National Park Service
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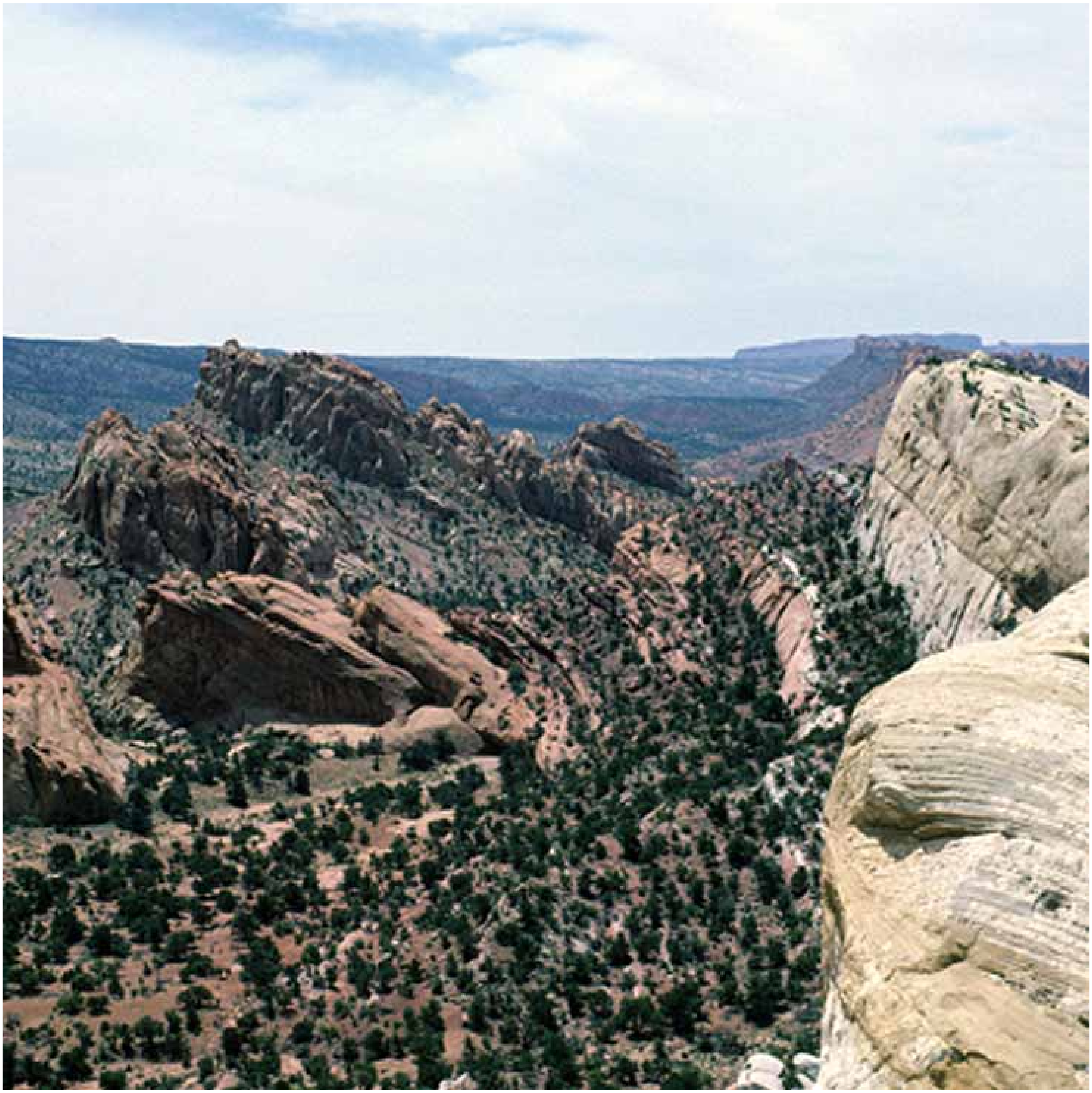
Natural Resource Program Center

Capitol Reef National Park
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/005



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Geologic Resources Division
Natural Resource Program Center
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Table of Contents

List of Figures

Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Capitol Reef National Park in Utah. It contains information relevant to resource management and scientific research.

Capitol Reef National Park is located within the Colorado Plateau Physiographic Province. The dominant geologic feature in the park is the north-south trending Waterpocket Fold, a nearly 160-km (100-mi) long step-like flexure called a monocline. West of the fold lies the flattop topography of the High Plateaus subprovince, to the east are the narrow, steep-sided gorges of the Utah Canyon Lands subprovince.

Erosion has produced most of the unique geologic features in the park. Exposed within Capitol Reef National Park are monolithic structures reminiscent of cathedrals, as well as pinnacles, arches, bridges, slot canyons, landslides, and elongated valleys. Streams eroding downward through bedrock form sharp, incised meanders or "goosenecks."

The strata exposed in Capitol Reef represent a variety of depositional environments that span the last 275 million years. Geologic structures present in the park include large-scale folds, faults, and fractures. Igneous dikes and sills intrude into the softer sedimentary strata.

A Geologic Resource Inventory (now Geologic Resource Evaluation) scoping meeting, convened in September 1999, and a Geoindicators scoping meeting, held in June 2002, served as a forum for discussing mapping and geologic issues relevant to the park. The following geologic issues were identified as important to park management:

- Geohazards
    - Flash flooding and debris flows
    - Swelling clays
    - Uranium and radon contamination
    - Rockfalls and landslides
- Groundwater
- Disturbed lands
- Paleontological resources
- Mineral occurrences
- Seismicity

Groundwater quality and quantity are significant issues in the semi-arid climate of the Colorado Plateau. Steep, narrow canyons in semi-arid and arid climates are prone to flash flooding in response to intense rainfall events. Flash flooding may occur in the narrow, steep canyons cut into the Waterpocket Fold or along the Fremont River and its tributaries. Flash floods in arid environments carry a high sediment load and with enough rock fragments, soil, and mud can become debris flows as they travel downstream. Flash flooding related to stream channel morphology, erosion, streamflow, and debris flows are significant park management issues.

Several Mesozoic formations in the park contain clays that swell with the addition of water and shrink upon drying. This shrink-swell characteristic causes unstable conditions with regard to roads, building construction, and infrastructure maintenance.

Mesozoic rocks host deposits of uranium, vanadium and radium in Capitol Reef National Park. Uranium and radon contamination are indicated by elevated levels of radiation. The stratigraphic units at Capitol Reef that contain abnormal radioactivity include: the Moenkopi Formation, the Shinarump Member of the Chinle Formation, the middle and upper members of the Chinle Formation, and the Salt Wash Member of the Morrison Formation.

Fractures in the massive, cross-bedded Mesozoic sandstones and the Permian limestone cliffs combined with physical and chemical weathering processes increase the potential for rockfalls in the park. Cliffs that are undercut by the erosion of less resistant strata below may collapse.

Ten abandoned mine sites are known to exist in the park including 27 individual mine openings. Three sites have been mitigated: the Oyler, Terry, and Rainy Day.

Paleontological resources are abundant in Capitol Reef. Marine invertebrate fossils are found in Permian strata and thick accumulations of Cretaceous oysters form the Oyster Reef exposed along the Notom-Bullfrog Road. Ancient marine and terrestrial vertebrates such as turtles, crocodiles, and dinosaurs are also preserved in Capitol Reef. Reptile and amphibian tracks are present in the Triassic Moenkopi Formation. Poaching and theft of fossils are resource management concerns.

In addition to Uranium minerals identified in the park include gypsum, copper, and manganese. Oil and gas exploration and production occur outside but adjacent to the park boundary. The park is closed to mineral entry under the 1872 mining law and federal mineral and oil and gas leasing under federal statute.

Mostly minor earthquake activity occurs on the Colorado Plateau. The potential for an earthquake with a magnitude more than 5.5 in the Capitol Reef area is considered low.

Introduction

The following section briefly describes the regional geologic setting and the National Park Service Geologic Resource Evaluation program.

Purpose of the Geologic Resource Evaluation Program

Geologic features and processes serve as the foundation of park ecosystems and an understanding of geologic resources yields important information for park decision making. The National Park Service (NPS) Natural Resource Challenge, an action plan to advance the management and protection of park resources, has focused efforts to inventory the natural resources of parks. Ultimately, the inventory and monitoring of natural resources will become integral parts of park planning, operations and maintenance, visitor protection, and interpretation.

The Geologic Resource Evaluation (GRE) Program, which the NPS Geologic Resources Division administers, carries out the geologic component of the inventory. Staff associated with other programs within the Geologic Resources Division (e.g., the abandoned mine land, cave, coastal, disturbed lands restoration, minerals management, and paleontology programs) provide expertise to the GRE effort. The goal of the GRE Program is to provide each of the identified 270 "natural area" parks with a digital geologic map, a geologic resource evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of park resources and is designed to be user friendly to non-geoscientists.

GRE teams hold scoping meetings at parks to review available data on the geology of a particular park and to discuss specific geologic issues affecting the park. Park staff are afforded the opportunity to meet with park geology experts during these meetings. Scoping meetings are usually held for individual parks although some address an entire Vital Signs Monitoring Network.

Bedrock and surficial geologic maps and information provide the foundation for studies of groundwater, geomorphology, soils, and environmental hazards. Geologic maps describe the underlying physical framework of many natural systems and are an integral component of the physical inventories stipulated by the NPS in its Natural Resources Inventory and Monitoring Guideline (NPS-75) and the 1997 NPS Strategic Plan. The NPS GRE is a cooperative implementation of a systematic, comprehensive inventory of the geologic resources in National Park System units by the Geologic Resources Division; the Inventory, Monitoring, and Evaluation Office of the Natural Resource Program Center; the U.S. Geological Survey; and state geologic surveys.

For additional information regarding the content of this report, please refer to the Geologic Resources Division of the National Park Service, located in Denver, Colorado. Up-to-date contact information is available on the GRE website (http://www2.nature.nps.gov/geology/inventory/).

Park History

The Fremont people, contemporaries of the Ancestral Puebloans, lived on the northern border of the Colorado Plateau from A.D. 500 to A.D. 1300. They grew crops in the rich soils on the floodplains of the Fremont River and other perennial rivers. Game was plentiful due to abundant water in the river valleys, water pockets, springs, and seeps.

For several centuries following the disappearance of the Fremont culture, no significant human activity is known in the region. The first European explorers found Ute and Southern Paiute nomads in the area. After the Civil War, Mormon Church officials in Salt Lake City tried to establish missions in remote niches of the intermountain west. However, it wasn't until Major John Wesley Powell and his team of surveyors entered the Capitol Reef country that the geomorphology and physiographic features of the area were systematically described.

Early visitors to the area saw the numerous rounded "domes" of rock and were reminded of the impressive, white, rotundas in Washington, D.C. At the time of these first pioneers, the term "reef" referred to any rocky barrier or escarpment that hindered travel and the rugged spine of the Waterpocket Fold certainly qualified. Thus the area came to be known as "Capitol Reef" as a result of its geologic features.

On August 2, 1937, President Roosevelt signed a proclamation setting aside 37,711 acres as Capitol Reef National Monument. President L B. Johnson placed an additional 215,056 acres under NPS control in 1968. A series of bills were introduced to change the status of the monument to a park. On December 18, 1971 the 241,904 acres (378 square mi) of Capitol Reef National Monument became Capitol Reef National Park.

Regional Geology

Capitol Reef National Park has some of the most spectacular geology in the western United States. Because of the brilliantly colored canyon walls, the Navajo people called it the Land of the Sleeping Rainbow. Examples of the natural beauty of this desert landscape include: the rugged spine of the Waterpocket Fold, high-walled gorges cut through the fold, monoliths, ridges, buttes, and miles of colorful canyons.

Located in southern Utah, Capitol Reef is part the Colorado Plateau Physiographic Province (figures 1 & 2). The Colorado Plateau is bordered on the east by the Southern Rocky Mountains, on the north by the Middle Rocky Mountains and the Wyoming Basin and on the west and south by the extensional Basin and Range Physiographic Province (figure 2).

Rocks at Capitol Reef National Park range in age from Permian to Tertiary and record 275 million years of the earth's history. The strata represent a variety of ancient environments including open marine, nearshore, fluvial (river), lacustrine (lake), and desert.

The highest point in the Capitol Reef area is Blue Bell Knoll, a low, rounded hill on top of Boulder Mountain at 3,446 m (11,306 ft) in elevation. The irregular outline of Boulder Mountain has been deeply cut by several broad glaciated valleys. Thousand Lake Mountain is a smaller flat-topped feature located north of Boulder Mountain (figure 3).

Folds and Faults

Capitol Reef National Park is geologically defined by the escarpment of the Waterpocket Fold, a nearly 160-km long (100-mi) step-like flexure (monocline) in the sedimentary rock. Associated large-scale geologic structures include anticlinal and monoclinal folds, faults, and fractures. Other prominent structural features of the Capitol Reef region are the Teasdale Anticline, the Teasdale Fault, and the Thousand Lake Fault (figure 3), discussed in Geologic Features and Processes below.

Most of the major faults lie west of the Waterpocket Fold (figure 3) (Smith et al. 1963; Billingsley et al. 1987). On the surface, the majority of the faults have been mapped as normal faults that follow the northwest-southeast trend of the anticlines and synclines (Billingsley et al. 1987). While some normal faults are thought to have fractured rocks from the surface down through the Precambrian, most are interpreted as relatively shallow (Billingsley et al. 1987). However, interpretations of the faults at depth may be suspect because of limited subsurface geologic data.

Reverse faults in the subsurface have been mapped as dipping 60° to the southwest (Billingsley et al. 1987). Billingsley and others (1987) mapped the reverse faults below Capitol Reef as blind thrust faults that disturb Precambrian through Mississippian rocks. Blind faults are buried faults that have no surface expression. Younger strata have been folded over the axis of the reverse faults beneath Capitol Reef but have not been offset, or fractured, by the underlying faults.

While the Waterpocket Fold is the dominant geologic feature of Capitol Reef National Park, the park also contains classic elongated "strike" valleys, dikes and sills, intrusive gypsum domes, massive landslides, fossilized oyster reefs, petrified logs, dinosaur bones, bentonitic hills, and unusual soft-sediment deformational features.

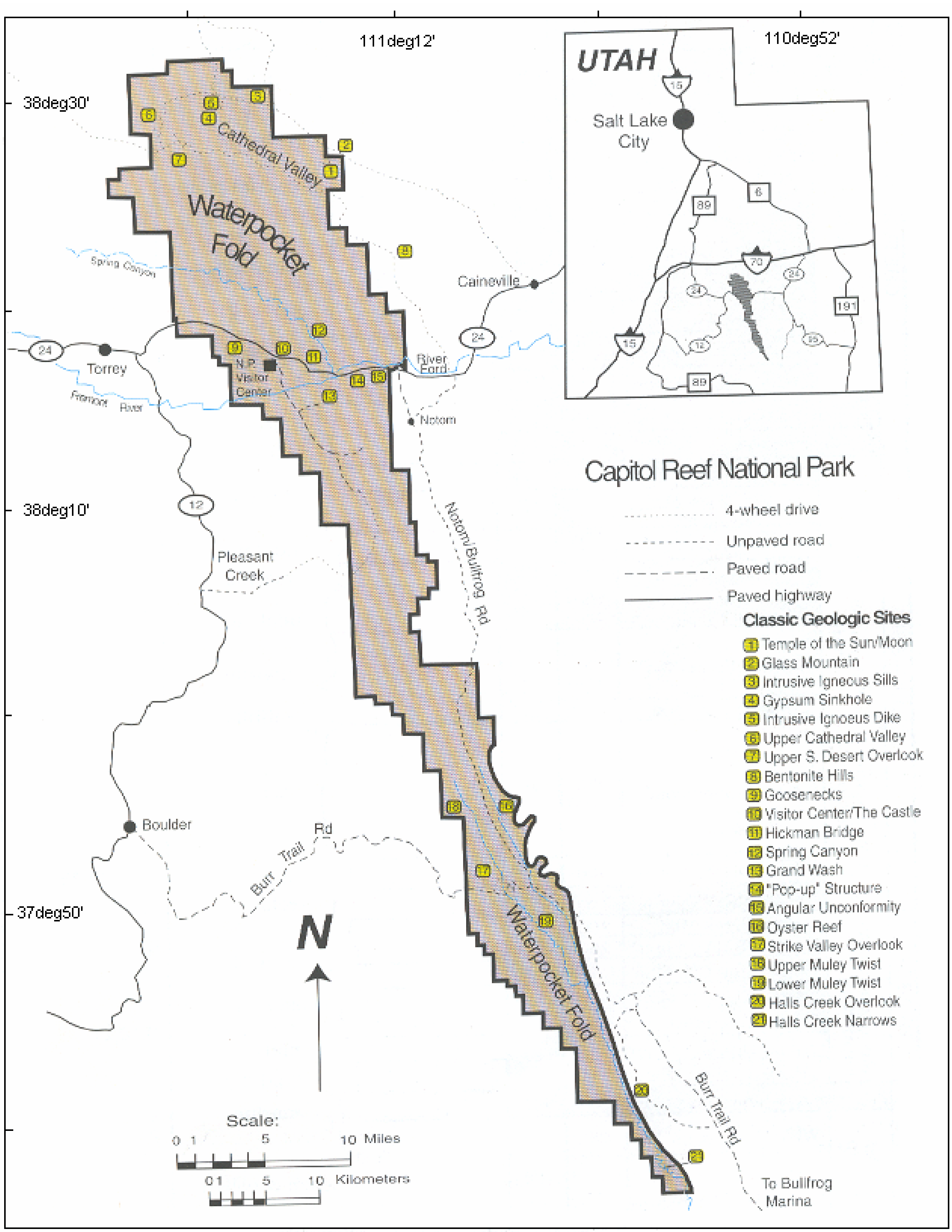


Figure 1. Location map of Capitol Reef National Park. From Morris and others, 2000.

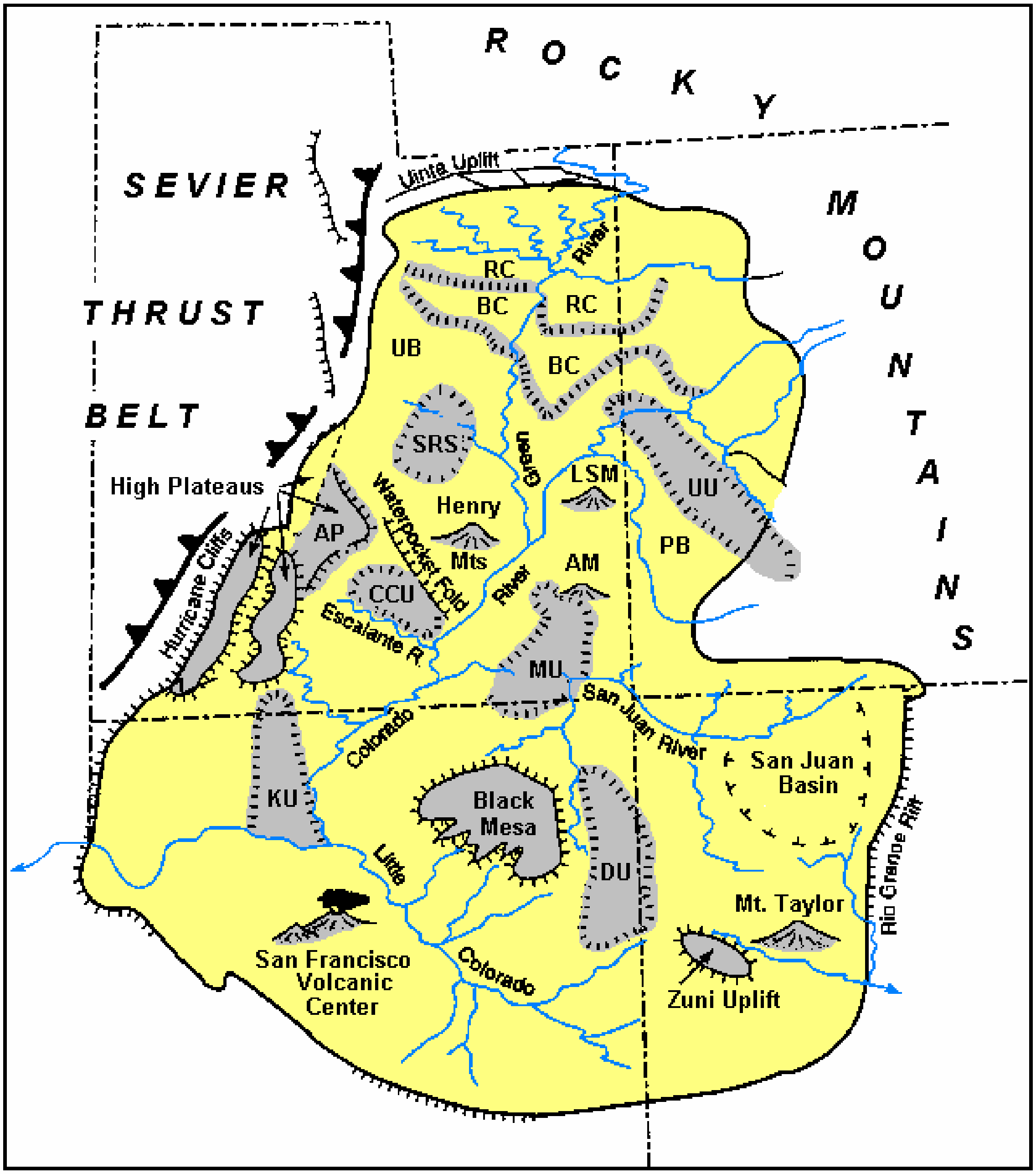


Figure 2. The Colorado Plateau physiographic province, showing some of the significant uplifts, basins, faults, volcanic centers, and rivers. High areas are shown in gray: AM, Abajo Mts.; AP, Aquarius Plateau; BC, Book Cliffs; CCU, Circle Cliffs Uplift; DU, Defiance Uplift; KU, Kaibab Uplift; LSM, La Sal Mts.; MU, Monument Upwarp; RC, Roan Cliffs; SRS, San Rafael Swell; UU, Uncompahgre Uplift. Basins: PB, Paradox Basin; UB, Uinta Basin. Capitol Reef National Park is located on the Waterpocket Fold. Leading edge of Sevier Thrust Belt is shown with sawteeth on upper, overriding thrust plate. Modified from Kiver and Harris, 1999.

