National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Colorado National Monument
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/007

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

March 2006

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

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KellerLynn, K. 2006. Colorado National Monument Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/007. National Park Service, Denver, Colorado.

NPS D-86, March 2006

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Executive Summary

This report has been developed to accompany the digital geologic map of Colorado National Monument, which was produced by Geologic Resource Evaluation staff. It contains information relevant to resource management and scientific research.

The brightly colored cliff- walled canyons and towering monoliths of Colorado National Monument are part of the canyonlands region of the Colorado Plateau province that stretches hundreds of miles to the west and south of the monument. The eastern margin of the monument and the Uncompahgre Plateau is marked by a great monocline—a textbook example of a Laramide structure. Many such spectacular geologic structures extend for miles across the Colorado Plateau of Colorado, Utah, Arizona, and New Mexico (fig. 1). The uppermost sedimentary strata that cap the plateau bend across the monoclinal hinge line and plunge nearly 2,000 feet (610 m) to the valley below. These strata display an exceptional record of Mesozoic rocks. Wind, water, and frost action have carved the variegated sedimentary rocks into pinnacles and massive rock spires that rise from the floors of the canyons. Scoured rocks "balance" atop tall columns of sandstone. Erosion has formed natural bridges and arches, and shear- walled canyons.

Colorado National Monuments is one of the only places on the Colorado Plateau to view Precambrian rocks. Exposed on the floors of the canyons, Triassic rocks overlie the ancient basement, marking an unconformity in the geologic record of about 1.17 billion years.

Geologic processes that began millions of years ago are ongoing today. Recognition of these active processes will aid the park in planning for rapid urban development near and up to the boundary of the park, as well as planning for an expected increase in visitation as a result of local population growth. Planning and resource management benefit from an awareness of geologic features and processes when working to preserve or restore them as appropriate. Some of the geologically significant issues for Colorado National Monument are:

- Flash Floods—Flash floods are one of the principal agents that form and modify the landscape of the monument. They are natural process that is of concern to homeowners at the mouths of the canyons just outside the park boundary. Because the park is often held responsible for the destruction property near the park boundary, it behooves park staff to educate local residents about the long history of flash flooding in the area and help them to make informed decisions with respect to the location of their homes.
- Slope Failure—Slope failure happens continuously throughout the park and is a constant maintenance issue along Rim Rock Drive. Slope failure is a concern for park management, particularly with respect to potential road failure. In addition, rockfalls are also a concern for visitor safety, especially along Rim Rock Drive and at overlooks.
- Erosion—The process of erosion, which created many of the landforms of Colorado National Monument, is a fundamental natural process that has been operating for millions of years. The present- day ecosystem was developed through the process of erosion. However, erosion may also expose paleontological resources increasing the potential for fossil theft and vandalism.
- Groundwater—Decrease in groundwater level could have a direct effect on seeps and springs in the monument and the plants and animals that depend on them. In addition, a decrease in groundwater could affect wetlands in the monument. Quantifying groundwater levels is important for management planning and future decision making as it relates to development outside of the monument boundary.
- Soil Crusts—Biological and physical soil crusts are a distinctive and fragile resource that require protection because they protect underlying fine material from wind erosion; fix atmospheric nitrogen vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surfaces; and decrease surface albedo. Also, depending on soil characteristics, biological crusts may either increase or reduce rates of water infiltration; by increasing surface roughness. Biological and physical soil crusts often reduce runoff, thus increasing infiltration and the amount of water stored for plant use.
- Wetlands—The scarcity of wetlands increases their importance to plants and wildlife as a source of water. Wetlands provide cooler temperatures and greater plant and animal diversity. These areas are sites of hanging gardens that provide habitat for threatened and endangered species. A significant human influence on wetlands in the monument has been the Fruita pipeline, which leaked and created artificial habitats ideal for exotic plants. Additionally, two reservoirs were constructed to provide water to the citizens of Fruita. These are no longer in use, but future demand could cause them to be restored.
- Sand and Gravel Resources—Sand and gravel resources are abundant in the vicinity of Colorado National Monument (Scott and others, 2001a). These resources have been and are being developed in the Grand Valley to the north. Since sand and gravel are used for road maintenance in the park and for a variety of other needs, an awareness of nearby sources outside the park is important. As Grand Junction continues to grow, the demand for sand and gravel is increasing and availability is becoming more scarce in the vicinity of the monument.

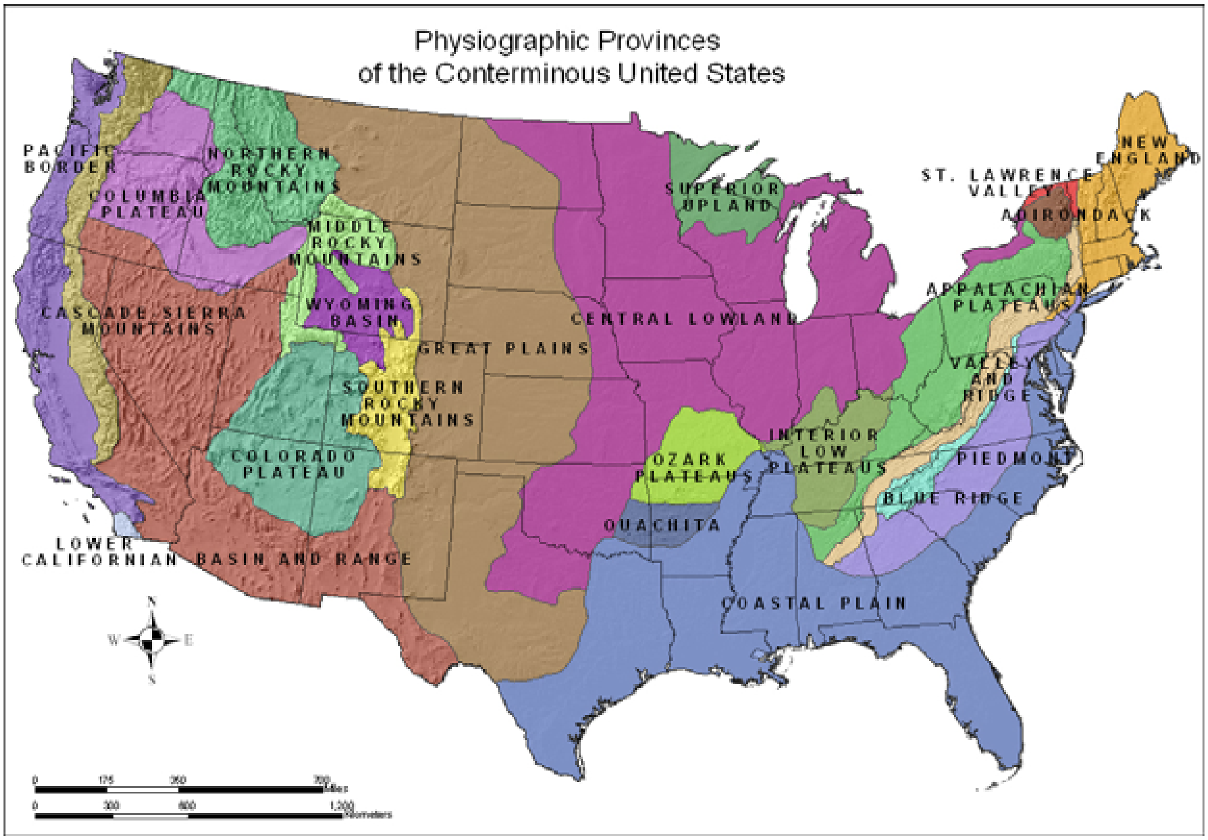

Figure 1. Physiographic Provinces of the Conterminous United States. Colorado National Monument is part of the Colorado Plateau physiographic province—an eroded desert landscape that covers parts of Colorado, Utah, Arizona, and New Mexico. Colorado National Monument stands as the province's most visible beginnings on the western Grand Junction skyline.

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 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 component is carried out by the Geologic Resource Evaluation (GRE) Program administered by the NPS Geologic Resources Division. 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.

The 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. During these meetings park staff are afforded the opportunity to meet with experts on the geology of the park. Scoping meetings are usually held at each park, which permits a focused discussion and exploration of available information on a park's resources. However, some scoping meetings have involved multiple parks or an entire Vital Signs Monitoring Network to expedite the inventory process.

Geologic Setting

The Colorado Plateau and its eroded desert landscape covers parts of Colorado, Utah, Arizona, and New Mexico, including the canyonlands of Utah and the Grand Canyon in Arizona (figure 1). Heading west, this spectacular region has its most visible beginnings on the western Grand Junction skyline in Colorado National Monument (Carpenter, 2002).

Geologic processes have been creating the features of Colorado National Monument for nearly 2 billion years. These processes include volcanism in island arcs along the growing ancestral North American continental margin, high- grade metamorphism, several periods of mountain building and deep erosion, deposition of marine and non- marine sediments, more uplift, and finally erosion that carved the present- day landforms.

Colorado National Monument lies along the northeastern flank of a large topographic feature known as the Uncompahgre Plateau—a high, relatively flat, elongated region that extends from Ridgeway, Colorado, northwestward to near Cisco, Utah. Metamorphosed crystalline rocks (1.7 billion years old) seen in the monument underlie the entire length of the plateau. The Triassic Chinle Formation rests directly (and unconformably) on these ancient basement rocks. Investigators have not found any rocks deposited on the eroded basement surface between Late Proterozoic (Precambrian) and Late Triassic time, a period of some 1.5 billion years (Baars, 1998).

During Precambrian time, island- arc volcanic rocks and related sediments accumulated along the continental margin as one lithospheric plate descended under another. Compressive mountain building and intrusion of granitic rocks and pegmatite dikes followed the formation of Earth's early crust. From the Cambrian through Mississippian time (554–320 million years ago), relatively thin marine sandstone, limestone, dolomite, and shale were deposited, covering much of the North American craton. During Pennsylvanian and Permian time (320–251.4 million years ago), Colorado was subject to a second period of compression and uplift, which formed the Ancestral Rocky Mountains. During this period of mountain building, the previously deposited marine rocks—if ever present in the monument—were eroded, transported, and deposited away from the monument area in great thicknesses into the Paradox Basin. Today, the highly metamorphosed cores of ancient mountains lay exposed in Colorado National Monument, but remnants of Paleozoic rocks in the monument are gone.

After the Paleozoic, deposition began again as evidenced by the impressive display of Mesozoic sedimentary rocks in the monument. Triassic- to Cretaceous- age sediments were deposited throughout Colorado, though this time under largely non- marine conditions until Late Cretaceous seas covered the area. During the Mesozoic, non- marine sandstone and shale were deposited on Precambrian basement rock. Most of the cross- bedded sandstone was deposited under desert conditions, and shale commonly was deposited in shallow non- marine lakes. Thick, marine Mancos Shale and younger near - shore and non- marine sandstones, shales, and coal beds (Mesaverde Group) covered these strata. Although Mancos Shale has been eroded from the monument, it underlies the nearby Grand Valley.

Beginning about 70 million years ago, mountain building once more affected Colorado. The Laramide orogeny began during the Late Cretaceous and continued into the middle Eocene Epoch (about 50 million years ago). This mountain- building episode caused uplift, folding, and faulting in the Colorado Plateau region. Most of the present- day structural framework for Colorado National Monument was formed during the Laramide orogeny.

After the Laramide orogeny, but during a significant part of the Cenozoic Era, great volumes of sedimentary rocks—particularly soft shales—were slowly eroded from the Colorado Plateau. During periods of relative tectonic quiescence, rivers in the area tended to meander and began to carve broad valleys into the areas underlain by Mancos Shale, such as Grand Valley. Regional uplift(s) in the late Cenozoic caused rivers to entrench their meanders into the more resistant rocks beneath the Mancos Shale, forming such notable features as the Grand Canyon, Westwater Canyon, and the Goosenecks of the San Juan River.

This process of exhumation as a result of regional uplift continued during the Pleistocene Epoch and persists today. Erosion of the canyons on the northeastern edge of the Uncompahgre Plateau at Colorado National Monument is beginning to remove the Mesozoic rocks from the plateau. And for a fourth time, Precambrian rocks are being exposed.

Today, canyon- cutting processes, including flash flooding, are creating the magnificent scenery of Colorado National Monument. Geologic features are a result of the process of erosion, which creates both its beauty and its hazardous conditions. Intense summer thunderstorms are common and quickly produce large volumes of water that rush through the canyons of the monument. These flash floods erode the canyons, and flood buildings and roads in their paths. Another erosional process, mass wasting, works on unstable cliffs such as the Wingate Sandstone, producing rockfalls that pose safety hazards in areas where visitors travel, notably at overlooks and along Rim Rock Drive where undercutting during construction of the road has destabilized the cliffs. In addition, expansive clays, present in rocks in the monument, swell when wetted, and increase the probability of landslides in the area.

Geologic Issues

On June 23 and 24, 1998, a geologic resources inventory scoping session was held at Colorado National Monument to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. In addition, on September 9 and 10, 2002, a geoindicators scoping meeting was held to identify active geologic processes and human impacts on these processes. The following section synthesizes these scoping results, in particular, those issues that may require attention from resource managers.

Abandoned Mine Lands

In the early 1990s, as part of an inventory effort, staff from the NPS Geologic Resources Division (GRD – previously known as Mining and Minerals Branch) investigated five sites at Colorado National Monument: (1) Kodel Gold Mine, located at the north end of the monument in Kodels Canyon; (2) Ella Lode, a vertical mine shaft located 50 feet (15 m) below Rim Rock Drive near the southeast boundary of the monument; (3) Red Canyon Overlook borrow pit, noticeable from a bluff just west of Red Canyon Overlook; (4) Columbus Canyon borrow pit, located northwest of the head of Columbus Canyon but not visible from any nearby vantage points; and (5) Columbus Canyon drainage diversion, a mined tunnel underneath Rim Rock Drive that diverts intermittent drainage at the head of Columbus Canyon. The first two sites appear to have been mined for precious metals (e.g., gold and silver). Material from borrow pits was used for road maintenance (John Burghardt, NPS Geologic Resources Division, written communication, 2003).

Upon investigation, GRD staff determined that one of the five sites, Kodel Gold Mine, merited further mitigation because of moderate visitation to the site and its close proximity to a residential area. Park staff constructed a locked gate at the entrance of the mine in 1987. In 1989, three teenagers died in a nearby mine, not far from the park, as a result of breathing oxygen-deficient air when they bypassed a vandalized gate. Similarly, the winzes (deeply inclined passageways) in Kodel's mine could be potential air traps. Park managers were concerned that if curious, but unaware, visitors breached the gate at the mine, a fall into one of the winzes could result in a life- threatening injury or entrapment in bad air.

Park and GRD staff decided that, though neatly installed, a hacksaw or portable torch would easily cut the 1- inch (2.5- cm) steel tubing of the gate at Kodel's mine, leaving two particularly hazardous winzes accessible to the public. In order to preserve the historical integrity of the site, staff agreed that the safest alternative for mitigation was to backfill the winzes and leave the gate in its present condition. Backfilling the winzes would remove the primary hazards, leaving only a gated 18- feet (5.5- m) deep, nearly horizontal adit in very stable rock, which would allow visitors to look through the gate and still get the sensation of being in a mine.

