National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Arches National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2004/005

THIS PAGE:
Canyon, Arches NP.

ON THE COVER:
Delicate Arch, Arches NP

NPS Photo's

Arches National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2004/005

Geologic Resources Division
Natural Resource Program Center
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Table of Contents

List of Figures

Executive Summary

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

The 76,359 acres of Arches National Park (ARCH) in east- central Utah preserves the greatest concentration of rock arches in the world. In addition to the arches, Arches National Park is home to an extraordinary collection of balanced rocks, salt dissolution structures, folds resulting from salt tectonics, petrified dune fields, and a maze of deep narrow canyons.

Mesozoic sedimentary rocks are the primary strata exposed in ARCH. Arches formed mainly within the Entrada Sandstone, which was deposited about 150 million years ago. The arches result from a continual process of weathering and erosion, and they accent the significant role that water plays in a semi- arid climate. Fins are the result of salt tectonics and wind and water erosion. Salt- cored anticlines form prominent features in ARCH.

Geologic resource issues arise in the park due to the heterogeneous lithology of the rock strata, weathering and erosion processes, and human influence. These issues impact road construction and maintenance projects, groundwater quality, and visitor protection.

The list of geologic issues includes:

- Hydrocarbon development
- Uranium mining
- Water quality and flash flooding
- Preservation of fossils
- Landslides and rockfalls
- Swelling clays
- Radon contamination
- Earthquakes
- Sonic booms and arch stability
- Livestock grazing effects on soils
- Proposed toxic waste incinerator impact on geologic features
- Viewshed issues (dust, oil/gas development)
- Acid rain impacts
- Preservation of Cryptobiotic soils

Scientific research projects suggested for the park include:

- Evaluation of acid rain impacts on deterioration of the sandstone arches
- Connections between gypsiferous rocks and cryptobiotic soils
- Erosion rate of Delicate Arch
- Engineering studies of landslides
- High resolution GPS and rock movement
- Rock color studies
- Void spaces in the Needles
- Stratigraphic studies to identify unconformity contacts, planes of weaknesses, and porosity/permeability relationships of various strata
- Inventory, monitoring, and protection of paleontological resources, especially in the Dalton Wells area
- Hydrogeologic studies to identify groundwater flow, aquifers, and potential groundwater contamination

For additional information regarding the contents of this report contact the Geologic Resources Division of the National Park Service, in Denver, Colorado, through the following website: http://www.nature.nps.gov/geology, or by calling 303- 969- 2090.

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 resources serve as the foundation of park ecosystems and yield important information needed 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. 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 274 "Natural Area" parks with a digital geologic map, a geologic evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of park resources and each is designed to be user friendly to non- geoscientists. In preparing products the GRE team works closely with park staff and partners (e.g., USGS, state geologic surveys, and academics).

The GRE teams hold scoping meetings at parks to review available data on the geology of a particular park and to discuss the geologic issues in the park. Park staff are afforded the opportunity to meet with the experts on the geology of their park. Scoping meetings are usually held in each park individually to expedite the process although some scoping meetings address multiple parks within a Vital Signs Monitoring Network.

For additional information regarding the Geologic Resources of Arches National Park, see the Geologic Resources Division website at:
http://www2.nature.nps.gov/geology/parks/arch

Regional Information

Over two thousand natural sandstone arches, the greatest concentration of rock arches in the world, are preserved in Arches National Park (ARCH). This 74,000- acre park is located 5 miles (8 km) north of Moab, Utah, along Highway 191 and is about 25 miles northeast of Canyonlands National Park (figure 1). In addition to the arches, a collection of balanced rocks, fin- shaped rock features, rock pinnacles, folded rock strata draped over salt diapirs, stark exposures of millions of years of geologic history, petrified sand dunes that once swept across a desert landscape millions of years ago, evidence of a sea that once drowned eastern Utah, and a maze of deep narrow canyons grace the park.

Cultural History

Water, or the lack thereof, and the harsh landscape have long discouraged settlers to the area. Prehistoric hunter-gatherers migrated into the area about 10,000 years ago at the end of the Ice Age. They explored the area and found pockets of chert and chalcedony, microcrystalline quartz, and used these minerals to make stone tools.

About two thousand years ago, agriculturalists, known as the ancestral Puebloan and Fremont people, entered the Four Corners region and began to raise maize, beans, and squash. Villages of these people were similar to those preserved in Mesa Verde National Park in southwestern Colorado. None of their dwellings, however, have been discovered in Arches. Instead, these ancestral settlers left pictographs on the rock to mark their passing and lithic fragments around waterholes where they may have shaped tools as did the people before them. Both the Fremont and the ancestral Puebloans left the region about 700 years ago.