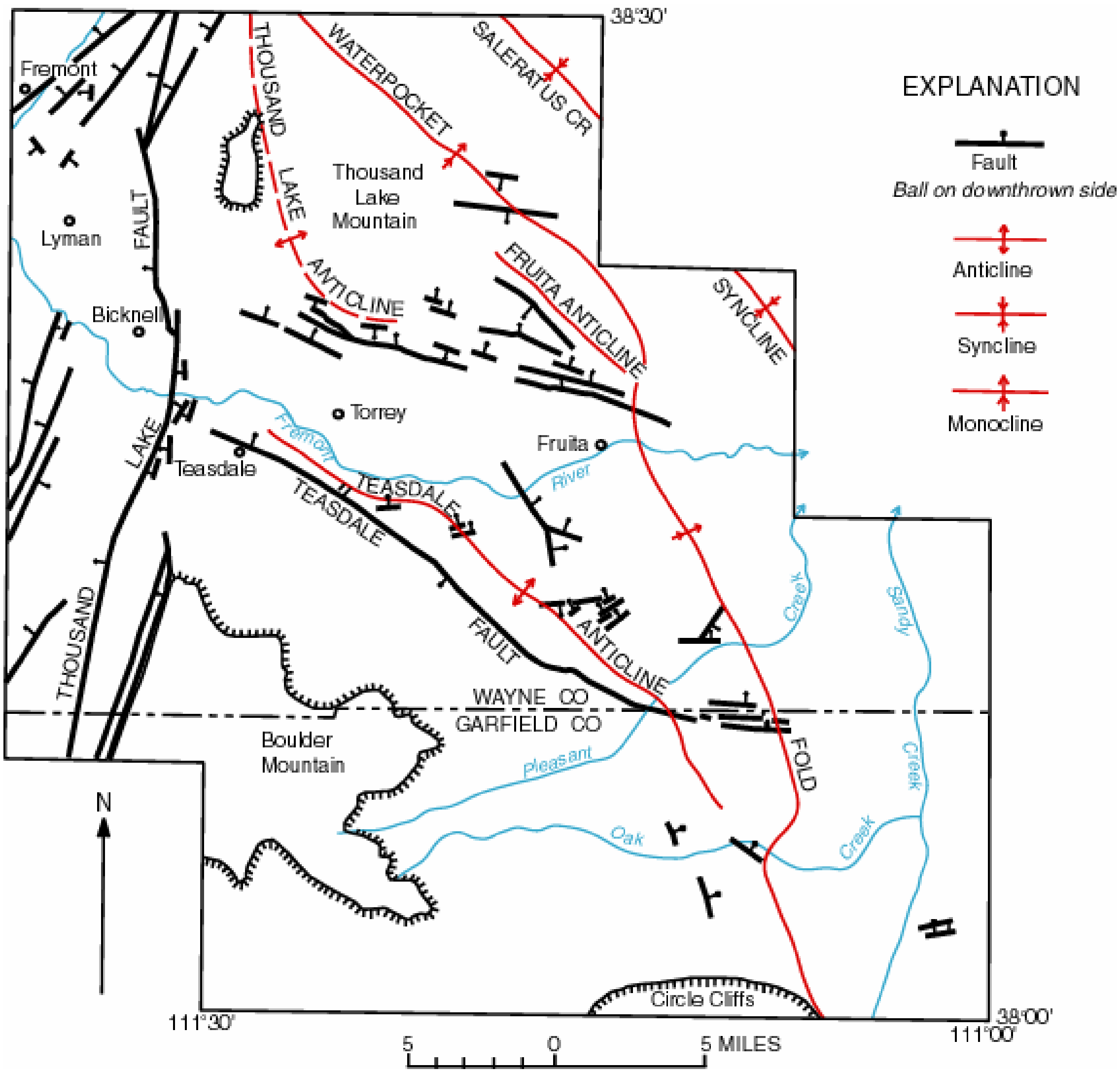


Figure 3. Major structural features in the Capitol Reef area. Modified from Smith and others, 1963.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Capitol Reef National Park on September 27-28, 1999, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results, in particular, those issues that may require attention from resource managers.

In addition to the GRE scoping session in 1999 a geoindicators meeting was held in Moab, UT from June 3-6, 2002 to discuss geologic issues for four NPS units in southeastern Utah. Discussions from this meeting and the GRE scoping meeting identified the following geologic issues as significant to park management.

Geohazards

Flash Flooding and Debris Flows

Surface water issues relating to stream channel morphology, erosion, streamflow, surface water quality, and wetlands are also considered significant to park management (Appendix C). The Water Resources Division of the NPS may be contacted for additional information regarding many of these surface water issues at Capitol Reef.

Capitol Reef lies within a semi-arid climatic zone that experiences intense thunderstorms of short duration. Flash flooding may result from rapid runoff of surface water into narrow, steep canyons that cut into the Waterpocket Fold. Intense storms may also lead to flooding in the Fremont River and its tributaries. Because vegetation is sparse, flash floods carry a high sediment load and can become debris flows transporting downstream large quantities of unsorted sediment ranging in size from clay to boulders. Flash floods and debris flows are a potential hazard to hikers in these canyons as well as to roads, trails, structures, and other infrastructure that intersect the canyons and streams.

Swelling Clays

Clays that shrink and swell are composed primarily of smectites, clay minerals formed by the chemical alteration of glassy volcanic ash (bentonite) or by alteration of other silicates in contact with water. Clay minerals are arranged in layers, much like the pages of a book. These clays expand with the addition of water between these layers and shrink upon drying (Moore and Reynolds 1989). This shrink and swell characteristic results in surface instability impacting roads, buildings, and infrastructure. Formations that contain expandable clays and which may pose a potential problem in Capitol Reef include: the Blue Gate Shale Member and Tununk Member of the Cretaceous Mancos Shale, the Brushy Basin Member of the Jurassic Morrison Formation, and the Petrified Forest Member and Monitor Butte Member of the Triassic Chinle Formation. The abundance of smectite in the Morrison Formation suggests that large quantities of volcanic ash fell over the region during its deposition (Morris et al. 2000).

Uranium and Radon Contamination

Uranium exploration was allowed in Capitol Reef from 1953 to 1956. Uranium bearing rocks have been mapped throughout the park although economic concentrations of uranium have not been discovered (Smith et al. 1963; Doelling and Tooker 1983). The principal host rocks for the radium, vanadium, and uranium deposits are fluvial deposits in Mesozoic rocks. The stratigraphic units at Capitol Reef that contain abnormal radioactivity include: the Moenkopi Formation, the Shinarump Member of the Chinle Formation, the middle and upper members of the Chinle Formation, and the Salt Wash Member of the Morrison Formation. The volcanic rocks a few miles west of the mapped area of figure 4 also contain abnormal radioactivity although the volcanic rocks inside the park do not (Smith et al. 1963).

Details of any uranium and radon contamination in the park were not discussed during the scoping workshop. However, the United States Environmental Protection Agency (EPA) joined the NPS and the Utah Abandoned Mineral LandsProgram to study radioactive contamination at the Rainy Day and Duchess Mine sites in September 2002. EPA has compiled the data but has yet to complete a report of findings. There does not appear to be an environmental problem except for radioactive contamination in the immediate area of the sites (alpha and gamma radiation). Park visitors should be advised not to camp on the spoil piles from the abandoned mines or to drink the nearby water, which possibly has additional contaminants such as arsenic (Burghardt, Geologic Resources Division, personal communication, 2006).

Rockfall and Landslides

Potential rockfall and landslide hazards exist in Paleozoic and Mesozoic strata that form steep slopes and cliffs. Rockfalls may also occur in the Permian Cutler Group and Kaibab Limestone, although these strata are exposed only in deeply incised canyons along the western margin of the park.

Rockfall and cliff collapse are potential hazards in the massive, cross-bedded sandstones of the Mesozoic strata. These same hazards are associated with the Lower Jurassic Navajo Sandstone and Wingate Sandstone, the Middle Jurassic Entrada Sandstone and Page Sandstone, and the Upper Cretaceous Ferron Sandstone Member and Emery Member of the Mancos Shale, and the Mesaverde Formation. Minor rockfall potential is present in some of the steep outcrops of the Triassic Moenkopi Formation, the Middle Jurassic Curtis

Formation, and the Lower Cretaceous Dakota Sandstone.

The Red Slide is a geologic feature that formed in the Moenkopi Formation during the wetter climate of the Pleistocene Epoch. Underlain by more resistant sandstone beds of the Torrey Member, red mudstones of the Moody Canyon Member became unstable when saturated with water. Intense rainfall of long duration combined with intense erosion and debris flows could result in similar landslides today. At risk are roads, trails, and any structures or infrastructure that may be in the path of major downslope movement.

Groundwater

A well drilled in the Fremont River Gorge in 1993, about 0.8 km (0.5 mi) west of the campground, provides the public water supply for Capitol Reef (Martin 1998). The well produces water from a 1.5-meter (5 ft) thick quartz sandstone aquifer in the Moenkopi Formation. The well produced 15,000 gallons per day during peak demand in the summer of 1998 (Martin 1998). There are no other water wells in the area; hence, the hydraulic gradient, groundwater flow direction, and effective porosity cannot be calculated accurately. Groundwater flow is presumed to follow the general northeast dip of bedding.

No contaminant sources were identified within protection zones of 250-day, 3-year, and 15-year groundwater travel times to the well. Initial water quality studies found no connection between the river and the well, no presence of cryptosporidium (a parasitic protozoan), giardia, or microscopic particulates (Martin 1998). However, water samples collected in 1993 and 1996, exceeded the maximum contaminant levels (MCL) for both sulfate and total dissolved solids (TDS). The MCLs for sulfate and TDS are 250 mg/l and 500 mg/l, respectively. The Capitol Reef well contained 320 mg/l sulfate and 720 mg/l TDS. Sulfate and TDS are secondary (recommended) drinking water standards that do not require system compliance.

In 1993, water sample analyses using a detection limit of 0.001 mg/l for thallium did not detect any thallium in the well (Martin 1998). However, results from the 1996 analysis reported 0.008 mg/l of thallium (Martin 1998). This high level is thought to reflect a lab error. Thallium is a primary drinking water standard with a MCL of 0.002 mg/l. Sources for thallium include ore-processing sites and discharge from electronics, glass and pharmaceutical companies (EPA website www.epa.gov/safewater/mcl.html, access April 2005). As of this report, the Water Resources Division does not have any more recent water quality data on the well (Larry Martin, Water Resources Division, NPS, personal communication 2006).

Disturbed Lands

According to John Burghardt (GRD), ten abandoned mine sites are recorded in the park, entailing 27 individual mine openings. The Oyler, Terry, and Rainy Day abandoned mineral landsites have been fully mitigated by closing 20 openings. Seven openings remain at the other 7 sites. Some low-grade coal can be found in the Carmel Formation just east of the intersection of Notom Road and State Highway 24. A few small borrow pits may be present along the Burr Trail.

Cattle grazing has disturbed the area around Oak Creek and Pleasant Creek. A preliminary disturbed lands map GIS layer for roads that the park wants closed, cattle ponds, dams, tanks, and other features is available to management (Tom Clark, Capitol Reef National Park, Natural Resources 1999).

Paleontological Resources

The Permian White Rim Sandstone (Cutler Group) crops out locally within the park and contains marine trace fossils of *Thalassinoides* and *Chondrites*. The fossiliferous Kaibab Limestone interfingers with the White Rim Sandstone and contains fragments of marine invertebrates such as bryozoans, brachiopods, gastropods, bivalves, and crinoids (Koch and Santucci 2002).

Brachiopods, gastropods, bivalves, and ammonites are found in the Sinbad Limestone Member of the Triassic Moenkopi Formation. The Moenkopi also contains fossil vertebrate tracks of *Rotodactylus* and swimming traces of *Chirotherium* (Mickelson 2004). Invertebrate fossil traces of *Palaeophycus*, and *Diplidnites* are reported from the Torrey Member of the Moenkopi Formation (Santucci et al. 1998).

The Shinarump Member of the Triassic Chinle Formation contains abundant paleobotanical fossils such as *Zamites powelli*, *Palissya* sp., *Sphenozamites* sp., abundant stems of the fossil horsetails, *Equisetites*, *Phlebopteris*, *Cyneopteris*, *Cladophlebis*, *Pagiophyllum*, and *Araucarioxylon* (Koch and Santucci 2002). Leaves of the palm-like plant *Sanmiguelia* cf. *S lewisi* have been found in the Owl Rock Member of the Chinle Formation. Other fossils from the Chinle include tetrapod remains, lungfish toothplates and burrows, coprolites, marine snails, and bivalves.

Dinosaur and tritylodont tracks are reported from the Lower Jurassic Kayenta Formation (Santucci et al. 1998). The Lower Jurassic Navajo Sandstone, primarily an eolian deposit, also contains algal mounds formed in interdunal playa deposits in Capitol Reef NP (Koch and Santucci 2002).

The Middle Jurassic Carmel Formation preserves a small marine assemblage including *Ostrea* sp., *Trigonia* sp., *Camptonectes* sp., and the star-shaped columnals of the crinoid *Pentacrinus asteriscus*. Upper Jurassic dinosaur bones and petrified logs have been found in the Salt Wash Member of the Morrison Formation in and near Capitol Reef National Park.

Turtle and dinosaur remains have been discovered in the Lower Cretaceous Cedar Mountain Formation just north of the park. The Oyster Reef is a geologic feature exposed along the Notom-Bullfrog road where thick accumulations of oyster shells, principally *Pycnodonte* sp.

and *Exogyra (Costagyra) olisiponensis*, can be seen in the Upper Cretaceous Dakota Sandstone. Marine fossils, including bivalves, gastropods, ammonites, and shark's teeth, are found in the Tununk Shale Member and Blue Gate Member of the Mancos Shale. Vertebrate remains of turtles, crocodiles, and ceratopsian dinosaurs have been found in the Masuk Member of the Mancos Shale.

The Late Paleocene or Early Eocene age Flagstaff Limestone contains charophytes (green algae), ostracods, bivalves, and gastropods that indicate a freshwater origin for the carbonate unit.

Although theft and vandalism of fossils do not present a problem, the abundance, variety, and accessibility of fossils in Capitol Reef, make fossil poaching and fossil preservation potential issues for resource management.

Mineral Occurrences

Capitol Reef National Park has been closed to mineral entry including oil and gas since it was established as a National Monument in 1937, with the exception of a period from 1953 to 1955 when uranium exploration was allowed (Smith et al. 1963). Mineral occurrences in the area include uranium, vanadium, copper, manganese, gypsum, minor coal, building stone, sand and gravel, and oil and gas (figure 4) (Smith et al. 1963; Doelling and Tooker 1983).

Uranium

The presence of uranium in the Capitol Reef area has been known for many years and the presence of ten abandoned mineral land sites related to uranium mining attest to development of these uranium deposits (figure 4). The monument was again closed to mineral entry after May 1955. The Oyler mine, established on the north side of Grand Wash in Capitol Reef, was located in 1901 and is the oldest uranium-radium prospect in the Capitol Reef area.

Uranium minerals in the Moenkopi Formation are not widespread in the park. Perhaps the only significant locality is 2.4 km (1.5 mi) northwest of Torrey (figure 4). Found in a massive sandstone channel about 10 meters (32 ft) thick and 122 m (400 ft) below the top of the formation, the uranium mineral, metazeunerite, is a green mineral associated with a black substance that is layered parallel to bedding and also found as black spots within the sandstone (Smith et al. 1963).

Throughout the Colorado Plateau, uraniferous deposits are found in Shinarump sandstones that fill channels cut into the underlying Moenkopi Formation. More uranium minerals are found in the Shinarump Member of the Chinle Formation than any other stratigraphic unit in the Capitol Reef area. East of the Waterpocket Fold, the Shinarump forms a discontinuous, uranium-bearing unit from about 4 km (2.5 mi) northwest of Fruita, Utah, southeastward along the Waterpocket Fold to Oak Creek and North and South Coleman Canyons (figure 4). West of the Waterpocket Fold, where the Shinarump forms a more continuous deposit, uranium-bearing rocks are less abundant and found in lower concentrations compared to the discontinuous Shinarump in the Capitol Reef area (Smith et al. 1963). Nearly all the uranium minerals and radioactive material, and most copper minerals present in the abandoned Oyler mine, are found in an almost continuous tan and yellow clay layer at the base of the Shinarump (Smith et al. 1963).

Radioactive material also occurs in the middle and upper members of the Chinle, but no large concentrations have been found in the Capitol Reef area (Smith et al. 1963). Most of the abnormal radioactivity is found in widely scattered fossil logs in South Coleman Canyon, just north of Oak Creek, east of Sand Creek, and northwest of Teasdale, Utah (figure 4).

Other than in the Shinarump, channel deposits in the Salt Wash Conglomerate Member of the Morrison Formation appear to be the most favorable locations for uranium minerals. These deposits are generally 0.6 to 2 meters (2 to 6 ft) long, 0.6 to 1 meters (2 to 3 ft) wide, 5 to 15 cm (2 to 6 in) thick, and contain abundant carbonized plant fragments (Smith et al. 1963). The primary uranium mineral found in the Salt Wash Conglomerate is carnotite.

Other Minerals

Several old copper prospects are located on Miners Mountain (figure 4). Workings from these prospects have collapsed and are mostly inaccessible (Smith et al. 1963). In the early part of the 20th century, "a few hundred pounds of high-grade ore is reported to have been shipped" from the Capitol Reef area, but Smith and others found no evidence of any further copper production when they visited the area in 1954 (Smith et al. 1963). Samples of uranium ore from the Shinarump Member of the Chinle Formation in the Capitol Reef area showed abnormal amounts of copper, lead, zinc, molybdenum, and arsenic along with uranium. The quantities of these metals, however, were of little economic value (Smith et al. 1963).

A manganese deposit is located north of Spring Gulch on the east side of Boulder Mountain (figure 4). The manganese mineral is pyrolusite (MnO2) which forms cylindrical, pipe-like masses as much as 5 cm (2 in) in diameter. The manganese oxide holds the sand grains together in parts of the Carmel Formation. Iron oxide is associated with manganese in the sandstone.

Gypsum, Building Stone, and Sand and Gravel Resources

Non-metallic mineral resources also exist within the boundaries of Capitol Reef National Park. Glass Mountain is composed largely of gypsum (CaSO4º 2H2O). Gypsum beds, up to 24 meters (80 ft) thick, are exposed in the Carmel Formation, particularly in the area of Black Ridge west of Teasdale (Smith et al. 1963). On the east side of the Waterpocket Fold, a north-south trending area of gypsum and anhydrite has been mapped that extends to the north and south of the park (Doelling 1983).

The sandstone beds in the Moenkopi Formation have been quarried and used for buildings in the local communities and for the Capitol Reef headquarters building near Fruita (Smith, et al. 1963). These fine-grained sandstone beds split easily along bedding planes to make flat and relatively uniform building stone. Pediment gravels and terrace gravels along the Fremont River have been used for aggregate and general construction activities.

Oil & Gas

The potential for oil and gas reservoirs in both structural and stratigraphic traps in the Capitol Reef area is unknown. The Teasdale, Fruita, and Thousand Lake anticlines are structures with the potential to trap hydrocarbons (figure 5A) (Smith et al. 1963).

The youngest formation to yield oil and gas in the area is the Moenkopi Formation, and Moenkopi traps may be present in both the Fruita and Thousand Lake anticlines. On the Teasdale anticline, however, erosion has exposed the beds of the Moenkopi to the surface so that any oil has been biodegraded and any gas has escaped to the atmosphere. All three structures have the potential for yielding oil and gas from older formations such as the Permian White Rim Sandstone or the Pennsylvanian Paradox Formation.

As of 1963, only the Teasdale anticline had been tested for hydrocarbons (Smith et al. 1963). Three wells were drilled in the vicinity of the Teasdale anticline, but only one was located on the structure. The Pacific Western Oil Corp. Teasdale 1, drilled in 1949, reached a total depth of 1503 meters (4932 ft) in Cambrian-aged limestone. Oil-stained beds were found in the Permian Coconino Sandstone (called the Cedar Mesa Sandstone in other areas of the Colorado Plateau) and in the upper part of the Pennsylvanian Hermosa Limestone (Smith et al. 1963). In 1950, the Parry Oil Company Teasdale 1 was drilled to a depth of 159 m (523 ft). No hydrocarbons were discovered. Another dry hole was drilled by Smith and others (1963) during fieldwork in 1953-54, no information is available for this hole.

By 1963, six wells had been drilled about 8 km (5 mi) northeast of the Capitol Reef area on an anticline having 180 meters (600 ft) of trap closure. Gas was produced from five of these wells from the Sinbad Limestone Member of the Moenkopi Formation and from a sandstone bed above the Sinbad in the Torrey (?) Member of the Moenkopi (Smith et al. 1963). The daily gas production in four of the wells ranged from 1 million to 21 million cubic feet of gas per day.

Increased interest in the exploration and development of oil and gas resources in the State of Utah has resulted in the Bureau of Land Management offering numerous oil and gas leases for competitive bid directly north and northeast of Capitol Reef National Park. The Bureau of Land Management has placed several protective stipulations on these leases to help protect the park's air, water, visual, wildlife, vegetation, and soundscape resources. Although the various tracts were successfully bid upon, limited exploratory drilling has not resulted in any producing wells near the park.

Capitol Reef National Park is closed to leasing, however, approximately one square mile of the park is encumbered by the Viking oil and gas lease. The Viking lease is a valid existing right that predates the park. The owner of the Viking lease continues to propose development of his lease holdings, but no action has taken place to date.

In the early 1980's and again in 2006, Utah's tar sand resources were considered for federal leasing. While the park is closed to tar sand leasing, such leasing and development adjacent to the park could take place if the technological and economic conditions were right. Areas adjacent to the park considered for tar sand leasing will be identified by the 2006-2007 programmatic environmental impact statement that is currently being prepared by the Bureau of Land Management.

Seismicity

Seismicity on the Colorado Plateau is relatively low both in number and magnitude. Diffusely distributed earthquakes have small to moderate magnitudes (Humphrey and Wong 1983). From December 1978 to January 1980, a spatially and temporally isolated swarm of at least 38 earthquakes, with magnitudes ranging from 1.0 to 3.6, occurred near Capitol Reef National Park. This was the highest level of natural seismicity historically observed within the interior of the Colorado Plateau (Humphrey and Wong 1983).

The earthquakes occurred in a structurally complex area where the Waterpocket Fold meets the Caineville monocline just west of Henry Mountains. The location suggests a possible association with basement faults generated by the Cretaceous-Tertiary Laramide Orogeny, which controlled the development of both the fold and monocline. The earthquakes may represent an occurrence of Basin-and-Range extensional tectonism along a reactivated Laramide structure within the transition zone between the Basin-and-Range and Colorado Plateau physiographic provinces (Humphrey and Wong 1983). The potential for a major earthquake with a magnitude greater than 5.5 is considered very low in the Capitol Reef area.

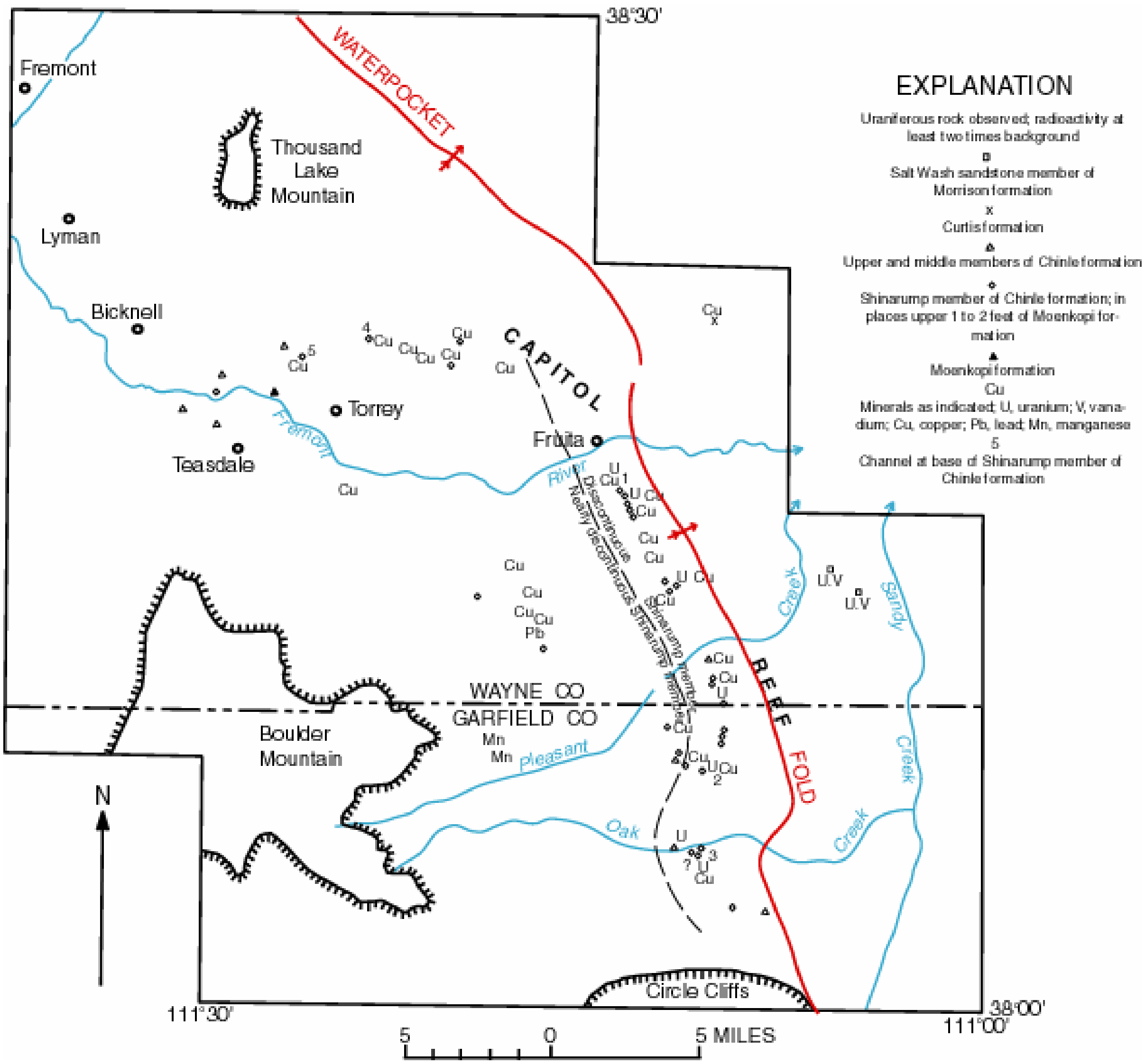
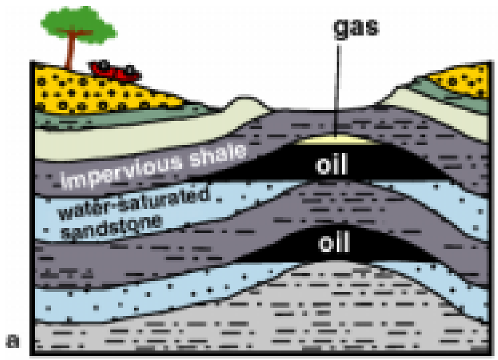
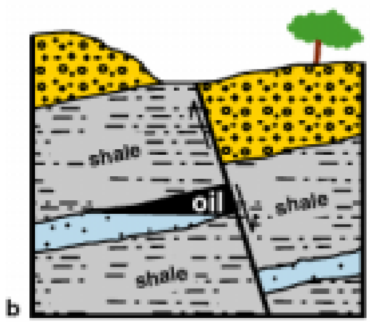


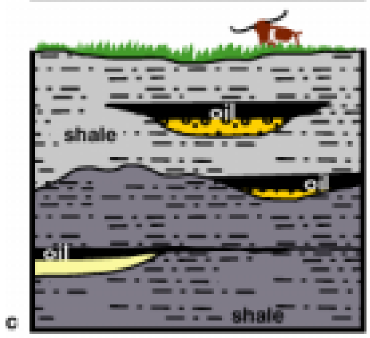
Figure 4. Mineral and abnormal-radioactivity map of the Capitol Reef area. Modified from Smith and others (1963).



