Nebraska, Colorado and northwestern New Mexico . Before the end of the Early Ordovician, the sea receded from the craton. Throughout the Devonian, erosion stripped much of the Cambrian and Ordovician strata from the area. Silurian age rocks are not present in the Black Hills area because of either erosion or nondeposition.

From the Late Devonian to the Middle Mississippian, the western margin of North America was being deformed as the North American lithospheric plate collided with oceanic crust to the west (Johnson et al. 1991). This collision caused another west to east transgression of the sea onto the craton. In some intracratonic basins such as the Williston Basin in North Dakota and Montana, organic- rich marine shale accumulated in deep subtidal, dysaerobic (low oxygen) environments. These black shales are primary petroleum source rocks in these basins today. In the Black Hills, Devonian and Mississippian marine limestones overlie Devonian shales that were deposited in shallower, subtidal marine environments. Deposited in aerobic environments, the organic matter was biodegraded so that these shales did not become rich petroleum source rocks.

The Mississippian- age Madison (also called Pahasapa) Limestone records deposition in a warm, shallow-marine environment (fig.8). When the sea regressed again in the Late Mississippian, this limestone was exposed at or near the land surface. Extensive erosion and elaborate karst (solution) features developed in the Madison Limestone at this time.

During the Pennsylvanian and Permian, the South American plate collided with the southern margin of North America, generating the forces responsible for the Ancestral Rockies in Colorado. The Pennsylvanian-Permian Minnelusa Formation unconformably overlies the Madison Limestone and is a coastal deposit with dune structures at the top of the formation that may preserve beach sediments (Driscoll et al. 2002). In general, the Pennsylvanian and Permian strata in the Black Hills record episodic transgressive and regressive cycles of the sea into the Black Hills basin. Marine sandstone, shale, siltstone, and limestones are overlain by evaporite deposits (anhydrite) and terrigenous red clastics.

Mesozoic History of the Black Hills Region

By the Early Triassic, the major landmasses had come together to form a supercontinent called Pangaea (fig.9). The red shale, siltstone, and evaporite deposits in the Spearfish Formation preserve a record of subaerial deposition in a continental setting. By the end of the Triassic, Pangaea was breaking apart (fig.5) and the relatively high velocities of plate movements caused a eustatic (worldwide) sea level rise in the Jurassic.

To the west during the Jurassic, the Farallon plate was subducted beneath the North American plate as the early phases of the Sierra Nevada batholithic intrusions and related volcanic eruptions occurred (Brenner 1983). As relative sea level rose, the sea encroached southward from the Arctic and into the Western Interior of North American. Between the Early and Late Jurassic, the Black Hills area moved from 15° north latitude to about 35° north latitude as the North American continent drifted northward (Kocurek and Dott 1983; Brenner 1983). The abundance of red beds, evaporites, and shallow water carbonates suggest that Jurassic paleoclimate in this area was generally warm and dry. The shale, glauconitic sandstone, and limestone of the Sundance Formation in the Black Hills preserve at least two transgressive - regressive cycles, including the last and most extensive transgression of the Jurassic. Extending as far south as present- day New Mexico, this broad epeiric sea covered much of the Western Interior of North America. The sea covered an area bordered by rising mountains to the west as the Sevier Orogeny began to deform the west coast and on the east by the stable mid- continent craton (fig. 10). The widely distributed Morrison Formation records continental environments of deposition during the subsequent marine regression in the uppermost Jurassic.

Although the subduction zone along the western margin of North America was far to the west of the Black Hills region, compressive forces caused by the collision were felt far inland. Several processes acted in concert to change the landscape of the Western Interior. As layers of rock were thrust up into mountains along the western margin, the land east of the concentrated mass responded by bending, folding, and flexing downward into an expanding foreland basin. In addition, as the mountains were thrust above sea level, weathering and erosion produced a vast amount of cobbles, pebbles, sand, silt and clay, which were deposited into this down-flexing and expanding Western Interior basin. The sediments added more weight to the basin and resulting in further subsidence.

As the mountains rose in the west and the roughly north- south trending Western Interior basin subsided, the Gulf of Mexico separating North and South America rifted open in the south, and marine water flowed into the basin. At the same time, marine water began transgressing from the Arctic region in the north. The Early Cretaceous sandstones, shales, minor carbonates and coal of the Inyan Kara Group were deposited in fluvial, floodplain, and marsh environments, but these depositional patterns changed in the Upper Cretaceous when four main transgressions and regressions of shallow seas encroached into the area (Driscoll et al. 2002).

The multidirectional transgressions of the Late Cretaceous produced the most extensive interior seaway ever to cover the North American craton (fig. 11). The Western Interior Seaway extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 4,800 kilometers (3,000 mi) (Kauffman, 1977). During periods of maximum transgression, the width of the basin was 1,600 kilometers (1,000 mi). The basin opened into the Gulf of Mexico to the south and the Arctic Ocean to the north (Kauffman, 1977). The Skull Creek Shale and younger Cretaceous shale and sandstone beds in the Black Hills record cycles of relative sea level rise and fall of this epeiric seaway.

Cretaceous – Tertiary Laramide Orogeny

As the Cretaceous neared an end, the Western Interior Seaway regressed across the area of the future Black Hills uplift. The seas gradually receded, forming a sedimentary sequence that thinned upward. The offshore marine Pierre Shale was overlain by nearshore marine sediments of the Fox Hills Sandstone (not exposed in the Black Hills), which transition upward into the fluvio- deltaic Lance Formation and Hell Creek Formation (not exposed in the Black Hills). The Lance Formation and equivalent Hell Creek Formation were deposited in the last 3 million years of the Cretaceous. Streams flowed eastward from the east side of the Powder River Basin and across the area that would become the Black Hills. Not until the Paleocene would sedimentation in the Powder River Basin indicate an uplift to the east. By the Eocene, a radial drainage pattern had developed around the core of the Black Hills uplift (Lisenbee and DeWitt 1993).

The combination of interaction of the subducted Farallon plate and northward movement of the Colorado Plateau geologic province initiated the Late Cretaceous to Early Tertiary Laramide Orogeny (Lisenbee and DeWitt 1993). The orogeny was marked by a pronounced eastward shift in deformation throughout Utah and into Colorado. Laramide thrust faults cut deeply into the earth's crust, forcing ancient plutonic and metamorphic basement rocks to the surface. These thrust faults have steeply dipping fault planes at the surface that curve and flatten out in Precambrian basement crystalline rock at depths up to 9 kilometers (30,000 ft or 5.7 miles) below sea level (Gries, 1983; Erslev, 1993).