The winzes at Kodel's mine afforded an excellent opportunity to test the use of polyurethane foam for plugging mine openings in a remote area (figure 2). The components of the plugging operation were backpacked to the site where they were hand mixed, as opposed to using conventional mechanized methods where vehicular access is not an issue. The success of this project had far- reaching implications for portable, economic closures in other remote and environmentally sensitive areas in the National Park System. Polyurethane foam is now the primary closure method where backfill is not feasible (John Burghardt, NPS Geologic Resources Division, written communication, 2003).

As a side note, although NPS staff had previously inventoried Kodel's Gold Mine for endangered species, partway though the closure (on January 8, 1991), two bats, believed to be Townsend's big- eared bats *(Plecotus townsendii)*, emerged from one of the winzes. At the completion of the project, one bat remained in the upper portion of the mine (figure. 3).

Biological and Physical Soil Crusts

Biological and physical soil crusts are a distinctive resource in Colorado National Monument and should be preserved because of their potential to protect underlying fine material from wind erosion; fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Also, depending on soil characteristics, biological crusts may either increase or reduce rates of water infiltration. By increasing surface roughness, soil crusts reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

In order to protect and preserve soil crusts, it would be beneficial to identify the locations of these crusts and incorporate this information into the GIS of the park. A spatial inventory of crusts would enable park managers to plan the placement of trails and educate visitors appropriately. Since these crusts are more abundant in areas that are predominately piñon and juniper, there is concern that without proper consideration, fire management plans related to prescribed burns or mechanical fuel reduction could have a negative impact on soil crusts. Linking the locations of these crusts to the fire management plan could address these concerns.

Human impacts on biological and physical soil crusts have been intense in some of the canyon areas in the monument. For example, starting in the 1930s, a herd of bison (up to 60 head) grazed throughout the canyon areas and disturbed soil crusts. The herd was an attempt by the first custodian of the park, John Otto, to encourage visitors to come to Colorado National Monument however, this practice ended in the 1980s. In addition, damage to crusts occurred in CCC camps and along major trail corridors.

Visitor use disturbs soils and biological soil crusts, resulting in compaction or increasing the susceptibility of the soils to erosion and the invasion of nonnative plants. These impacts occur on trails; in areas adjacent to trails, roads, and overlooks; during cross- country travel, including access to climbing areas; through proliferation of visitor- created trails (social trails); at backcountry campsites; around developed areas; and by off- road vehicle use.

One method of addressing visitor use impacts would be to develop an educational program about biological and physical soil crusts. To maximize effectiveness the program should emphasize "hotspot" areas and target hikers and climbers.

Erosion

The process of erosion, a fundamental natural process that has been operating for millions of years, created the landforms of Colorado National Monument and developed the foundation for of the present- day ecosystem. Erosion and the susceptibility of rocks to erosion are both variables in landscape evolution, exposing fossils to natural deterioration and possible vandalism. Depending on thickness, the least erodible rock formations in the monument form cliffs, canyons, and ledges. The more erodible formations tend to form slopes; they also contain the better part of the monument's paleontological resources (table 1).

Although erosion is a fundamental and complex natural process, it is strongly modified (generally increased) by human activities. Human influences on soil and sediment erosion in Colorado National Monument occur on a local scale, the primary influence being Rim Rock Drive (e.g., road cuts and increased runoff). The proliferation of social trails, which is tied to increasing visitation, also causes erosion on a local scale (e.g., in Monument Canyon, lower Liberty Cap Trail, No Thoroughfare Canyon, trail between the visitor center and Book Cliffs View, and Alcove Trail). Furthermore, the use of climbing equipment, such as bolts and pitons, results in erosion of rock faces; impacts are both aesthetically displeasing and physically damaging to the rocks.

TABLE 1. Erodibility of Rocks at Colorado National Monument

Erodibility	Formation
Least erodible	Precambrian
↓	Kayenta Formation
	Dakota Sandstone
	Wingate Sandstone
	Entrada Sandstone
	Burro Canyon Formation
	Morrison Formation
	Wanakah Formation
	Chinle Formation
Most erodible	Mancos Shale

Note: Mancos Shale is not exposed within the monument, but is present in the adjacent Grand Valley. Within the uplifted formations of the monument, it has been entirely eroded away.

Expansive Soils and Clays

The Brushy Basin Member of the Morrison Formation and some of the younger formations contain expandable clays that can swell when wet. For example, watering lawns in the Redlands area, outside but adjacent to the park, has locally caused the expansion of soils and clays damaging homes and roads. This is evident, throughout the area covered by the Grand Junction 7.5- minute quadrangle.

Smectitic clays (e.g., bentonite) are alternation products of volcanic ash and therefore retain the radioactivity of the volcanic ash. In 1999 investigators used a portable gamma ray spectrometer to detect concentrations of gamma ray–producing radioactive elements in the strata that have the highest occurrence of expansive clays and, therefore, are those most prone to landsliding (Cole and others, 1999).

Flash Floods

Flash floods affect all park management divisions (e.g., maintenance, interpretation, and resource management). They present a serious geologic hazard not only to park visitors on foot in narrow canyons, but also to houses and roads north of the park close to flood- prone ephemeral streams that exit through narrow canyons into the Redlands area.

Collaboration among park staff, the U.S. Geological Survey, Colorado Geological Survey, and local geologists and hydrologists could result in a long- term plan for educating the public about flash floods. These educational plans could be modeled after fire management plans, which have been successful in the past.

Studies pertaining to flash- flood recurrence intervals are needed to help quantify the risks associated with flash flooding, particularly with respect to roads, buildings, and visitor safety. These studies in Colorado National Monument would benefit the Grand Junction area by determining the risks associated with external development at the mouths of canyons.

Repeat photography is an option for gathering baseline information on flash floods. Because floods leave debris, photography during flood events may not be necessary. Photos taken after the event could capture the extent and magnitude of flood events.

Modeling flash flood processes for drainages in Colorado National Monument would also yield valuable information to park management and the surrounding community. In order to verify flash flood models, data collection that measures peak flow is needed. Installation of crest- stage gages and the rating of stream channels using the step- backwater method would provide the basic data needed to support flash- flood models. The U.S. Geological Survey and the local community may be interested in participating in flash flood modeling projects.

Groundwater Level and Quality

Water is scarce in Colorado National Monument, and wildlife and plants, including threatened and endangered species such as the Winkler cactus, depend upon it. Groundwater supplies seeps and springs, which are areas of high biodiversity. Groundwater levels are very important on a local scale, for example, in Ute Canyon, where groundwater discharge feeds plants on the southern side of the canyon.

Groundwater level is significant for management because a decrease in groundwater level could have a direct effect on the monument's seeps and springs. Quantifying groundwater level is important because park managers could use this information for planning and future decision making as it relates to development outside the monument's boundary.

Baseline data are needed in order to detect groundwater depletion caused by increased development in areas bordering Colorado National Monument, such as Glade Park. Increased extraction of groundwater could have a negative effect on seeps and springs and the organisms that rely on them. Upon determining a baseline groundwater level, periodic monitoring would be beneficial. At a minimum, a network of wells should be monitored at least annually, but preferably quarterly or even more frequently. Because the monument does not have a monitoring well, one option would be for park managers to attain permission from homeowners in Glade Park to monitor water levels in private wells. The U.S. Geological Survey has capabilities to advise or participate in this activity.

Another significant source of information would be to identify the groundwater recharge area for Colorado National Monument. Determining the rate of groundwater withdrawal in the recharge area will be an important step in understanding the impacts of outside development on groundwater resources of Colorado National Monument.

Baseline data should also include water chemistry at seeps and springs, and at selected wells in Glade Park. Groundwater from samples from the Entrada Sandstone or the Entrada–Wingate sandstones has a soft sodium bicarbonate water quality with hardness of less than 50 ppm (parts per million) (Lohman, 1965). Groundwater from the Morrison Formation is soft sodium bicarbonate–sodium sulfate water. Water from these aquifers is good for domestic use, but the high sodium content may be harmful to certain plants or crops. The Burro Canyon–Dakota sandstone aquifer contains generally brackish or salty water.

Changes in land use and water may pose threats to groundwater quality. For example, changes in groundwater chemistry could affect organisms at seeps and springs. Although the risk of contamination is probably not high at present, this could change in the next 50 to 100 years. As Glade Park grows, the chances of groundwater contamination will increase. The risk also depends on the kinds of changes that take place in land use and water use in the recharge area, as some changes will pose more serious threats than others (see Appendix C). Park staff have hand- drawn locations of seeps and springs on 7.5- minute topographical maps. These data are assumed to have been collected at the same time as a vegetation study in 1984.

Hydrocompaction

Surficial deposits that contain debris from the Brushy Basin Member of the Morrison Formation are particularly susceptible to shrinking, swelling, and hydrocompaction; these deposits make an unstable base for roads and buildings. Quaternary deposits, such as eolian sand, are probably susceptible to hydrocompaction and possibly piping. Cienaga deposits, which have been deposited by eolian or sheetwash processes in marshy areas, are poorly suited for supporting roads and structures or for the efficient operation of septic systems. Hazards commonly associated with these deposits include seasonal high water tables, low bearing capacity, and the presence of sulfate minerals, which deteriorate untreated concrete and steel. The Brushy Basin Member, which underlies Cienaga deposits, is relatively impermeable and contains abundant expansive clay (Scott and others, 2001a).

Mineral Resources

Federal mineral leasing is prohibited within the boundaries of Colorado National Monument as is the location of new mining claims. All lands within Monument boundaries are federally owned therefore there is no potential for private mineral development within Monument boundaries.

Oil Shale

The BLM is preparing to amend existing applicable Resource Management Plans to address oil shale and tar sands resources leasing in Wyoming, Colorado and Utah. Although tar sands do not occur in the vicinity of Colorado National Monument, the area is bordered on the northeast, east, and southeast by the Piceance Creek Basin which is a primary target for proposed oil shale leasing and development. The Uinta Basin is also located somewhat farther to the northwest of the park and may also be subject to oil shale leasing. Therefore, the park could be impacted from such development.

Coal

The largest reserves of bituminous coals are found primarily in the Upper Cretaceous Dakota and Mesaverde Groups in western Colorado. A measured section of Dakota Sandstone in No Thoroughfare Canyon contained minor beds of lignite 1–4 inches (2.5–10 cm) thick and a 6- inch (15- cm) bed of lignite at the top of a 58- foot (18- m) shale section. A 76- foot (23- m) measured section along old East Creek road contained a 2- foot (0.6- m) and a 3- foot (0.9- m) layer of "lignitic" shale (Lohman, 1965). Some low- grade, thin coal seams exist along the Gunnison River valley, but mining ceased because better bituminous coal was abundant elsewhere (e.g., the Grand Mesa and the Book Cliffs coal fields) (Lohman, 1965). The Mesaverde Group, a major coal unit in southwestern Colorado, has been eroded from the Uncompahgre Plateau.

Oil and Gas

Colorado National Monument is located in Mesa County, Colorado. 2004 data show over 46,000 acres of mineral leases in Mesa County. Garfield and Rio Blanco Counties are two of the most productive gas areas in the state and are located to the north of Mesa County. Garfield County expects that the number of gas wells in the county will double in the next ten years with many western slope counties following suit.

Sand and Gravel

Abundant sand and gravel resources are in the vicinity of Colorado National Monument (Scott and others, 2001a) and have been and are being developed in the Grand Valley. Most of these deposits contain rounded, well-sorted pebble- cobble gravel composed of basaltic rocks, quartzite, micaceous red sandstone, fine- to medium-grained granitic rocks, shale clasts of the Green River Formation, and other volcanic rocks. About 3.3 to 6.6 feet (1 to 2 m) of sand, possibly of eolian origin, overlies the gravel. The gravels may be suitable for road base, but probably are not suitable as an aggregate for concrete and asphalt (Scott and others, 2001a). Drill- hole data suggests that the thickness of the gravel deposits may exceed 23 feet (7 m) locally.

Other Mineral Deposits

Attempts were made to mine copper ore in Unaweep Canyon to the south of the monument, but the mines were abandoned. In the past, Entrada Sandstone was quarried from several places in and near Colorado National Monument, providing building stone for some of the older buildings in the monument and curbstone for Rim Rock Drive (Lohman, 1965). Mica—a mineral used in paints, insulation, and greases—was mined until 1950 from an operation about 6.5 miles (10 km) southwest of Grand Junction. This mine was known as the Williamson Mine (Lohman, 1965).

Outdoor Classroom

Colorado National Monument could serve as a premier outdoor classroom. Geologic features at the monument illustrate a long, dynamic history of Earth's processes and their effects on the geology of the Colorado Plateau. Particularly notable are the rock layers, which visibly record geologic history, and the distinctive monoliths and canyon walls that inspired the establishment of the monument (Colorado National Monument GMP, draft, September 2003).

The structural complexities of the Ancestral Rocky Mountains and the Laramide orogeny also are quite pronounced at Colorado National Monument. Monoclines, anticlines, synclines, faults, fractures, and joints all provide an excellent outdoor classroom for the structural geology students and professional geologists (figure 5).

Colorado National Monument is a world class setting for the study of structural geology, sedimentology and stratigraphy. Communicating this to the scientific and academic community could generate a large amount of data and information for making management decisions regarding the natural resources of the monument. This information can also be used in preparing interpretive materials and exhibits at the visitors center, overlooks, and along trails.

Paleontological Resources

Because a park- wide fossil inventory has not been conducted and a monitoring program has not been established, the extent of risk, exposure, and fossil loss in the monument cannot be measured at present (Colorado National Monument GMP, draft, September 2003). Some data from preliminary inventories are available, however, and document the kinds of paleontological resources found at Colorado National Monument. For instance, during a paleontological resource inventory of the Morrison Formation, Callison (1977) documented 14 fossil localities in the monument. Investigators introduced new discoveries of trace fossils at the geologic resources inventory workshop in 1998 (Appendix B). Further studies of these trace fossils could provide additional clues to the paleo- ecosystem of the Uncompahgre Plateau and climate and habitat changes through time. Moreover, in 2001 Scott and colleagues presented a preliminary inventory of paleontological resources at the monument, which indicated the potential for future fossil discoveries (Scott and others, 2001b).

In 2000 G. F. Engelmann and A. R. Fiorillo resurveyed the sites documented by Callison (Engelmann and Fiorillo, 2000). Englemann indicated that the specimen at one of the localities had been removed (personal communication toVincent Santucci (chief ranger, GWMP), 2000). This incident illustrates the potential for loss of fossils at Colorado National Monument and highlights the need for a systematic inventory and monitoring program.

An inventory of fossil resources at Colorado National Monument may include identification of areas most susceptible to potential threats (e.g., vandalism and erosion), intervention thresholds for protecting and preserving fossils, and protocols for recovering and documenting fossils after intervention. An agreement with the Museum of Western Colorado, or other qualified institution, would aid in storing, protecting, and making available to researchers the paleontological specimens collected at Colorado National Monument. Incorporating new knowledge of paleontology, resulting from an inventory, into interpretation, education, and outreach at the monument would enhance visitor enjoyment. In addition, the park could determine localities from which fossils have been found, document localities, fill out paleontology locality forms, and conduct condition assessment to meet GPRA goal 1A9.

Seismicity and Eolian Sediments

Although seismicity and eolian (wind- blown) sediments are of low management significance, having a seismic station and eolian sediment monitoring stations in the park would have scientific value and encourage collaboration between the park and the local academic community (see Appendix C).