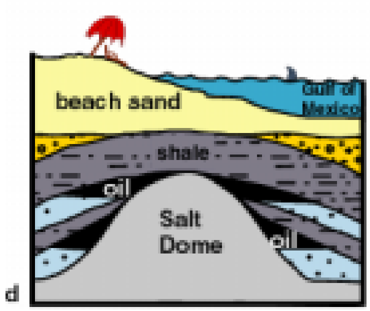
a. Anticline: Structural trap in which hydrocarbons migrate to the highest point on the anticline and are sealed by overlying, impervious shale.



b. Fault: Structural trap in which hydrocarbons are sealed against the fault by the juxtaposition of an impervious shale layer.



c. Stratigraphic Traps: 1) Hydrocarbons trapped in channel sandstones and sealed from migrating by encasing impermeable flood plain deposits, 2) unconformity trap with oil trapped in incised valley fill deposits, 3) updip pinch-out where hydrocarbons follow paleotopography. In this example, oil is trapped in beach facies at the intersection with impermeable tidal flat facies



d. Salt Dome: Rising salt thins overlying units and acts as a barrier to further oil migration.

Figure 5. Schematic diagrams illustrating common types of hydrocarbon traps (gas is omitted except in "a").

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Capitol Reef National Park.

Waterpocket Fold

The Waterpocket Fold is one of the longest continuously exposed monoclines in the world and is the centerpiece geologic structure of Capitol Reef (figure 3) (Morris et al. 2000). The Waterpocket Fold monocline stretches for almost 161 km (100 mi), from the Colorado River south of the Henry Mountains, along the east side of the Circle Cliffs, northward to the north end of Thousand Lake Mountain. The general trend of the Waterpocket Fold is northwest-southeast. Between Oak Creek and the Fremont River, the fold trends approximately N 25° W, but north of the Fremont River the fold trends more westward to N 50° W (figure 3).

The rock layers on the western limb of the fold are more than 2,100 m (7,000 ft) higher than the rock layers on the east. From the crest of the fold, the High Plateaus Section of the Colorado Plateau extends westward. To the east lies the desolate beauty of the Canyon Lands Section. Water is a powerful erosive agent, especially in a desert environment with scarce vegetation. Over time, water has carved catchments for surface runoff in the uplifted and tilted sandstone layers of the Waterpocket Fold. These small basins, also known as water pockets, are common throughout the fold and give this feature its name.

Within the park, the sedimentary beds on the western limb of the fold dip generally to the east and northeast about 10° to almost 35° (Smith et al. 1963; Billingsley et al. 1987). East of the near vertical fold of the monocline, the dips are gentler and appear to be more consistent, ranging from 4° - 7° (Billingsley et al. 1987). Local bends or kinks in the fold alter the northwest trend of the beds along the monocline. One prominent bend occurs just north of Fruita, Utah, and another is just north of Oak Creek (figure 3). Bends or kinks in the Waterpocket Fold may represent offset along a reverse fault within the subsurface Precambrian section of rocks.

The geologic processes that form many of the exceptional landforms of the desert southwest are evident throughout Capitol Reef National Park. The features below can be seen along the Cathedral Valley Loop, Highway 24, the Notom-Bullfrog Road, and throughout the park.

Teasdale Anticline

The Teasdale anticline extends at an angle of approximately 20° - 30° from the Waterpocket Fold (figure 3). The general northwest trend of the Teasdale Anticline is N 55° W but changes to N 75° W north of Grover, Utah (near Torrey). If the surface expression of the Teasdale anticline is projected to the southeast, the fold will intersect the Waterpocket Fold at the Oak Creek bend. Both the northwestward and southeastward hinge line extensions of this anticline disappear, or plunge, below the surface, making the Teasdale anticline a doubly plunging anticline. The Teasdale anticline is an asymmetric anticline with dips ranging from 20° - 50° SW on the southwest limb and from 10° - 14° NE on the northeast limb (figure 3). Major uplifts on the Colorado Plateau such as the Circle Cliffs and the San Rafael Swell are also asymmetric, but unlike the Teasdale anticline, their steeper limbs are on the east side of the fold (Smith et al. 1963).

Teasdale Fault

The Teasdale fault lies southwest of the Teasdale anticline and follows a similar trend of N 60° W except south of Pleasant Creek where the trend is about N 70° W (figure 3). The southwest side of this high-angle to vertical normal fault has dropped as much as 335 m (1,100 ft) relative to northeast side (Smith et al. 1963). The Teasdale fault is a 40- km (25- mi) long fault zone composed of two dominant faults and many small branching faults and cross faults. The fault crosses the southeastern nose of the Teasdale anticline and splays into several eastward-trending faults at its southeastern end. These faults extend for about 6 km (3.7 mi) into the Waterpocket Fold (figure 3). The north sides of these shorter, normal faults have dropped down relative to their south sides. Several east-west trending faults also extend for about 5.6 km (3.5 mi) into the Waterpocket Fold from east of the Teasdale anticline (figure 3). These smaller faults also have their north sides downthrown. Maximum vertical displacement is about 30 m (100 ft).

Sedimentary strata within or adjacent to the fault zone dip from 20° SW to vertical with some overturned beds dipping 75° NE (figure 3) (Smith et al. 1963). On the downthrown side near the Teasdale fault, beds consistently dip at high angles, flattening to almost horizontal less than 0.8 km (0.5 mi) from the fault.

Thousand Lake Fault

Dutton recognized and named the Thousand Lake fault in 1880. This normal fault zone west of the park boundary, begins east of Fremont, Utah, and trends southward for over 32 km (20 mi) becoming unrecognizable along the western edge of Boulder Mountain (figure 3) (Smith et al. 1963). The fault zone may continue to the northeast, north of the park boundary, as the Paradise fault.

The western block of the Thousand Lake fault has dropped relative to the eastern block. Total displacement along the fault is about 762 m (2,500 ft) (Smith et al. 1963). Displacement along the fault can be calculated by measuring the difference in elevation between volcanic layers on Thousand Lake Mountain and the area west of the mountain.

Other Folds and Faults

Other folds in the region include the Fruita Anticline, the Circle Cliffs Upwarp, the Thousand Lake Anticline, and the Saleratus Creek Syncline (Smith et al. 1963; Billingsley et al. 1987; Morris et al. 2000). The asymmetric Fruita Anticline and the Saleratus Creek Syncline have geomorphic trends similar to the Waterpocket Fold (figure 3). The Circle Cliffs Upwarp and the Thousand Lake Anticline lie south and west of the park boundary, respectively, although the east limb of the Thousand Lake Anticline is part of the Waterpocket Fold.

Beginning just north of Fruita, Utah, a zone of normal faults trends approximately N 70°-80º W and extends for about 24 km (15 mi) (figure 3)(Smith et al. 1963). Most of the faults are downthrown to the north. The maximum length of a single fault is only about 10 km (6 mi). Smith and others (1987) measured a maximum displacement along the faults of 110 m (360 ft), but found that most of the fault movement is less than 30 m (100 ft).

Also present in the Capitol Reef area are faults that are not as concentrated or pronounced as those discussed above. Near Fremont, Utah, several high-angle normal faults trend chiefly northeastward with west sides downthrown. West of Boulder Mountain, northeast-trending high-angle normal faults cross an area of volcanic rocks (figure 3). The Y-shaped fault southwest of Fruita, Utah, is on the north side of Miners Mountain. The maximum displacement on this fault is 53 m (174 ft) measured near the split in its trace. Reverse faults cut the Moenkopi Formation on the flanks of the Teasdale anticline (Smith et al. 1963). These reverse faults have maximum displacements of 3 m (10 ft) and are too small to be shown on the geologic map.

Joints

Numerous vertical joints are also present in Capitol Reef NP. Joints, like faults, are semi-planar breaks in the rock, but unlike faults, there is relatively little displacement along a joint. The most prominent joints are along the Waterpocket Fold. South of latitude 38º 13' N (near the border of Wayne and Garfield counties) the joints trend from about N 15º W to N20º W. North of this latitude, their trends change to N 15º E - N 15º W with many of these joints trending almost due north.

Prominent cross joints trending N 50º - 80º W also cut through the Waterpocket Fold at three locations along warps in the fold. One is found in the synclinal trough along Oak Creek south of the southeast extension of the Teasdale anticline as it projects into the Waterpocket Fold. A second is in the synclinal trough north of Fruita and on the south side of the southeast extension of the Fruita anticline as it projects into the fold. The third area of cross joints is in the area of Deep Creek east of Thousand Lake Mountain (Smith et al. 1987).

Dikes and Sills

The dikes and sills in Capitol Reef NP have been interpreted as part of a larger basaltic dike complex that extends out of the park to the north and into the San Rafael Swell. Resistant dark gray igneous dikes intrude into Entrada sandstones just north of the Gypsum Sinkhole. Tabular sills parallel to sedimentary bedding can be found in Cathedral Valley and on the steep west-facing hillsides adjacent to the road just a few miles to the east of the Gypsum Sinkhole turnoff. These are some of the best exposed tabular sills in the world. A breccia-filled volcanic pipe (diatreme) is exposed at the Upper South Desert Overlook, emplaced into (generally) flat-lying sedimentary rock by a gaseous explosion.

Quaternary Features

Pleistocene and Holocene features in the park include pediment deposits (deposits on a gently inclined surface eroded into bedrock), glacial till, outwash gravel, terrace gravel, colluvial deposits, landslide deposits, eolian deposits, and alluvium and alluvial fan deposits. Pediment deposits of volcanic boulders, cobbles, sand and gravel occur on gently sloping surfaces several hundred feet above adjacent streams and valleys as well as on some flat-topped hills and benches in Capitol Reef (Billingsley et al. 1987). The volcanic boulders are round to oblong and average 0.9 to 1.5 m (3 to 5 ft) in the long direction with some reaching more than 4.5 m (15 ft) in length. Lenticular beds of gravel are generally between 6 to 15 m (20 to 50 ft) thick. Many of the exposed boulders have grooved or fluted top surfaces indicative of sand blasting caused by prevailing southwest winds.

Boulder deposits, distinct from the boulders found in the pediment gravels, have been mapped near the mouths of Fish and Carcass Creeks and near Browns Reservoir and Tantalus Flats along Pleasant Creek (Smith et al. 1963; Billingsley et al. 1987). Caliche, a near surface crust of crystallized calcite commonly found in desert soils, coats many of the boulders. The thickness of the caliche varies with altitude. Caliche at 2,100 m (7,000 ft) averages 0.6 cm (0.25 in) thick while caliche at 2,400 m (8,000 ft) is only a thin coating. The advanced dissection of the boulder deposits indicates that the boulders are erosional remnants of deposits whose original topographic forms have been destroyed.

Glacial till, outwash gravel, terrace gravel, and landslide deposits near the west boundary of Capitol Reef are associated with an ice cap that formed on Boulder Mountain. Moraines composed of till and some outwash gravels form a landscape of ridges, irregular knobs, and kettles. Remnants of glacial moraines may be found along Donkey, Fish, Carcass, Pleasant, Oak, East Boulder, West Boulder, and Miller Creeks (Smith et al. 1963).

Terrace gravels and sands along the Fremont River and its tributaries rest on erosional surfaces cut in the bedrock that are elevated above the present floodplain. The distance from the terrace to the river increases downstream. At the mouth of Carcass Creek, west of

Fruita, for example, the terrace is about 46 m (150 ft) above the Fremont River while Johnson Mesa, a large terrace remnant at Fruita, is about 76 m (250 ft) above the river. The terrace deposits range in thickness from less than 6 to more than 12 m (20 to 40 ft) and contain a few rounded volcanic boulders and pebbles from Boulder Mountain, chert and quartzite from the Salt Wash Member of the Morrison Formation or from the Flagstaff Limestone, and limestone clasts probably from the Carmel Formation.

Alluvial fan deposits form fan-shaped aprons of poorly sorted silt, sand, pebbles, cobbles, and boulders at the mouth of canyons. Alluvial fans are convex topographic features with a main stream channel providing sediment from the mouth of the canyon to the fan. The stream channel, however, is difficult to define across the fan as its channel morphology changes as in-channel sediment is deposited, choking the stream and modifying its slope so that the channel shifts to a new location on the fan.

Grand Wash, Capitol Wash, Pleasant Creek, Sheets Gulch, and Oak Creek flow in precipitous gorges being eroded into the Waterpocket Fold. A dirt road connecting Fruita to Hanksville, Utah, extends through the narrow gorge of Capitol Wash, a gorge that is typical of all the gorges crossing the fold. Cliffs of Navajo Sandstone tower hundreds of feet above the road and at its narrowest point, Capitol Wash is only 7.6 m (25 ft) wide at road level.

Tour of Park Features

Cathedral Valley Loop

Cathedrals and Monoliths of Cathedral Valley

Accessible only by high clearance or four-wheel drive vehicles, Cathedral Valley is located in the northern portion of the park where bedrock dips about 3°- 5° to the northeast. Erosion of the red-orange mudstone, siltstone, and fine-grained sandstone of the Entrada Sandstone formed the valley and sculpted numerous freestanding masses of rock (monoliths) (Morris et al. 2000). Temple of the Sun, Temple of the Moon (figure 6), and erosional features in the Upper Cathedral Valley (figure 7) are outstanding examples of monoliths that resemble cathedrals or temples rising from the valley floor.

Occasionally, the more resistant gray-green sandstones of the Curtis Formation cap the monoliths in the park. Closely spaced rock towers, the precursors to monoliths, are found at a number of places along the southwest wall of the valley. Headward erosion by streams and rivers resulting in downcutting and slope retreat will, in time, strand these towers and create monoliths (Morris et al. 2000).

The Entrada and Curtis were once buried and when the overlying strata were removed by erosion, the release of the overlying pressure produced fractures and joints in the rock. Fractures and joints expose more surface area and accelerate weathering and erosion. Once water penetrates along the fractures, mechanical and chemical weathering begin to erode the fractured rock. The fractures expand, the rock crumbles, and the less fractured more resistant rock is left free-standing. Where the resistant Curtis Formation directly overlies the Entrada, it forms a resistant cap rock protecting the underlying strata from further erosion.

Glass Mountain and Gypsum Sinkhole

Fractures may be filled with evaporite (salt) deposits that may flow upward from underlying strata forming a salt diapir. A diapir is a dome or bulge that forms when plastic, lower density rock layers (as salt) are squeezed upward through denser, more resistant sedimentary rock. When seawater evaporated during Carmel Formation time, approximately 165 million years ago, a thick gypsum layer formed. At increased pressures and temperatures various salts as well as gypsum will flow as a viscous fluid under conditions in which other sedimentary rocks would deform in a brittle fashion. As sedimentation buried the gypsum, it began to plastically deform and to flow upward. Where the gypsum encountered areas of lower pressure, perhaps created by faults and fractures in the overlying rock column, the gypsum formed small domes or plugs in the overlying Entrada Sandstone. Glass Mountain is a surface expression of one of these plugs. Rising more than 3 m (10 ft) above the valley floor, Glass Mountain (figure 6) is composed of selenite, a clear, colorless variety of gypsum (Morris et al. 2000).

Although gypsum is somewhat soluble, Glass Mountain remains exposed at the surface because of the dry climate. Gypsum Sinkhole, located approximately 11 km (7 mi) to the northwest of Glass Mountain, was likely created by the dissolution of another gypsum plug, possibly when the climate was wetter (Morris et al. 2000).

Volcanic Features

Igneous dikes exposed just north of the Gypsum Sinkhole are examples of differential erosion. Dikes are tabular igneous rock bodies that intrude at angles into sedimentary strata. The dark gray igneous dikes of Capitol Reef National Park are more resistant to erosion than the relatively soft red-orange sandstones of the Entrada. Dikes are often exposed above the surrounding sedimentary strata that have eroded around them.

Dikes are often associated with igneous sills, tabular sheet-like bodies that intrude parallel to bedding planes. Capitol Reef contains exceptional exposures of sills on steep west-facing hillsides adjacent to the road just a few miles to the east of the Gypsum Sinkhole turnoff (Morris et al. 2000).

A diatreme, a breccia-filled volcanic vent or pipe, is exposed adjacent to the walking path on a west-facing pillar of rock at the Upper South Desert Overlook. The diamond-bearing kimberlite pipes of South Africa are probably the most well-known diatremes in the world.

Bentonite Hills

To the east of North Blue Flats, just outside Capitol Reef, the Brushy Basin Member of the Morrison Formation has eroded into barren, color-banded, rounded hills or badlands. Vegetation is scarce in the area and the surface of the hills has a “popcorn” texture from the bentonitic clay. The hills are best viewed approximately 14 km (9 mi) north of the River Ford (Fremont River crossing). Exposures of Morrison Formation in the park are located north of Highway 24.

The Morrison Formation is world-renowned for its abundant and diverse Jurassic-age dinosaurs, and dinosaur bones in this formation can be seen in and around the park. At Bentonite Hills, a number of large petrified logs have also been found. The petrified logs and dinosaur bones indicate that a lush, humid, tropical climate probably existed in the Capitol Reef area during Morrison time. Research in the Morrison Formation at Dry Mesa Dinosaur Quarry, located 400 km (250 mi) east of Capitol Reef in western Colorado, suggests that major climate shifts occurred in the Jurassic so that the normally humid, wet conditions were interrupted by large-scale, cataclysmic drought (Richmond and Morris 1998). The drought caused dinosaurs to gather at shrinking watering holes where they died, creating concentrated accumulations of bones such as those at Dry Mesa Dinosaur Quarry.

Highway 24: west to east transect

“The Goosenecks” at Sulfur Creek

The Goosenecks of Sulfur Creek are classic examples of a superposed meandering stream (Morris et al. 2000). Rivers often follow the structural trend of a region, but at Capitol Reef, the rivers cut through (i.e., are superposed on) the structural features as if folding, faulting, and rock hardness did not influence the path of the river’s channel.

The meandering river pattern at Capitol Reef originally developed on a relatively flat topographic surface during Paleocene-Eocene time, about 66 to 38 million years ago. About 20 million years ago, the Colorado Plateau began uplifting (Morris et al. 2000). The meandering rivers either cut into the underlying sediment and flat-lying rocks faster than the rocks were uplifted or the river had already entrenched its channel by the time uplift began. The river began cutting the channel vertically downward rather than laterally across its floodplain. Once the stream eroded through the flat-lying rocks, it cut into the underlying folded strata. In this way, the meandering pattern was superposed on the underlying folded rocks and today cuts across the structural trend rather than being influenced by the geologic structure.

Permian age rocks that are part of the 250 to 290 million-year-old Cutler Group, some of the oldest rocks at Capitol Reef, are exposed on the canyon floor at the Goosenecks. Massive exposures of the Permian Kaibab Limestone, as well as the Black Dragon Member, the Sinbad Limestone Member, the Torrey Member, and the Moody Canyon Member of the Triassic Moenkopi Formation overlie sandstones of the Cutler Group.

Visitor Center: “The Castle”

The “Castle” (figure 8), seen from the Visitor Center parking lot, is a geomorphic feature resulting from tectonism and erosion. The vertical fractures in the well-indurated eolian (wind blown), Jurassic-age Wingate Sandstone developed during uplift of the Colorado Plateau (Morris et al. 2000). The fractures on the walls of the “Castle” have been enlarged over the years due to ice wedging and dissolution. Ice wedging is the mechanical process wherein water trapped in a fracture (or pore space) freezes, expands, applying pressure on the surrounding matrix, and loosens the bonds holding grains together. When the water melts, the loosened grains are washed away.

The Visitor Center and campground area lie on the contact between the Moenkopi and Chinle Formations. The area is relatively flat because of differential erosion between the two formations. The mudstone and siltstone beds of the Chinle erode more easily than the underlying siltstone and sandstone of the Moenkopi. Consequently, the variegated colored beds of the Chinle Formation retreated northwestward off the Moenkopi, creating a relatively flat surface.

Arches and Bridges

Arches National Park is best known for its extraordinary arches, but Capitol Reef National Park also has a number of natural arches and bridges. Hickman Bridge, Brimhall Double Bridge, and Saddle Arch (near Upper Muley Twist Canyon) are examples of these unique features. Differential erosion, fractures, and groundwater contribute to the formation of bridges and arches.

Capitol Dome and Navajo Dome

Capitol Dome and Navajo Dome, two of the more spectacular and easily observed domes in the park, were formed by a number of processes including headward erosion, downcutting, slope retreat, and weathering operating on cross-bedded sandstone. The two domes can be viewed from a number of places along Highway 24 between the Hickman Bridge turnout (mile marker 81.8) and Grand Wash (Morris et al. 2000). The numerous rounded “domes” of rock are typical of the weathering pattern of eolian, cross-bedded Navajo Sandstone.

Cavernous Weathering

A latticework of small pockets in the sandstone walls called stone lace or honeycomb weathering can be seen along the base of sandstone faces throughout the park and along Highway 24 (figure 9). The small pockets may enlarge to form larger caverns or alcoves. The pockets are irregularly oblong to hemispherical in shape with some individual pockets reaching depths as much as two to three times the opening diameter. The pockets may branch internally to form several chambers.

Caverns are the result of both chemical and mechanical weathering (Morris et al. 2000). Mineral grains are loosened due to hydration and dehydration enlarging the hollows and recesses (Mustoe 1983). In areas where the sandstone is not protected by a surface coating of desert varnish, this process accelerates formation of pockets and caverns. These areas are frequently found in dark slot canyons and at the bases of sandstone cliff faces where the sandstone can absorb salt from underlying formations, thus making the rock even more susceptible to cavernous weathering. These chemical and mechanical processes, however, are not evenly distributed in the rock and so some parts of the rocks erode, creating caverns, while others do not.