The Laramide Orogeny formed the modern Rocky Mountains, crystalline - cored arches bounded by thrust faults and separated by deep sediment- filled basins. The north- south trending, doubly- plunging Black Hills anticline is the easternmost expression of this orogeny (fig. 12). The initial phase of uplift in the region occurred in the Paleocene about 62 Ma. Igneous activity accompanied deformation. Stocks, dikes, sills, and laccoliths intruded across the northern Black Hills uplift during this initial tectonism (Lisenbee and DeWitt 1993). Devils Tower exemplifies this Paleocene magmatic event.

With uplift, erosion quickly produced sediments that were shed into the Powder River Basin and the Williston Basin. Erosion rates during the Paleocene averaged 10 to 13 centimeters (4 to 5 in) per 1,000 years (Lisenbee and DeWitt 1993).

A second phase of deformation related to the Laramide Orogeny affected the Black Hills region in earliest Eocene time (approximately 56 Ma). A second magmatic pulse followed at about 39 Ma. The plutons lie along a zone that offsets the boundary between the Wyoming Archean province and the Early Proterozoic Trans-Hudson province (fig. 5). This zone, with associated plutons, can be traced northward into Montana.

By the Late Eocene, the Laramide Orogeny was over. Erosion carved valleys into the uplift, creating the topographic form of the present Black Hills. These valleys were then filled by the post- tectonic White River Group.

The Black Hills uplift is bounded on the west by north- and northwest- trending monoclines, chiefly west facing. Smaller scale monoclines are common across the uplift where Paleozoic strata are exposed (Lisenbee and DeWitt 1993). Monoclines are inferred to overlie unexposed thrust faults formed during regional horizontal compression. Overlapping(en echelon) folds suggest an additional strike- slip component to faulting. Ancient Precambrian margins, structures, and fabrics involving the Wyoming Archean province and the Early Proterozoic Trans- Hudson province may have influenced Laramide folding, faulting, and magmatic activity (Lisenbee and DeWitt 1993).

Quaternary History of the Black Hills Region

Both the Cheyenne River that drains the southern part of the Black Hills and the Belle Fourche River that drains the northern part cut across north trending structures. These east- west flowing rivers incised their channels at such a rate that they were able to maintain their original course as erosion exposed the Black Hills uplift. The subradial drainage pattern in the Black Hills developed as many tributaries also incised their channels into bedrock. These tributaries are discordant to major structures and perpendicular to the bedding of the Paleozoic and Mesozoic strata that surround the uplift (Wayne et al. 1991).

The Black Hills region was unglaciated during the Pleistocene so that many Pleistocene deposits are preserved along creeks in the Black Hills. Five terrace deposits have been identified in the Black Hills (fig. 13) (Wayne et al. 1991). The oldest and topographically highest terrace deposit is the Mountain Meadow erosional surface. The gravel beneath the surface is dominated by Precambrian siliceous clasts. A camel ankle bone from *Gigantocamelus* was found in the Mountain Meadow gravel just south of Rapid City.

The Rapid terrace is composed of locally derived clasts. The terrace lies 55 meters (180 ft) above Rapid Creek, near Rapid City, and can be traced along the eastern flank of the Black Hills uplift. The Rapid terrace has been correlated with the Hot Springs mammoth site, a natural elephant trap formed by a karst depression containing a warm spring. A mammoth bone from this site yielded a radiocarbon date of 26,075 ± 880 years before present (ybp) (Wayne et al. 1991).

Ages for the Sturgis, Bear Butte, and Farmingdale terraces have not been determined. The Sturgis terrace contains well cemented clasts of Permian Minnekahta Limestone and is at least 30 meters (100 ft) thick along Fall River.

The Bear Butte terrace and lowermost Farmingdale terrace were identified below the Sturgis terrace along Bear Butte Creek. The Bear Butte terrace is a major terrace along the Belle Fourche River and along Bear Butte Creek as far upstream as Bear Butte. Farmingdale terrace extends along Rapid Creek from Farmingdale, South Dakota, east to the Cheyenne River.

Three hypotheses have been proposed for the origin of the Rapid and younger terraces (Wayne et al. 1991). These include:

- damming by glacial ice along the Missouri River
- local tectonism
- rejuvenated uplift of the Black Hills starting about 4.5 Ma.

Today, the Black Hills experiences an overall continental climate. Low precipitation, hot summers, cold winters, and extreme variations in both precipitation and temperatures impact erosion rates, vegetation growth, and sediment transport in the various drainage basins

(Carter et al. 2002). Lithologic heterogeneity of the Paleozoic and Mesozoic sedimentary strata, fracturing of Precambrian rocks, and differential weathering contribute to a complex groundwater system in the area. Diverse geologic conditions also influence stream flow and surface water quality. Alluvial gravel, sand, silt, and mud continue to be deposited by perennial and ephemeral streams while colluvium and talus slopes continue to be eroded and their sediment transported down slope.

Eon	Era	Period	Epoch	Ma		Life Forms	N. American Tectonics
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Holocene	0.01	Age of Mammals	Modern humans	Cascade volcanoes (W)
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada (W)
			Miocene	23.0		Whales and apes	Linking of N. and S. America
			Oligocene	33.9			Basin-and-Range extension (W)
			Eocene	55.8		Early primates	Laramide Orogeny ends (W)
			Paleocene	65.5			
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	Mass extinction Placental mammals Early flowering plants	Laramide Orogeny (W) Sevier Orogeny (W) Nevadan Orogeny (W)
		Jurassic		199.6		First mammals Mass extinction	Elko Orogeny (W) Breakup of Pangaea begins
		Triassic		251		Flying reptiles First dinosaurs	Sonoma Orogeny (W)
	Paleozoic	Permian		299	Age of Amphibians	Mass extinction Coal-forming forests diminish	Supercontinent Pangaea intact Ouachita Orogeny (S) Alleghenian (Appalachian) Orogeny (E)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant	Ancestral Rocky Mts. (W)
		Mississippian		359.2		Variety of insects First amphibians First reptiles	Antler Orogeny (W)
		Devonian		416	Fishes	Mass extinction First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	Mass extinction First primitive fish Trilobite maximum Rise of corals	Taconic Orogeny (NE)
		Cambrian		542		Early shelled organisms	Avalonian Orogeny (NE) Extensive oceans cover most of N. America
Proterozoic ("Early life")		Precambrian		2500		First multicelled organisms Jellyfish fossil (670 Ma)	Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
				≈4000		Early bacteria and algae	Oldest known Earth rocks (≈3.96 billion years ago)
				4600		Origin of life? Formation of the Earth	Oldest moon rocks (4-4.6 billion years ago) Earth's crust being formed

Figure 5. Geologic time scale; adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years.