Slope Failure

Slope failure includes landslides, rockfalls, and debris flows, which are an integral part of the landscape at Colorado National Monument. Slope failure occurs continuously throughout the monument, although not all rock units disintegrate at the same rate. In general slope failure creates piles of rubble that have greater permeability and porosity than the original surfaces, increasing water- infiltration potential and creating "new" land surfaces upon which habitats can evolve.

Old landslide deposits partly veneer all sides of Black Ridge and have flowed across lower stratigraphic units onto the floor of Monument Canyon. They also locally cover the dip slope of the Morrison–Burro Canyon–Dakota Formations. These old landslides may be found at about 0.6 to 0.9 miles (1 to 1.5 km) south of the northern park boundary and 2.5 to 3.1 miles (4- 5 km) south of the northern border of the map area. Although many of these landslides probably were generated during previous wetter climatic episodes and seem relatively stable now, bulges in road cuts along Rim Rock Drive suggest that these slides may have been reactivated after road construction (Scott and others, 2001a).

Slope failure is a natural process, which is exacerbated by human activities, such as the construction of Rim Rock Drive and vibration from heavy vehicles (e.g., trucks, tour buses, and school buses) on the road. Slope failure is a constant maintenance issue along Rim Rock Drive (Appendix C). Rim Rock Drive is an important park resource, which facilitates public enjoyment and the ability to view the monument. Slope failure is a concern for park managers, particularly with respect to potential road failure. Rockfalls also are a concern because of visitor safety, particularly along Rim Rock Drive and at overlooks.

A geologic assessment is needed along the Serpents Trail, a trail requiring "massive repair." Public safety and geologic issues along the trail include rockfalls from climbing. Such impacts are a degradation of a natural resource and are an issue with respect to maintaining the monument's viewshed.

Unstable cliffs formed by Wingate Sandstone, the Kayenta Formation, and the Salt Wash Member of the Morrison Formation produce rockfalls that pose local geologic hazards. Where road construction has destabilized the rock, large rockfalls have occurred, damaging Rim Rock Drive. Such a rockfall occurred in January 2000 when automobile- size blocks of sandstone from the Salt Wash Member slid on thin clay layers and toppled onto the road, blocking traffic for at least a month (figure 6).

An inventory of areas along Rim Rock Drive and overlooks with high potentials for slope failure would have value for inventory, monitoring, and planning. High- risk areas could be identified with GPS and incorporated into the monument's GIS. Such an inventory would enable park managers to focus on particular areas, rather than the entire 23 miles (37 km) of road. Also, park staff should monitor cracks in the asphalt along Rim Rock Drive and the slow downhill movement (creep) of landslide material.

In addition, fire plays a role in (and could indirectly trigger) landslides; therefore, slope failure should be part of the fire management plan. The potential to mitigate landslides with smaller, prescribed burns should be considered.

Urban Development

As discussed in the general management plan (draft, September 2003), urban development is occurring rapidly in areas adjacent to Colorado National Monument. How the monument is managed in light of this change is the main issue to be addressed in the general management plan. Residential areas directly adjoin the monument boundary, both in the Grand Valley to the north and east of the monument and at a lesser density in and near Glade Park to the south and west. Residential and other development is likely to continue on available private lands near the monument. Population growth has placed increasing local and regional demands on a national resource. Zoning on adjacent private lands is primarily residential but a change to commercial zoning could result in incompatible "gateway" development.

Another impact arising from urban development is the increase in traffic on Rim Rock Drive, the shortest route from Grand Junction to Glade Park. Vibration from heavy trucks and busses may cause rockfalls and slope failure along the road. Heavy vehicles have some difficulty negotiating the sharp curves and the steep grade. This means that they drive rather slowly and the result is traffic congestion from the automobile traffic of visitors.

Recent history shows that a road closure is a reality, e.g., Rim Rock Drive was closed for one year when the area between the two tunnels was washed out. Park managers have a short- term plan for closure of Rim Rock Drive but not a long- term plan, in the event that large sections of the road are destroyed. A long- term plan for road closure, rerouting, maintenance, and visitor safety needs to be part of the monument's general management plan. Park staff should work with geologists, engineers, and the Federal Highway Administration to plan alternatives. The plan for rerouting the road should take into consideration geologic strata, location of facilities, and wilderness.

Wetlands

In 2001, the U.S. Geological Survey collected and analyzed water samples from springs and other water sources from seven canyons in the monument. However, seeps, springs, and wetlands have not been systematically inventoried and mapped nor has a fundamental assessment been conducted. During the 2001 assessment, however, investigators identified locations of many wetlands in the monument. The Colorado Natural Heritage Program has identified three potential conservation areas within the monument that contain wetlands (see Appendix C).

Lithology controls wetlands in Colorado National Monument. Groundwater, which feeds wetlands, is controlled by rock bedding layers in the underlying geologic formations and is recharged by meager precipitation. The monument's drinking water supply is obtained from the Ute Water Conservancy District (Colorado National Monument GMP, draft, September 2003), thereby not affecting the local groundwater system. The scarcity of wetlands increases their importance to plants and wildlife as a source of water. Wetlands also provide cooler temperatures. Investigators have identified greater plant and animal diversity in wetland areas than in other habitats in the monument. For example, wetlands are sites of hanging gardens, which provide habitat for threatened and endangered species (Appendix C).

Riparian areas are ecologically important in the monument's semi- desert environment, and are used by people who are drawn to the shade and occasional water found there. Trails in the canyons follow or run parallel to riparian areas. As a result, hikers, horses, and backcountry campers are prone to damage riparian areas and interfere with ecological interactions (Colorado National Monument GMP, draft, September 2003).

Park managers have some information about wetlands in the monument from a completed tamarisk survey. To date, investigators have identified two wetland areas (i.e., upper Ute Canyon and upper No Thoroughfare Canyon), totaling about 20 acres (8 ha). Wetlands in the monument will be inventoried through the vegetation mapping program using GIS (see Appendix C). Locations of all wetlands need to be mapped, verified and classified during field investigations, and then digitized.

A significant human influence on wetlands in the monument has been the Fruita pipeline, which leaked enough water to create artificial habitats ideal for exotic plants. In the future, if more water is needed for Fruita, reactivating this old water line is a possibility. According to the geoindicators report, intense damage to park resources would accompany reactivation of the water line largely as a result of associated reconstruction activities (Appendix C).

Two reservoirs were constructed to provide water to the citizens of Fruita. Although no longer in use, future demand for water could result their being reactivated, this is a concern for park managers. It is likely that construction work (earthmoving) with associated impacts would be required for these reservoirs to become usable. Also the park may be libel in the event of a failure of these reservoirs. In addition, the Civilian Conservation Corp (CCC) camp members dammed the spring in Monument Canyon, and present- day trails pass through wetlands in many canyon areas.

Figure 2. Polyurethane foam used for mitigating hazardous mine openings. An abandoned mine land site, Kodel's mine, provided an excellent opportunity to test the use of polyurethane foam for plugging mine openings in a remote area. National Park Service staff tested the strength of the foam with hydraulic jacks placed between a plug and the roof of the adit. NPS photo by John Burghardt.

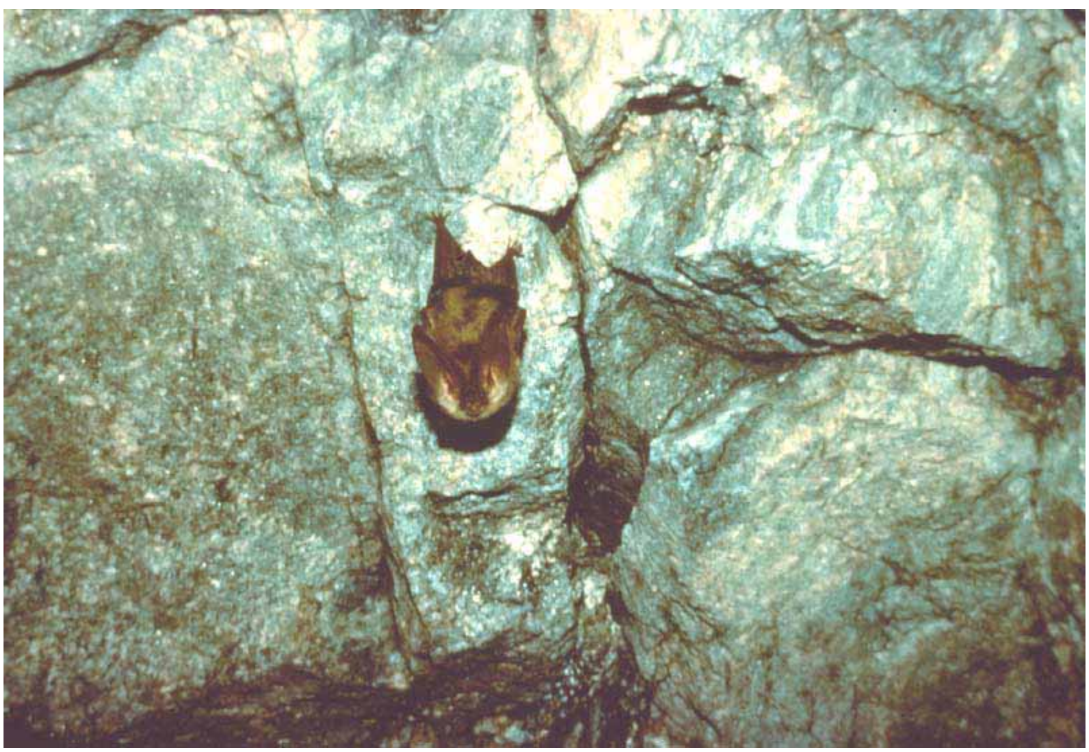

Figure 3. Bat in Kodel Gold Mine. Although investigators had previously inventoried the mine for endangered species, partway though the closure, two bats, believed to be Townsend's big-eared bats *(Plecotus townsendii)*, emerged from one of the winzes. At the completion of the project, one bat remained in the upper portion of the mine. NPS photo by John Burghardt.

Figure 4. Flash Flood Deposit. Flash flooding is an ongoing process in Colorado National Monument that has occurred in the canyons for thousands of years. The deposit preserved in the canyon wall of No Thoroughfare Canyon is graded, which is an indication that the deposit was laid during flash flooding events, not debris flows. Photo by Katie KellerLynn.

Figure 5. Monocline. Colorado National Monument could serve as an outdoor classroom for structural geology. A classic example of a monocline (shown in photo), as well as anticlines, synclines, faults, fractures, and joints display the character of the structural complexities of the both the Ancestral Rocky Mountains and the Laramide orogeny. Photo by Katie KellerLynn.

Figure 6. Rockfall Area. Wingate Sandstone, the Kayenta Formation, and the Salt Wash Member of the Morrison Formation produce rockfalls that pose local geologic hazards. For instance, a rockfall occurred in January 2000 when automobile-size blocks of sandstone from the Salt Wash Member slid on thin clay layers and toppled onto the road. Photo by Katie KellerLynn.

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Colorado National Monument.

Alluvial Fans

In semiarid environments like that of Colorado National Monument, ephemeral streams and debris flows commonly deposit gravelly sediment in alluvial fans along steep mountain and plateau fronts. Alluvial fans are present in two depositional settings in the vicinity of Colorado National Monument: (1) A few alluvial fans presumably formed where steep- gradient, ephemeral streams deposited gravelly sediment along the northeast front of the Uncompahgre Plateau. However, overlying eolian sand and sheetwash deposits have so severely modified the fans that their fan- shaped landforms are no longer recognizable. Therefore, these presumed fans are called "younger alluvial- slope deposits" and "older alluvial- slope deposits" by Scott and others (2001a). (2) A few small fan- alluvium and debris- flow deposits of Holocene age formed on the floodplain of the Colorado River. These types of deposits are not common in the area mapped by Scott and others (2001a) because such deposits have been removed by the river.

Eolian Processes

The action of wind on exposed sediments and friable rock formations causes erosion (and abrasion) and entrainment of sediment and soil particles. Changes in wind- shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of environmental change in arid lands (Berger and Iams, 1996). In the vicinity of the monument, eolian sand consists of silty, very fine to fine wind- blown sand that blankets areas of the Uncompahgre Plateau. Thin, discontinuous deposits of eolian sand mantle other surficial deposits and bedrock on the upland areas of the Uncompahgre Plateau and Redlands area near the Colorado River. In the upland areas, deposits of eolian sand locally form subdued, stabilized dunes and blankets of eolian sand. Eolian sand on the uplands is locally stabilized by piñon and juniper trees and in other areas by sage, rabbitbrush, bunch grass, and cheat grass (Scott and others, 2001a).

Erosional Features

The most important geologic resource in Colorado National Monument and vicinity is the beauty of the erosional features and rocks exposed at the margin of the Uncompahgre Plateau (Scott and others, 2001a). The fantastically eroded and vividly colored canyons are filled with arches, natural bridges, alcoves, pinnacles, and balanced rocks. The sweeping cross- beds of ancient sand dunes are preserved in the rock, and panoramic views inspire and delight visitors. Many of these features are carved into the thick Wingate Sandstone. For example, driving along Rim Rock Drive from the west entrance of the monument, the road loops past a balanced rock of Wingate Sandstone at the head of Fruita Canyon.

From the overview of Fruita Canyon, visitors can see the dark- colored, 1.7- billion- year- old Proterozoic rocks; the red slopes of Chinle Formation; and the cliffs of Wingate Sandstone, which are capped by the resistant beds of the lower Kayenta Formation. Desert varnish adds to colors and covers many sandstone cliffs.

Window Rock Nature Trail leads from the northeast corner of a campground near the visitor center and connects with the scenic Canyon Rim Trail from which hikers can see a "window" eroded along a vertical joint near the top of the Wingate Sandstone. Independence Monument, jutting up 450 feet (137 m) from the canyon floor, can also be seen from the Canyon Rim Trail. This monument, a thin erosional remnant of a narrow wall that once connected mesas to the northeast and southwest, separates the two entrances of Monument Canyon.

From Pipe Organ Overlook, visitors can see erosional remnants in Monument Canyon that resemble pipe organs. And from the Coke Ovens Overlook, they can see alcoves forming in the Wingate Sandstone. A short trail leads from Artists Point to an overlook of both the Coke Ovens and the spires and pinnacles of Monument Canyon.

At the Ute Canyon Overlook, cliffs of mottled salmon- and- white Slick Rock Member of the Entrada Sandstone and overlying "board beds" unit are visible. Other distinctive features carved by erosion include Cold Shivers Point, a toadstool- shaped rock balanced on a Wingate cliff, and the Devils Kitchen, erosional columns of Wingate Sandstone capped by the Kayenta Formation in No Thoroughfare Canyon.

Flash Floods

Intense summer thunderstorms are common on the Uncompahgre Plateau. These storms supply large volumes of water in a short period time to canyons of Colorado National Monument, where constrictions in the canyons increase both the rate of flow and the flood heights (Scott and others, 2001a). A single thunderstorm may produce enough rain to trigger a flash flood, turning a dry creek bed into a ranging, sediment- laden river. Flash floods are the principal agent that form and modify the present- day canyons and are significant for the monument's ecosystem because of the role they play in the formation of the landscape. Boulders more than 6.6 feet (2 m) in diameter have been moved during historic and prehistoric flash floods (Scott and others, 2001a). In addition, the Colorado River floods each spring following the period of maximum melting of thick snow packs in mountainous areas upstream from the monument (Scott and others, 2001a).