Slot Canyons

Most of the narrow, steep-walled slot canyons in Capitol Reef are cut into the thick Navajo Sandstone along the Waterpocket Fold. When the Waterpocket Fold was uplifted and the overlying flat-layered rocks eroded away, the dipping strata of the Waterpocket Fold allowed water to run off rapidly. The erosive energy of the water was focused along fractures that widened into a myriad of steep-walled canyons (Morris et al. 2000). Some well-known slot canyons in the park include Spring Canyon, Grand Wash, Upper and Lower Muley Twist Canyons, and Halls Creek Narrows.

Soft-Sediment Deformation

Soft-sediment (or contemporaneous) deformation occurs in semi-consolidated sediment that is deformed prior to lithification. Outcrops of the Navajo Sandstone that contain soft-sediment deformation can be observed between mile marker 86.2 and 87 on Highway 24 (Morris et al. 2000). Often, soft-sediment deformation occurs in water saturated sediment due to changes in groundwater dynamics, or by seismic activity.

Contorted or convolute bedding is a type of soft-sediment deformation in which highly contorted laminae are bounded above and below by parallel undisturbed layers. These contorted laminae may form recumbent folds (folds that roll over on themselves) or flower (also called "pop-up") structures that look like a flower on a stem. Both of these features can be seen on the southeast vertical wall at mile marker 86.2 (figure 12 in Morris et al. 2000). The structures suggest that semi-cohesive lamina sets moved downward and laterally along a depositional slope. There also appears to be a basal surface on which the contorted lamina sets detached and slid (Morris et al. 2000). The detachment surface is largely composed of silt- and clay-sized particles that are finer-grained than the host sandstone.

Approximately 2.4 km (1.5 mi) up the canyon from the confluence of Spring Canyon and the Fremont River is another example of large-scale soft-sediment deformation. About one third of the way up the west wall of the canyon is a distinctive curl within the Navajo Sandstone that Morris and others (2000) have termed "The Elf's Toe" (figure 13 in Morris et al. 2000). Downslope movement (landslide-like movement) when the sand was cohesive, but not lithified, caused this feature. Closer to the canyon floor on the same wall is another soft-sediment feature termed the "Sea Lion" (Morris et al. 2000).

Unconformities

At Capitol Reef, numerous unconformities, representing substantial breaks or gaps in the geologic record, separate the sedimentary strata. Unconformities reflect periods of time when no sedimentation occurred and/or substantial erosion took place. If strata underlying the unconformity are tilted at an angle from the horizontal, then some tectonic event must have occurred to disturb the originally horizontal strata. Following tilting, erosion then leveled the plain to form an angular unconformity between the tilted strata and subsequent horizontally deposited sediments.

A particularly striking angular unconformity is found at mile marker 87.5 along Highway 24 (figure 14 in Morris et al. 2000) where gently dipping beds of Quaternary deposits of basalt-rich alluvium (black cobble and gravel) overlie the more steeply dipping Carmel Formation and Entrada Sandstone (Morris et al. 2000). More than 100 million years of Earth history is missing between the Mesozoic strata and the Quaternary deposits in this area.

Notom-Bullfrog Road

Oyster Reef

As a sea inundated the Capitol Reef area during the Late Cretaceous, brackish marine environments supported an abundance of oysters (Morris et al. 2000). The shells of these oysters were concentrated in high-energy environments such as beaches preserved in the Dakota Sandstone. Thick accumulations of oyster shells can now be seen just a few yards east of the road approximately 39 km (24 mi) from the Highway 24 turnoff.

Strike Valleys

When tilted sedimentary rocks differentially erode, the harder, more resistant strata develop into ridges, sometimes referred to as hogbacks, while the less resistant strata form valleys that parallel the strike orientation of bedding. The strike is the direction measured on a compass that is perpendicular to the dip of the inclined strata. Roads are often constructed in strike valleys, and the Notom-Bullfrog Road follows a strike valley of upper Jurassic and Cretaceous age rocks (figure 6 in Morris et al. 2000). The road trends north-south and parallels the length of the Waterpocket Fold on its east side. The Strike Valley Overlook offers the best view of the park's strike valleys.

A number of geologic features can be observed at Halls Creek Overlook, located approximately 79 km (49 mi) from Highway 24 on the Notom-Bullfrog Road. Strike valleys offer a stunning view to the north. Brimhall Double Bridge lies to the west. The Circle Cliffs, a cross section of the Waterpocket Fold, can be seen to the southwest. Erosion of the Glen Canyon Group exposes variegated redbeds of the Moenkopi and Chinle at the crest of the fold (Morris et al. 2000).

Landslides

The fine-grained redbeds of the Moenkopi Formation were unstable during the wetter climatic conditions earlier in the Quaternary. With increased precipitation, the mudstones and siltstones became saturated with water, reducing the friction between the layers of rock. The unstable red mudstones of the Moody Canyon Member of the Moenkopi slid down slope under the force of gravity. The more sand-rich beds of the underlying Torrey Member were more coherent than the Moody Canyon and thus acted as a detachment surface allowing downslope movement of the Moody Canyon (Morris et al. 2000). The mudflow spilled out of the higher ridges of the Waterpocket Fold into the Entrada strike valley forming the Red Slide that can be seen to the south (Morris et al. 2000).

Figure 6. View to the south of Glass Mountain (foreground), Temple of the Sun, and Temple of the Moon. Large selenite crystals pushed upward as a plug or diapir from the underlying Carmel Formation to form Glass Mountain. Temples of the Sun and Moon are monoliths within the Entrada Sandstone. Photograph from Morris and others (2000).

Figure 7. Upper Cathedral Valley looking to the northwest. The Jurassic Curtis Formation (Jcs) forms the light gray caprock on the monoliths in the valley center (left edge of photo). Overlying the Curtis are the red mudstone, siltstone, and sandstone of the Jurassic Summerville Formation (Js). The light-colored sandstones of the Salt Wash Member of the Morrison Formation (Jms) are on the skyline, overlying the Summerville strata. Je: Entrada Sandstone. Photograph from Morris and others (2000).

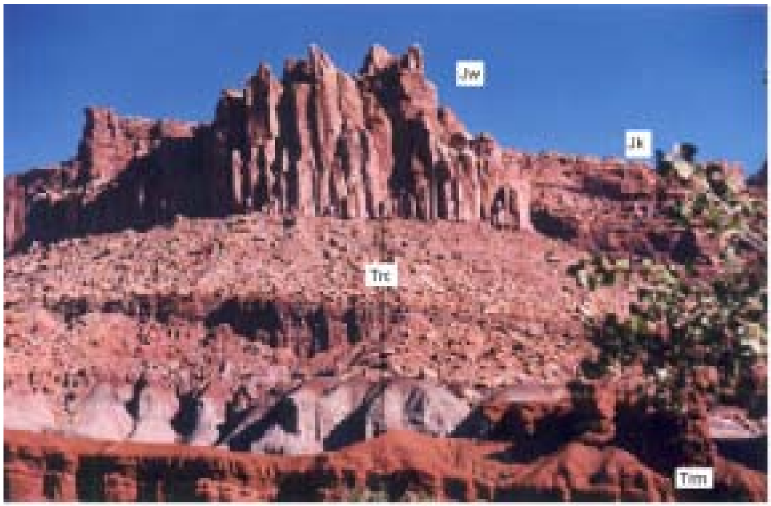


Figure 8. The red rock at the lower part of this photograph of "the Castle" from the Visitors Center parking lot is the Moody Canyon Member of the Triassic Moenkopi Formation (Trm). The Shinarump Conglomerate that normally overlies the Moody Canyon is absent at this locality. Above the Moody Canyon are the gray and purple beds of the Monitor Butte Member of the Chinle, the slope-forming red siltstone and sandstone of the Petrified Forest Member with the resistant "Capitol Reef bed" capping this member (ledge in the middle f the slope). The Owl Creek Member of the Chinle Formation (Trc) comprises the upper slope of mudstone, siltstone, and fine sandstone. "The Castle" is fractured Jurassic Wingate Sandstone (Jw). The Jurassic Kayenta Formation (Jk) caps the Wingate on the skyline. Photograph from Morris and others (2000).

Figure 9. Stone lace or Honeycomb weathering in large-scale, high-angle trough cross-stratified dune sets of the Jurassic Navajo Sandstone in Spring Canyon. View is to the south. Location is approximately 0.8 km (0.5 mi) up-canyon from the confluence of Spring Canyon and the Fremont River. Person for scale. Photograph from Morris and others (2000).

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Capitol Reef National Park. The table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table. More detailed unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the NPS Geologic Resources Division.

Exposed sedimentary rocks at Capitol Reef range in age from Permian in the west to Cretaceous in the east. The Permian Cedar Mesa Sandstone is the oldest sedimentary rock unit and the Cretaceous Mesaverde Formation is the youngest. The Flagstaff Limestone exposed northwest of the park boundary is the youngest sedimentary rock formation in the vicinity of the park (Smith et al. 1963).

Tertiary-age, intrusive and extrusive igneous rocks have limited exposure in the park. The dikes and sills are remnants of a volcanic field that covered the northern quarter of Capitol Reef about 4.6 to 3.7 million years ago (Billingsley et al. 1987; Morris et al. 2000). About 145 and 107 m (475 and 350 ft) of volcanic deposits cap Boulder and Thousand Lake Mountains, respectively (Smith et al. 1963).

Erosion of the sandstones of the Lower Jurassic Glen Canyon Group has formed many of the distinctive arches, domes, and slot canyons of Capitol Reef National Park. Together, the three formations of the Glen Canyon Group (Wingate Sandstone, Kayenta Formation, and Navajo Sandstone) reach a thickness ranging from 460 to 820 m (1,500 to 2, 700 ft) and form the backbone of the Waterpocket Fold.

West of the Waterpocket Fold, the Permian Kaibab Limestone and Cutler Group are exposed in steep, relatively inaccessible canyons. On the east flank of the Waterpocket Fold, the Cretaceous Mancos Shale forms a series of parallel strike valleys and subdued hogbacks (Morris et al. 2000).

Unconsolidated Quaternary deposits reflect Pleistocene glacial processes and more recent fluvial and eolian deposits. At an elevation of more than 3,400 m (11,000 ft), the Aquarius Plateau, west of Capitol Reef, holds the distinction of being the only highland in Utah that was covered by an ice cap during Pleistocene glaciation (Fillmore 2000). The effects of this glaciation are seen in the Capitol Reef Quaternary deposits.

The following Map Unit Properties Table presents a list of features for rock units mapped in Capitol Reef National Park. This table includes a description of the formation or map unit, its map symbol, significant sedimentary structures and paleontologic resources, topographic expression, resistance to erosion, hazard potential, mineral and cultural resources, and any global significance attached to the unit.

Map Unit Properties Table

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Resistance to Erosion	Paleontological Resources	Hazards	Mineral Resources	Cultural Resources	Other
Quaternary (Holocene)	Alluvium (Qal)	Heterogeneous mixture of clay, silt, sand, and gravel; local organic-rich layers (Tantalus Creek) of peat; coarse gravel forms lenses and channel fill with gently dipping cross-laminations; sandy alluvium forms thin, regular beds with steeply dipping cross-laminations; evenly bedded silty alluvium; thickness ranges from 3-12 m (10-40 ft)	Flat lowlands bordering streams; alluvial fans (fan-shaped aprons) at mouth of canyons	Variable – silt more easily eroded than boulders	Mammoth, goat, musk ox, sloth, fragile snail shells; skull of bighorn sheep, elk antler, deer jawbone	Possible debris flows in flash floods	Thin layers of peat	Charcoal; stone points	N/A
	Rock glacier deposits (Qmr)	Boulder deposits near the summits of Boulder Mountain and Mt. Pennell	Boulder slopes	High	None	Rock slippage	Unknown	Unknown	N/A
	Eolian deposits (Qed)	Windblown sand, fine to medium grained; limited aerial extent	Small dunes	Low	None	None	None	Unknown	N/A
	Colluvial deposits (Qms)	Includes rockslides, slumps and talus slopes consisting of a mixture of boulders, gravel, sand, and silt; thickness ranges from 0-6 m (0-20 ft)	Talus slopes	High if disturbed	None	Low	None	Unknown	N/A
	Terrace gravel deposits (Qat)	Boulders, gravel, sand, and silt; includes glacial outwash and pediment gravels; cross-laminations & horizontal bedding	Form terraces above current streams	Variable	Unknown	Low	None	Unknown	N/A
Quaternary (Pleistocene)	Glacial till (Qgt)	Unstratified mixture of unsorted angular boulders, gravel and sand; boulders are o.3 to 1 m (1-3 ft) in length (one over 9 m, 30 ft, in length); locally up to at least 60 m (200 ft) thick; includes some glacial outwash deposits which overlie the till; probably deposited about 12,000 BP.	Moraines along Donkey, Fish, Carcass, Pleasant, Oak, East Boulder, West Boulder, Miller Creeks; irregular knobs; kettle depressions	Variable	None	Low	None documented	Unknown	Remnants of the only highland in Utah (Aquarius Plateau) to have been covered by an ice cap during Pleistocene glaciation.
	Boulder deposits (Qnb)	Diverse mixture of soil and boulders that generally mantle the upper slopes of Thousand Lake and Boulder mountains; includes undifferentiated glacial landslide and alluvial deposits	Mouths of Fish and Carcass Creeks; near Browns Reservoir; Tantalus Flats along Pleasant Creek	High	None	Rock slippage	None	Unknown	N/A
	Pediment gravels (Qap)	Volcanic boulders, cobbles, sand, and gravel; round to oblong volcanic boulders are 0.9 to 1.5 m (3-5 ft) in the long direction (some more than 4.5 m, 15 ft, in length); lenticular beds of gravel between 6 to 15 m (20-50 ft) thick; dissection of pediment surfaces suggest deposition at more than 75,000 years BP	Cap flat-topped hills and benches in Capitol Reef; on gently sloping surfaces several hundred feet above adjacent streams and valleys	Variable to low due to position in landscape	None	Low	None	Unknown	N/A
Regional Unconformity									
Tertiary (Pliocene)	Volcanic rocks (Tv)	Mostly lava flows of porphyritic andesite; black to dark gray; light-gray phenocrysts of plagioclase feldspar; individual flows may reach 30 m (100 ft) thick and can be traced for over a kilometer; about 145 m (475 ft) thick on Boulder Mountain and 107 m (350 ft) thick on Lake Mountain	Lava flows	High	None	Limited aerial extent	Plagioclase feldspar	None documented	N/A
	Diorite porphyry intrusion (Tdp)	Intrusions of diorite porphyry; includes some monzonite porphyry on Mt. Pennell	Limited aerial extent	High	None	Limited aerial extent	Unknown	None documented	NA
	Sedimentary and igneous rocks (Ts)	Sedimentary and igneous rocks irregularly intruded by igneous materials; many dikes and sills	Limited aerial extent	Insignificant	None	Limited aerial extent	None documented	None documented	N/A
	Intrusive igneous rocks (Ti)	Intrusive dikes, sills, and a few plug-like dikes with intrusive breccias, remnants of a volcanic field; mostly dark gray, fine-grained porphyritic basalts with vesicles filled with calcite and analcite (a zeolite mineral); pyroxene most prominent phenocryst; volcanic field dated as 4.6 to 3.7 Ma	Dikes trend N 15^{o} E, parallel to major joint trend	High	None	Limited aerial extent	Analcite (a zeolite mineral)	None documented	N/A
Regional Unconformity									

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Resistance to Erosion	Paleontological Resources	Hazards	Mineral Resources	Cultural Resources	Other
Tertiary (Paleocene-Eocene)	Flagstaff Limestone (Tf)	Limestone; light gray tuff, tuffaceous sandstone, to almost quartz sandstone, siltstone, claystone and conglomerate; tuff and tuffaceous beds are as abundant as limestone beds; limestone is yellowish-gray and grayish-orange and weathers to tints of cream pink; conglomerate is poorly sorted with well rounded pebbles and cobbles of white quartz, black chert, tan quartzite, and tan to gray silicified limestone; limestone beds are thin, 1.3 to 20 cm (0.5-8 in) thick; beds of tuff and tuffaceous sandstone range from 0.08 to 20 cm (0.03-8 in) thick; 150 m (500 ft); exposed NW of the park.	Not exposed in Capitol Reef	Variable – not exposed in Capitol Reef	Pebbles contain Paleozoic corals, bryozoans, crinoid stems, brachiopods; fresh-water ostracods (*Metacypris* sp. & *Paracypris* sp.); algae (*Chlorellopsis coloniata*); gastropods	Not exposed in Capitol Reef; contains incompetent clay layers	None	Not exposed in Capitol Reef	N/A
Regional Unconformity									
Cretaceous	Mesaverde Formation (Kmv)	Light brown, thick-bedded sandstone and thin interbedded dark gray shale; intertongues with Masuk mbr of the Mancos Shale; 90 to 120 m (300-400 ft) is exposed in extreme southeastern corner of Capitol Reef	Cliff former	High	None	Rockfall	None	None documented	N/A
	Masuk mbr of Mancos Shale (Kmm)	Yellowish-gray mudstone and minor bluish-gray to black mudstone with interbedded light gray sandstone; gradational contact with Emery mbr.; 200-230 m (650-750 ft) thick	Mudstones form slopes; sandstones form cliffs	Mudstones have low resistance; sandstones relatively high resistance	Gastropods, bivalves, turtles, crocodiles, ceratopsian dinosaurs	Minor rockfall hazard	None	None documented	Part of last North American interior seaway
	Emery mbr (Muley Canyon mbr) of Mancos Shale (Kme)	Light gray to yellow, medium-bedded sandstone containing interbedded carbonaceous shale and coal beds in the upper part; lower beds intertongue with the Blue Gate Shale mbr; about 90 to 120 m (300-400 ft) thick	Cliff former	Carbonaceous shales have low resistance; sandstone high	Unknown	Rockfall & cliff collapse – esp. if coal beds eroded	Minor coal	None documented	Part of last North American interior seaway
	Blue Gate Shale mbr of Mancos Shale (Kmb)	Laminated blue-gray and black bentonitic shale with a few interbedded light yellow sandstone and limestone lenses; thickness ranges from 365 m (1,200 ft) in the south to 455 m (1,500 ft) in the north	Weathers to gullied slopes similar to the slopes of the Tununk Shale	Low	Planktonic foraminifera (*Clioscaphites vermiformis* & *Clioscaphites choteauensis*)	Bentonite in shales may be hazard to development	Bentonite	None documented	Part of last North American interior seaway
	Ferron Sandstone mbr of Mancos Shale (Kmf)	Fine-grained laminated brown sandstone and white cross-bedded sandstone containing interbedded carbonaceous shale and gray, impure coal in the upper part; intertongues with the Tununk Shale mbr; 60-120 m (205-385 ft) thick.	Cliff and ledge former	Relatively high	*Ophiomorpha* trace fossil; marine bivalve, *Inoceramus*	Rockfall & cliff collapse	Coal seams found north of Capitol Reef	None documented	Part of last North American interior seaway
	Tununk mbr of Mancos Shale (Kmt)	Bluish-gray and black bentonitic shale; interbedded mudstone, siltstone, and very fine-grained sandstone; locally fossiliferous; 165-220 m (540-720 ft) thick	Slope former	Low – erodes into gullied slopes	Marine invertebrate shell fragments	Clays may be a hazard to development	Bentonite	None documented	Part of last North American interior seaway
	Dakota Sandstone (Kd)	Yellowish-brown to gray quartz-rich sandstone and conglomerate with interbedded carbonaceous shale and thin coal beds; locally fossiliferous; deposited 92-96 Ma; 0 to 46 m (0-150 ft) thick	Weathers to small cliffs and hogbacks	Relatively high	Marine bivalves *Pycnodonte newberryi* & *Corbula sp.* in upper part; petrified wood in lower section	Minor rockfall	Coal	None documented	N/A
	Regional Unconformity								
	Cedar Mountain Formation (Kcm)	Variegated mudstone including some white, gray and brown sandstone and conglomerate (the Buckhorn Conglomerate mbr); deposited 97.5 to 113 Ma; 0 to 50 m (0-166 ft) thick in the north	Slope former; north of Capitol Reef, Buckhorn Conglomerate mbr forms a cliff at base of the formation.	Low except for Buckhorn Conglomerate mbr.	Freshwater mollusks & ostracods, fish scales, dinosaur bones, charophytes, pollen, and a *Tempskya* fern	Low	None	None documented	N/A

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Resistance to Erosion	Paleontological Resources	Hazards	Mineral Resources	Cultural Resources	Other
Upper Jurassic	Brushy Basin mbr of Morrison Fm. (Jmb)	Variegated, bentonitic mudstone including some white, gray and brown sandstone and conglomerate containing abundant red and green chert pebbles; gradational contact with Salt Wash member; thickness averages 60 m (200 ft) in the south and 60-100 m (200-350 ft) in the north	Slope former	Low; bentonite weathers to a "popcorn" surface	Contains many dinosaur quarries in UT & western CO	Swelling clays may be a hazard to development	Clays	None documented	World class dinosaur fossils
	Salt Wash mbr of Morrison Fm. (Jms)	Thick-bedded light gray sandstone and chert-pebble conglomeratic sandstone interbedded with greenish to reddish mudstone; sandstones are fine- to medium-grained with moderate sorting; thickness varies from 30-60 m (100-200 ft) in the north to 150 m (500 ft) in the south	Discontinuous lenses of sandstone and conglomerate form ledges and small cliffs; shale forms slopes	Sandstone and conglomerate lenses more resistant than shales	Fragments of dinosaur bones and teeth	Minor occurrence of swelling clays	Uranium found in the Salt Wash in Utah and Western CO.	None documented	N/A
	Tidwell mbr of Morrison Fm. (not mapped)	Red, green, or gray mudstone; difficult to recognize from the underlying Summerville Formation; maybe 15 to 30 m (50-100 ft) thick in Capitol Reef	Slope former	Low	Not differentiated in Capitol Reef	Not differentiated in Capitol Reef	None	None	N/A
Regional Unconformity									
Middle Jurassic	Summerville Formation (San Rafael Gp) (Js)	Thin beds of reddish-brown siltstone and mudstone and fine-grained sandstone; map unit includes interbedded red and gray mudstone, pink and white gypsum, gray limestone, and gray sandstone in the Tidwell mbr of the Morrison Fm; mudstone and siltstone beds are 2.5 to 15 cm (1-6 in) thick, sandstone beds are 0.15 to 0.6 m (0.5 to 2 ft) thick; gypsum beds are 0.3 to 8.5 m (1-28 ft) thick; total about 15-75 m (50-250 ft) thick	Reddish slopes in Cathedral Valley; Exposed in steep slopes or cliffs on northeast side of Waterpocket Fold	Low	None documented in Capitol Reef	Contains some incompetent clay layers	Gypsum	None	N/A
	Regional Unconformity								
	Curtis Fm (San Rafael Gp) (Jcu)	Thin- to thick-bedded white, fine-grained calcareous sandstone and siltstone and minor sandy limestone; sandstones contain glauconite; gradational with the Summerville Fm; discontinuous to the south and increases to about 55 m (175 ft) in the north;	Forms resistant caprock on some monoliths & cathedrals	Sandstone high; siltstone low	Unknown	Minor rockfall	Gypsum in other parts of Utah	None documented	N/A
	Regional Unconformity								
	Entrada Sandstone (San Rafael Gp) (Je)	Thin- to thick-bedded reddish brown sandstone and siltstone (upper and lower part of formation); siltstone (middle part of formation); subangular to subrounded, fine-grained to very fine-grained quartz sandstone; calcareously cemented; Crossbedded units may reach 12 m (40 ft) thick; sandstone and siltstone in the north, siltstone in the south; ranges from 120 to 275 m (400-900 ft) thick	Cliff former in the north; slope former in the south	Erodes into knobby pinnacles (hoodoos), monoliths, and cathedrals	None documented	Rockfalls & cliff collapse	None documented	None documented	N/A
	Carmel Fm (San Rafael Gp) (Jc)	Very fine-grained thin-bedded orange-red sandstone and siltstone; calcareous mudstone common in the lower half; pink gypsiferous siltstone & gray limestone beds in upper part; beds generally only a few inches thick but may reach 1.2 m (4 ft) thick; gypsum as veinlets and beds 0.3 to 0.6 m (1-2 ft) thick (beds 24 m, 80 ft, thick reported on black Ridge); gypsum is white, massive, finely crystalline or granular but may be greenish gray or green; banded appearance produced by alternation layers of whitish-gray limestone and gypsum with reddish-brown siltstone and sandstones; formation ranges from 60 m (200 ft) in the south to 305 m (1,000 ft) in the north	Reddish to red-brown flatirons (triangular-shaped spurs) form eastern rampart of Waterpocket Fold; ledge and slope former	Sandstone is resistant; siltstone and gypsum is not as resistant to erosion	None documented	Rockfalls	Gypsum	None documented	N/A
	Page Sandstone (not mapped)	Light reddish-brown, fine-grained large-scale cross-bedded sandstone; divided into Harris Wash, Judd Hollow, and Thousand Pocket members; red cliff above falls of Fremont River at mile marker 86.5 is Judd Hollow mbr; sandstone above cliff is Thousand Pockets mbr; ranges from 0 to 30 m (0-100 ft) thick in Capitol Reef	Red cliff above falls of Fremont River	High	None documented	Rockfalls	None	None documented	N/A
Regional Unconformity									