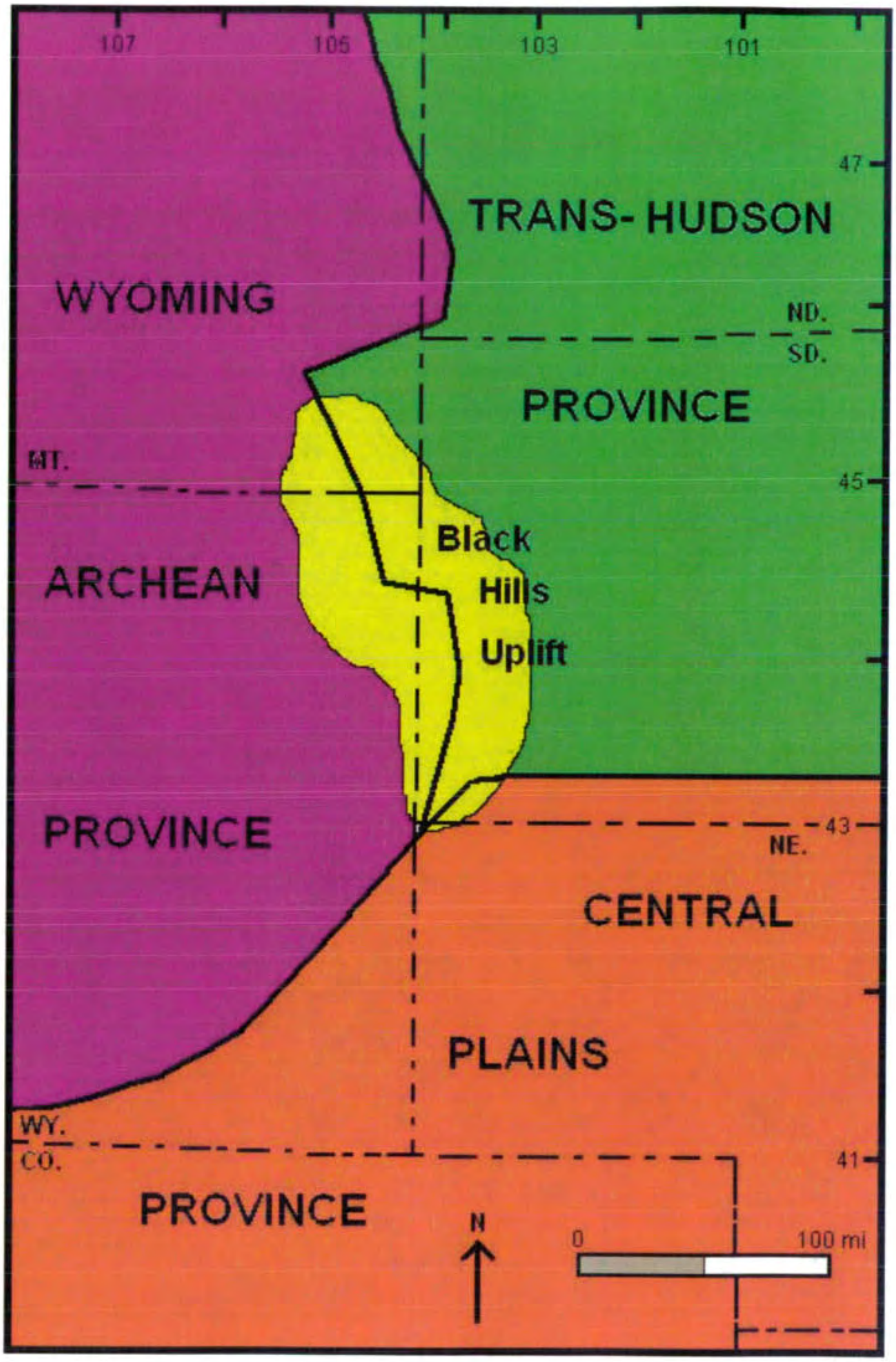

Figure 6. Location of the Black Hills Uplift with regard to Precambrian terranes, northern Great Plains region. Modified from Lisenbee and DeWitt (1993).