The first Europeans to explore the Southwest were Spaniards who crossed the territory in 1776. When they came into the country, they met nomadic Shoshonean peoples such as the Ute and Paiute. What they thought of the arches remains a mystery. Although the Old Spanish Trail linking Santa Fe and Los Angeles ran along the same route, past the park's Visitors Center, that the highway does today, they left no written description of their impressions of the arches. The first reliable date regarding exploration within the Arches is from Denis Julien, a French- American trapper, who carved this description in the rocks, "Denis Julien, June 9, 1844", but left no other impressions.

The Mormons attempted to establish the Elk Mountain Mission in what is now Moab in 1855, but they abandoned the effort due to conflicts with the Utes. By the late 19th century, the United States government had restricted the Southern Ute Reservation to a small portion of southwestern Colorado so that ranchers, prospectors, and farmers permanently established the settlement of Moab in the 1880s and 1890s. A homestead cabin was built by John Wesley Wolfe, a veteran of the Civil War, in 1898 but was abandoned ten years later when he and his family returned to Ohio. The cabin remains on Salt wash, at the beginning of the Delicate Arch Trail.

Establishment of Arches National Park

In 1911, a young man, Loren "Bish" Taylor became owner of the Moab newspaper and began writing about the marvels of Moab and the rock wonderland just north of the frontier town. He explored the area with John "Doc" Williams, Moab's first doctor whose name graces Doc Williams Point that overlooks a series of rock fins. Word spread until the government eventually sent research teams to investigate the area and to gather evidence to support preservation. In 1929, President Herbert Hoover signed the legislation creating Arches National Monument to protect the arches, spires, balanced rocks, and other sandstone formations. Notably, this was in the midst of intense oil exploration in southeastern Utah during the 1920s but about twenty years prior to the uranium boom that would strike southeastern Utah after World War II. Soon after the monument was created, geologists began to take a serious look at Arches. Carle H. Dane (1935) was the first geologist to make a comprehensive geologic study of the area in 1935 as part of his Ph.D. dissertation. As the unique character of the area became more and more apparent, more geologists came to the area and more visitors began arriving to see the arches. Eventually, in 1971, Congress elevated the status of Arches to a National Park.

Additional information may be found on the Arches National Park web site:
http://www.nps.gov/arch/hist.htm.

Geologic Setting

Located in the southeastern corner of Utah, Arches National Park is part of a much larger geological feature called the Colorado Plateau Province. Covering parts of Colorado, Utah, Arizona, and New Mexico, the Colorado Plateau is a region of high plateaus, deep narrow canyons, and broad, rounded uplands separated by vast sage lands used for cattle grazing. Beneath the rangelands are large, elliptical basins.

The structural fabric of gently warped, rounded folds contrasts with the intense deformation and faulting of the terranes bordering the Colorado Plateau. Northeast and east of the Colorado Plateau are the jagged peaks of the Rocky Mountains formed by thrust faulting.
The extensional, normal- faulted Basin- and- Range Province borders the Colorado Plateau to the west and south. The Rio Grande Rift forms the southeast border. The sedimentary rock layers on the Colorado Plateau, while gently folded into anticlines and synclines, remain relatively undisturbed by faulting except in areas associated with salt tectonics. Within the park, the arches and many of the unique features are associated with northwest- southeast trending synclines, anticlines, and normal faults caused by the growth of salt structures and the subsequent dissolution of the salt.

Salt (evaporite) deposits date from the Permian Period when a shallow sea covered the region. Upper Paleozoic through Mesozoic sedimentary rocks are exposed in ARCH or the immediate area (figure 9).

The Entrada Sandstone, which forms the arches, was deposited about 150 million years ago during the Jurassic Period. The Entrada is about 300 feet (91 m) thick and is believed to have been deposited by the wind in a vast coastal desert. Upon hardening into rock, the Entrada Sandstone was uplifted and fractured. After erosion stripped away the overlying layers, the sandstone was exposed to weathering, and the formation of the arches began.

The southern boundary of the park is outlined by the Colorado River. The Colorado River's channel has incised obliquely across the folds suggesting that the river developed independently of any structural control from the surrounding features. These features are illustrated in Doelling (2000).