Hydrogeology

Water is a precious commodity to the plants and animals living in the semiarid climate of the Uncompahgre Plateau. Pinon Mesa, the crest of the Uncompahgre Plateau, receives about 25 inches (64 cm) of annual precipitation while the slopes and mesa at lower altitudes receive between 10 and 25 inches (25 to 64 cm) (Lohman, 1965). In contrast, Grand Valley is an arid climate, receiving less than 10 inches (25 cm) of precipitation annually. Most of the precipitation is in the form of summer thunderstorms primarily during the high-evaporation months of August and September. Thunderstorms on the Colorado Plateau are usually intense events of short duration. The erosive power of flash floods cannot be matched by any other process in this desert climate. Where vegetation is scarce, surface runoff is rapid and higher drainages often have large temporary flows during thunderstorms. The streams that drain the plateau are ephemeral, that is, they are typically dry except after a sudden rainstorm when runoff fills and erodes their banks moving large boulders as well as red fine- grained sediment from the Chinle Formation.

At Colorado National Monument, the ephemeral streams flow northeastward towards the Colorado and Gunnison Rivers that drain the Grand Valley. Control of the drainage patterns on the Colorado Plateau has been tied to basement faults in some areas (Maarouf, 1983), but at Colorado National Monument, the canyons and associated streams do not seem to be influenced by faulting (Scott and others, 2001a). The dendritic drainage patterns of the canyons are perpendicular to the Redlands fault and monocline that form the northeast margin of the Uncompahgre Plateau. The canyon spacing and thus, drainage pattern, is similar to the pattern formed on non- vegetated slopes during initial rill and gully formation. Probably, the drainage pattern is a composite geometry developed because of the rate of uplift, the differential rates of erosion of the sedimentary rocks, and the past and present climate. A detailed study of the fracture patterns in the Precambrian rocks that underlie the canyons and the geometry of the drainages may shed additional light on the origin of the drainage patterns at Colorado National Monument.

The sedimentary rocks at Colorado National Monument serve as important recharge areas for confined or artesian aquifers. Four aquifers provide groundwater in the Grand Junction area. In order of importance and productivity, these include (1) the Entrada Sandstone, (2) Wingate Sandstone, (3) lenses of sandstone in the Salt Wash Member of the Morrison Formation, and (4) Dakota Sandstone and sandstones in the Burro Canyon Formation (Lohman, 1965). These artesian aquifers are found northeast of the Redlands fault and monocline where they are overlain by younger, relatively impermeable strata that serve as confining beds. Because of its depositional environment, Entrada Sandstone is distributed over a broad areal extent in contrast to lenticular, fluvial sandstones in the Morrison Formation whose consistency is not predictable. Sedimentary structures, unconformity contacts, and pore- restricting cement all play roles in defining vertical and horizontal permeability in these sandstones. Fractures also increase fluid flow through the sandstone.

The Summerville and Morrison Formations do not yield significant quantities of groundwater to wells in the area. They do, however, act as confining layers to artesian water in the Entrada and Wingate Sandstones.

The relatively thin sandstone lenses in the Dakota Sandstone and Burro Canyon Formation yield small quantities of water to a few non- flowing artesian wells (Lohman, 1965). Groundwater quantities are limited and the water may be salty or brackish. Some areas even contain pockets of natural gas.

The Mancos Shale in the Redlands area serves as a confining layer above the Burro Canyon and Dakota Sandstone. Generally, the Mancos Shale is not a source of water but some weathered zones contain meager amounts of highly mineralized water (Lohman, 1965).

Because of their low permeability, all of these aquifers have small yields. For example, most of the wells reported by Lohman (1965) operated at rates of 5 to 40 gallons per minute (gpm). In effect, the wells would be considered dry holes in more humid regions. However, in the arid Grand Valley where good quality water is scarce, these wells are highly valued.

The artesian aquifers are recharged on the Uncompahgre Plateau mainly in areas where streams cross the outcrops. A small amount of recharge also will take place from precipitation on the outcrop. Recharge is dependant primarily on precipitation as all streams on the plateau are ephemeral. The rate of recharge to the aquifers is probably very small owing to the low permeability of the aquifers. The average linear velocity of groundwater flow in the Entrada is only about 5 feet (1.5 m) per year. At that rate, about 6,500 years are required for groundwater to flow from the recharge area on the northeastern margin of the Uncompahgre Plateau to Grand Junction, and about 3,000 years to flow to the large group of wells in the eastern part of the Redlands and the western part of Orchard Mesa. In other words, groundwater wells are, in effect, “mining” (i.e., depleting) groundwater that has been stored in the aquifers.

Late Cenozoic Uplift

The Colorado Plateau serves as a classic example of the interaction between uplift and erosion. The region was at sea level during the Late Cretaceous, but now the deeply eroded land surface is at about 1.2 miles (2 km) in elevation. The path of the landscape between these two endpoints is not clear and geologists have long debated the mechanisms, amounts, and timing of uplift and erosion.

Recent studies using geographic information system (GIS) to map, interpolate, and calculate Cenozoic uplift and erosion of the Colorado Plateau during the Cenozoic Era provide insights into the development of the landscape through time (Pederson and others, 2002). Initial results indicate uplift and erosion are spatially highly variable with mean values of 6,946 feet (2,117 m) for uplift and 1,332 feet (406 m) for net erosion after the Late Cretaceous coastal sandstones were deposited. Investigators estimate 2,766 feet (843 m) of erosion in the past 30 million years, which can account for 2,096 feet (639 m) of post- Laramide rock uplift by isostatic processes.

Based on initial results, investigators suggest two end-member scenarios for uplift of the Colorado Plateau. First, all uplift on the Colorado Plateau is about 1.2 miles (2 km) of Laramide uplift and subsequent erosion, with no other sources of later Cenozoic uplift. Second and alternatively, proposed mantle sources of middle- late Cenozoic uplift are valid, but then with isostatic rebound from erosion included, Laramide uplift of the Colorado Plateau must then be minor (less than 1,640 feet [500 m]).

In either scenario, Laramide uplift of the Colorado Plateau is much less than that in the neighboring Rocky Mountains. This may be expected, considering the plateau contains the Unita, Piceance, and San Juan sedimentary basins that have subsided, not uplifted, since the Cretaceous. Ironically, the problem with the Colorado Plateau is that investigators have proposed sources for more uplift than there is actual uplift. Initial data from Pederson and others (2002) support a resolution wherein early Cenozoic events provided the bulk of uplift (by whatever mechanism) with little passive erosional isostasy in the later Cenozoic.

Although regional uplift occurred throughout the Colorado Plateau during the late Cenozoic and the monument area was part of this, investigators have not found evidence of post- Laramide uplift in Colorado National Monument. However, the absence of evidence does not exclude the possibility of minor, local, post-Laramide uplift in the monument and vicinity. Differential amounts of local late Cenozoic uplift superimposed on a background of general regional uplift are consistent with evidence found elsewhere in the Rocky Mountains of Colorado (Scott and others, 2001a).

Paleontology and Fossils

Although investigators have discovered various vertebrate, invertebrate, and trace fossils at Colorado National Monument, in general fossiliferous exposures are not well inventoried. However, in 1977 G. L. Callison conducted an inventory of the Morrison Formation in Colorado National Monument and documented 14 fossil localities that contained bivalves, gastropods, turtles, crocodilians, and dinosaurs (Callison, 1977). Most of the sites were located in the lower Salt Wash–Brushy Basin Members of the Morrison Formation. In 1985 investigators resurveyed many of the sites, which yielded unionid (freshwater) bivalves, gastropods, and dinosaur skeletal fragments (i.e., a sauropod caudal vertebra). In addition, though much of the formation is poorly exposed within the monument, the Morrison Formation contains trace fossils such as plant roots and animal and insect burrows. In 1995 investigators reported several new sites. In 1996 investigators discovered horseshoe crab traces within the park in the lower units of the Tidwell Member of the Morrison Formation, representing the first report of these traces from Jurassic rocks (Scott and others, 2001b). Only one site that is adjacent to Black Ridge Trail appears to have been vandalized (Scott and others, 2001b).

The Chinle Formation has yielded trace fossils such as a theropod track discovered in 1990. Investigators have identified other Chinle trace fossils within Colorado National Monument such as *Scoyenia gracilis*, *Koupichnium nopsca*, and *Camborygma* along with crayfish burrows and plant roots (rhizoliths) (Scott and others, 2001b). Investigators have found petrified wood in the Chinle elsewhere on the Colorado Plateau and may be present in the rocks in the monument.

The Dakota Sandstone contains plant fossil fragments and evidence of plant roots and animal burrows; the Burro Canyon Formation contains petrified wood. The Wanakah Formation contains evidence of plant roots and animal burrows. The Entrada, Kayenta, and Wingate Formations contain very few fossils.

In 1965 investigators discovered a Pleistocene mastodon tooth in No Thoroughfare Canyon. Unfortunately, the current whereabouts of this tooth are unknown. Pleistocene- Holocene packrat middens are known from the park and can provide important clues regarding the paleoecology of the park thousands of years ago.

Additionally, a number of significant fossil discoveries have occurred near the monument. For example, in 1900 the first skeleton of *Brachiosaurus*, the giant plant- eating dinosaur, was discovered at Riggs Hill just east of the monument. The forelimb and shoulder blade of *Camarasaurus* were discovered just north of the monument. Though it contains gigantic and bizarre dinosaurs that were the most obvious animals of the Mesozoic Era, the exposures of the Morrison Formation around Fruita are most famous for fossils of smaller vertebrates. One of at least two kinds of tiny dinosaurs found in the Fruita area is listed in the *Guinness Book of World Records* (Callison, 1987). Adults of the species were smaller than an average chicken, lightly built, and could run rapidly on their hind legs. Relatives of these dinosaurs lived in western Europe. The plant eater, *Echinodon*, has been named positively from Fruita and is otherwise known only from England and Portugal. During the Late Jurassic, the landmasses of the British Isles and the rest of western Europe were attached to eastern North America, so these dinosaurs and other terrestrial animals were able to move from one place to the other. Shortly thereafter, however, the continents separated and intercontinental travel became impossible.

Investigators have identified three kinds of sphenodonts (small reptiles) at Fruita: one predator and two plant eaters. The plant eaters are members of a new subfamily of sphenodonts, based on species discovered at Fruita, and have rather flat- topped teeth, wider than they are long, that are closely packed along the jaws. The dentition resembles the corrugated surface of an old-fashioned washboard, and plant material caught in this washboard is pounded and shredded (Callison, 1987).

In addition to vertebrate animals, invertebrates such as aquatic clams and semiaquatic crayfish and snails have been found at Fruita. Both crayfish burrows and body parts in the sedimentary rocks resemble present- day freshwater river ecosystems (Callison, 1987).

Plants found in the Fruita area support the hypothesis that the climate during Morrison time was relatively dry because none of the plant remains formed coal deposits nor do they indicate swamp or marsh environments. The most abundant organic material is conifer wood and pollen of *Exesipollenites* species (related to yews or *Bennettitiales*) and *Callialisporites* species (related to the present- day Norfolk Island pines). Less abundant plants include cycadeoids, *Bennettitaleans*, lycopods, bryophytes, Mesozoic "seed ferns," and ginkophytes (Callison, 1987). The suite of plants provides evidence of food resources such as seeds, fruits, shoots, and leaves available to plant- eating animals.

A wide variety of fossils is already known from Colorado National Monument, and investigators have found many other paleontological materials in the area. Hence, a systematic inventory of the fossil resources at the monument would undoubtedly uncover new material. Such an inventory would provide baseline data for a monitoring program, which would limit the loss of paleontological material in the future, and provide for its availability for scientific study. In addition, a comprehensive inventory would provide a basis for NPS and public understanding of the paleontological resources at the monument.

Tectonic Structures

The geologic features of Colorado National Monument include an impressive sequence of Mesozoic strata, an excellent example of a monocline, and one of the only places on the Colorado Plateau to observe Precambrian basement rocks. The monocline—the simplest type of fold where flat beds are offset by a double flexure (S-shaped) bend connection— defines the eastern margin of the Uncompahgre Plateau. Uplift and formation of the monocline most likely occurred during the Laramide orogeny when Precambrian basement faults were reactivated. As uplift occurred along these faults, the overlying sedimentary strata were bent slowly to conform to the new shape of the basement rocks. Uplift of the Uncompahgre Plateau brought Precambrian schist, gneiss, and granite close to Earth's surface and subsequent erosion has resulted in exposing these units at the base of the canyons in the monument (Foos, 1999).

For the most part, Mesozoic sediments now exposed in the monument accumulated near sea level. Now they stand about 7,000 feet (2,134 m) higher atop the Uncompahgre Uplift, which is another faulted anticline initiated in Laramide time and raised with little tilt to its present elevation by regional uplift, starting in mid-Tertiary time. On top of the uplift, the sedimentary strata rest horizontally and unconformably on 1.7- billion-year- old Precambrian basement rock exposed in the floors and lower walls of the deeper canyons. As they fold and ultimately break over the basement- penetrating reverse and normal faults beneath the northeast flank of the uplift, the Mesozoic sediments form the spectacular monocline, a textbook example of the Laramide structural style. That is, monoclinal folds in the Mesozoic sedimentary rocks above high- angle reverse faults in basement rocks are characteristically Laramide deformation. In contrast, normal faults are commonly associated with post- Laramide extension. Some areas on the Uncompahgre Plateau margins display only high-angle reverse faults, and one area displays only normal faults (Scott and others, 2001a).

The rocks in Colorado National Monument host two types of faults: high- angle reverse faults and normal faults. High- angle reverse faults dip more than 45° and place older rocks above younger rocks. The most notable high- angle reverse fault in the monument is the Redlands fault. It dips to the southwest between 62° and 83°, averaging 72°. Based on numerous foliation attitudes of Proterozoic rocks, the foliation in both the meta-sedimentary and meta- igneous body is sub- parallel to the northwest- trending mountain front between No Thoroughfare and Ute Canyons; but the foliation in meta- sedimentary rocks is nearly perpendicular to the mountain front in the more northerly canyons. Therefore some preexisting structural control may exist for the southern part of the Redlands fault. In contrast, between Gold Star and Kodels Canyons, where the fault progressively changes from a northwestern trend to a western trend, no control from metamorphic foliation attitudes is apparent (Scott and others, 2001a).

Unconformities

Unconformities are gaps in the rock record. The absence of rocks of a certain age in a stratigraphic sequence represents a time during which no sediment was deposited or if deposited has been eroded away. In Colorado National Monument, the basal contact of the sedimentary Chinle Formation on Proterozoic metamorphic rocks (gneisses and schists) is an unconformity that represents a break in the rock record between about 1.4 billion and 230 million years ago, totaling about 1.17 billion "missing" years.

Valley-Fill Deposits

The origin of Unaweep Canyon and the affects of glaciation vs. valley- fill deposits in the canyons of Colorado National Monument remain a controversial subject. Further geophysical studies could shed light on the extent of glaciation and the association of glaciers on the Grand Mesa (to the east) with the Uncompahgre

Plateau. Valley fill studies would shed light on this controversy and could improve knowledge of the history of drainage development and drainage diversion on the Uncompahgre Plateau during Pleistocene and Holocene time. In addition, the results of such a study would integrate geology with fire protection, defining the fire history of the monument using carbon- 14 dating of charcoal horizons in the valley fill. Charcoal layers would provide an estimate of fire return rates and subsequently aid in managing fire threats to historical structures. Generally speaking, this study would provide valuable information to park managers regarding rates of erosion, sources of sediment, past climate change, and fire history.