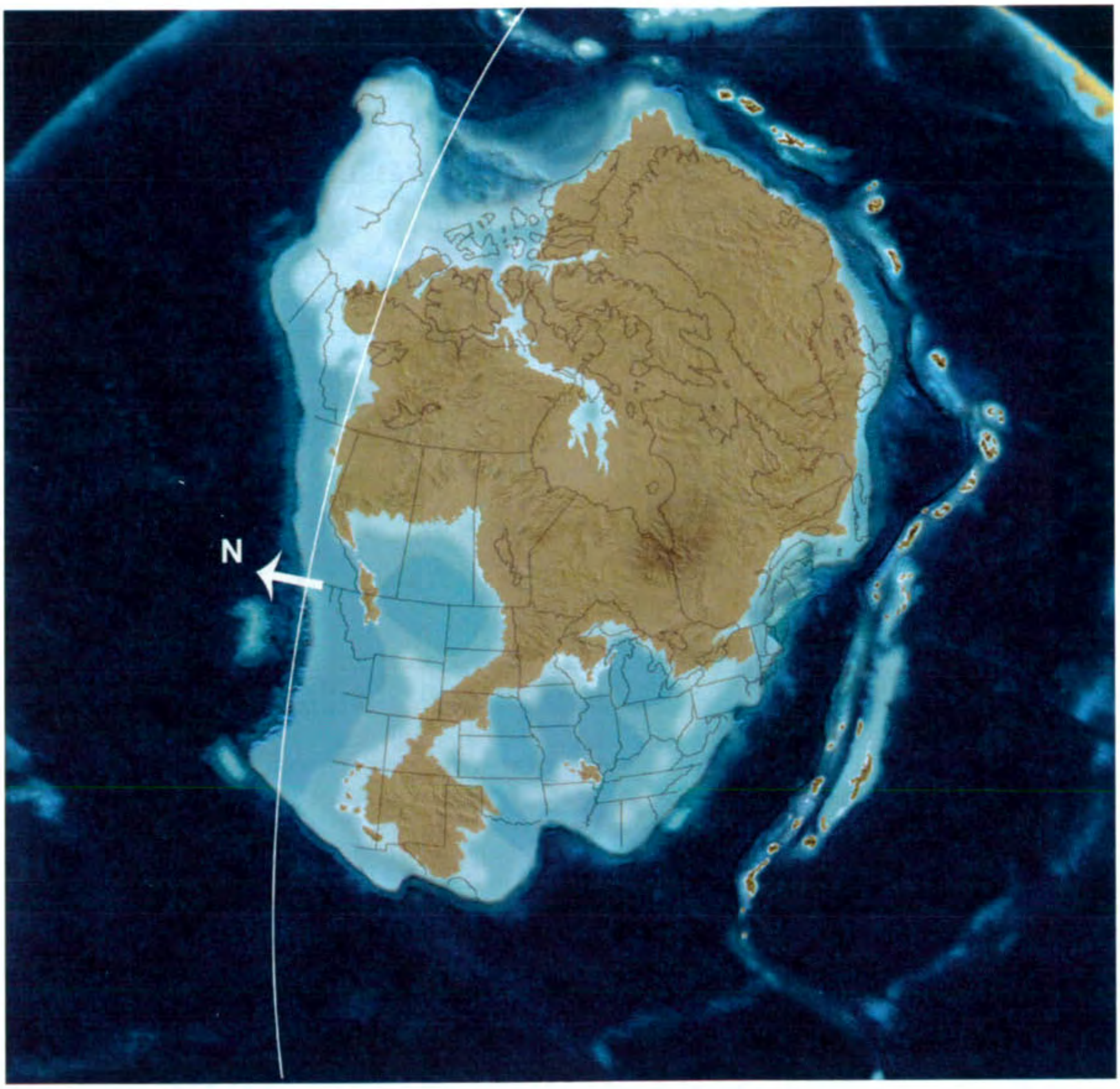

Figure 7. Paleogeographic map of the Late Cambrian, about 500 Ma. The Transcontinental Arch is the narrow landmass that transects South Dakota, northwestern Nebraska, and Colorado. Relatively shallow water and nearshore environments occupy the region of the Black Hills while a deeper water basin (darker shade of blue) is forming in the area of the Williston Basin. From Dr. Ron Blakey, Northern Arizona University, http://jan.ucc.nau. edu/~rcb7/namC500.jpg (access February 27, 2006).

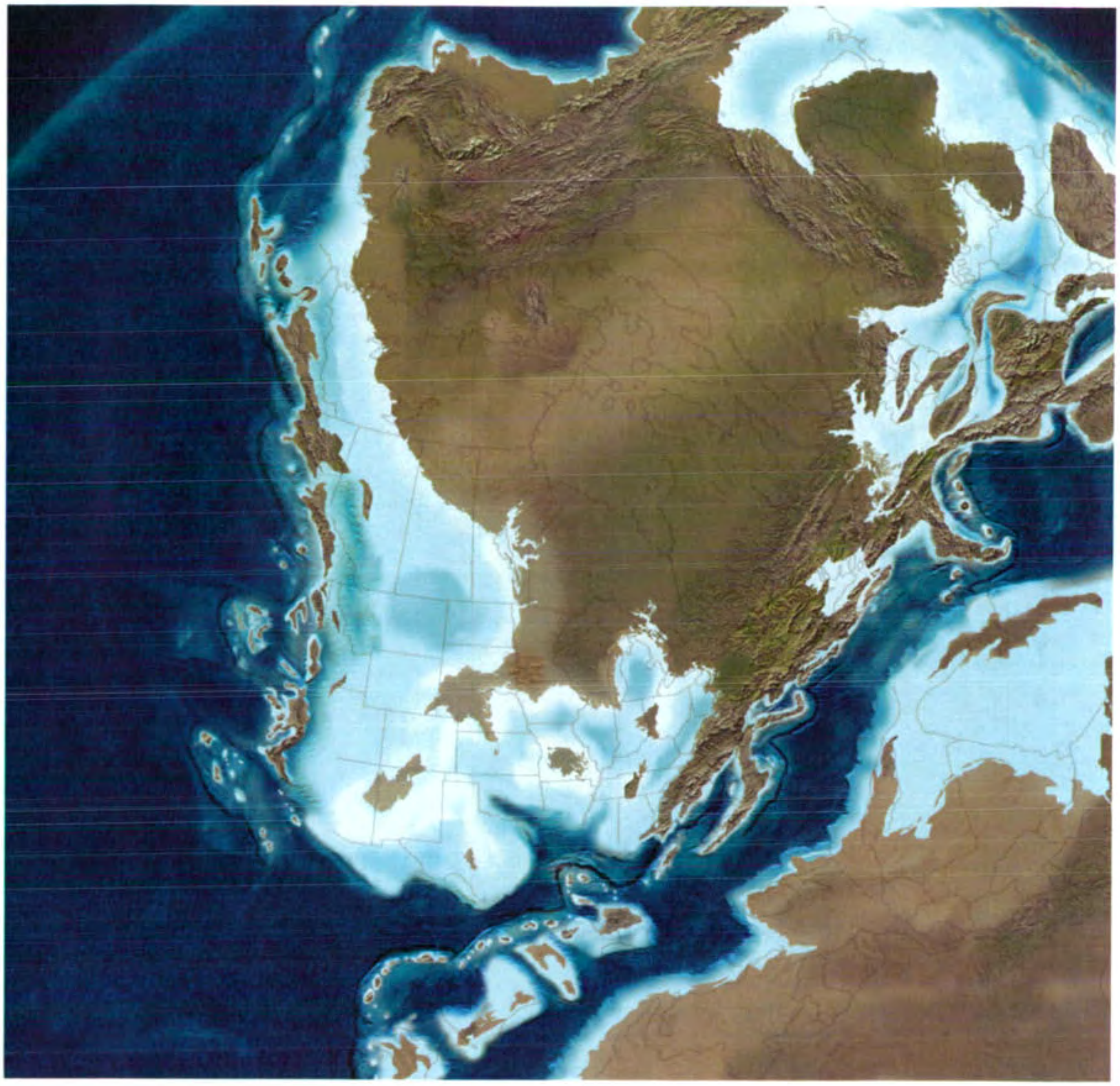

Figure 8. Paleogeographic map of North America during the Early Mississippian Period, about 345 Ma. Note that much of the conterminous United States is covered with a shallow sea, including the area of the Black Hills, and the Transcontinental Arch has been breached. The Williston Basin continues to be a physiographic feature at this time. From Dr. Ron Blakey, Northern Arizona University, http://jan.ucc.nau.edu/~rcb7/namM345.jpg (access February 27, 2006).