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Resistance to Erosion	Paleontological Resources	Hazards	Mineral Resources	Cultural Resources	Other
Lower Jurassic	Navajo Sandstone (Glen Canyon Group) (Jn)	White, yellow, and light reddish-brown, large-scale (60 ft) crossbedded fine-grained sandstone; well-rounded, frosted quartz sandstone; contact with Kayenta is gradational; thickness ranges from 240 m (800 ft) to 335 m (1,100 ft) along Waterpocket Fold	Forms massive white to reddish-brown cliffs, monoliths & domes (Capitol & Navajo)	High	None documented	Rockfalls & cliff collapse	None	None documented	Dunes possibly part of largest erg recorded on Earth
	Kayenta Fm. (Glen Canyon Group) (Jk)	Divided into three units based on weathering features; lower ledge and middle cliff units are very fine-grained sandstone; upper unit contains abundant siltstone; clay-pebble conglomerate and traces of interbedded mudstone and limestone throughout the formation; horizontal and small-scale lenticular and tabular cross-beds; cross-beds are small (few ft thick); gradational contact with Wingate; 107 m (350 ft) thick	Lower ledge forming unit; middle cliff forming unit; upper slope forming unit	Lower and middle units are more resistant than upper unit	Theropod dinosaur tracks	Rockfalls & cliff collapse in lower and middle units	None	None documented	N/A
	Wingate Sandstone (Glen Canyon Group) (Jw)	Reddish-brown, thin- to thick-bedded, fine-grained quartz sandstone; massive and crossbedded; well-rounded quartz grains; large-scale, low- to high-angle trough cross-sets; iron oxide cement produces reddish, salmon color; 107 m (350 ft) thick, thins slightly from east to west	Cliff former; caps the western escarpment of Waterpocket Fold; forms features like Castle & Fruita Cliffs	High except where undercut and then litters slopes of Owl Rock mbr of Chinle Fm	None documented	Rockfalls & cliff collapse	None	None documented	Dunes possibly part of largest erg recorded on Earth
Regional Unconformity									
Upper Triassic	Chinle Formation (TRc)	Owl Rock mbr: orange and purple mudstones, siltstones, and fine-grained sandstones with characteristic 0.3 to 3 m (1-10 ft) thick interbeds of mottled pink to green limestone; not bentonitic; micritic limestones have a knobby texture from coalescence of carbonate nodules; mudcracks filled with Wingate Sandstone; 46 to 61 m (150-200 ft) thick	Slopes below Wingate Sandstone cliffs	Low, but protected by cliffs	Large cylindrical burrows & ostracodes	Atypical of Chinle mudstones; not bentonitic	None	None documented	N/A
		Petrified Forest mbr: reddish-orange bentonitic siltstones and clayey quartz sandstone; lower 46 to 61 m (150-200 ft) forms slopes capped by a regionally persistent, crossbedded sandstone known as the "Capitol Reef bed" that forms a prominent cliff or ledge	Lower slopes capped by sandstone ledge or cliff of "Capitol Reef bed"	Low; bentonitic mudstones	Tetrapod remains, lungfish toothplates, coprolites, marine gastropods & mollusks, vertebrate fossils, petrified wood, crocodilian and amphibian teeth	Swelling clays may be a hazard to development	Green mica and feldspar in some beds	None documented	N/A
		Monitor Butte mbr: light purplish-gray, bentonitic claystones and clayey sandstones with interbeds and lenses of crossbedded sandstone and carbonate nodules; distinct color makes it readily traceable along the lower to middle slopes of the Waterpocket escarpment; most heterogeneous member of Chinle Fm	Slope former	Low; bentonitic mudstones	Lung fish burrows (5 in dia; 5 ft long); petrified plants	Swelling clays may be a hazard to development	Bentonite	None documented	N/A
		Shinarump mbr: yellowish-gray, fine- to coarse-grained, friable sandstone with lenses and interbeds of conglomerate and conglomeratic sandstone; pebbles comprised of quartz, quartzite, and chert; near west entrance, fills broad channels eroded into top of Moenkopi Fm; discontinuous, where absent, Monitor Butte rests on Moenkopi; up to 27 m (90 ft) thick	Prominent white cliff; forms caprock for Twin Rocks, Egyptian Temple, & Chimney Rock	More resistant than mudstones, but sandstones are friable	None documented	None documented	Not in Capitol Reef	None documented	N/A
Regional Unconformity									

Age	Map Unit (symbol)	Unit Description	Topographic Expression	Resistance to Erosion	Paleontological Resources	Hazards	Mineral Resources	Cultural Resources	Other
Lower Triassic	Moenkopi Formation (TRm)	Moody Canyon mbr: lower unit of horizontally laminated reddish-brown siltstones and upper unit of ripple laminated reddish-orange siltstones; lower unit is 61 to 91 m (200-300 ft) thick; upper unit is well exposed in lower part of the Egyptian Temple and at Chimney Rock and forms reddish-orange cliffs at base of Waterpocket escarpment	Lower unit forms slopes; Upper unit forms cliffs	Rippled siltstones are relatively resistant	None documented	None documented	None	None documented	N/A
		Torrey mbr: reddish-brown to chocolate colored siltstone and fine-grained sandstone with rare interbeds of mud-pebble conglomerate, sandy dolomite, dolomitic limestone, and claystone; sandstones have horizontal bedding & low angle cross-bedding; ripple marks & mudcracks in finer grained beds; halite crystal casts in upper part; about 76 to 98 m (250-320 ft) thick	Ledge former	Relatively resistant	Well known for large reptile and amphibian trackways	Minor rockfall	None documented	None documented	N/A
		Sinbad mbr: yellowish fossiliferous to muddy limestone and dolomite with subordinate amounts of siltstone and sandstone; oolitic layers (composed of tiny carbonate spheres) are characteristic of lower part; yellowish color and carbonate lithology distinguishes Sinbad from other Moenkopi members; carbonates are thin-bedded to laminated with some small-scale trough crossbedding; about 21 to 43 m (70-140 ft) thick	Ledge former	Relatively resistant	Inarticulate brachiopod, *Lingula*; ammonite cephalopod, *Meekoceras*	Minor rockfall	None documented	None documented	N/A
		Black Dragon mbr: reddish conglomerate, siltstone, and sandstone; abundant angular chert in basal conglomerates from underlying Kaibab Ls.; interbeds of dolomite and limestone with sparse marine fossils in upper part; 15 to 34 m (50-110 ft) thick	Slope former	Less resistant than bordering formations	Sparse marine fossils in carbonates	None documented	None	None documented	N/A
Regional Unconformity									
Permian	Kaibab Limestone (PNk)	Light gray to white, cherty dolomite interbedded with thin calcareous sandstone and siltstone layers; limestone especially in lower half; exposed only in the deeply incised canyons along the western margin of Capitol Reef; middle and upper parts contain silcretes (siliceous paleosols) and calcretes (calcitic paleosols); channels reaching 30 m (100 ft) deep were scoured into the Kaibab when its surface was exposed during Middle Permian time; averages 61 m (200 ft) thick	Relatively inaccessible cliffs	Highly resistant	Brachiopods, *Neospirifer pseudocamer-atus*, *Dictyoclostus bassi*; pelecypods, gastropods, crinoids, bryozoans	Rockfalls & cliff collapse	Asphalt blebs found in some vesicles; geodes with quartz and calcite crystals	None documented	Last shallow Paleozoic sea covering western North America
	Cutler Group (PNc)	White Rim Sandstone and Cedar Mesa Sandstone: light-yellow to gray, crossbedded quartz sandstones; well-rounded, moderately well-sorted with grains ranging in size from very fine- to medium grained; White Rim Sandstone cannot be distinguished from older Cedar Mesa Sandstone because the Organ Rock Shale that usually separates the two formations pinches out east of Capitol Reef; exposed only in the deeply incised canyons along the western margin of Capitol Reef; Cutler sandstones reach a thickness of 244 m (800 ft)	Relatively inaccessible cliffs	Highly resistant	Marine trace fossils, shark teeth	Rockfalls & cliff collapse	None	None documented	N/A

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Capitol Reef National Park and puts them in a geologic context in terms of the environment in which they were deposited and the timing of geologic events that created the present landscape.

Figure 10 summarizes the significant life forms, major extinctions, and tectonic events in North America from the Precambrian to the Quaternary. The geologic history exposed at Capitol Reef begins in the Permian Period, approximately 275 million years ago.

Paleozoic Era

Permian Period

During the Permian, most of Utah was located near 10° north latitude (Morris et al. 2000). A dry, high atmospheric pressure climatic belt, analogous to that of the Sahara Desert today, prevailed in this region and resulted in restricted marine evaporitic conditions over much of the cratonic shelf seaway (Peterson 1980). Large dune fields or ergs migrated across southeastern Utah as the climate became more arid (figure 11). These eolian deposits became the Cedar Mesa Sandstone and White Rim Sandstone (Loope 1984; Huntoon et al. 1994; Dubiel et al. 1996; Morris et al. 2000). Sand and sand-sized marine fossil fragments blew inland from a coastline located to the northwest and formed the dunes (Huntoon et al. 2000). Capitol Reef is located near the northern border of this dune field (figure 11) where the eolian dune complex may have been subjected to periodic marine flooding (Morris et al. 2000).

Trending northwest-southeast, the peaks of the Uncompahgre Mountains were rising in western Colorado. The coarse grained, arkosic clastic rocks (sedimentary rocks high in feldspar) eroded from the rising Uncompahgre Mountains represent a complex depositional system of eolian-fluvial-alluvial fan sediments that affected the Capitol Reef region (Campbell 1980; Cole et al. 1996).

Oolitic dolomite, fine-grained sandstone, and fossiliferous limestone are formed in normal to marginal marine environments. Limestone deposition transgressed over the ergs, preserved as the Kaibab Limestone, and recorded the last in a long series of shallow seas that covered Capitol Reef and the Colorado Plateau throughout the Paleozoic Era (Morris et al. 2000).

The interfingering of the Kaibab with the White Rim Sandstone suggests that the marine facies of the Kaibab migrated eastward (transgressed) in response to a relative sea-level rise (Dubiel et al. 1996). At times, the area was subaerially exposed and eolian sand with large sweeping cross-beds covered the area. Cross-beds such as these can be found along Pleasant Creek in a sandstone unit that forms a prominent ledge and cliff above dolomite and dolomitic limestone (Smith et al. 1963). During the Permian, episodic transgressions and regressions occurred across the area, and with each sea level regression, erosion created a regional unconformity (figure 12) (Smith et al. 1963; Blakey 1996).

With the final Permian regression of the sea, the limestone was exposed to erosion (Morris et al. 2000). Dissolution of the Kaibab created karst topography and channels, reaching 30 m (100 ft) in depth, scoured into the limestone surface (Morris et al. 2000). Rubbly silcretes and calcretes are found in the middle and upper portions of the Kaibab (Morris et al. 2000). Silcretes and calcretes are paleosols rich in silica and calcite, respectively. Paleosols are significant paleo-environmental indicators because, like soils today, they developed during episodes of subaerial exposure and represent unconformities between depositional regimes.

On the western margin of the continent in the Permian, in the vicinity of central Nevada, continental shelf and slope rocks were being compressed against the continental margin as the Sonoma Orogeny advanced eastward (Silberling and Roberts 1962). Subduction of the encroaching lithospheric plate from the west beneath the continental crust of North America caused melting of the oceanic plate and would eventually form a volcanic island chain on the western margin of the continent (in the area of western Nevada) during the Triassic.

The third, and most severe, major mass extinction of geologic time occurred at the close of the Permian. Although not as famous as the extinction event that exterminated the dinosaurs at the end of the Mesozoic, the Permian extinction was much more extensive. As much as 96% of all species were eliminated at the end of the Permian (Raup 1991). Thousands of species of insects, reptiles, and amphibians died on land while in the oceans, species of coral, snails, urchins, sea lilies, some fish, and the once-prolific trilobites vanished.

Mesozoic Era

Triassic Period

Prior to the Mesozoic, all the continents had come together to form a single landmass (supercontinent) called Pangaea which was located symmetrically about the equator (Dubiel 1994). During the Triassic (250 to 206 million years ago), Pangaea reached its greatest size. To the west, explosive volcanoes formed a north-south trending arc of islands along the border of present-day California and Nevada (Christiansen et al. 1994; Dubiel 1994; Lawton 1994). Clastic sediments continued to be shed from the Uncompahgre Highlands in Colorado. As sea level fell, the shoreline of the shallow sea that extended into eastern Utah in the Early Triassic moved far to the west and off the continent.

The terrestrial red beds of the Lower Triassic Moenkopi Formation were deposited in fluvial, mudflat, sabkha, and shallow marine environments (figure 13) (Stewart et al. 1972A; Christiansen et al. 1994; Doelling 2000; Huntoon et al. 2000). Fluvial systems drained uplifted areas throughout central and southeastern Utah (Huntoon et al. 2000). Ripple marks, mudcracks, thin interbeds of dolomite and limestone with sparse marine fossils are common on bedding planes in the upper part of the Black Dragon Member of the Moenkopi, indicating deposition in coastal plain and tidal flat environments.

Brachiopod and ammonite fossils in the overlying Sinbad Limestone Member of the Moenkopi record a relatively short-lived incursion of the ocean into eastern Utah (Stewart et al. 1959). When the Sinbad Sea retreated to the west, tidal flat conditions returned to Capitol Reef, depositing redbeds of the Torrey and Moody Canyon members of the Moenkopi. The fossilized plants and animals in the Moenkopi are evidence of a climate shift to warm tropical conditions that may have experienced monsoonal, wet-dry periods (Stewart et al. 1972A; Huntoon et al. 2000; Morris et al. 2000).

The Middle Triassic remains a mystery. No rocks that span this time ranging from 235-400 Ma have been preserved in Utah, resulting in a regional unconformity.

The Upper Triassic Chinle Formation represents a complex assemblage of alluvial (Shinarump Conglomerate Member, Monitor Butte Member, Petrified Forest Member) marsh, lacustrine (Owl Rock Member), playa, and eolian deposits (Stewart et al. 1972B; Dubiel 1987). Throughout the region, layers of smectite clays are interlayered with the clastic sediments. The clay layers indicate a period of renewed volcanism to the west caused by active lithospheric plate subduction (Christiansen et al. 1994).

In the lower part of the Chinle, paleovalleys eroded into the underlying Moenkopi Formation forming a dendritic pattern that fed a northwest-trending, paleovalley trunk system (figure 14). Choked with sediment, braided streams (Shinarump Member) tended to occupy these paleovalley systems. Channel-fill deposits may reach a thickness of 27 m (90 ft). Weathering of the Shinarump has formed a prominent white cliff and cap rock for such features as the Egyptian Temple, Twin Rocks, and Chimney Rock (Smith et al. 1963; Morris et al. 2000).

Fluvial processes formed the cross-bedded sandstones in both the Shinarump and Petrified Forest members of the Chinle. The cross-bedded sandstones of the Petrified Forest Member were formed in meandering (high sinuosity) river channels. The persistent, cross-bedded sandstone known as the Capitol Reef bed forms a prominent cliff or ledge in Capitol Reef National Park.

During the final phases of Chinle deposition, lower water table conditions existed. Lacustrine mudflat siltstones and mudstones, ephemeral fluvial-channel sandstones, and eolian sand-sheets and dunes were deposited during extended dry periods (Dubiel 1994). The monsoonal precipitation that characterized the Early Triassic depositional systems was disappearing in the Late Triassic. As Pangaea began to break apart in the latest Triassic and earliest Jurassic, the monsoonal climate changed. The Western Interior of North America was slowly rotating into a position farther north of the equator. Soon, the jungle on the Colorado Plateau was to become a desert.

Lower Jurassic Period

The Jurassic western margin of North America was associated with an Andean-type margin where the eastward subduction of the seafloor gave rise to volcanism similar to that found in the Andes of South America today. Volcanoes formed an arcuate north-south chain of mountains off the coast of western Pangaea in what is now central Nevada The Ancestral Rocky Mountains and the Monument Upwarp remained topographically high during the Jurassic.

The Jurassic of Western North America was a time of extensive eolian (ergs or sand sheets) deposition. Vast sand deposits are preserved in the Wingate and Navajo sandstones, which represent an environment similar to the Sahara and Sahel deserts today. The region was located about 18° north latitude at the beginning of the Jurassic (about 208 Ma) and moved to 30° - 35° north latitude by the end of the Jurassic (about 144 Ma) (Kocurek and Dott 1983; Peterson 1994). This is the latitude of the present day northeast trade wind belt where most modern hot deserts occur.

The Jurassic deserts that occupied the Colorado Plateau for roughly 40 million years (not counting the time represented by erosion) contained sand dunes that may be the largest recorded in the history of the earth (Kocurek and Dott 1983). Like today's Sahara Desert, the Jurassic ergs formed on a coastal and inland dune field. Sand dunes were deposited in the present areas of southern Montana, eastern Utah, westernmost Colorado, southwest Colorado, northeastern Arizona, and northwestern New Mexico (Kocurek and Dott 1983; Peterson 1994).

Erosion of Triassic and Upper Paleozoic sandstones exposed from as far north as Montana and Alberta provided abundant quantities of sand to be transported by wind to the Colorado Plateau (Kocurek and Dott 1983). The volcanic arc to the west acted as a barrier to block the wind and channel it to the south (figure 15) (Kocurek and Dott 1983). The perpetually arid climate may have lowered the ground water table, which would have kept the surface sediments dry and available for movement by the wind. These eolian deposits are found today in the massive Wingate Sandstone that forms such features as the Castle and Fruita Cliffs.

A change from eolian to fluvial deposition is recorded in the sandstones of the Jurassic Kayenta Formation. In contrast to the sweeping eolian cross-beds of the Wingate and Navajo sandstones, the cross-beds in the Kayenta are only a few feet in thickness. Interbedded sandstone, basal conglomerates, siltstones, and mudstones are typical channel and floodplain deposits. Paleocurrent studies show that rivers flowed in a general westward to southwestward direction during Kayenta time (Morris et al. 2000). The large natural bridge near Fruita is carved out of the Kayenta Formation.

The Navajo Sandstone records a return to arid conditions and the development of extensive ergs on the Colorado Plateau. Sand dune deposits reaching 240 to 340 m (800 to 1,100 ft) in thickness gradually overtook the fluvial systems of the Kayenta (Morris et al. 2000). Differential weathering of the Navajo cross-beds has produced the massive white to reddish-brown cliffs, monoliths, and domes such as Capitol and Navajo Domes.

Middle Jurassic Period

As plate tectonic activity increased in the Middle Jurassic, the sea transgressed onto the continent from the north. Middle Jurassic strata on the Colorado Plateau represent a complex interfingering of marine and nonmarine sediments. Broad tidal flats formed along the margin of the shallow sea that lay to the west of Capitol Reef (Wright et al. 1962).

The Page Sandstone is separated from the underlying Navajo Sandstone by a regional unconformity. Above the unconformity, eolian deposits (Harris Wash Member) are overlain by a sabkha environment (Judd Hollow Member) followed by a series of two eolian episodes separated by a marine incursion into the area (Thousand Pocket Member) (Blakey 1994; Morris et al. 2000).

Restricted marine and marginal marine environments (Carmel Formation) similar to those in the Page Sandstone record a period of intermittent marine flooding and evaporation in the Capitol Reef area prior to development of the next aerially extensive erg (Entrada Sandstone) (Morris et al. 2000).

The cross-stratified Entrada Sandstone covers the entire Colorado Plateau and is the most widespread of the preserved late Paleozoic and Mesozoic eolian deposits on the Colorado Plateau. In the southern part of Capitol Reef, the Entrada consists predominantly of tidal flat deposits (figure 16) (Doelling 2000; Morris et al. 2000). Marine conditions had retreated to the north by this time and as the groundwater table dropped, the wind moved the sand into huge dune fields south of Capitol Reef (Kocurek and Dott 1983; Hintze 1988). When groundwater levels rose, the sand grains were held together by water and became unavailable to wind transport.

In the Curtis Formation, glauconite, a green iron- and potassium-bearing (usually marine) clay, indicates a major transgression of marine environments into the area from the north. Transgression of the sea destroyed the vast dune fields and coincided with the onset of the Sevier Orogeny (about 157.1 Ma) (Kocurek and Dott 1983).

Regression of this shallow sea left mudcracks, ripple marks, and inch-scale cross-bedding in tidal flat siltstones and mudstones (Summerville Formation) (Morris et al. 2000).

Upper Jurassic Period

Eventually, the sea receded from the western continental United States followed by the deposition of the extensive Upper Jurassic, Morrison Formation (figure 17). The Morrison at Capitol Reef represents hypersaline lagoon deposits (Tidwell Member), a meandering stream system with associated channel and floodplain deposits (Salt Wash Member), and a fluvial-deltaic depositional system (Brushy Basin Member) (Haynes et al. 1972; Petersen and Roylance 1982; Morris et al. 2000). The thicker, continuous sandstone deposits of the Salt Wash Member contain small and large uranium deposits eroded from the adjacent highlands and transported into the area (Haynes et al. 1972).

Compared to the Salt Wash Member, the Brushy Basin Member contains only minor amounts of conglomerate and sandstone deposited in river channels. The more abundant siltstone and mudstone are interpreted as flood-plain deposits. Some of the most complete dinosaur skeletons ever found have been discovered in the lake-floor and floodplain deposits of the Morrison Formation. Deposits of disarticulated bones in channel sandstones are oriented so that their long axes are parallel to the paleo-current direction.

The character of the shale slopes also is distinct between the Salt Wash and the Brushy Basin because of the bentonite in the Brushy Basin Member. These swelling clays expand when wet and dry to a crumbly “popcorn” surface that characterizes the Brushy Basin slopes.

Cretaceous Period

Accelerated lithospheric plate collision during the Cretaceous caused mountains to form along the western margin of North America. The Sevier Orogeny formed a roughly north-south trending thrust belt that is well defined in present-day southern Nevada, central Utah, and western Montana (figure 10). As the mountains rose in the west, the Gulf of Mexico separating North and South America continued to rift open in the south, and seawater extended northward into an expanding depression called the Western Interior Basin (or, Western Interior Seaway). Marine water also began to transgress southward from the Arctic region.

In the Lower Cretaceous, continental fluvial conditions prevailed in the Capitol Reef region with the low-energy floodplain, fluvial, and interfluvial lacustrine deposits of the Cedar Mountain Formation (97.5 to 113 Ma) (Fouch et al. 1983; Elder and Kirkland 1994; Morris et al. 2000; Doelling 2000). Paleocurrent directions show that Cedar Mountain sediments came from rivers originating in central Utah where an unconformity between the Cedar Mountain strata and the underlying Morrison Formation is marked by a calcrete, a layer that forms in semi-arid climates.

As the shoreline continued to advance into eastern Utah and western Colorado, a heterogeneous mixture of terrestrial and shallow marine environments prevailed (Dakota Sandstone). Strata in the lower Dakota Sandstone contain petrified wood and are dominated by fluvial, lagoonal, and marsh environments (Morris et al. 2000). As the Cretaceous interior seaway widened, however, the fluvial-dominated system changed to a coastal plain depositional system with deposition in coastal swamps, lagoons, and beaches (Condon 1991). Marine bivalves, especially the chunky clam shells of *Gryphaea* and *Exogyra*, make some of the beds look conglomeratic (Smith et al. 2000).