Holocene and late Pleistocene valley fill deposits that cover parts of many canyons in the monument consist chiefly of sand and silt of stream terrace alluvium and probably sandy, debris flow deposits. Locally the valley fill deposits consist of stony colluvium on valley sides as well as minor deposits of eolian sand (Qe) and sheetwash (Qsw). The valley fill deposits contain several buried, weakly developed paleosols and common small (less than 0.08 inches [2 mm]) charcoal fragments. Some of these paleosols are darker than the rest of the valley fill because of the accumulation of organic matter; they contain abundant charcoal, presumably from burnt woody vegetation. Charcoal not associated with paleosols is concentrated at bedding breaks in the sediments, but charcoal also occurs within beds.

The age of the valley- fill deposits, based on calibrated carbon- 14 ages, ranges from at least 1,180 to 6,200 years BP (before present, actually before 1954) in the upper part to at least as old as 10,360 years BP in the lower part (Scott and others, 1999). The discovery in No Thoroughfare Canyon of a mastodon tooth, which was probably eroded from the undated lowest part of the unit, is consistent with a late Pleistocene age for the lower part of the map unit. Valley- fill deposits are best exposed in terrace scarps in the upper part of No Thoroughfare Canyon, but isolated remnants are widespread in most canyons throughout the monument.

Map Unit Properties

This section serves as a critical link between resource managers and the digital geologic map of Colorado National Monument. 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.

The information provided in this section was taken from *Geologic Map of Colorado National Monument and Adjacent Areas, Mesa County, Colorado* (pamphlet; Scott and others, 2001a). The prepared table is meant to be a quick reference for park staff on the locations, descriptions, and significant features of the monument's rock units and deposits. This table is by no means a substitute for the descriptions provided in Scott and others (2001a).

Rocks and deposits outside the boundary of the monument (e.g., deposits along the Colorado River and underlying the Grand Valley) are listed only if they provide useful information regarding park management (e.g., resource protection, interpretation of geologic history, and public education of geologic hazards). An explanation for valley- fill deposits is not provided in this section but can be found in the "Geologic Issues" section. Investigation of this resource is significant for reconstructing an environmental record for the past 10,000 years, including climate, fire, sedimentation rates, and biotic response. Alluvial fan (and alluvial slope) deposits are discussed in the section "Geologic Features and Processes" and are not included here.

Map Unit Properties Table

Age	Unit Name (Symbol)	Features and Description	Location	Depositional Setting and Significance	Hazard Potential	Development and Resource Potential
Quaternary	Artificial fill (af)	Includes compacted and uncompacted material, mostly of silt, sand, and rock fragments; < 33 ft (10 m) thick; beneath Rim Rock Drive >164 ft (50 m)	Beneath segments of Rim Rock Drive and reservoir in lower Fruita Canyon			
	Alluvium (Qal)	Chiefly of stream- channel deposits including minor undifferentiated colluvial deposits; includes boulders as large as 6.6 ft (2 m) in diameter; exposed thickness about 3.3 to 13 ft (1 to 4 m)	Along tributary streams of the Colorado River	Streams, alluvial fans, debris flows, and sheetwash	Associated with flash floods; low- lying areas prone to periodic flooding and debris-flow deposition	
	Flood- plain and stream channel deposits (Qfp)	Clast- supported, slightly bouldery, pebble and cobble gravel in a sand matrix; thickness may locally exceed 23 ft (7 m)	Not in monument; deposited along the Colorado River		In low- lying areas, subject to flooding	Nearby gravel operations
	River- gravel deposits (Qrg)	Chiefly clast- supported, bouldery, cobble and pebble gravel in a sand matrix; clasts generally < 20 in (50 cm) in diameter, sub- rounded to well- rounded, and poorly to moderately sorted; scour- and- fill structures; imbricate clast fabric consistent with the W flow direction of the Colorado River; clasts include the diagnostic moderate- red Maroon Formation and the yellowish- gray Green River Formation among other rock types typical of those transported by Colorado River; thickness 3.3–13 ft (1–4 m)	Outside monument; hilltops on the S side of Colorado River	Indicates erosional history of Colorado River and climate history of the region		
	Local gravel deposits (Qlg)	Poorly sorted, sub- rounded, clast- and matrix- supported pebble and cobble gravel that locally contains boulders as large as 6.6 ft (2 m); clasts consist primarily of metamorphic and igneous Proterozoic rocks and secondarily of sedimentary rocks eroded from the adjacent highlands in the Uncompahgre Plateau; locally fills channels as deep as 3.3 ft (1 m) that are cut in the underlying bedrock; thickness as much as 20 ft (6 m)	Hilltops in the Redlands area	Deposited at different times between about 42,000 and 480,000 years ago by tributary streams of the Colorado River, probably includes both stream alluvium and debris- flow deposits		
	Colluvium, undivided (Qc)	Colluvium reflects bedrock and surficial units from which derived; clast-supported pebble, cobble, and boulder gravel with matrix of silty sand, minor clayey silt, and locally, gravelly silt derived from steep slopes; clasts angular to sub- angular and as large as 6.6 ft (2 m) in diameter; max. ~16 ft (5 m) thick	Along the steeper slopes of mountain front	Sheetwash, debris flows, and landslides	Associated with rockfall deposits (Qr) at base of cliffs of Wingate Sandstone (Jwg)	Colluvium from Morrison Formation contains expansive clays; colluvium from Chinle Formation (TRc) is silty and non-expansive
	Rockfall deposits (Qr)	Include boulders and smaller debris deposited on slopes; clasts typically 3.3–6.6 ft (1–2 m) in diameter, some exceed 39 ft (12 m); clasts on younger rockfall deposits unweathered with light bedrock colors; clasts on older rockfall deposits weathered and coated with a brownish- gray to brownish- black desert varnish; thickness 3.3 ft (1 m) to > 9.8 ft (3 m)	Along Rim Rock Drive	At base of cliffs, particularly of Wingate Sandstone (Jwg)	Concern for visitor safety where Rim Rock Drive and overlooks were built in areas of Qr	
	Younger landslide deposits (Qlsy)	Mostly intact, active, or recently active earth- block slides, commonly have crescentic headwall scarps; sizes and rock types of the clasts and the grain- size distributions and colors of the matrices reflect those of the displaced bedrock units and surficial deposits; thickness 26 ft (8 m)–115 ft (35 m)	Not in monument; formed where S side of Colorado River locally cut steep slopes on uppermost Dakota Formation (Kd) and lowermost Mancos Shale (Km)	Prone to continued movement; poses a hazard to roads or structures built on bluffs close to the river	Toes of landslides are being removed by Colorado River	
	Older landslide deposits (Qlso)	Chiefly unsorted and unstratified rock debris characterized by hummocky topography; often complex including debris from the Brushy Basin Member (Jmb), the Burro Canyon Formation (Kb), and the Dakota Formation (Kd); sizes and rock types of the clasts and the grain- size distributions and colors of the matrices reflect those of the displaced bedrock units and surficial deposits; contain blocks as large as 20 ft (6 m)	Particularly abundant on the slopes of Black Ridge	Formed on unstable slopes underlain by the Brushy Basin Member of the Morrison Formation (Jmb)	Prone to continued movement or reactivation; contains expansive smectitic clay and locally has high shrink- swell potential	Housing or other development on this unit may encounter landslide hazards
	Sheetwash deposits (Qsw)	Chiefly of light- gray sandy and silty clay on very gentle slopes with gradient of ~ 9.8 to 13 ft per .62 miles (3 to 4 m/km) N of the Colorado River where derived by erosion of the Mancos Shale (Km); 9.8–26 ft thick (3–8 m) close to the river, nearly 49 ft (15 m) thick at NE corner of map area	Grand Valley		Commonly vertical desiccation cracks partly filled with clay	Contains expansive clays that may cause stability problems for roads and buildings
	Eolian sand (Qe)	Silty, very fine to fine wind- blown sand; commonly massive to weakly bedded and lacks eolian sedimentary structures, which may have been obliterated by biotic processes; sand derived chiefly from weathering of poorly cemented Slick Rock Member (Jes) and "board beds" unit (Jeb) of the Entrada and Wingate Sandstones (Jwg); lesser amounts derived from sandstone members of the Morrison Formation (Jmt, Jms, and Jmb);, subject to redeposition as sheetwash on slopes; thickness about 26 ft (8 m)	Blankets upland areas of the Uncompahgre Plateau	Several climbing dunes are banked against bedrock and are as thick as 16 ft (5 m)		Structures built on unit commonly sustain minor damage from settling related hydrocompaction

<table>
<tr><th>Age</th><th colspan="2">Unit Name (Symbol)</th><th colspan="2">Description</th><th>Location</th><th>Depositional Setting and Significance</th><th>Hazard Potential</th><th>Development and Resource Potential</th></tr>
<tr><td rowspan="2">Quaternary</td><td colspan="2">Eolian sand and sheetwash deposits (Qse)</td><td colspan="2">Similar to Qe but contains more abundant clasts; consist chiefly of silty, very fine to fine sand commonly containing scattered granule- to cobble- size fragments from bedrock units exposed upslope, esp. between mountain front and Colorado River; contain discontinuous layers and lenses of poorly sorted clasts; thickness about 16 ft (5 m)</td><td>Mantles level to gently sloping surfaces, and silt, sand, and rock fragments on valley sides and hill slopes</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Cienaga deposits (Qcg)</td><td colspan="2">Silty sand, chiefly of eolian or sheetwash origin, deposited in marshy areas; where water table is at or near the surface, evaporation leaves precipitate of alkali crust a few inches thick, white, mostly devoid of vegetation; thickness 3.3 to 9.8 ft (1 to 3 m),</td><td>Marshy places in the Redlands area</td><td>Fed by seeps, generally well vegetated, upstream from constrictions of resistant beds of the Burro Canyon Formation (Kb) and the Dakota Formation (Kd)</td><td></td><td>Low bearing capacity and poses hazard to roads and structures built on it</td></tr>
<tr><td rowspan="3">Cretaceous</td><td colspan="2">Mancos Shale (Km)</td><td colspan="2">Chiefly medium dark- gray, dark- gray, brownish- gray, and brownish- black fissile shale that weathers to light gray and forms gentle slopes; thickness > 4,495 ft (1,370 m) in W Colorado but < 66 ft (20 m) of lowermost Mancos is exposed south of the Colorado River in the map area</td><td>Only lowermost Mancos Shale exposed along the N boundary of the map area near the Colorado River</td><td>Lowermost stratum deposited in a shallow marine sub- tidal setting</td><td></td><td>Sedimentary structures (e.g., ripple marks and cross laminations) and fossils (e.g., trace fossil burrows and pelecypods and cephalopods)</td></tr>
<tr><td colspan="2">Dakota Formation (Kd)</td><td colspan="2">20 to 50% sandstone, 5 to 20% conglomerate, 40 to 60% mudstone, and < 5% impure coal; four parts (from top to bottom): interbedded sandstone and shale part, sandstone part, mudstone part, and conglomeratic part; upper part transitional with Mancos Shale (Km); thickness at Black Ridge about 102 ft (31 m) where uppermost part of unit has been removed by erosion; total unit thickness estimated at 148 to 164 ft (45 to 50 m)</td><td>Caps Black Ridge and forms a series of low hogbacks in the Redlands area</td><td>Sandstone and mudstone deposited in estuaries, tidal channels, distributary channels, bays, lagoons, strandlines, and barrier islands</td><td></td><td>Sandstone and conglomerate form prominent and resistant ledges and ridges; mudstone and interbedded sandstone and shale form slopes; bioturbation common throughout, includes plant roots and burrows; dinosaur tracks preserved in sandstone beds in Redlands area</td></tr>
<tr><td colspan="2">Burro Canyon Formation (Kb)</td><td colspan="2">40 to 80% mudstone, 20 to 60% sandstone, and 0 to 15% conglomerate; usually upper part dominated by mudstone and forms slopes; lower third to two- thirds dominated by sandstone and forms cliffs; thickness 96 ft (29.3 m) at Black Ridge</td><td>Saddle on Black Ridge</td><td>Flood plain and lacustrine</td><td></td><td>Sandstone includes large amounts of petrified wood; conglomerate clasts are mostly chert and quartz pebbles but include minor petrified wood and dinosaur bone</td></tr>
<tr><td rowspan="4">Jurassic</td><td rowspan="3">Morrison Formation</td><td>Brushy Basin Member (Jmb)</td><td>85 to 95% mudstone, 5 to 15% sandstone, with trace of limestone; multicolored mudstone forms gentle rounded slopes; thicker channel (sandstone) sequences commonly have small- scale trough cross- stratification and scour surfaces accentuated by basal layers of pebble- size mud chips and granules of chert and quartz; thinner sandstone beds are commonly bioturbated; about 312 ft (95 m) thick</td><td rowspan="3">Morrison Formation consists of three members: <u>Brushy Basin Member</u> (slope- forming upper member), <u>Salt Wash Member</u> (cliff- forming middle member), and <u>Tidwell Member</u> (slope- forming lower member); total thickness about 525 ft (160 m)</td><td>In the vicinity of Black Ridge and Monument Mesa</td><td>Mud flat to saline lacustrine setting that was locally invaded by highly sinuous fluvial channels</td><td>Susceptible to mass wasting, particularly landsliding; bentonitic mudstone expands and dries to form a popcorn- like weathered surface</td><td>Contains barite nodules and dinosaur bones; commonly bioturbated</td></tr>
<tr><td>Salt Wash Member (Jms)</td><td>30 to 80% sandstone, 20 to 70% mudstone, and traces of limestone; exhibits considerable lateral variation in thickness and rock type; thickness 102 ft (31 m) at Artists Point; within the sandstone portion, thicker sand bodies (up to 16 ft [5 m]) commonly exhibit small- to large- scale trough, tabular- tangential and sigmoidal cross- bedding, and scour surfaces</td><td>Road cuts on Rim Rock Drive S of Highland View Overlook</td><td>Fluvial setting and associated flood plains and shallow ponds</td><td>Salt Wash- Brushy Basin contact commonly obscured because of mass wasting</td><td>Elongate, narrow burrows are common near the tops of the thicker sand bodies; mudstone intervals commonly bioturbated by insect burrows and plant roots and are slightly fossiliferous, containing ostracodes and charophytes</td></tr>
<tr><td>Tidwell Member (Jmt)</td><td>Laterally variable proportions of multi- colored, interbedded mudstone, 50 to 70%; sandstone, 10 to 40%; limestone, 5 to 20%; forms slopes broken by relatively thin ledges of sandstone and limestone; about 125 ft (38 m) thick at Artists Point</td><td>In road cuts along Rim Rock Drive between Artists Point and Highland View Overlook</td><td>Deposited in several environments: (1) fresh to brackish- water lacustrine setting, (2) beaches in lake- margin settings, and (3) fluvial and distributary channel systems</td><td></td><td>Mottled and bioturbated (burrows) limestone; stromatolitic lamination (algal [cyanobacteria?] growth); oncolites (algal biscuits); sparse fossils: ostracodes, charophytes, and very small gastropods</td></tr>
<tr><td colspan="2">Wanakah Formation</td><td colspan="2">80 to 90% interstratified mudstone, 5 to 15% sandstone and silty sandstone, 0% to 5% impure limestone, with traces of volcanic ash and gypsum; slope- forming; recognized by distinctive green- over- red colors and by a noticeable reduction of vegetation; thickness 31 ft (9.4 m) thick at Artists Point</td><td>Entire formation exposed at Artists Point</td><td>Non- marine mud flat or shallow lacustrine environment</td><td></td><td>Bioturbation (burrows and roots); nodules (< 2 in [5 cm] in diameter) in limestone</td></tr>
</table>