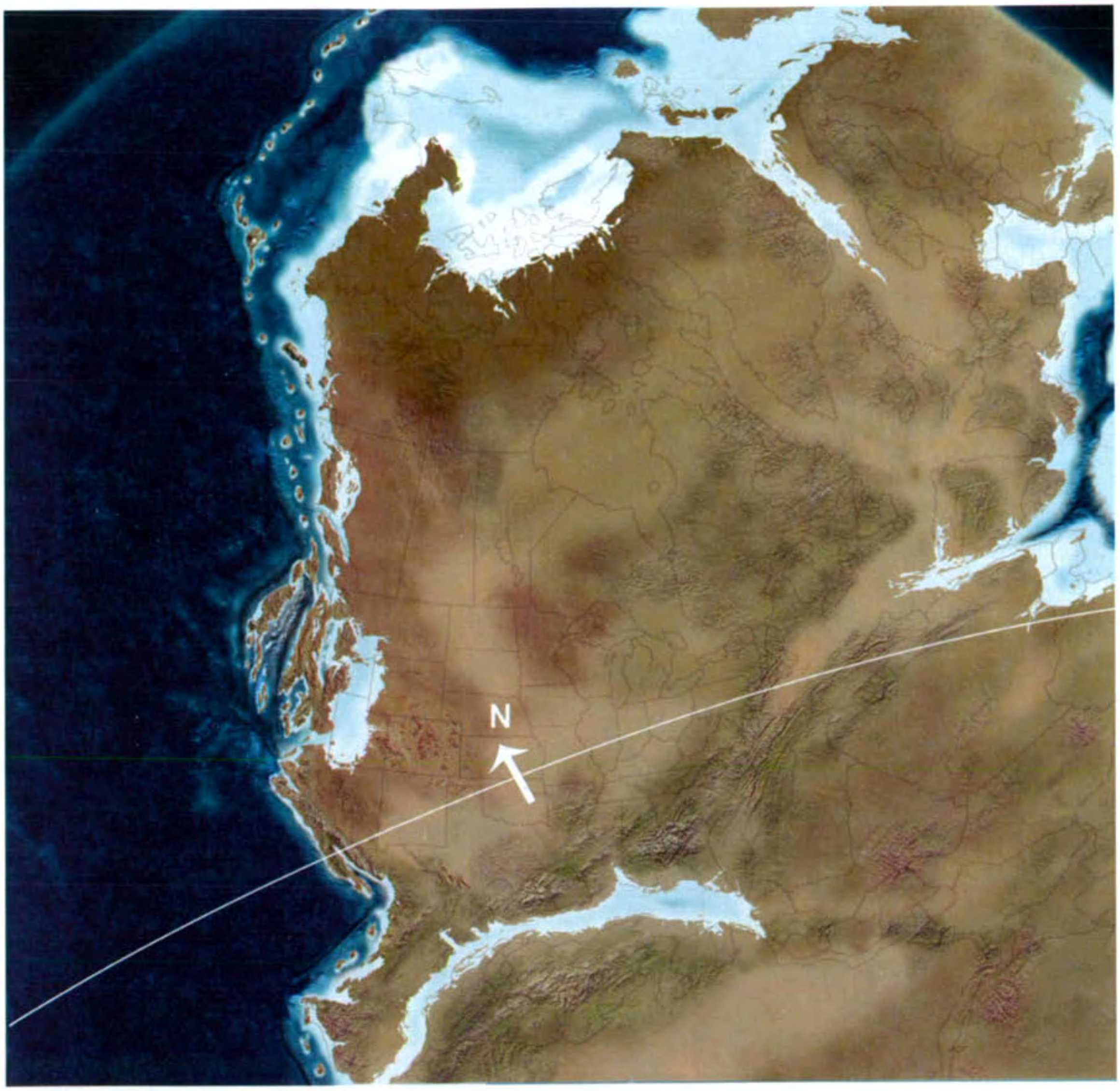

Figure 9. Paleogeographic map of North America during the Early Triassic Period, about 245 Ma. The landmasses had come together at this time to form the supercontinent, Pangaea. From Dr. Ron Blakey, Northern Arizona University, http://jan.ucc.nau. edu/~rcb7/namTr245.jpg (access February 27, 2006).