Gradually, as sea level rose, the sparsely fossiliferous, dark-gray muds of the Mancos Shale were deposited in the deepening Western Interior Seaway above the Dakota Sandstone. The paleobathymetry over eastern Utah was approximately 100-200 m (328-656 ft) at this time (Sageman and Arthur 1994).

The seas advanced and retreated many times during the Cretaceous until the most extensive interior seaway ever recorded drowned much of western North America (figure 18). The Western Interior Seaway was an elongate basin that extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 4,827 km (3,000 mi) (Kauffman 1977). During periods of maximum transgression, the width of the basin was 1,600 km (1,000 mi) from western Utah to western Iowa. The basin was relatively unrestricted at either terminus (Kauffman 1977). The western margin of the seaway coincided with the active Cretaceous Sevier Orogenic belt so that sedimentation into the basin from the rising mountains was rapid. Rapid sedimentation led to further sediment loading and downwarping along the western margin.

The calcareous marine mudstones that comprise the lower part of the Tununk Member were deposited during a transgression that flooded the Dakota Sandstone environments (Gardner and Cross 1994). The lower Tununk shales represent the maximum extent of the Cretaceous Interior Sea (figure 19) (Elder and Kirkland 1994). The bluish shales of the Tununk are responsible for the scenery at Blue Desert just southeast of Cathedral Valley (Morris et al. 2000).

At Capitol Reef, the hummocky to low-angle cross-stratification, ball-and-pillow structures, the *Ophiomorpha* trace fossils and the marine bivalve *Inoceramus* indicate deposition in the middle to lower shoreface, marine environment and signal a regressive episode (Ferron Sandstone Member) (Peterson et al. 1980; Morris et al. 2000). Hummocky cross-stratification forms undulating cross-bed sets of both swales (depressions) and hummocks (mounds). Today, hummocky cross-stratification is commonly produced by large storm waves in near-shore marine environments. Ball-and-pillow structures are contorted features found in sandstone beds that overlie shale beds. Liquefaction of the mud layers causes water to escape upward, deforming and breaking up the semi-consolidated sand into hemispherical masses that resemble balls or pillows.

Another transgression produced the fossiliferous, marine mudstones of the Blue Gate Member, and like the Tununk, the mudstones represent deposition under open marine conditions (Morris et al. 2000). Bentonite in the clays records continued volcanic activity to the west.

Subsequent regression brought about a succession of facies from fine-grained sandstones to carbonaceous shales and coal, reflecting a transition from a marine shoreline to a continental coastal plain (Muley Canyon Member) (Morris et. al. 2000). Gastropods, bivalves, turtles, crocodiles and ceratopsian dinosaurs are present in the cross-bedded and ripple laminated sandstone of the Masuk Member, indicating continued regression of the Cretaceous Seaway (Peterson et al. 1980; Morris et al. 2000).

For roughly ten million years, clay, silt, sand, and shell debris were deposited in the Mancos Sea. As sea level continued to fall, barrier beaches and deltas of the Mesaverde Formation were deposited in the region (Morris et al. 2000). The Mesaverde Formation is conformable with the underlying Masuk Member of the Mancos Shale.

Cretaceous – Tertiary Laramide Tectonics

The regional folds in Capitol Reef are products of the Laramide Orogeny (about 75-35 Ma), which resulted when the North American lithospheric plate, moving westward, collided with the Farallon lithospheric plate, moving relatively eastward. The oceanic crust of the Farallon plate was subducted beneath the less dense continental crust of the North American plate. The sedimentary rocks at Capitol Reef responded to the collision mostly by folding in a plastic fashion and although some faulting occurred, no major faults cut the sedimentary rocks at the surface.

The Waterpocket Fold monocline resulted from a reverse fault at depth (Billingsley et al. 1987; Morris et al. 2000). When the Waterpocket Fold monocline formed, brittle Precambrian rocks at depth ruptured due to west-southwest compressional forces and the Precambrian section detached and moved eastward along a reverse fault or a series of reverse faults. The overlying sedimentary strata, being more ductile than the Precambrian rocks, draped over the fault forming the monocline.

The asymmetry of the folds in Capitol Reef and the coincident northwest trends suggest that these folds formed at about the same time, probably due to the same northeast directed compressive stress that generated the thrust fault at depth. Like a throw rug on a wooden floor, the surface strata deformed into a series of folds as the deeply buried Precambrian basement rocks were displaced by the thrust.

Cenozoic Era

Tertiary Period

Near the end of the Laramide Orogeny, about 26-35 million years ago, in early mid-Tertiary time, volcanic activity again erupted across the Colorado Plateau. A volcanic field covered the northern quarter of Capitol Reef from approximately 4.6 to 3.7 million years ago. The igneous dikes and sills mapped in Capitol Reef served as a feeder system to a large volcanic field that has subsequently eroded away (Gartner 1986; Delaney and Gartner 1997; Morris et al. 2000).

The laccoliths that formed the Sleeping Ute Mountain, La Plata Mountains, Henry Mountains, La Sal Mountains, and Abajo Mountains were emplaced by mid-Tertiary volcanism (figure 2) (Baars 2000: Fillmore 2000). The Henry Mountains laccolith is part of the vista seen from both Canyonlands National Park and Capitol Reef National Park.

A vast outpouring of lava spread over southern Utah from about 6.5 to 3.4 Ma (Fillmore 2000). Rather than erupting from volcanoes, the lava flowed from numerous fissures in the landscape. The lava formed thin, basalt layers that resisted erosion and today cap many of the plateaus and mesas on the Colorado Plateau including the Aquarius and Thousand Lakes Plateaus. Basalts constitute the bulk of the igneous rocks that cover about 259 square km (100 square mi) of the Capitol Reef area, west of the park boundary (Smith et al. 1963).

The Flagstaff Limestone (about 58 to 35 Ma), exposed northwest of the park boundary, is the only record of Tertiary sedimentary deposition in the Capitol Reef region. The Flagstaff is a lacustrine limestone that formed in Lake Uinta from 58 to 35 million years ago (Morris et al. 2000). The locally abundant tuffaceous beds are the result of extensive volcanic ash fall.

Uplift of the Colorado Plateau

Late Cretaceous marine shoreline sediments were deposited near sea level. Today, these shoreline deposits are found on the Colorado Plateau at several thousand feet in elevation. Since the end of the Cretaceous Period 66 million years ago, the Colorado Plateau has risen about 3,660 m (12,000 ft) (Fillmore 2000). Erosion began to strip away the highlands, exposing the structure of the Waterpocket Fold and creating the domes, cathedrals, and other spectacular desert landforms for which Capitol Reef is famous.

Some of this uplift occurred quite rapidly in geologic time. As the rate of uplift increased, so did the rate of erosion. The Colorado River, for example, carved its present course within the last 6 million years.

The Colorado Plateau has been subjected to repeated minor uplifts since the end of the last ice age. Today, the climate is drier than during the Pleistocene ice ages yet the intermittent streams in the canyons are still in a period of active downcutting, only more slowly than in the past. Like other parts of the Canyonlands section of the Colorado Plateau, the geologic units that form the cliffs, slopes, benches, domes, natural bridges, and other physiographic features reflect their varying susceptibility to erosion.

Quaternary Period

During the Pleistocene epoch (1.6 to 0.01 Ma), extensive deposits of pediment gravels, boulder deposits, glacial till, outwash, and landslide material accumulated in the Capitol Reef region (Smith et al. 1963). Pediment gravels that cap many of the flat-topped hills and benches in the Capitol Reef area are believed to have been deposited more than 75,000 years B.P. (Smith et al. 1963).

Like the pediment gravels, the boulder deposits were probably once covered by a deep soil that has largely been removed, leaving only the caliche or carbonate-rich lower layer. The advanced dissection of the boulder deposits indicates a period of erosion that destroyed the original topographic forms associated with the boulders.

The glacial drift on and around the Aquarius Plateau has not been directly dated, but geologists speculate that the deposits range in age from 70,000 years to about 12,000 years B.P. (Fillmore 2000). As the climate cooled during the Wisconsin glacial stage and precipitation increased, a large icecap formed on top of Boulder Mountain. Long tongues of ice moved down several valleys carving into the mountain rim. Glacial moraines formed with each advance and retreat of the glaciers. In places, up to 60 m (200 ft) of till was deposited. A broad ice tongue extended into the lowlands near Grover, southwest of Fruita, Utah, to an altitude of about 2,100 m (7,000 ft) (Smith et al. 1963).

The top of Boulder Mountain was scoured by Wisconsin glacial ice. Unweathered volcanic rock is exposed as bare rock knolls and roche moutonneés. Volcanic rock also underlies shallow basins and is thinly veneered with drift throughout the area. Volcanic flow surfaces have been abraded and grooved by glacial ice. The alignment of the grooves and of linear topographic depressions revealed on aerial photographs, records the radial direction of ice movement from the top of Boulder Mountain (Smith et al. 1963).

Melt water flowed from these valleys and spread outwash gravels along the drainage routes. Outwash sediments carried by meltwater streams subsequently formed a deltaic fan in the Fremont River Valley. The fan dammed the river to form a glacial lake in which sandy lake sediments were deposited.

Rain-saturated slopes collapsed in areas not covered by ice and formed landslide deposits on the flanks of Boulder and Thousand Lake Mountains. Most mass movements in the Capitol Reef area probably took place during or shortly after Wisconsin glaciation when precipitation was high and the ground was saturated (Smith et al. 1963).

Terrace gravels and sands along the Fremont River and its tributaries may hold the key to the age of glaciation in the Capitol Reef area. Recent isotope analyses of beryllium-10 and aluminum-26 from three widely preserved terraces revealed ages of about 60,000 years, 102,000 years, and 151,000 years B.P. (Fillmore 2000). These ages, however, are quite a bit older than the previous interpretations of 12,000 B.P. If the age dates hold up to repeated testing, then glacial and interglacial activity occurred over a much longer time frame than was previously thought.

Following the Wisconsin glacial stage, a warming trend melted the glacial ice completely from the region and deposits of alluvium, colluvium, alluvial fan, and rock glaciers became the dominant sediments.

The most recent erosional history involves dissection of the alluvial deposits and continued downcutting. Streams have entrenched about 8 m (26 ft) along Bullberry Creek just east of Teasdale and about 3 m (10 ft) along lower Donkey Creek. Some of the best agricultural land is being destroyed by erosion of the alluvium. Livestock grazing accelerates stream bank erosion by trampling and denuding vegetation destabilizing the fluvial regime. Both climate and grazing have played a part in the rate of erosion and entrenchment of the alluvium (Smith et al. 1963). Streams also continue to erode the gorges that have been carved into the Waterpocket Fold.

Eon	Era	Period	Epoch	Ma		Life Forms	N. American Tectonics
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Recent, or Holocene	0.01	Age of Mammals	Modern man	Cascade volcanoes
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada
			Miocene	23.0		Whales and apes	Linking of N. & S. America
			Oligocene	33.9			Basin-and-Range Extension
			Eocene	55.8		Early primates	Laramide orogeny ends (West)
			Paleocene	65.5			
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	**Mass extinctions** Placental mammals Early flowering plants	Laramide orogeny (West) Sevier orogeny (West) Nevadan orogeny (West)
		Jurassic		199.6		First mammals Flying reptiles	Elko orogeny (West) Breakup of Pangea begins
		Triassic		251		First dinosaurs	Sonoma orogeny (West)
	Paleozoic	Permian		299	Age of Amphibians	**Mass extinctions** Coal-forming forests diminish	Super continent Pangea intact Ouachita orogeny (South) Alleghenian (Appalachian) orogeny (East)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant Variety of insects	Ancestral Rocky Mts. (West)
		Mississippian		359.2		First amphibians First reptiles	
		Devonian		416	Fishes	**Mass extinctions** First forests (evergreens)	Antler orogeny (West) Acadian orogeny (East-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	**Mass extinctions** 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		1st multicelled organisms Jellyfish fossil (670Ma)	Formation of early supercontinent First iron deposits Abundant carbonate rocks
Archean ("Ancient")				~3600		Early bacteria & algae	Oldest known Earth rocks (~3.93 billion years ago)
Hadean ("Beneath the Earth")				4600		Origin of life? Formation of the Earth	Oldest moon rocks (4-4.6 billion years ago) Earth's crust being formed

Figure 10. Geologic time scale; adapted from the U.S. Geological Survey and International Commission on Stratigraphy. 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.

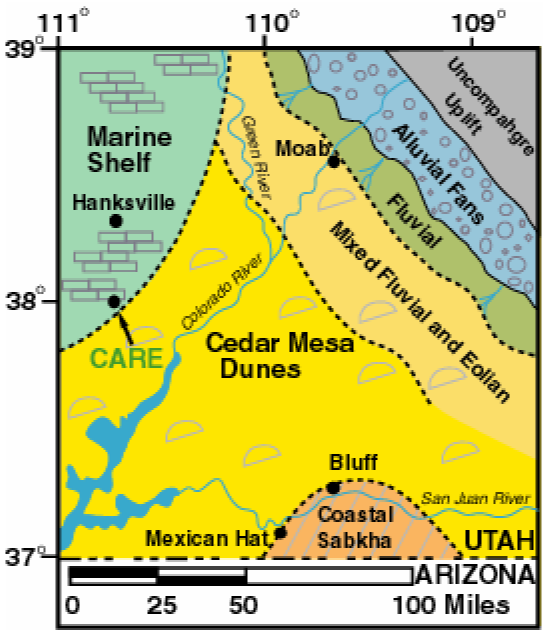


Figure 11. Lower Permian depositional environments in southeastern Utah during deposition of the Cedar Mesa Sandstone. CARE: Capitol Reef National Park. Modified from Huntoon and others (2000).

Age	Northern Arizona	Southern Utah	Sequence
Triassic	Tr - 1		
PERMIAN	Kaibab Fm.	Kaibab Fm. White Rim Ss.	4
	P - k		
	Toroweap Fm. Coconino Ss.	Toroweap Fm. White Rim Ss.	3
	P - tw		
	Coconino Ss. Shnelby Hill Fm.	Coconino Ss.	2
	P - sc		
	Hermite Fm. Esplanade Ss.	Organ Rock Fm. Cedar Mesa Ss. Cutler Fm.	1
Penn.	P - O		

Figure 12. Unconformities and depositional sequences in the Permian of the Colorado Plateau. Shaded areas indicate gaps in time between depositional episodes. Yellow shading indicates rocks exposed at Capitol Reef National Park. Modified from Blakey (1996).

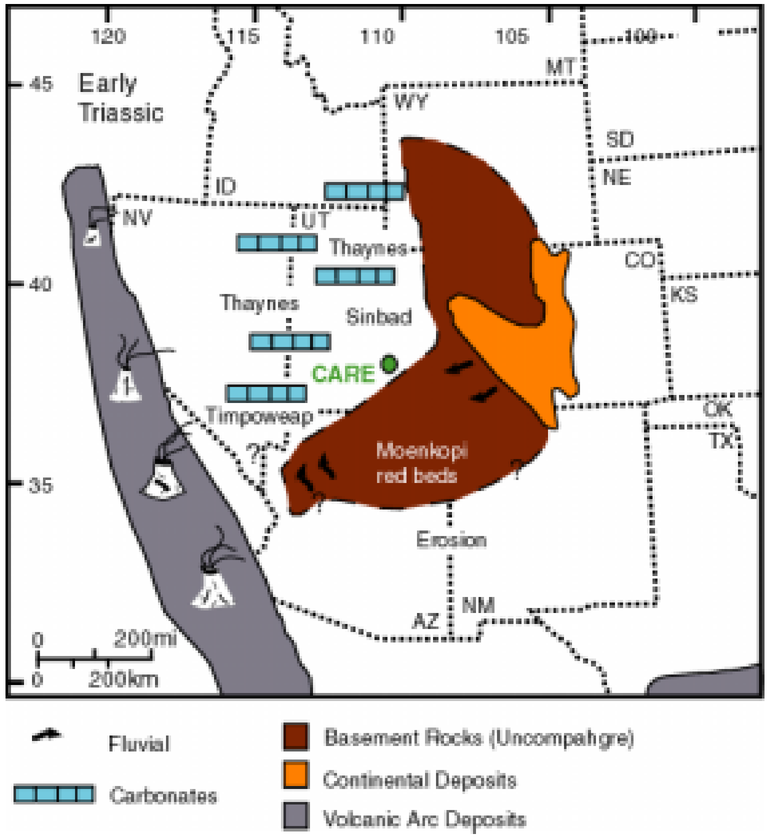


Figure 13. Paleogeographic map of the Lower Triassic, Moenkopi Formation during the second transgressive episode of the Early Triassic (Black Dragon and Sinbad Limestone members). CARE: Capitol Reef National Park. Modified from Dubiel (1994).

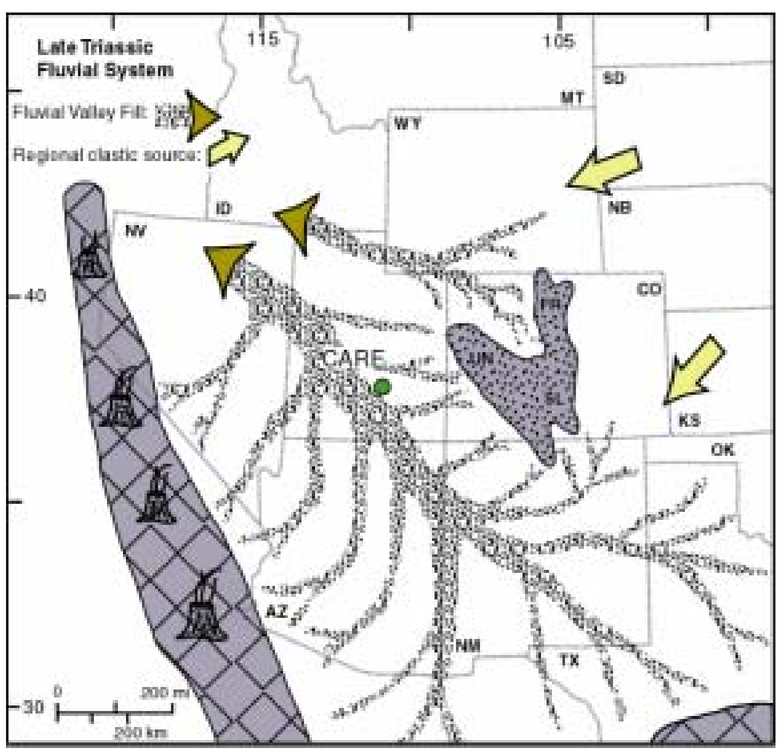


Figure 14. Paleogeographic map of the fluvial system in the Upper Triassic. CARE: Capitol Reef National Park. UN: Uncompahgre uplift; SL: San Luis uplift; FR: Front Range uplift. Highlands are shaded a solid gray. Modified from Dubiel (1994).

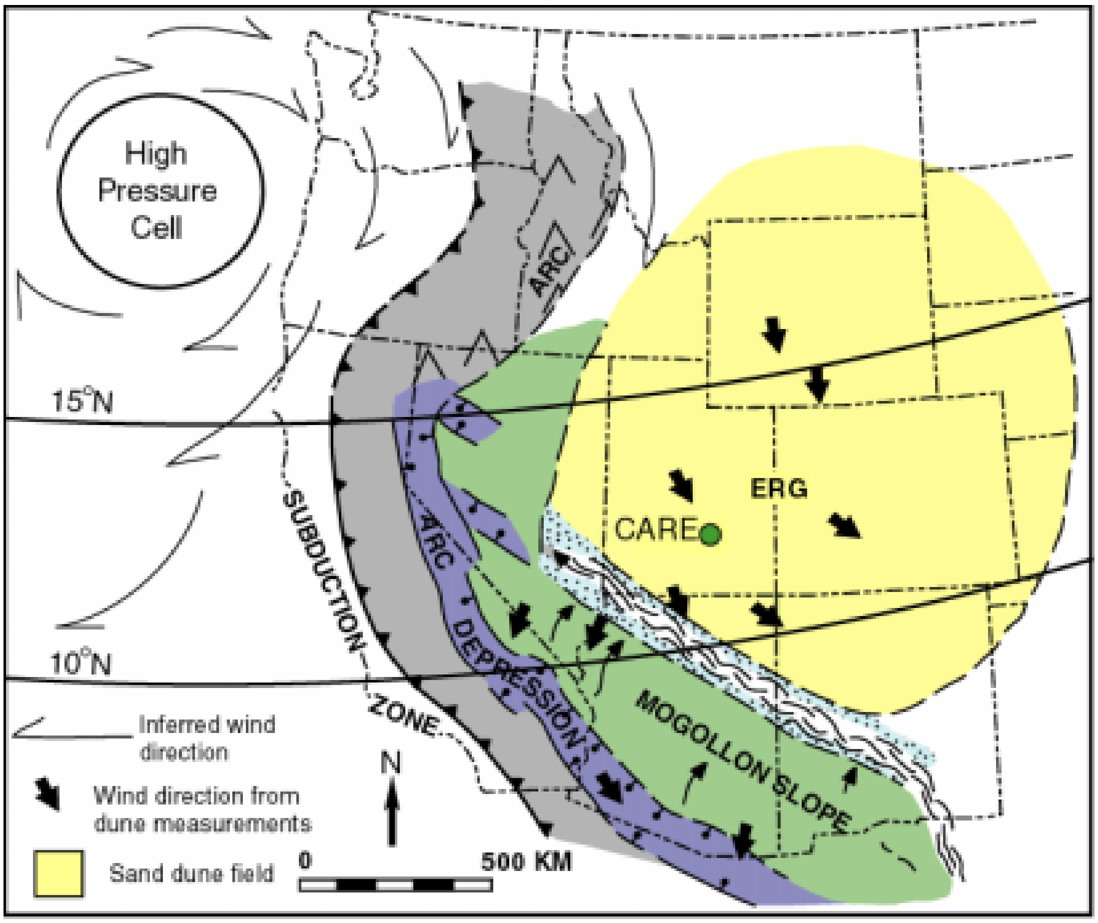


Figure 15. Lower Jurassic paleogeography. Thick arrows indicate eolian transport of sand. Thin arrows on Mogollon Slope indicate fluvial transport of sediments. Gray shading shows the location of the volcanic arc. Saw teeth indicate the location of the subduction zone with the teeth on the overriding, upper lithospheric plate. CARE: Capitol Reef National Park. Modified from Lawton (1994).

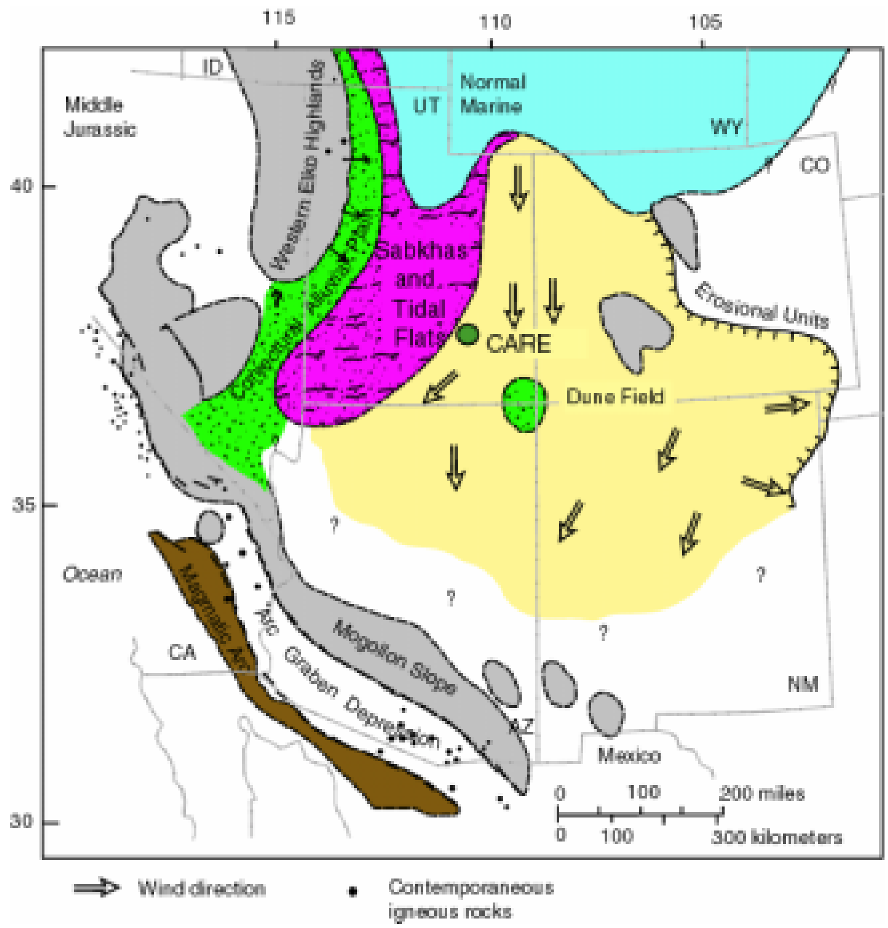


Figure 16. Middle Jurassic paleogeography during deposition of the Entrada Sandstone. Note that the northern marine environments have eliminated the sand source to the north (compare with Figure 18), yet Entrada ergs are widespread. CARE: Capitol Reef National Park. Modified from Peterson (1994).