Age	Unit Name (Symbol)		Description		Location	Depositional Setting and Significance	Hazard Potential	Development and Resource Potential
Jurassic	Entrada Sandstone	"Board beds" unit (Jeb)	60–70% interbedded sandstone and 30–40% mudstone; interbedded resistant sandstone and less resistant mudstone form slabby exposures that resemble stack of boards; thickness about 43 ft (13 m) along Upper Monument Canyon Trail	Entrada Sandstone consists of two parts: "boards beds" (prominent white cap) and Slick Rock Member (conspicuous pale- orange, ribbon- like cliffs)	In road cuts along Rim Rock Drive between Artists Point and Coke Ovens Overlook	Coastal setting—wet sand flat		SW of No Thoroughfare Canyon sandstone beds locally contain gray petroleum residue (dead oil)
		Slick Rock Member (Jes)	Consists almost entirely (99%) of cross- bedded sandstone; weathers to form rounded benches or cliffs that are almost totally free of vegetation; thickness 112 ft (34 m) along Upper Monument Canyon Trail		Isolated hill by the N side of Rim Rock Drive about 131 ft (400 m) W of Red Canyon Overlook	Coastal eolian setting—dunes and wet sand flats (interdune areas)		
	Kayenta Formation (Jk)		80 to 90% sandstone (throughout), 0 to 10% conglomerate (mainly in upper half), and 0 to 10% mudstone (mainly in upper half); commonly forms resistant caps or ledges; thickness about 77 ft (23.5 m) along Upper Monument Canyon Trail		Rim Rock Drive follows Kayenta Formation ledges in many areas; well exposed in road cuts S of headquarters and above tunnels	High- energy braided- river systems; sediment transport to the W- NW		
	Wingate Sandstone (Jwg)		Consists of about 95% sandstone and about 5% mudstone; typically forms high, reddish- orange cliffs and monuments; thickness 328 ft (100 m) along Upper Monument Canyon Trail		From W entrance, in road cuts between Chinle Formation (TRc) and the tunnels	NE margin of a large dune area (erg); series of dune complexes (draas) and wet sand flats fluctuating in size and shape in accordance with climatic variations		
Triassic	Chinle Formation (TRc)		Interbedded 80 to 90% mudstone, 0 to 10% sandstone, 0 to 5% sandy conglomerate, and 0 to 5% limestone; forms distinctive red slopes; thickness 89 ft (27 m) along Upper Monument Canyon Trail		Exposures in the road cut in Fruita Canyon	Densely vegetated flood plain or mud flat containing localized shallow ponds and small, shallow, sinuous streams; water-table fluctuations common during deposition		Carbonate nodules (rhizocretions?), root traces, and burrows (crayfish?) common in mudstone portion; some limestone beds have stromatolitic (algal?) structures
Precambrian	Lamprophyte dikes (Yl)		Slightly altered, thin, dark- greenish- gray to greenish- black dikes; contain phenocrysts of biotite, hornblende, and pyroxene in a fine- grained matrix; subparallel and dip to the SE at 50° to 73°; thickness 6.6–9.8 ft (2– 3 m)		NE part of No Thoroughfare Canyon and at the junction of Red and Columbus Canyons	About 1,400 million years old		
	Meta- igneous gneiss (Xi)		Biotite- bearing granitic rock with weak foliation and locally containing large feldspar phenocrysts		Exposed chiefly in E part of Ute Canyon	About 1,721 ± 14 million years ago		
	Migmatitic meta-sedimentary rocks (Xm)		Chiefly a mixture of schist and migmatitic pegmatite		N or E entrances to Monument Canyon; the freshest exposures are in the deepest drainages off the trails	1,741 ± 11 million years old (preliminary date)—probably age of metamorphism, not age of old rocks that eroded to produce sediments		

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Colorado National Monument 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.

Colorado National Monument lies about 66 miles (110 km) west of the northeastern edge of the Colorado Plateau where the Colorado River cuts through the steeply dipping strata of the Grand Hogback, marking the western border of the Rocky Mountain region (figure 7). Covering parts of Colorado, Utah, Arizona, and New Mexico, the Colorado Plateau is an elevated, mildly folded and faulted physiographic province underlain by relatively flat- lying sedimentary rocks (see figure 1). The structural fabric of gently warped, rounded folds of the Colorado Plateau contrasts with the intense deformation and faulting of the adjacent terrains. Northeast and east of the Colorado Plateau are the jagged peaks of the Rocky Mountains, and the Basin and Range province lies to the west and south. During the Miocene Epoch, the extensional tectonics that created the Basin and Range region extended the Mesozoic thrust belt (also called the overthrust belt) whose easternmost expression forms the western border of the Colorado Plateau.

Colorado National Monument overlaps the northeastern margin of the Uncompahgre uplift, expressed physically and topographically by the Uncompahgre Plateau, which stretches in a northwest- southeast trending direction for 90 miles (150 km) and is 27 miles (45 km) wide (Scott and others, 2001a). The Grand Valley separates the Uncompahgre Plateau from the Book Cliffs and Grand Mesa. The Redlands forms a geographic area between the Colorado River and the boundary of the Uncompahgre Plateau that contains many surficial, Quaternary- age deposits (Scott and others, 2001a).

Faults and folds are not the only prominent structural features on the Colorado Plateau. The La Plata Mountains, Ute Mountains, and Carrizo Mountains in northeastern Arizona, and the Henry Mountains and La Sal Mountains in Utah are the result of hot, mobile magma material rising up from deep within the Earth during the early to middle Tertiary (see figure 8). This rising magma squeezed and intruded into cracks and fissures in the sedimentary rock and caused the overlying layers to bulge upward. These mushroom- shaped intrusions of igneous rock are called “laccoliths.” Over time, erosion has exposed the inner igneous core of the ranges.

Violent volcanic extrusions of molten material erupted onto the Colorado Plateau during Tertiary time. Two of the Navajo’s sacred mountains, Mount Taylor near Grants, New Mexico, and San Francisco Peak near Flagstaff, Arizona, are extinct volcanoes (Baars, 1995). Huge eruptions occurred where the San Juan Range sits now, and continued into the middle Tertiary. Ash and cinders belched from numerous calderas. One large caldera extends for several miles north of Silverton, Colorado. Today, Animas and Mineral Creeks mark the caldera’s margins. Several thousand feet of tuff (volcanic ash) and lava flows blanketed the central and eastern San Juan Mountains and adjacent regions (Baars, 2000).

Including rocks that have eroded away, the Colorado Plateau has been uplifted about 12,000 feet (3,660 m) since the end of the Cretaceous Period (about 66 million years ago) (Fillmore, 2000). Some of this uplift occurred rapidly, geologically speaking. 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. With uplift, streams throughout the Colorado Plateau began to dissect the topography into the landscape we see today.

The regional stratigraphy surrounding Colorado National Monument forms a rich tapestry of rock units that illustrate this complex geology. Both the strata present on the surface and in the subsurface, as well as the missing strata in unconformities, record major orogenic uplifts and subsequent basin formation in western Colorado. The stratigraphy documents a variety of environmental conditions: from marine incursions to deserts, leaving an array of imprints including tropical plants mixed with dinosaur footprints, which are overlain by strata containing sharks’ teeth.

Northwest of the Uncompahgre Plateau, all of the geologic time periods except the Silurian Period are represented by sedimentary rocks. Precambrian meta- sedimentary and meta- volcanic rocks underlie the Paleozoic sedimentary package. Approximately 400 million years of time is missing between Cambrian- and Precambrian- age rocks. Another 400- million- year gap in time separates these Precambrian rocks (i.e., the Uinta Mountain Group) from the oldest meta- volcanic gneisses.

Southwest of the Uncompahgre Plateau, rocks representing both the Ordovician and Silurian Periods are missing, but otherwise, the geologic time scale is well represented. At least 850 million years is missing between the Cambrian- age Ignacio Quartzite and Precambrian- age granite, the youngest Precambrian rock identified in southwest Colorado. This 850- million- year time gap is 300 million years longer than the time represented by the Cenozoic, Mesozoic, and Paleozoic Eras combined.

Unlike Tertiary time in the Northwest, the Tertiary of the Southwest also includes some igneous rocks. At Colorado National Monument, erosion has removed all the strata representing the Paleozoic Era and some of the Triassic Period. More than 1,155 million years is missing between the Chinle Formation and the 1,400-million- year- old igneous dikes found in the monument, and more than 1,355 million years is missing between the Precambrian meta- igneous and meta- sedimentary rocks found in the canyons and the overlying Mesozoic strata (Scott and others, 2001a). The gap in the stratigraphic record represents a time of active mountain building during the upper Paleozoic when the Ancestral Rocky Mountains formed.

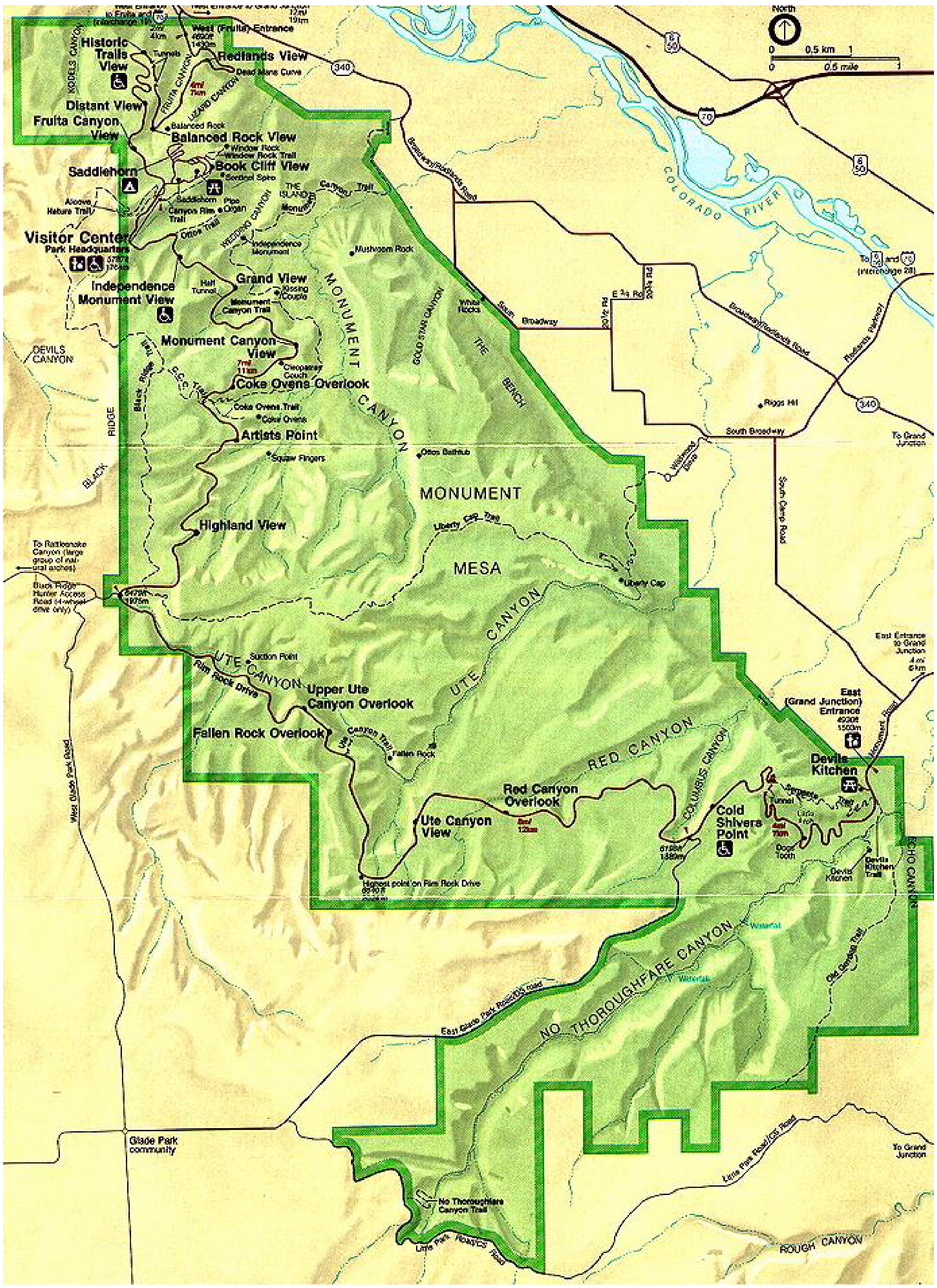

Figure 7. Map of Colorado National Monument. Colorado National Monument is part of the Colorado Plateau where the Colorado River cuts through the steeply dipping strata of the Grand Hogback, which marks the western border of the Rocky Mountain region.

Geologic Time Scale

Eon	Era	Period		Epoch	Age (Ma)	Age of
Phanerozoic	Cenozoic	Neogene	Quaternary	Holocene	0.01	Mammals
				Pleistocene	1.81	
			Tertiary	Pliocene	5.33	
				Miocene	23.0	
		Paleogene		Oligocene	33.9	
				Eocene	55.8	
				Paleocene	65.5	
	Mesozoic	Cretaceous			145.5	Reptiles
		Jurassic			199.6	
		Triassic			251.0	
	Paleozoic	Permian			299	Amphibians
		Carboniferous	Pennsylvanian		318	
			Mississippian		359.2	
		Devonian			416.0	Fishes
		Silurian			443.7	
		Ordovician			488.3	Invertebrates
		Cambrian			542.0	
Proterozoic	Also known as Precambrian				2,500	
Archean					2,500–3,800?	
Hadean					3,800–4,600?	

Figure 8: Geologic Time Scale
Notes: Dates are in millions of years (Ma) and reflect the International Union of Geological Sciences (IUGS) International Stratigraphic Commission (ICS) International Stratigraphic Chart (2003) at http://www.stratigraphy.org/chus.pdf. Exceptions include the boundary between Archean and Hadean, which the International Stratigraphic Commission does not list. However, the U.S. Geological Survey lists the boundary between Hadean and Archean at approximately 3,800 Ma and the formation of Earth at approximately 4,600 Ma, which are used here. Mississippian and Pennsylvanian are terms used primarily in North America, and Tertiary and Quaternary are no longer used by the International Commission on Stratigraphy (2003) but are listed here because they are still in common use.

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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.