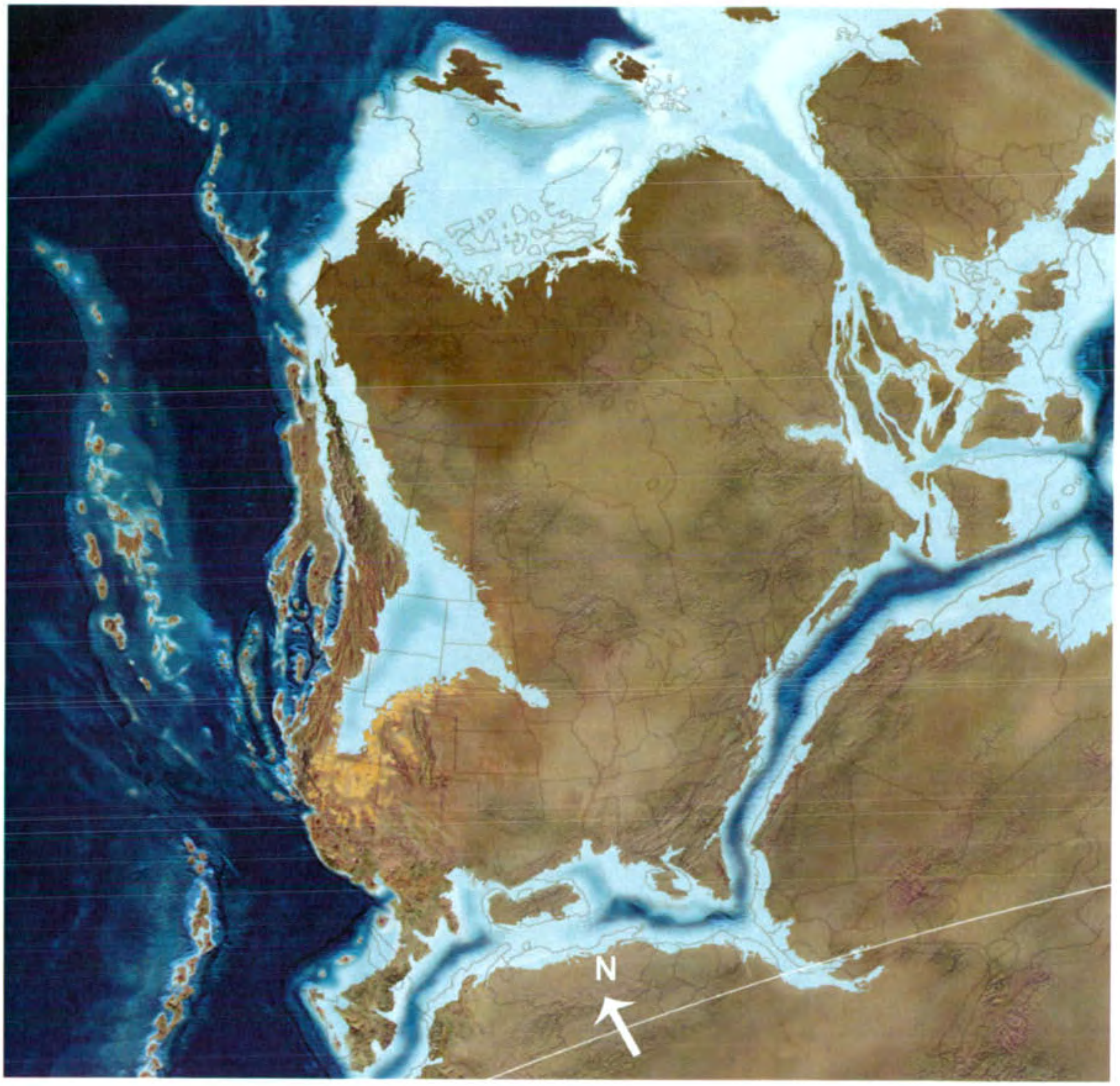

Figure 10. Paleogeographic map of North America during the Jurassic Period, about 170 Ma. The Western Interior of North America has been inundated by shallow marine environments. From Dr. Ron Blakey, Northern Arizona University, http://jan.ucc.nau. edu/~rcb7/namJ170.jpg (access February 27, 2006).

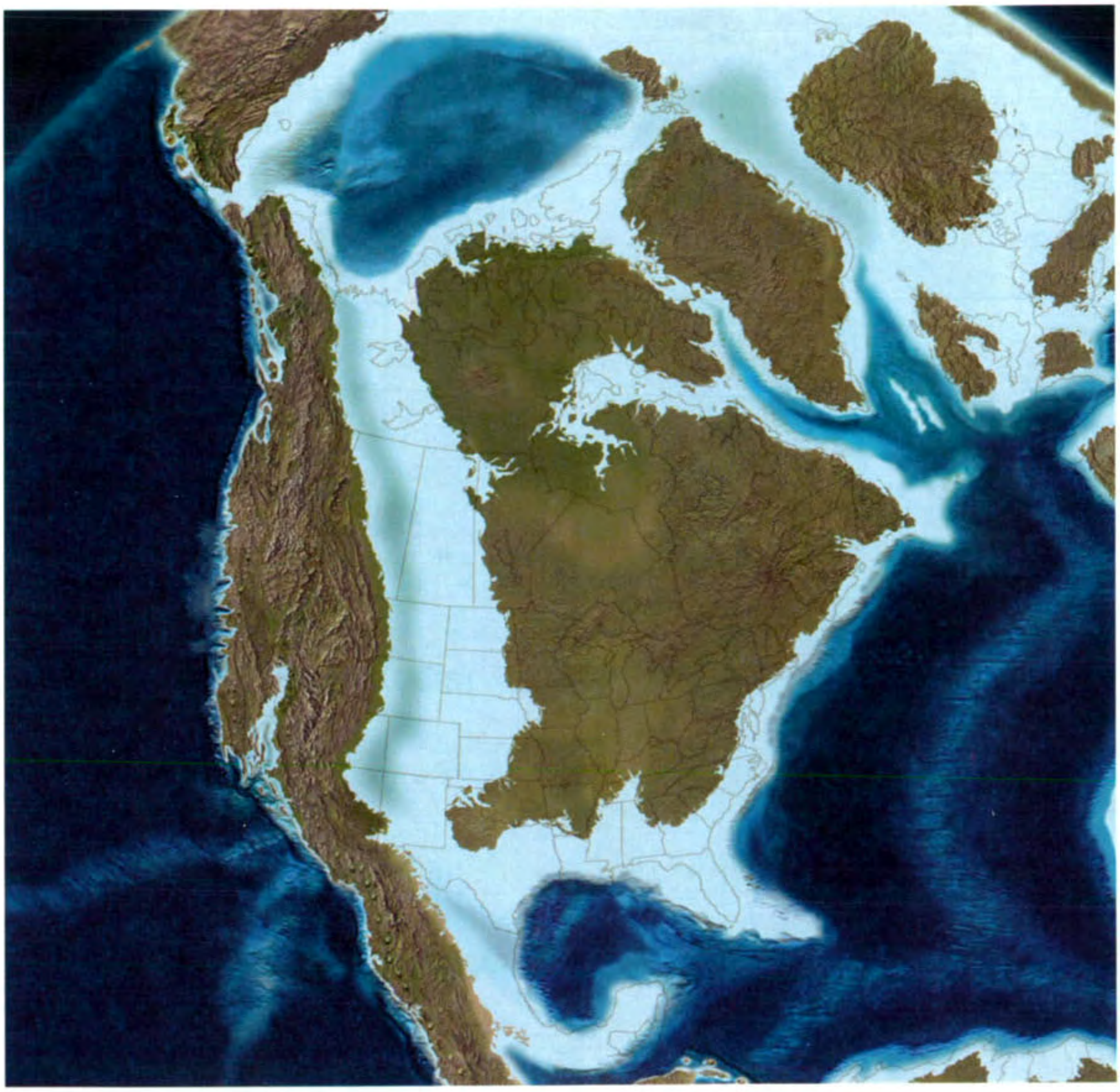

Figure 11. Western Interior Seaway during the Cretaceous, about 85 million years ago. Relatively shallow water covered the MORU region at this time. From Dr. Ron Blakey, Northern Arizona University, http://jan.ucc.nau. edu/~rcb7/namK85.jpg (access February 27, 2006).