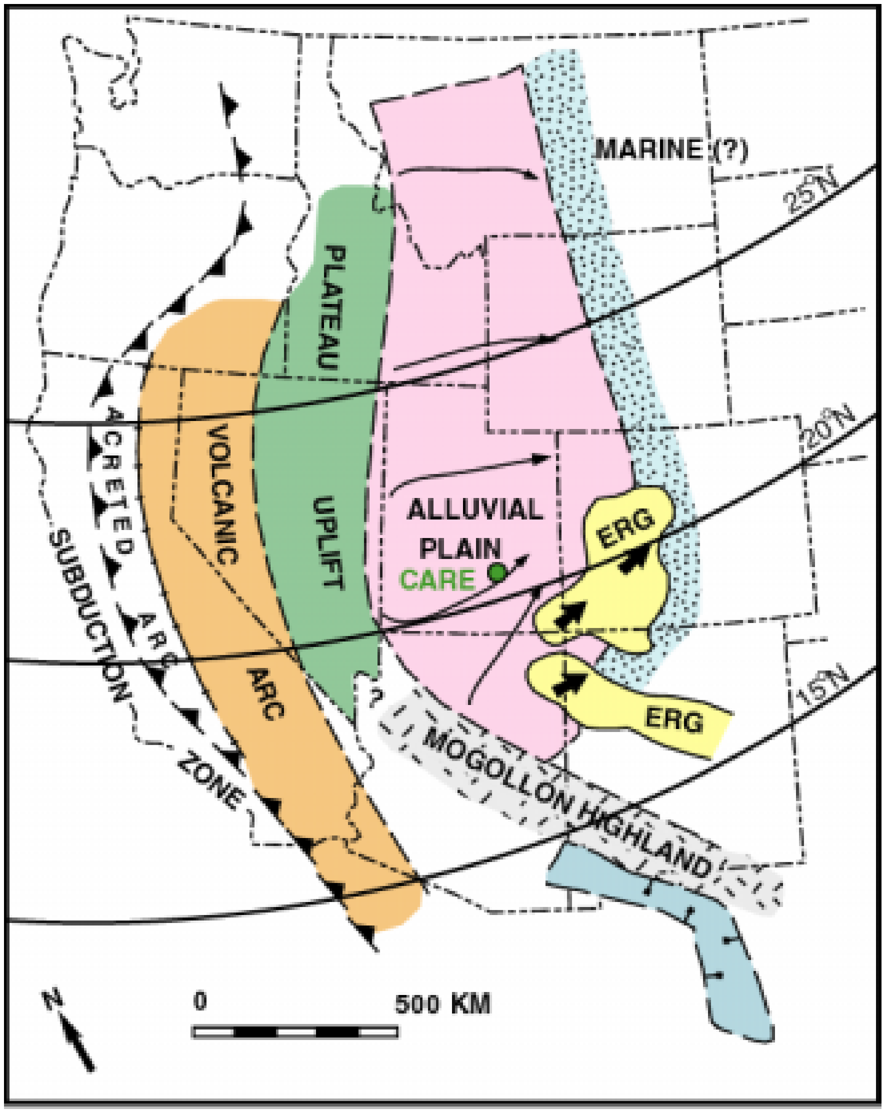


Figure 17. Upper Jurassic paleogeography. Thin arrows indicate fluvial dispersal. Thick arrows indicate wind directions. Saw teeth indicate the location of the subduction zone with the teeth on the overriding, upper lithospheric plate. Note the possible marine environment to the east where continental environments were previously established. The alluvial plain expanded to the east with time. CARE: Capitol Reef National Park. Modified from Lawton (1994).

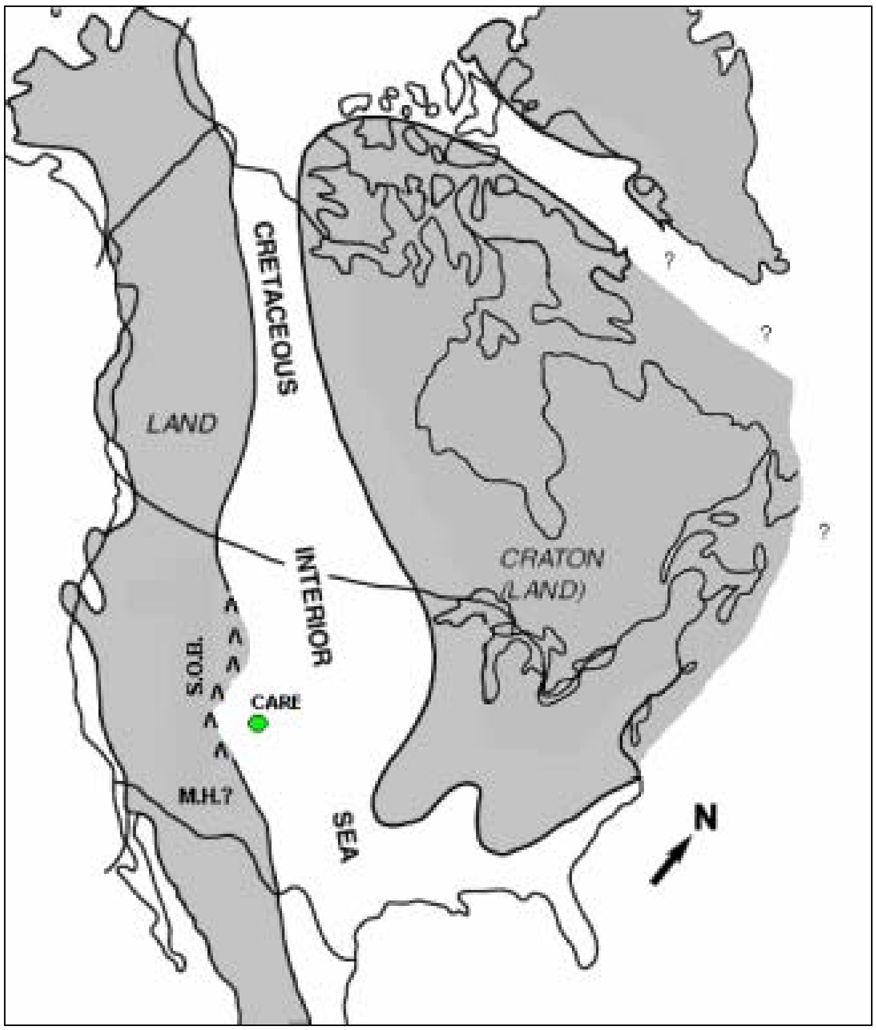


Figure 18. Location of the Cretaceous Period, Western Interior Seaway. Shaded areas indicate land above sea level. North indicates the Cretaceous north. Modified from Rice and Shurr (1983).

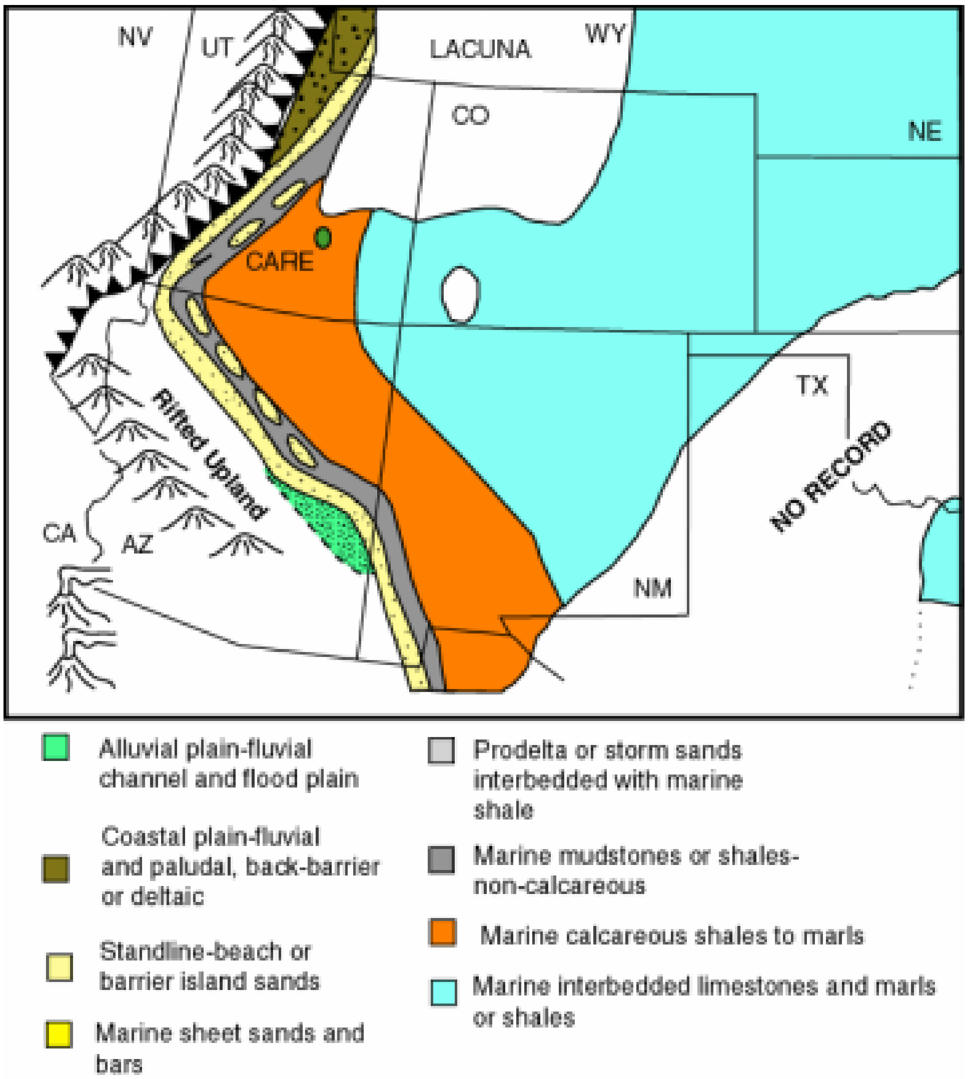


Figure 19. Upper Cretaceous paleogeography at the time of deposition of the Tununk Shale Member of the Mancos Shale. Saw teeth mark the leading edge of thrust faulting with the teeth on the overriding plate. Modified from Elder and Kirkland (1994).

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.

angular unconformity. An unconformity where the strata above and below are oriented differently; generally caused by structural deformation and erosion prior to deposition of the upper bed.

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

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

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

carbonaceous. A rock or sediment with considerable carbon, esp. organics, hydrocarbons, or coal.

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.

continental shelf. The shallowly-submerged portion of a continental margin extending from the shoreline to the continental slope with water depths of less than 200 m (656 ft).

craton. The relatively old and geologically stable interior of a continent (also see continental shield).

cross-bedding. Uniform to highly-varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions.

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).

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

dike. A tabular, discordant igneous intrusion.

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

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

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

fold axis. A line connecting the points of maximum curvature of the bedding in a fold (hinge line).

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

kettle. A bowl-shaped depression in glacial drift formed by the melting of a large block of ice left by a glacier; often contain a lake or swamp.

laccolith. A concordant igneous intrusion with a domed or convex-up roof and flat floor.

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

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 geologic past (e.g. the Laramide orogeny).

paleosol. A soil formed in the past with distinctive characteristics resulting from a soil- forming environment that no longer exists.

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

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.

reverse fault. A contractional, high angle (>45^{o}), dip-slip fault in which the hanging wall moves up relative to the footwall (also see thrust fault).

roche moutonneé. A small (usually a few meters) elongate knob of bedrock sculpted by a large glacier oriented in the direction of ice movement.

sabkha. A coastal environment in an arid climate where evaporation rates are high.

sill. A tabular, igneous intrusion that is concordant with the country rock.

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.

till. Unsorted, unstratified, unconsolidated mixture of clay, silt, sand, gravel and boulders left by a glacier.

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

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

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

References

This section provides a listing of references cited in this report. A more complete geologic bibliography is available and can be obtained through the NPS Geologic Resources Division.

Baars, D. L., 2000, The Colorado Plateau: University of New Mexico press, Albuquerque, NM, 254 p.

Billingsley, G. H., Huntoon, P. W., and Breed, W. J., 1987, Geologic Map of Capitol Reef National Park and Vicinity, Utah: Utah Geological and Mineral Survey, Map 87, scale 1;62,000, 4 plates.

Blakey, R. C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, in Mario V. Caputo, James A. Peterson, and Karen J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 273-298.

Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau, in M.W. Longman and M.D. Sonnenfeld, eds., Paleozoic Systems of the Rocky Mountain Region: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 405-426.

Brown, K. W. and Ritzma, H. R., 1982, Oil and gas fields and pipelines of Utah: Utah Geological and Mineral Survey, Map 61, Scale 1:750,000.

Campbell, J.A., 1980, Lower Permian depositional systems and Wolfcampian paleogeography, Uncompahgre basin, eastern Utah and southwestern Colorado, in T.D. Fouch, E.R. Magathan, eds., Paleozoic Paleogeography of the West-Central United States: Society of Economic Paleontologists and Mineralogists (SEPM), Rocky Mountain Section, p. 327-340.

Campbell, J. A. and Bacon, R. S., 1976, Penetration chart of Utah oil and gas fields: Utah Geological and Mineral Survey, Oil and Gas Field Studies #14.

Christiansen, E. II, Kowallis, B. J., and Barton, M. D., 1994, Temporal and spatial distribution of volcanic ash in Mesozoic sedimentary rocks of the Western Interior: an alternative record of Mesozoic magmatism, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 73-94.

Cole, R.D., Moore, G.E., Trevena, A.S., Armin, R.A., and Morton, M.P., 1996, Lithofacies definition in Cutler and Honaker Trail Formations, Northeastern Paradox Basin, by sedimentologic observations and spectral gamma-ray data, in A.C. Huffman, Jr., W.R. Lund, and L.H. Godwin, eds., Geology and Resources of the Paradox Basin: Utah Geological Association Guidebook 25, p. 169-178.

Condon, S. M., 1991, Geologic and structure contour map of the Ute Mountain Ute Indian Reservation and adjacent areas, southwest Colorado and northwest New Mexico: USGS Map I-2083, Scale: 1:100,000.

Delaney, P.T., and Gartner, A.E., 1997, Physical processes of shallow mafic dike emplacement near the San Rafael Swell, Utah: Geological Society of America Bulletin, v. 109, no. 9, p. 1177-1192.

Doelling, H. H., 1983, Non-metallic mineral resources of Utah: Utah Geological and Mineral Survey, Map 71, Scale 1:750,000.

Doelling, H. H., 2000, Geology of Arches National Park, Grand County, Utah, in D.A. Sprinkel, T.C. Chidsey, Jr., and P.B. Anderson, eds., Geology of Utah's Parks and Monuments: Utah Geological Association Publication 28, p. 11-36.

Doelling, H. H. and Tooker, E. W., 1983, Utah mining district areas and principal metal occurrences: Utah Geological and Mineral Survey, Map 70, Scale 1:750,000.

Dubiel, R.F., 1987, Sedimentology of the Upper Triassic Chinle Formation, Southeastern, Utah: Boulder, Colorado, University of Colorado, Ph.D. dissertation, 132 p.

Dubiel, R. F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 133-168.

Dubiel, R. F., Huntoon, J. E., Condon, S. M., Stanesco, J. D., 1996, Permian deposystems, paleogeography, and paleoclimate of the Paradox Basin and vicinity, in M.W. Longman and M.D. Sonnenfeld, eds., Paleozoic Systems of the Rocky Mountain Region: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 427-444.

Dutton, C.E., 1880, Geology of the High Plateaus of Utah: U.S. Geographical and Geological Survey of the Rocky Mountain Region.

Elder, W. P. and Kirkland, J. I., 1994, Cretaceous paleogeography of the southern Western Interior Region, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 415-440.

Fillmore, R., 2000, The Geology of the Parks, Monuments and Wildlands of Southern Utah: The University of Utah Press, 268 p.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1983, Patterns and timing of synorogenic sedimentation in Upper Cretaceous rocks of Central and Northeast Utah, in M. W. Reynolds and E. D. Dolly, eds., Mesozoic Paleogeography of the West-Central United States: Rocky Mountain Paleogeography Symposium 2, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists (SEPM), p. 305-336.

Fouret, K. L., 1996, Depositional and diagenetic environments of the Mississippian Leadville Limestone at Lisbon Field, Utah, in A.C. Huffman, Jr., W.R. Lund, and L.H. Godwin, eds., Geology and Resources of the Paradox Basin: Utah Geological Association Guidebook 25, p. 133-138.

Gardner, M. H. and Cross, T. A., 1994, Middle Cretaceous paleogeography of Utah, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 1471-502.

Gartner, A.E., 1986, Geometry, emplacement history, petrography, and chemistry of a basaltic intrusive complex, San Rafael and Capitol Reef areas, Utah: U.S.G.S. Open-Rile Report 86-61, 112 p.

Harr, C. L., 1996, Paradox oil and gas potential of the Ute Mountain Ute Indian Reservation, in A.C. Huffman, Jr., W.R. Lund, and L.H. Godwin, eds., Geology and Resources of the Paradox Basin: Utah Geological Association Guidebook 25, p. 13-28.

Haynes, D. D., Vogel, J. D., and Wyant, D G., 1972, Geology, structure, and uranium deposits of the Cortez Quadrangle, Colorado and Utah: USGS Map I-629, Scale 1:250,000.

Hintze, L.F., 1988, 1993, Geologic history of Utah: Brigham Young University Studies Special Publication 7, 202 p.

Huntoon, J. E., Dolson, J. C., and Henry, B. M., 1994, Seals and migration pathways in paleogeomorphically trapped petroleum occurrences: Permian White Rim Sandstone, Tar-Sand Triangle area, Utah: in J. C. Dolson, M. L. Hendricks, and W. A. Wescott, eds., Unconformity-Related Hydrocarbons in Sedimentary Sequences: Rocky Mountain Association of Geologists, p. 99-118.

Huntoon, J. E., Stanesco, J. D., Dubiel, R. F., and Dougan, J., 2000, Geology of Natural Bridges National Monument, Utah, in D.A. Sprinkel, T.C. Chidsey, Jr., and P.B. Anderson, eds., Geology of Utah's Parks and Monuments: Utah Geological Association Publication 28, p. 233-250.

Kauffman, E. G., 1977, Geological and biological overview: Western Interior Cretaceous Basin: Mountain Geologist, v. 14, p. 75-99.

Kiver, E.P., and Harris, D.V., 1999, Geology of U.S. Parklands: John Wiley & Sons, Inc., New York, p. 466-478.

Koch, Alison L., and Santucci, Vincent L., 2002, Paleontological Resource Inventory and Monitoring Northern Colorado Plateau Network: National Park Sercice, TIC #D-206, p. 18-21.

Kocurek, G. and Dott, R. H. Jr., 1983, Jurassic paleogeography and paleoclimate of the central and southern Rocky Mountain region, in M. W. Reynolds and E. D. Dolly, eds., Mesozoic Paleogeography of the West-Central United States: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 101-118.

Lawton, T. F., 1994, Tectonic setting of Mesozoic sedimentary basins, Rocky Mountain region, United States, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 1-26.

Loope, D.B., 1984, Eolian origin of Upper Paleozoic sandstones, southeastern Utah: Journal of Sedimentary Petrology, v. 54, no. 2, p. 563-580.

Martin, L., 1998, Capitol Reef National Park drinking water source protection plan Fremont River Gorge well: Water Resources Division, NPS, 22 p. and appendices.

Mickelson, D.L., 2004, The diversity and stratigraphic distribution of pre-dinosaurian communities from the Triassic Moenkopi Formation, Capitol Reef National Park and Glen Canyon National Recreation Area, Utah: Park Paleontology, v. 8, no. 1, p. 1-4.

Moore, D. M. and Reynolds, R. C., Jr., 1989, X-ray Diffraction and the Identification and Analysis of Clay Minerals: Oxford University Press, New York, 332 p.

Morris, T., H., Manning, V. W., and Ritter, S. M., 2000, Geology of Capitol Reef National Park, Utah: in D.A. Sprinkel, T.C. Chidsey, Jr., and P.B. Anderson, eds., Geology of Utah's Parks and Monuments: Utah Geological Association Publication 28, p. 85-106.

Mustoe, G.E., 1983, Cavernous weathering in the Capitol Reef Desert, Utah: Earth Surface Processes and Landforms, John Wiley and Sons Ltd., New York, v. 8.

Nuccio, V. F. and Condon, S. M., 1996, Burial and thermal history of the Paradox Basin, Utah and Colorado, and petroleum potential of the Middle Pennsylvanian Paradox Formation, in A.C. Huffman, Jr., W.R. Lund, and L.H. Godwin, eds., Geology and Resources of the Paradox Basin: Utah Geological Association Guidebook 25, 1996 Field Symposium, p. 57-76.

Petersen, L.M., and Roylance, M.M., 1982, Stratigraphy and depositional environments of the Upper Jurassic Morrison Formation near Capitol Reef National Park, Utah, in K.W. Hamblin, and C.M., Gardner, eds., Brigham Young University Geology Studies, v. 29, pt. 2, p. 1-12.

Peterson, F., 1994, Sand dunes, sabkhas, stream, and shallow seas: Jurassic paleogeography in the southern part of the Western Interior Basin, in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 233-272.

Peterson, F., Ryder, F.T., and Law, B.E., 1980, Stratigraphy, sedimentology, and regional relationships of the Cretaceous System in the Henry Mountains region, Utah, in M.D. Picard, ed., Henry Mountains Symposium: Utah Geological Association Publication 8, p. 151-170.

Peterson, J. A., 1980, Permian paleogeography and sedimentary provinces, west central United States, in T. D. Fouch and E. R. Magathan, eds., Paleozoic Paleogeography of the West-Central United States: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 271-292.

Raup, D. M., 1991, Extinction: Bad Genes or Bad Luck?: W.W. Norton and Company, New York, 210 p.

Rice, D. D. and Shurr, G. W., 1983, Patterns of sedimentation and paleogeography across the Western Interior Seaway during time of deposition of Upper Cretaceous Eagle Sandstone and equivalent rocks, northern Great Plains, in M. W. Reynolds and E. D. Dolly, eds., Mesozoic Paleogeography of the West-Central United States: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 337-358.

Richmond, D.R., and Morris, T.H., 1998, Stratigraphy and cataclysmic deposition of the Dry Mesa Dinosaur Quarry, Mesa Country, Colorado, in K. Carpenter, D.J., Chure, and J.I. Kirkland, The Upper Jurassic Morrison Formation: An Interdisciplinary Study: Modern Geology, v. 22, pt. 1, p. 121-144.

Sageman, B. B. and Arthur, M. A., 1994, Early Turonian paleogeographic/paleobathymetric map, Western Interior, U.S., in M. V. Caputo, J. A. Peterson, and K. J. Franczyk, eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section, SEPM (Society for Sedimentary Geology), Denver, CO., p. 457-470.