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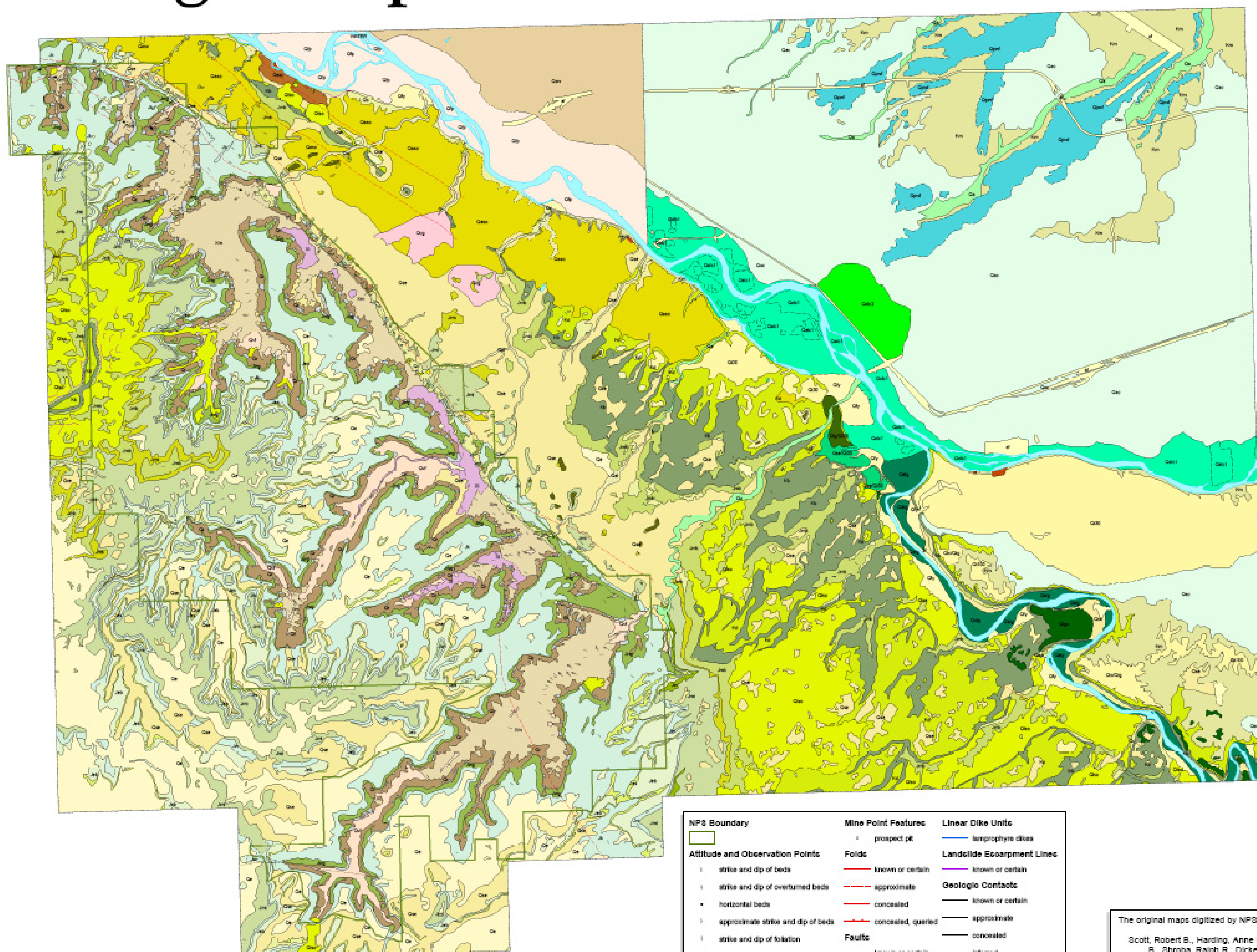
Appendix A: Geologic Map Graphic

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

Geologic Map of Colorado NM



Geologic Units

- af - artificial fill
- Qal - alluvium
- Qalc1 - youngest alluvium deposited by the Colorado River
- Qalg - youngest alluvium deposited by the Gunnison River
- Qfy - younger fan-alluvium and debris-flow deposits
- Qlsy - young landslide deposits
- Qcg - Cienaga deposits
- Qfp - floodplain deposits
- Qa - alluvium deposited by tributary streams
- Qvf - valley fill deposits
- Qalc2 - oldest alluvium deposited by the Colorado River
- Qc - colluvium
- Qac - alluvium and colluvium, undivided
- Qsw - sheetwash deposits
- Qe - eolian deposits
- Qes - eolian and sheetwash deposits
- Qr - rock-fall deposits
- Qes/Qt30 - eolian sand and sheetwash deposits
- Qasy - younger alluvial-slope deposits
- Qaso - older alluvial-slope deposits
- Qpwf - pediment deposits of Walker Field
- Qrg - river-gravel terrace deposits
- Qlg - local gravel deposits
- Qtgu - terrace alluvium of the Gunnison River, undivided
- Qlso - old landslide deposits
- Qlg/Qt30 - local gravel deposits
- Qt- terrace alluvium
- Km - Mancos Shale
- Kd - Dakota Sandstone
- Kb - Burro Canyon Formation
- Jmb - Morrison Formation, Brushy Basin Member
- Jms - Morrison Formation, Salt Wash Member
- Jmt - Morrison Formation, Tidwell Member
- Jw - Wanakah Formation
- Jeb - Entrada Sandstone, 'Board Beds' unit
- Jes - Entrada Sandstone, Slickrock Member
- Jk - Kayenta Formation
- Jwek - Kayenta, Entrada Sandstone, and Wanakah Fms.
- Jwg - Wingate Formation
- TRc - Chinle Formation
- Xi - meta-igneous gneiss
- Xm - migmatic meta-sedimentary rocks
- WATER

NPS Boundary

Attitude and Observation Points

- strike and dip of beds
- strike and dip of overturned beds
- horizontal beds
- approximate strike and dip of beds
- strike and dip of foliation
- strike of vertical foliation
- dip of fault plane
- U upthrown side of fault
- D downthrown side of fault
- fault down-thrown block indicator
- strike of approximately vertical joints
- strike and dip of beds, inferred

Mine Point Features

- prospect pit

Folds

- known or certain
- approximate
- concealed
- concealed, queried

Faults

- known or certain
- approximate
- concealed
- inferred

Linear Dike Units

- lamprophyre dikes

Landslide Escarpment Lines

- known or certain

Geologic Contacts

- known or certain
- approximate
- concealed
- inferred
- quadrangle/map boundary
- water/shoreline

The original maps digitized by NPS staff to create this product were:

Scott, Robert B., Harding, Anne E., Hood, William C., Cole, Rex D., Livaccari, Richard F., Johnson, James, B., Shroba, Ralph R., Dickerson, Robert P., 2001, Geologic map of Colorado National Monument and adjacent areas, Mesa County, Colorado: U.S. Geological Survey, Geologic Investigations Series I-2740, 1:24,000 scale.

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

Produced by Geologic Resources Division

February 2006

Appendix B: Scoping Summary

The following notes constitute the geologic scoping summary for Colorado National Monument. The scoping meeting occurred on June 23 and 24, 1998; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact to the Geologic Resources Division for current information.

On June 23 and 24, 1998, staff from Colorado National Monument, Mesa State College, the U.S. Geological Survey, and the NPS Natural Resources Program Center met at Colorado National Monument to discuss mapping and other geologic needs.

Participants

- Bruce Heise, NPS Geologic Resources Division
- Bill Hood, Volunteer, Colorado National Monument, and Adjunct Professor of Geology, Mesa State College
- Jack Roadifer, Volunteer, Colorado National Monument
- Joe Gregson, NPS Inventory and Monitoring Program
- Rick Livaccari, Professor of Geology, Mesa State College
- Patrick Perrotti, Chief, Natural Resources, Colorado National Monument
- Judi Lofland, Interpretation, Colorado National Monument
- Ron Young, Chief, Interpretation, Colorado National Monument
- Bob Scott, U.S Geological Survey
- Pete Larson, Volunteer, Colorado National Monument
- Steve Hickman, Superintendent, Colorado National Monument
- Jim Johnson, Professor of Geology, Mesa State College

Scoping Session

June 23, 1998
The scoping session was held at Mesa State College, Wubben Hall (Weldon Lecture Hall). Steve Hickman, Colorado National Monument Superintendent, made introductions, which were followed by Joe Gregson, NPS Inventory and Monitoring (I&M) Program, who provided a program overview and update of the geologic resources inventory. Bruce Heise provided an overview of the NPS Geologic Resources Division.

Staff from Colorado National Monument presented information about geological resource needs and issues at the monument (Steve Hickman) and geological resource issues for interpretation (Ron Young). Bob Scott of the U.S. Geological Survey (USGS) gave a summary of USGS geological mapping and research. The opening session also included discussions about other cooperators; authors for geologic resource report and other papers; deliverables from mapping, cooperators, and NPS inventory; and closed with a meeting wrap- up and feedback. Following lunch, Bob Scott led a field trip in the monument.

June 24, 1998
Today's session was held in Colorado National Monument. The meeting opened with NPS and USGS business. Discussions from June 23 were continued (as needed). In addition, the geology- GIS digital data model for Colorado National Monument and fiscal issues were addressed. The scoping session ended with meeting wrap- up (table 1) and feedback.

Significant Issues

The monument is presently being remapped and has a strong volunteer support group of local retired geologists and faculty from the college to assist in handling park geologic needs. Significant issues discussed or visited during the field trip include

1. Management issues such as flash flooding and landslides, threats to public safety and historic structures stemming from geologic hazards, and external development at the mouths of canyons
2. Exciting new discoveries including new trace fossil evidence and the fire history of the area revealed in canyon floor sediments
3. Interpretive display needs, including new "virtual" geologic displays in the visitor center
4. Evaluating research requests, including those from mineral development companies
5. A wide range of fiscal issues, mostly pertaining to the costs of digitizing, printing, and distributing the new geologic map and report

The plan now is to follow up on these points and reconvene in the fall (table 1).

One of the geologic features identified during USGS mapping at Colorado National Monument and discussed at the pilot mapping project meeting in July 1997 (?) was the occurrence of charcoal horizons in the valley fill. Carbon- 14 dating of these horizons gives a ±50 year indication of the fire history of the park. Pat Perrotti, resource manager for the park, relayed this information to NPS fire specialists, who were enthusiastically receptive. As a result of this find, a mid- October site meeting has been scheduled to look at the fossil record. Attending will be NPS specialists in fire ecology, fire protection, and piñon pines. USGS experts on soils, paleo- climatology, and sedimentology will also attend. This is a direct park management application of information obtained through geologic mapping.

Management Needs and Concerns

- Development outside the boundaries of the park, fire development, flash floods
- No general management plan
- Request by developers for access to park, not for public
- Public safety on Monument Canyon Trail
- Resource protection on Serpents Trail (e.g., massive repair, geologic and engineering assessments), climbing impacts

Research

- Which way should geological research go?
- Proposals
- Paleontology—new trace fossil
- In backcountry use GIS for analysis, geologic changes, modeling
- Fire Behavior—look at No Thoroughfare Canyon; on October 13–14, the fire ecologists and geologist in Colorado National Monument will look at fire history
- Valley fill—soils, paleo- climatology, carbon- 14 dating ±50 years, fire return rates based on charcoal layers in valley fill
- Fire threats to historical structures
- Utility corridors power, water, leaks

Fiscal Issues

- In conversations with natural history association director (since removed) considerable added expense to publish map; too great an investment for natural history association
- USGS publishing maps: I- map produced electronically, CD- ROM, Internet, print on demand
- According to Diane Wells, Chief of Publications, to print 3,000 maps would cost $10,000
- Of 3,000 maps published, USGS takes 1,000, would pay $3,300; remaining—$6,700 for 2,000 maps
- Opportunity for NPS collaboration, if to be digitized by USGS, I&M could use various contributions, possible ways to enhance selling maps

Action Items

Item	By Whom	Status
Geologic map	Bob Scott, others	In progress
Site bulletins	Bill Hood	One written, another in draft, others planned
Geologic road log	Bill Hood & Grand Junction Geological Society	Completed—visitor center to W. entrance station; Scheduled—visitor center to east entrance station
Geologic trail maps	Sandy & Bill Hood	Planned for autumn
Revised stratigraphic column hand- out	Bill Hood, Rex Cole	In progress
Simulated geologic field trip	Bill Hood	In progress, a long- term effort
Book on geology of Colorado National Monument	Bob and Anne Harding, others?	Planned
CD- ROM based display for lobby	Bill Hood, Ron Young, others	Dreaming about it
Revised strigraphic chart for exhibits room		
Revise roadside display (Fruita Canyon)		
Roadside display for Artists Point		
Flash Flood display on Old Gordon Trail		
Valley fill display in upper No Thoroughfare Canyon		
3- D model		
Road logs (Dinosaur National Monument, Moab, Black Canyon of the Gunnison National Monument)		

Appendix C: Geoindicators Report

The following excerpts are from the geoindicators report for Colorado National Monument. The geoindicators scoping session was held on September 9 and 10, 2002; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact to the Geologic Resources Division for current information.

Purpose of meeting

The purpose of the meeting was threefold: (1) to identify significant geological processes and features that are part of the park's ecosystem, (2) to evaluate human influences on those processes and features, and (3) to provide recommendations for studies to support resource management decisions, geologic inventory and monitoring projects, and research to fill data gaps. The scoping meeting was designed to use the participants' expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge- based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science- based decisions with regard to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at Colorado National Monument may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator Background Information

An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions.

Geoindicators guide the discussion and field observations during scoping meetings. The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant. The health and stability of an ecosystem is evaluated during the geoindicators scoping process. The geologic resources of a park soils, caves, streams, springs, beaches, volcanoes, etc.- provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility, hillside stability, and the flow styles of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts.

The 27 geoindicators

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

Additional Information

- Geologic resource monitoring in the National Park System: http://www2.nature.nps.gov/grd/geology/monitoring/index.htm.
- Detailed descriptions of the 27 geoindicators: http://www2.nature.nps.gov/grd/geology/monitoring/parameters.htm.
- IUGS Geoindicators Initiative: http://www.lgt.lt:8080/geoin/welcome.

Park Selection

The geoindicators scoping meeting in Colorado National Monument grew out of a technical assistance request, which park managers submitted to the Geologic Resources Division. The request was fourfold: (1) to identify human/outside influences on the park's geologic resources, (2) to quantify flash floods and other geologic hazards, (3) to identify research to better understand geologic resources, and (4) to request funding for a Geoscientist- in- the- Park (GIP). Staff at GRD recognized the connection between the request and the geoindicators scoping process, so it was agreed to carry out a scoping meeting. In addition Colorado National Monument was selected for is its unique geologic resources, park setting, and human use.

Summary of Results

Issues surrounding each geoindicator are identified, and have been rated by participants with respect to ecosystem importance ecosystem and human influence (table 1). Park staff rated the significance for park management. A compilation of the notes taken during the scoping session and the opening session and field trip are included in the appendices. These notes highlight additional information regarding geoindicators that may be useful to park managers.

Geoindicators with Importance to Park Ecosystem

Groundwater Level
Water is a rare resource in Colorado National Monument, wildlife and plants, including T&E species, depend upon it. Groundwater supplies seeps and springs, which are areas of high biodiversity. Locally groundwater levels are very important, for example, in Ute Canyon, where the south canyon- side gets groundwater discharge that feeds plants.

Slope Failure
Slope failure includes landslides, rockfalls, and debris flows, which are an integral part of the ecosystem at Colorado National Monument. Slope failure happens continuously throughout the park, although not all rock units disintegrate at the same rate. In general, slope failure creates piles of rubble that have greater permeability and porosity than the original surfaces, which increases infiltration potential and creates "new" land surfaces upon which habitats can evolve.