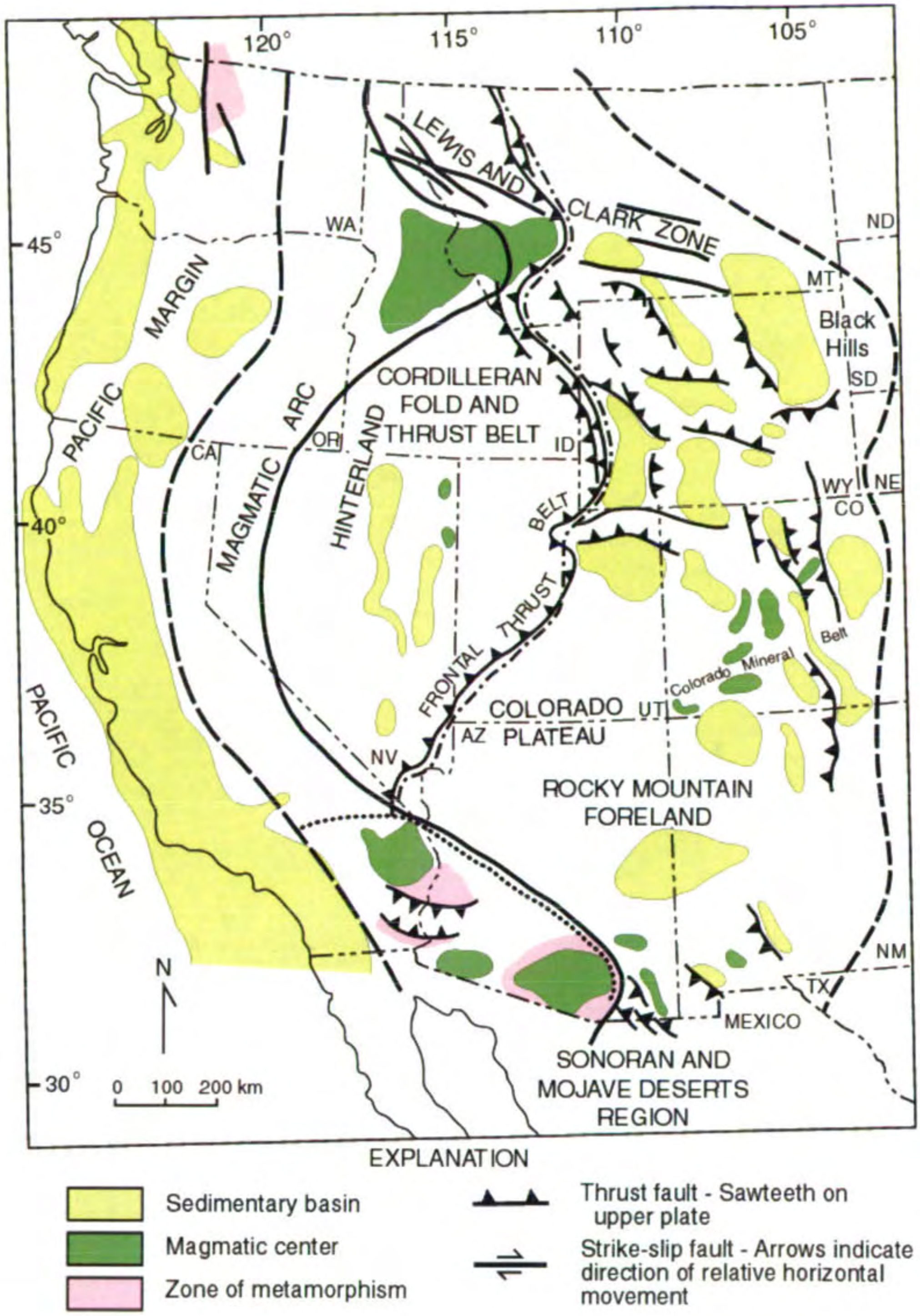

Figure 12. Major tectonic elements and locations of Late Cretaceous to Early Eocene sedimentary, igneous, and metamorphic rocks associated with the Laramide Orogeny. The Black Hills uplift is the easternmost expression of the Laramide Orogeny. The basin west of the Black Hills uplift is the Powder River Basin, a prolific hydrocarbon-producing basin. Modified from Miller and others, 1992.

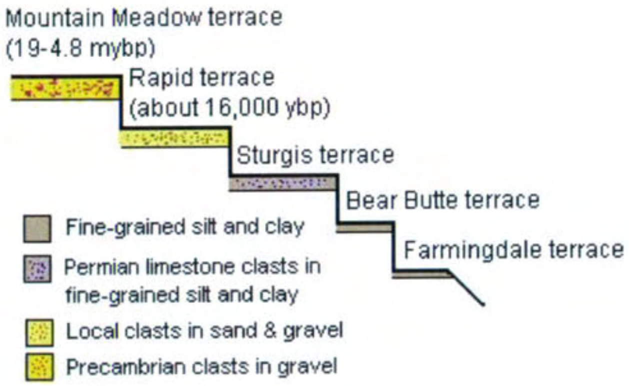

Figure 13. Diagram of Pleistocene terraces in and near the Black Hills. Modified from Wayne and others, 1991.

Glossary

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

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

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

aquifer. Rock or sediment that are sufficiently porous, permeable, and saturated to be useful as a source of water.

axis (fold). A straight line approximation that when moved parallel to itself generates the shape of a fold (see and use hingeline)

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.

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

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

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

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

bedding. Depositional layering or stratification of sediments.

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

calcareous. A rock or sediment containing calcium carbonate.

clastic. Rock or sediment made of fragments or pre-existing rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (<2 cm).

conglomerate. A coarse- grained sedimentary rock with clasts larger than 2 mm in a fine- grained matrix.

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25- 60 km (16- 37 mi) and a density of approximately 2.7 grams per cubic centimeter.

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

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

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

cuesta. An asymmetric ridge with one gently- sloping side (dip slope) and one steep side formed by the erosion of gently- dipping rock strata.

debris flow. A rapid and often sudden flow or slide of rock and soil material involving a wide range of types and sizes.

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

delta. A sediment wedge deposited at a stream's mouth where it flows into a lake or sea.

dike. A tabular igneous intrusion that cuts across, or is discordant with, the country rock it intrudes.

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

discordant. Having contacts that cut across or are set an angle to the orientation of adjacent rocks.

dome. A doubly plunging anticline that dips radially in all directions.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

dune. A low mound or ridge of sediment, usually sand, deposited by wind. **epeiric sea.** A sea on the continental shelf or within a continent. Also called an epicontinental sea.

epeiric sea. An epicontinental sea.

ephemeral stream. A stream that flows only in direct response to precipitation.

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

eustatic. Relates to simultaneous worldwide rise or fall of sea level in Earth's oceans.

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

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

foliation. A general term for a planar arrangement of textural or structural features in any type of rock, esp. the locally planar fabric in a rock defined by a fissility, a preferred orientation of crystal planes in mineral grains, a preferred orientation of irregular grain shapes, or from compositional banding.

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

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

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

grabbro. A dark- colored, coarse- grained, intrusive igneous rock; the intrusive equivalent to basalt.

graywacke. A dark gray well- indurated, coarse- grained sandstone with poorly sorted angular to subangular grains of quartz and feldspar, with a variety of dark rock and mineral fragments in a compact clay matrix; containing abundant very fine-grained illite, sericite, and chloritic minerals.

hogback. Any ridge having a sharp summit and steep slopes formed by steeply inclined resistant rock and produced by differential erosion.