Santucci, V.L., Hunt, A.P., and Lockley, M.G., 1998, Fossil Vertebrate Tracks in National Park Service Areas: Dakoterra Volume 5, p. 108-110.

Silberling, N. J. and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: GSA Special Paper 72, 58 p.

Smith, F.J, Jr., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1963, Geology of the Capitol Reef Area, Wayne and Garfield Counties, Utah: U.S.G.S. Professional Paper 102, p. 1-98.

Stewart, J.H., Poole, F.G., and Wilson, R. F., 1972A, Stratigraphy and origin of the Triassic Moenkopi formation and related strata in the Colorado Plateau region with a section on sedimentary petrology by R.A. Cadigan: USGS Prof Paper 691, 195 p.

Stewart, J.H., Poole, F.G., and Wilson, R. F., 1972B, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region with a section on sedimentary petrology by R.A. Cadigan and on conglomerate studies by W. Thordarson, H.F. Albee, and J.H. Stewart: USGS Prof Paper 690, 336 p.

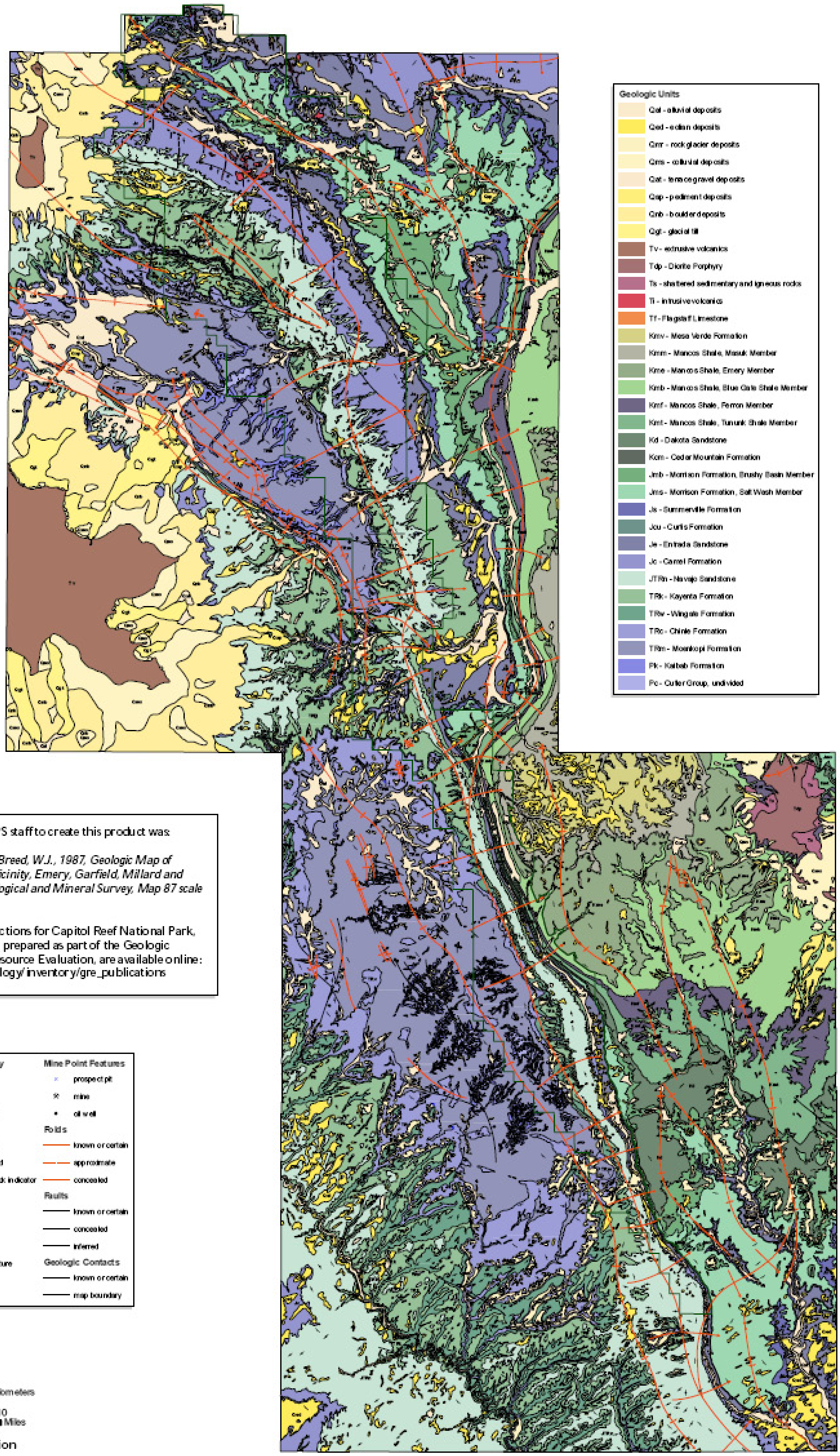
Stewart, J.H., Williams, G.A., Albee, H.F., and Raup, O.B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S.G.S. Bulletin, p. 487-573.

Wright, J.C., Shawe, D.R., and Lohman, S.W., 1962, Definition of members of Jurassic Entrada Sandstone in east-central Utah and west-central Colorado: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2057-2070.

Appendix A: Geologic Map Graphic

The following page provides a preview or "snapshot" of the geologic map for Capitol Reef National Park. For a poster size PDF of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm

Geology of Capitol Reef National Park



The original map digitized by NPS staff to create this product was:

Billingsley, G.H., Huntoon, P.W., Breed, W.J., 1987, Geologic Map of Capitol Reef National Park and Vicinity, Emery, Garfield, Millard and Wayne Counties, Utah: Utah Geological and Mineral Survey, Map 87 scale 1:24,000.

Digital geologic data and cross sections for Capitol Reef National Park, and all other digital geologic data prepared as part of the Geologic Resources Divisions Geologic Resource Evaluation, are available online: http://www2.nature.nps.gov/geology/inventory/gre_publications

Capitol Reef NP Boundary

Geologic Symbols
- strike and dip of beds
- horizontal beds
- strike of vertical joints
- fold plunge arrowhead
- fault down-thrown block indicator
- monocline
- anticline
- syncline

Geologic Features
- collapse breccia structure

Mine Point Features
- prospect pit
- mine
- oil well

Folds
- known or certain
- approximate
- concealed

Faults
- known or certain
- concealed
- inferred

Geologic Contacts
- known or certain
- map boundary

0 3.75 7.5 15 Kilometers

0 2.5 5 10 Miles

Produced by Geologic Resources Division

September 2006

Appendix B: Scoping Summary

The following excerpts are from the GRI (now GRE) scoping summary for Capitol Reef National Park. The scoping meeting occurred September 27-28, 1999; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact the Geologic Resources Division for current information.

Joe Gregson (NPS-NRID) presented an overview of the NPS I&M Program, the status of the natural resource inventories, and the GRI. Geologists familiar with GIS methods were quite impressed with the method of displaying geologic maps digitally, which Joe and NRID have developed.

Bruce Heise (NPS-GRD) followed with an overview of the GRD and GRI and outlined the following main goals of the program: to assemble a bibliography of associated geological resources for NPS units with significant natural resources, to compile and evaluate a list of existing geologic maps for each unit, to develop digital geologic map products, and to complete a geological report that synthesizes much of the existing geologic knowledge about each park.

Heise emphasized that the inventory is not to routinely initiate new geologic mapping projects, but to aggregate existing information and identify where serious geologic data needs and issues exist in the NPS.

Interpretation

The GRI also aims to help promote geologic resource interpretation within the parks. GRD has staff and technology to assist in preparation of useful materials including developing site bulletins and resource management proposal (RMP) statements appropriate to promoting geology.

UGA Guidebook of Utah's National and State Park Areas

In 1999, Doug Sprinkel (UGA) announced the compilation of a guidebook that would treat the geology of Utah's national and state parks and monuments. This guidebook was published in 2000, and while some of the guidebook may be too technical for non-geologists, the publication should be a part of every Utah park's library. The reference is:

- D.A. Sprinkel, T.C. Chidsey, Jr., and P.B. Anderson, eds., Geology of Utah's Parks and Monuments: Utah Geological Association Publication 28.

Soils Mapping Status

Pete Biggam (GRD) oversees the soil mapping program, and he handed out an overview of the current status of soils maps for Capitol Reef National Park (CARE). Questions regarding soil mapping or interpretation should be directed to Pete.

Paleontological and other natural resources

Vince Santucci (NPS) presented an overview of paleontological resources for CARE. Paleontology is not currently part of the first level of the I&M program.

Tom Clark (CARE-natural resources) is interested in having a paleontological survey conducted for CARE similar to the studies completed for Zion, Yellowstone, and Death Valley. Surveys of this type often uncover valuable, new information on previously unrecognized resources. Participants suggested that if additional significant findings occur, paleontological resource management plans should be produced for CARE involving some inventory and monitoring to identify human and natural threats to these resources. Collections taken from CARE and that now reside in outside repositories should be identified for inventory purposes. Special concern was noted for the protection of paleontological resources because of the "black market" fossil trade that has become quite lucrative and often results in illegal collecting from federal lands.

In 1999, significant paleontological resources for CARE included the following:

- Both invertebrate and vertebrate traces from the Moenkopi and Chinle formations
- Vertebrate tracks in the Kayenta Formation
- Dinosaur bones in the Morrison Formation
- Petrified trees in Salt Wash Member of the Morrison Formation outside the park boundary; some also near the Terry mines
- Cretaceous suite of marine invertebrates in Tununk Shale (*Griffia movaria*, *Exogyra*); oyster shell reef in Dakota Sandstone
- Pack-rat middens
- Ammonite zone in the Moenkopi Formation
- *Pentacrinus* zones in Sinbad Member of the Carmel Formation

Also mentioned were the current cases involving mineral and fossil poaching from CARE. Rock hounds have targeted the numerous "sunset" agate concretions in the Tidwell Member of the Morrison Formation, and gypsum crystals are also in high demand. Phil Cloues (GRD Mineral Economist) may be contacted for additional information.

Geologic Mapping

The following digital geologic map product that was projected for completion by December, 1999, has been completed and is now available:

- Billingsley, G. H., Huntoon, P. W., and Breed, W. J., 1987, Geologic Map of Capitol Reef National Park and Vicinity, Utah: Utah Geological and Mineral Survey, Map 87, scale 1:62,500, 4 plates.

At the workshop, additional improvements to the current coverage were noted that might be desirable for certain resource issues such as roads, campgrounds, vegetation, soil, and wastewater.

The following mapping improvements at a 1:24,000 scale were suggested. Contact Tim Connors (GRD) as to the status of these improvements.

- More detailed mapping of surficial units along the Fremont River
- Identification and placement of new map units not on existing 62,500 scale map.
- Mapping of gravel terraces that tell an important geologic story about CARE
- Mapping mountain top boulder deposits since they have an important role in groundwater recharge and geologic hazard identification
- Joint systems need to be incorporated onto the existing map and are important to the groundwater story
- Delineating range management and endangered species areas
- Waterpocket Fold
- Burr Trail (for hazard assessments); Wagon box Mesa, The Post, and Bitter Creek Divide were all mentioned by name along this route
- Heavy use areas ("threshold zone/backcountry") such as the Fruita-Scenic Drive (Twin Rocks, Fruita, and Golden Throne 24,000 scale quadrangles).

Other Sources of Natural Resources Data

- Participants noted that the UGS has a significant quadrangle database that they have furnished to NRID for the entire state of Utah. Contact Tim Connors for details.
- NRID has compiled a geologic bibliography for numerous parks and monuments including Capitol Reef NP. The website has undergone some changes since 1999. Contact Wendy Schumacher (NRID) (Wendy_Schumacher@nps.gov, 970-225-3548) for the current user id and password.
- Abandoned Mineral Land (AML) database by John Burghardt (GRD). Noted at the workshop were several reports from GRD on the Oyler, Terry and Rainy Day mine closures that existed in addition to inventories for several other sites within CARE. Three of ten sites were mitigated. At the time, there were 27 openings at 10 sites inventoried. All of the sites were uranium mines. Contact John Burghardt (GRD) for updated information (John_Burghardt@nps.gov).
- Smith, J.F. Jr., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1963, Geology of Capitol Reef Area, Wayne and Garfield Counties, Utah: USGS Professional Paper 363.
- Davis, G., 1999?, Structural Geology of the Colorado Plateau Region of Southern Utah with Special Emphasis on Deformation Bands: Geological Society of America Special Paper 342, (specifically thanks CARE staff for their cooperation).
- Allyson Mathis has maintained a database on CARE geologic features that was mentioned at the meeting, but needs still to be obtained by GRD (as of workshop).
- Engelmanns GPS locations from Morrison Ecosystem study
- Previously mentioned digital geologic map from Billingsley and others, 1987, map with fault layers
- UGS paper and digital 1:100,000 scale coverages of the Escalante and Hites Crossing sheets
- Soils data from NRCS

Geologic Hazards

The following were recognized as geologic hazards at the 1999 workshop:

- Rockfalls
- Floods
- Debris flows
- Uranium/radon
- Expansive clays
- Old adits from AML sites
- Faults: closest active fault is on the west side of plateau according to Grant Willis (UGS). Allyson Mathys (NPS) thinks there is an active fault somewhere next to Needles with a report on it (source unknown). Tom (Clark?) says a 3.8 earthquake shook the area in the Spring, 1999, up Fremont River\
- Water quality issues for the Water Resources Division (WRD)

Potential Research Topics for Capitol Reef NP

Participants at the workshop listed the following as potential research topics:

- Paleo current directions in Kayenta time
- Black boulder debris flows
- Track studies by Kirby and McAllister
- Possible new tracksite in Moenkopi (from Jackie Huntoon)
- Study playa deposits in Cottonwood Wash in Navajo Sandstone for flood events
- Joint systems/fracture study for entire park for water quality issues

- Study selenite deposits and structure of gypsum sinkhole
- Terrace deposits (rework late Cenozoic history of park); hasn't been done well to this point in time (1999).
- Study origin of honeycomb weathering patterns
- Soft sediment deformation in Navajo and Entrada Formations
- Conduct full Paleontological survey
- Study depositional environments of earthy Entrada facies, Curtis, Summerville, Morrison Formations, etc.
- Chinle Ecosystem study (for Russ Dubiel, then at USGS)\
- Dike/sill emplacement history, petrology, depth of source and emplacement and relate to uplift and erosion story of Colorado Plateau
- Study structure of Waterpocket Fold at depth
- Tie soil chemistry to rare plants; overall soil characterization
- Tie CARE story to adjacent areas for interpreters to present to public
- Inventory commercially valuable minerals for collecting
- Study entrenched meanders along Fremont River, Halls Creek drainage, Sulfur Creek

Disturbed Lands

Disturbed lands/abandoned mineral lands issues at CARE include the following:

- There are AML summaries from GRD that are in GIS layer already; according to John Burghardt (GRD) 3 of 10 sites mitigated (Oyler, Terry, Rainy Day). There are 27 openings at the 10 sites
- Preliminary (in 1999) disturbed lands map GIS layer exists according to Tom Clark for roads they want closed, cattle ponds, dams, tanks, etc.
- Some small borrow pits may be along the Burr Trail; also Notom Road has some low-grade coal near Highway 24 East in Carmel
- Oak Creek cattle grazing has hammered the area there, some disturbance along Pleasant Creek

Unique Geologic Features

- Type Sections: Torrey Member of Moenkopi Formation, Capitol Reef bed in Chinle Formation (member unknown, likely Petrified Forest Member). Moody Canyon Member (near Escalante, likely outside park) of Moenkopi Formation. San Raphael area has a few (San Raphael Group, Bluegate Member of Mancos Shale Formation, Tunnock Member in Mancos Shale, Muley Canyon, Tarantula Mesa Sandstone).
- Sills/dikes in north district
- Selenite crystals (Glass Mountain area)
- Cathedrals in Cathedral Valley
- Waterpocket Fold
- Black boulder deposits
- Geomorphology in general, specifically the slot canyons (Halls Creek narrows).
- Gypsum sinkholes
- Strike valley
- Soft sediment deformation
- Capitol Dome
- Sapping features – alcoves in Halls Creek area (cutoff meanders)
- Red Slide down by Halls Creek
- Hoodoos, demoiselles geomorphic features

GRI Workshop Participants, CARE, September 27-28, 1999

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Appendix C: Geoindicators Report

The following excerpts are modified from the Geoindicators Report for Capitol Reef National Park. This report was completed June 3-6, 2002; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact to the Geologic Resources Division for current information.

From June 3-5, 2002, staff of the National Park Service, Utah Geological Survey, U.S. Geological Survey, Bureau of Land Management, Northern Arizona University, and Brigham Young University participated in a geoindicators scoping meeting in Moab, Utah for four National Park Service units in southeastern Utah. The four parks were Arches National Park (ARCH), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), and Natural Bridges National Monument (NABR).

Purpose of meeting

The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes in the four park areas. The group used collective knowledge of the four parks' geology and natural resources to identify the geologic processes active in the parks, to identify the human activities affecting those processes, and to develop recommendations for long-term monitoring of geoindicators in conjunction with park Vital Signs monitoring.

In addition, the Northern Colorado Vital Signs Network is coming on-line in fiscal year 2002 and will be receiving its first funding for Vital Signs monitoring. The scoping meeting was timed so the Network could use the information gained during the meeting in the Vital Signs selection process.

This report summarizes the group's discussions and provides recommendations for studies to support resource management decisions, inventory and monitoring projects, and research needed to fill data gaps.

Park Settings

All four parks are located in the high desert of southeastern Utah. The climate is one of very hot summers, cold winters, and very little rainfall. On a daily basis, temperatures may fluctuate as much as 50 degrees Fahrenheit. Afternoon thunderstorms occur frequently from about mid-July through late summer. Snow occasionally falls in winter, especially at the higher elevations of the parks.

Capitol Reef National Park

Capitol Reef is a long, linear park that follows the mostly north-south trending Waterpocket Fold, a spectacular 100-mile long fold in Earth's crust known as a monocline. Elevations range from 4,200 feet to 9,800 feet. The lowest elevations are on the east side of the park—the downdropped side of the monocline, and the highest are on the west side of the park—the uplifted side of the monocline.

The park has several distinct regions. In the northern part of the park is Cathedral Valley. Rock layers in Cathedral Valley have a gentle inclination of 3 to 5 degrees to the east and appear nearly horizontal. Deep erosion has carved Cathedral Valley's free-standing monoliths, or temples, out of the soft reddish-orange Entrada Sandstone. South of Cathedral Valley, the Fremont River bisects the park east to west. South of the river is the park's scenic drive, which travels into an area of narrow gorges, towering cliffs, and large sandstone domes. The name Capitol Reef is partially derived from these large, white domes of Navajo Sandstone: "capitol" for the white domes that resemble capitol building rotundas, and "reef" for the rocky cliffs which are a barrier to travel, like a coral reef. The long, narrow southern region of the park includes many canyons, most notably the Halls Creek Narrows.

Topographic relief created a variety of habitats, such as perennial streams, water- pockets, hanging gardens, and dry washes, which are home to a diversity of flora and fauna in the park. "Waterpockets" are basins that form in many of the sandstone layers as they are eroded by water. These basins are common throughout the fold, thus giving it the name "Waterpocket Fold."

Early human occupation of the park was by the Fremont people, from about AD 700 to AD 1300. The culture was named for the Fremont River and its valley in which many of the first Fremont sites were discovered. Several types of artifacts left by the Fremont people have been identified, including baskets, smooth and corrugated gray pottery, and moccasins made from the hides of large animals. The most unique artifacts are clay figurines of unknown significance to the Fremont people. Also, a variety of pictographs and petroglyphs are scattered throughout parts of the park.

The pioneer community of Fruita, about one mile from the visitor center, was settled in 1880 by Mormon pioneers. The National Park Service now manages the historic orchards, which contain about 2,700 trees (mostly cherry, apricot, peach, pear, and apple), as part of Rural Historic Landscape.

The park was first designated a national monument in 1937, and was later expanded and re-designated a national park in 1971.

Park Geologic Setting

All four parks are located on the Colorado Plateau, a geologic province encompassing most of southern Utah and northern Arizona, northwest New Mexico, and western Colorado. The Plateau is characterized by relatively horizontal sedimentary rock layers that have been uplifted as much as 10,000 feet with relatively little deformation, with the exception of a number mostly north-south trending folds known as monoclines. Waterpocket Fold in Capitol Reef is a classic example of one of the monoclines.

For hundreds of millions of years, material was deposited in what is now southeast Utah. As movements in Earth’s crust altered surface features and the North American continent migrated north from the equator, the local environment changed dramatically. Over time, southeast Utah was flooded by oceans, crisscrossed by rivers, covered by mudflats, and buried by sand. The strata records changes in climate and biota spanning from the Pennsylvanian through Tertiary periods.

Until about 15 million years ago, most of the area was near sea level. Local uplifts and volcanic activity had created features like Capitol Reef's Waterpocket Fold and the La Sal Mountains near Moab, but then movements in Earth's crust caused the whole area to rise. Today, the average elevation is over 5,000 feet above sea level.

The following is a stratigraphic column of rock units in or near the four parks:

Capitol Reef National Park

Nearly 10,000 feet of sedimentary strata are found in the Capitol Reef area. These rocks range in age from the Permian White Rim Sandstone (as old as 270 million years old) to the Cretaceous Mancos Shale (as young as 80 million years old.). The Waterpocket Fold has tilted the geologic layers such that the layers on the west side of the Fold have been lifted more than 7,000 feet higher than the layers on the east. Therefore, the older rocks are found in the western part of the park, and the younger rocks are found near the east boundary.

Layer-upon-layer of sedimentary rocks records nearly 200 million years of geologic history. Rock layers in Capitol Reef reveal ancient climates as varied as rivers and swamps (Chinle Formation), Sahara-like deserts (Navajo Sandstone), and shallow ocean (Mancos Shale).

Waterpocket Fold formed between 50 and 70 million years ago when a major mountain-building event in western North America, the Laramide Orogeny, reactivated an ancient buried fault. When the fault moved, the overlying rock layers were draped above the fault and formed a monocline.

The following table was generated by scoping participants during the 2002 meeting:

Geoindicators Table

Geoindicators Identified in the Ecosystem	Importance to park ecosystem	Human impact	Significance to park management
ARID AND SEMIARID			
1. Desert surface crusts (bio and phys/chem) and pavements	5	5	5
2. Dune formation and reactivation	3	3	4
3. Dust storm magnitude, duration and frequency	1	5 / 3*	3
4. Wind erosion and deposition (ecosystem inputs and outputs)	5	5 / 3*	5
SURFACE WATER			
5. Stream channel morphology	5	5	5
6 Stream sediment erosion, storage and load	5	5	5
7. Streamflow	5	5	5
8. Surface water quality	5	5	5
9. Wetlands extent, structure, hydrology	5	5	5
GROUNDWATER			
10. Groundwater quality	5	4	3
11. Groundwater level and discharge	5	5	5
SOILS			
12. Soil quality (the capacity to function within "natural" range of variability—as reflected by dynamic soil properties that change in relation to management or climate—see SQIS definition)	5	1 / 5*	5
13. Soil and sediment erosion and deposition by water (upland environments)	5	3 / 5*	5
14. Sediment sequence and composition	1	5	3
HAZARDS			
15. Slope failure (landslides, rockfalls and debris flows)	3	1	2
16. Seismicity	1	0	1
17. Surface displacement (including salt dissolution features)	2	0	1
OTHER			
18. Fire Occurrence (e.g. spatial distribution and frequency may vary in relation to geophysical features/processes and can affect processes)	1	5	1
19. Atmospheric deposition (N, SO_4)	1	3	1
20. Paleontological resources	1	3	3
21. Climate	5	1	5

0 - Not Applicable (N/A)
1 - LOW or no substantial influence on, or utility for
3 - MODERATELY influenced by, or has some utility for
5 - HIGHLY influenced by, or with important utility for
UNK - Unknown; may require study to determine applicability
* Out of park/Inside park activity

Capitol Reef National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/005
NPS D-224, September 2006

National Park Service

Director • Fran P. Mainella

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Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross-cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

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