Soil and Sediment Erosion
The process of erosion created the landforms of Colorado National Monument. It is a fundamental natural process that has been operating for millions of years, and the development of the present- day ecosystem is an outcome of the processes of erosion.

Stream Channel Morphology, Streamflow, Stream Sediment Storage and Load
The primary reason that these three geoindicators are significant for the park's ecosystem is because of the roles they play in the formation of the park's landscape, particularly canyons. The significance of these three geoindicators is best appreciated during flash floods.

Wetlands Extent, Structure, and Hydrology
There is a lithologic control on the wetlands in Colorado National Monument. The scarcity of wetlands increases their importance to plants and wildlife as a source of water. They also provide cooler temperatures. Greater plant and animal diversity have been identified in wetland areas, and they are sites of hanging gardens, which provide habitat for threatened and endangered species.

Geoindicators with Significant Human Influences

Desert Surface Crusts and Fissures
The human- caused impact on surface crusts and fissures (biological and physical crusts) has been intense in the some of the canyon areas of the park. For example, starting in the 1930s, a herd of bison (up to 60 head) grazed throughout the canyon areas and disturbed some areas of soil crusts; this practice ended in the 1980s. The herd was an attempt by John Otto to encourage visitors to come to Colorado National Monument. In addition, damage of crusts occurred in Civilian Conservation Corps (CCC) camps and along major trail corridors.

Slope Failure
Slope failure, including rockfalls, is a natural process that has been exacerbated by human impacts, such as the construction of the Rim Rock Drive and by vibration from heavy vehicles (e.g., trucks, tour buses, and school buses).

Soil and Sediment Erosion
Erosion is a fundamental and complex natural process that is strongly modified by human activities. Human influences on soil and sediment erosion in Colorado National Monument occur on a local- scale, the primary influence being Rim Rock Drive (e.g., road cuts and increased runoff). The proliferation of social trails, which is tied to increasing visitation, also causes erosion on local- scale (e.g., in Monument Canyon, lower Liberty Cap trail, No Thoroughfare Canyon, trail between Visitor Center and Book Cliffs View, and Alcove Trail).

Wetlands Extent, Structure, and Hydrology
A significant human influence on wetlands in the park has been the Fruita pipeline, which leaked and created artificial habitats ideal for exotic plants. Additionally, two reservoirs were constructed to provide water to the citizens of Fruita. These are no longer in use, but future

demand could cause them to be restored, which is a concern for park management. In addition, the CCC-camp members dammed the spring in Monument Canyon, and present- day trails pass through wetlands in canyon areas.

Geoindicators with Management Significance

Desert Surface Crusts and Fissures
Park management recognizes that biological and physical crusts are a unique and fragile resource. An inventory of locations is needed in order for park management to plan for the proper placement of trails and for the purposes of visitor education.

Groundwater Level
Groundwater level has high management significance because a decrease in groundwater level could have a direct effect on the park's seeps and springs, which are important resources. Quantifying groundwater level is important for management because this information could be used for planning and future decision making as it relates to development outside of the park's boundary (e.g., in Glade Park).

Groundwater Quality
Changes in groundwater chemistry could affect organisms at seeps and springs. Although the risk of contamination is probably not high at present, this could change in the next 50 to 100 years. As Glade Park grows, the chances of groundwater contamination will increase. The risk also depends on the kinds of changes that may take place in land use and water use in the recharge area, as some changes will pose more serious threats than others.

Slope Failure
Slope failure happens continuously throughout the park and is a constant maintenance issue along Rim Rock Drive. Rim Rock Drive is an important park resource, which facilitates public enjoyment and the ability to view the park. Slope failure is a concern for park management, particularly with respect to potential road failure. Rockfalls are also a concern of park managers for reasons of visitor safety, especially along Rim Rock Drive and at overlooks.

Stream Channel Morphology, Streamflow, Stream Sediment Storage and Load
These three geoindicators are active components of flash floods, which are of primary management significance and affect all park divisions/units (e.g., maintenance, interpretation, resource management). Flash floods are the principal agent that form and modify the canyons, as well as being a concern for homeowners. Park staff has a role to fill as public educators regarding flash floods. Park managers recognize the significance of flash floods to the park's ecosystem. They also recognize the importance of educating homebuilders and homeowners about the long history of flash flooding in the area and making responsible decisions with respect to the location of homes.

Wetlands
If more water is needed in Fruita in the future, management has concerns that the old water line would be reactivated. Intense damage to park resources, associated with required reconstruction activities, would accompany reactivation of the water line.

Summary of Recommendations

The summary includes recommendations for inventory, monitoring, and research studies, as well as recommendations for public education and park planning. Recommendations are not listed in any order of priority.

Recommendations for Inventory and Monitoring

1. Identify areas with high potential for slope failure
An inventory of areas along the Rim Rock Drive and overlooks with high potential for slope failure would have value for inventory, monitoring, and planning. High potential areas could be identified with GPS and incorporated into the park's GIS. Such an inventory would enable park managers to focus on particular areas, rather than 23 miles of road. Rangers who regularly drive on the road could assist with the process by identifying cracks in the asphalt and entering those data into a GPS unit, which could be incorporated into GIS. A yearly monitoring day could be set aside to revisit and evaluate these areas.

Another simple monitoring technique is to place stakes in landslide material along the road to detect movement/creep. A survey of these areas could be performed once every two years. This is a low- cost project that would provide valuable information to park managers.

Once inventories of areas with high potential for slope failure are incorporated into the park's GIS, park managers will have a valuable planning tool that could be used for (1) locating "warning" signs, and (2) coming up with options for rerouting the road, if/when it fails.

2. Gather scientific information on seismicity and wind- blown sediments
Although seismicity and wind- blown sediments are of low management significance, having a seismic station and wind- blown sediment monitoring station in the park would have scientific value and encourage collaboration between the park and the local academic community. Mesa State College would be interested in having one seismic station located in Colorado National Monument, possibly in the maintenance or housing area. Three stations are needed to get accurate local information. Staff at Mesa State College would monitor and maintain the station.

Contact

- Verner Johnson, vjohnson@mesastate.edu, Mesa State Geology Program

Mesa State College needs a used computer to complete the seismic station. The NPS Natural Resource Program Center may be able to donate a computer.

Contact

- Bob Higgins, GRD, Bob_Higgins@nps.gov, 303- 969- 2018.

In addition, Mesa State College's Geology Program would be interested in having a monitoring station for wind- blown sediment in Colorado National Monument. They would need a collection permit and a sheltered spot to place the traps, which they would monitor once per year.

Contact

- Mesa State College's Geology Program, geology@mesastate.edu, 970- 248- 1020

3. Use geology to identify paleontological and archeological sites within the park
Park managers expressed the desire to use geology as a tool for identifying other natural and cultural resources. Participants identified some contacts for future studies.

Paleontological Contacts

- John Foster, Museum of Western Colorado, jfoster@westcomuseum.org, 970- 858- 7282
- Greg McDonald, Geologic Resources Division, Greg_McDonald@nps.gov, 303 - 969- 2821

Possible Archeology Contact

- Mesa Verde National Park

4. Gather baseline data on flash floods
Repeat photography may be an option for gathering baseline information on flash floods. Since floods will leave debris, photographing during the event may not be necessary. A volunteer could be trained to take photos after each flooding event, which occur approximately twice per year, typically during July and August. The NPS Geoscientist- in- the- Parks (GIP) program may be able to provide funding for camera equipment.

Contact

- Judy Geniac, GIP Program Manager, Geologic Resources Division, Judy_Geniac@nps.gov, 303- 969- 2015

Another possibility would be to install cameras in selected drainages (where homes are in the most jeopardy) to photo document flooding.

Contact

- Paul Vonguerard, 970- 858- 3617, pbvongue@mailscogjn.cr.usgs.gov

5. Include inventory of soil crusts in mapping of vegetation
Biological and physical soil crusts are a unique resource in Colorado National Monument and should be preserved because of their potential to protect underlying fine material from wind erosion; fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo.

Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use. It is recommended that locations of these crusts be identified and incorporated into the park's GIS in order to protect and preserve soil crusts. An inventory of crusts would enable park managers to plan the placement of trails accordingly and educate visitors appropriately. Locations of these crusts should also be linked to the fire management plan, since the greatest amount of crusts occurs where there is the greatest amount of piñon and juniper. Future plans for operations related to prescribed burns or mechanical fuel reduction could have a negative impact on soil crusts.

Contacts

- Eric Aiello, Eric_Aiello@nps.gov, 970- 242- 7385
- Jayne Belnap, U.S. Geological Survey in Moab, 435- 719- 2333, jayne_belnap@usgs.gov

6. Identify baseline level of groundwater and periodically monitor
Baseline data are needed in order to detect groundwater depletion caused by increased development in areas bordering Colorado National Monument, such as Glade Park. Groundwater is a valuable resource for the park's seeps and springs, and increased extraction could have a negative effect on these valuable resources, as well as on the organisms that rely on them.

Potential sources of data

- Rocky Mountain Drilling, Glade Park, 970- 434- 8554
- Dennis Karns, Ute Construction, 970- 243- 2469

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Lohman, S.W., 1965, Geology and artesian water supply of the Grand Junction area, Colorado: U.S. Geological Survey Professional Paper 451, 149p.

Lohman, S.W., 1963, Geologic map of the Grand Junction area, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I- 404, scale 1:31,680.

Upon determining a baseline of groundwater level, it is recommended that park managers perform periodic monitoring. At a minimum a network of wells should be monitored at least annually but preferably quarterly or more often. Since the park does not have a monitoring well, one option would be for park managers to attain permission from homeowners in Glade Park to monitor water level in private wells. The U.S. Geological Survey has capabilities to advise or participate in this activity.

Another important issue would be to identify the groundwater recharge area for Colorado National Monument. Determining the rate of groundwater withdrawal in the recharge area will be an important step in understanding outside development on groundwater resources of Colorado National Monument.

Contact

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7. Identify baseline for groundwater quality and periodically monitor
This baseline should include water chemistry at seeps and springs, and at selected wells in Glade Park. Changes in land use and water may pose threats to groundwater quality.

8. Inventory wetlands
Park managers in Colorado National Monument have some information about wetlands in the park because of the survey of tamarisk that was conducted. To date, two wetland areas have been identified (e.g., upper Ute Canyon and upper No Thoroughfare Canyon), with a total of about 20 acres. Wetlands in the park will be inventoried through the vegetation mapping program using GIS. Locations of all wetlands need to be mapped, ground truthed, and digitized.

Reference

Cowardian, L.M, Carter, V., Golet, F.C., and LaRoe,E.T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Department of the Interior, Fish and Wildlife Service, FWS/OBS- 79/31.

9. Work with soil scientist to better understand soil quality
Upon review of this scoping report, it was the opinion of a soil science expert that some of the observations made during the scoping session regarding soil quality were incorrect. It is recommended that soil quality of Colorado National Monument be revisited, and correction and clarification made prior to making management decisions.

Contact

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Recommendations for Research

1. Create a flash flood model
Create a flash flood model and run for each drainage in Colorado National Monument. This could be a GIP project. Park managers could work with local professors at Mesa State College (geomorphology, hydrology, and GIS). In order to verify the model, data collection is needed that measures peak flow drainages in Colorado National Monument. Installation of crest- stage gages and the rating of stream channels using the step- backwater method would provide the basic data needed to support flash - flood models. The U.S. Geological Survey may be able to participate.

Contacts

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2. Consider integrated research proposal to examine valley fill
This proposal could provide valuable information to park managers regarding rates of erosion, past climate change, and sources of sediment.

3. Put seeps and springs inventory into digital format
Currently park staff has hand- drawn maps seeps and springs on 7.5- minute topographic maps. These data are assumed to have been collected at the same time as a vegetation study in 1984. Eric Aiello, park Cartographic Aid and student at Mesa State College, has been making a 3D model of the park. He has acquired software to do some analysis on watersheds in Colorado National Monument. Participants thought that this project is a prime candidate for Geoscientist- in- the- Park (GIP) funding and encourage park managers to submit a GIP proposal.

Contact

- Judy Geniac, GIP Program Manager, Geologic Resources Division, Judy_Geniac@nps.gov, 303- 969- 2015.

Recommendation for Public Education

Develop a plan for educating the public about flash floods
It is recommended that park staff collaborate with the U.S. Geological Survey, Colorado Geological Survey, and/or local geologists to develop a long- term plan for educating the public about flash floods. The plan could be modeled after the fire community's efforts, which has been successful. A possible "kickoff" event may be to host a public field trip that highlights the long history of flash floods in the area. The trip could commemorate the 25th anniversary of the large flash flood that occurred in September 1978. The local community, including County Commissioners, should be invited.

Recommendation for Park Planning

Develop a long- term plan for road failure
The park has a short- term plan for closure of Rim Rock Drive but not a long- term plan, if large sections of the road are destroyed. Recent history shows that a road closure is a reality, e.g., Rim Rock Drive was closed for one year when the area between the two tunnels was washed out. A long- term plan for road closure, rerouting, maintenance, etc. needs to be part of general

management plan (GMP). It is recommended that park staff work with geologists, engineers, and the Federal Highway Administration to plan alternatives. The plan for rerouting the road should take into consideration the geologic strata, location of facilities, and wilderness. In addition, fire plays a role in (and could indirectly trigger) landslides; therefore, slope failure should be part of the Fire Management Plan. The potential to mitigate landslides with smaller, prescribed burns should be considered.

Participants

Colorado National Monument

Eric Aiello, Cartographic Aid
Don Baars, Geologist/Volunteer- in- the- Park
Bill Hood, Geoscientist- in- the- Park/Volunteer- in- the- Park
Pete Larson, Park Ranger
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Ron Young, Supervisory Park Ranger
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National Park Service

Pete Biggam, Natural Resources Information Division (review of soil quality geoindicator only)
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Geoindicators Table for Colorado National Monument

Geoindicators	Importance to park ecosystem	Human influence on geology	Significance for management
AEOLIAN			
Dune formation and reactivation	1	1	1
Dust storm magnitude, duration, and frequency	1	1	1
Wind erosion	1	1	1
GROUNDWATER			
Groundwater quality	2	2	3
Groundwater level	3	U	4
SURFACE WATER			
*Stream channel morphology	5	1	5
*Stream sediment storage and load	5	1	5
*Streamflow	5	1	5
Surface water quality	1	1	3
SOILS			
Soil quality	2	1	2
Soil and sediment erosion	5	4	2
Desert surface crusts and fissures	2	5	4
TECTONICS & LANDSLIDES			
Seismicity	1	N/A	1
Slope failure	5	3	5
Surface displacement	1	N/A	1
OTHER			
Wetlands extent, structure, hydrology	4	4	3
N/A - Not Applicable 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 U - Unknown; may require study to determine applicability NOTE - 2 and 4 are also rating options			
*Linked to flash floods			

The above Geoindicators table shows rankings for those geoindicators deemed (1) important to Colorado National Monument's ecosystem, (2) to have significant human influences, and (3) to be of significance for park management.

Colorado National Monument
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/007
NPS D-86, March 2006

National Park Service
Director • Fran P. Mainella

Natural Resource Stewardship and Science
Associate Director • Michael A. Soukup

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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