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

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

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

laccolith. A tack head- to arcuate-shaped, concordant pluton that domed or up-arched the overlying country rocks.

latite. A porphyritic extrusive igneous rock with phenocrysts of plagioclase (Na,Ca feldspar) and K feldspar in about equal amounts.

magma. Molten rock generated within Earth that is the parent of igneous rocks.

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

metagraywacke. A metamorphosed greywacke.

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

metatuff. Metamorphosed tuff.

monocline. A one-limbed flexure in strata, which are usually flat-lying except in the flexure itself.

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

orogeny. A mountain-building event, particularly a well-recognized event in the geological past (e.g. the Laramide orogeny).

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

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

pebble. Generally, small, rounded, rock particles from 4 to 64 mm in diameter.

pegmatite. An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dikes, lenses, or veins, esp. at the margins of batholiths.

permeability. A measure of the ease or rate that fluids move through rocks or sediments.

phonolite. A fine-grained extrusive igneous rock composed of Na and K feldspar and a feldspathoid (usually nepheline).

pluton. A body of intrusive igneous rock.

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

recharge. Infiltration processes that replenish groundwater.

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

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

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

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

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

sill. A tabular igneous intrusion, concordant with the country rock, that forms when magma is intruded into fractures and cracks that are parallel to bedding

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

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

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

stock. An igneous intrusion exposed less than 40 square miles at the surface.

strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).

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

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

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

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

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

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

trachyte. A fine-grained, generally porphyritic, extrusive rock composed mainly of Na and K feldspar with minor amounts of biotite, amphibole, or pyroxene.

transgression. Landward migration of the sea due to a relative rise in sea level.

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

turbidite. A sediment or rock deposited from, or inferred to have been deposited from, a turbidity current, which is a density current in water, air, or other fluid, caused by different amounts of matter in suspension.

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

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

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

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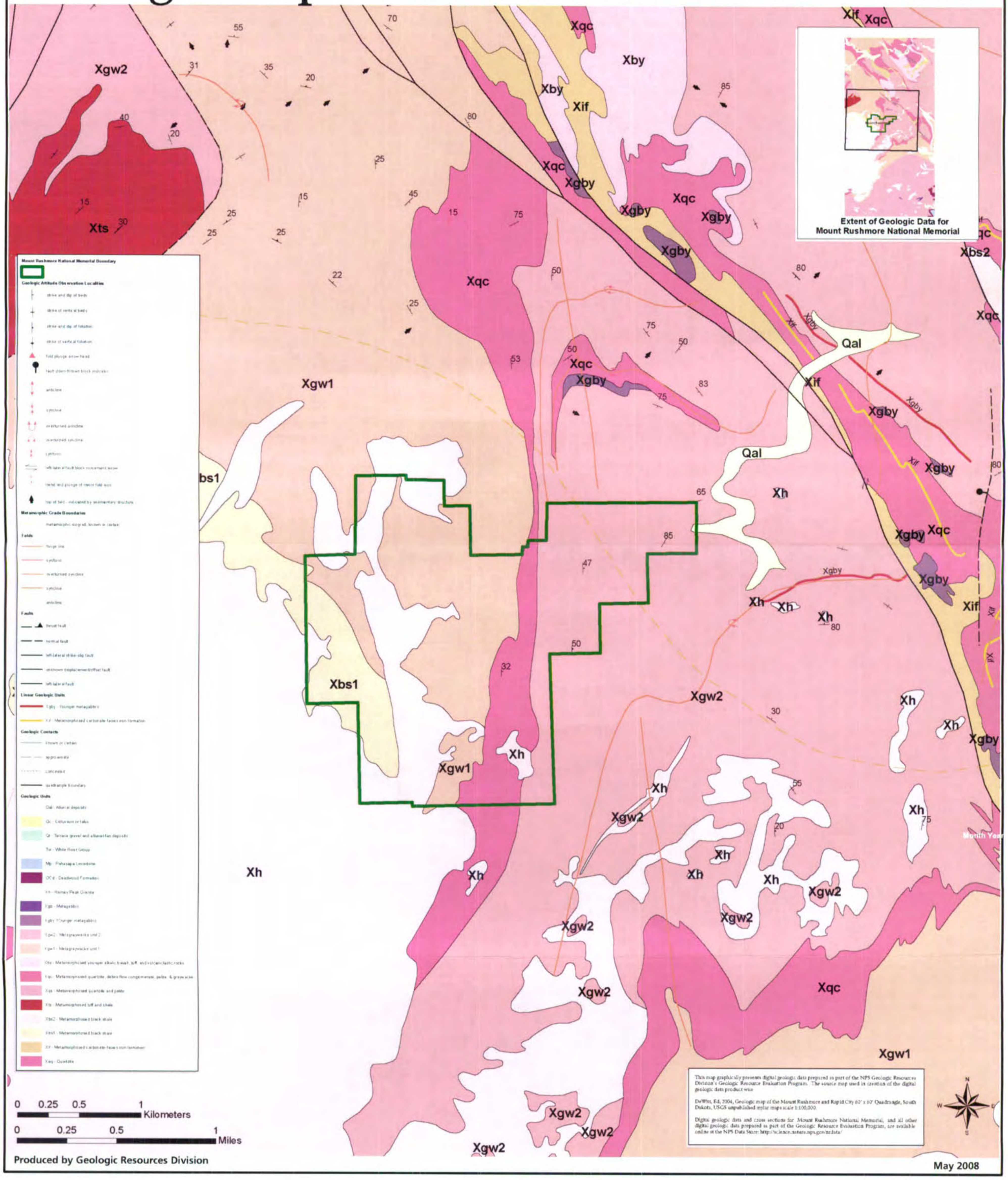
Appendix A: Geologic Map Graphic

The following page is a preview or snapshot of the geologic map for Mount Rushmore National Memorial. For a poster- size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www2.nature.nps.gov/geology/inventory/gre_publications).

Mount Rushmore National Memorial
South Dakota

National Park Service
U.S. Department of the Interior

Geologic Map of Mount Rushmore N MEM



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

DeWitt, Ed, 2004, Geologic map of the Mount Rushmore and Rapid City 60' x 60' Quadrangle, South Dakota, USGS unpublished mylar maps scale 1:100,000.

Digital geologic data and cross sections for Mount Rushmore National Memorial, and all other digital geologic data prepared as part of the Geologic Resource Evaluation Program, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

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Mount Rushmore National Memorial

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Natural Resource Program Center

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