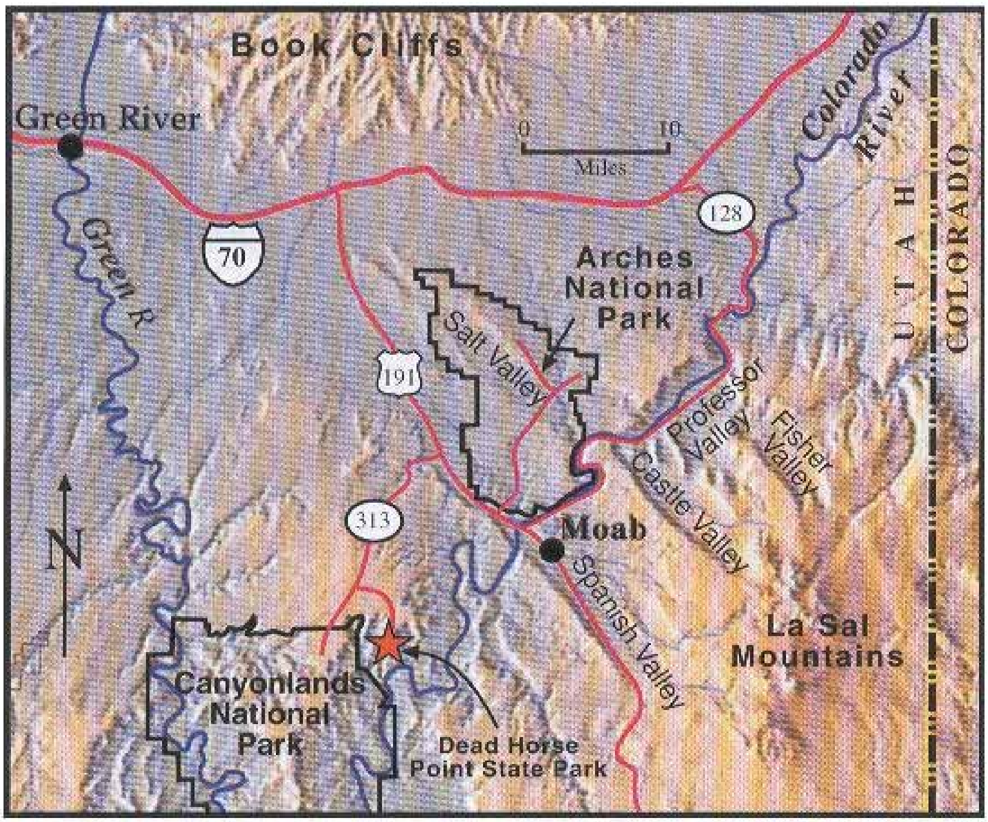


Figure 1: Location Map for Arches NP. From Doelling (2000).

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Arches National Park and other NPS units located in southeastern Utah on May 24- 27, 1999, to discuss geologic resources, to address the status of geologic mapping, and to assess resource management issues and needs. The following section synthesizes the scoping results, in particular, those issues that may require attention from resource managers.

Hydrocarbon Development

The combination of salt, organic- rich shale, porous limestone and sandstone, pressure and time resulted in large accumulations of oil and gas in the Paradox Basin. There are several oil reservoirs in the basin, the most prolific of which are in carbonate algal mounds in the Pennsylvanian age Paradox Formation. Following deformation in the Late Cretaceous- Mid Tertiary Periods, oil generated from Devonian and/or Mississippian- age shales migrated into these porous carbonate reservoirs that were sealed by the overlying salt. The reservoirs are found in Laramide- age anticlines as well as in stratigraphic pinch- outs where the porous reservoir rocks grade into nonporous sedimentary rocks. Hydrocarbons have also been discovered in Devonian and Mississippian limestones and sandstones and in Jurassic and Cretaceous sandstones.

The major hydrocarbon producing fields lie south of the Colorado River in southeast Utah. Lisbon field, the largest field in the vicinity of Arches National Park, lies about 48 km (30 mi) southeast of the park. The smaller Salt Wash field lies about 48 km (30 mi) northwest of the park. Long Canyon, Big Flat, and Shafer Canyon oil fields surround the northern end of the northwest- southeast trending Cane Creek anticline about 16 km (10 mi) southwest of the park (Fouret, 1996). There is also oil production southwest of the park in the vicinity of Dead Horse Point State Park.

The location of abandoned oil and gas wells in the park, if any, is unknown. Apparently, no oil and gas fields were discovered in Arches National Park prior to its designation as a national monument in 1929 although extensive exploration occurred in the Four Corners area during the 1920s. A project statement, ARCH- N-030.000, to locate any abandoned sites is contained in the Water Resources Management Plan prepared for Arches and Canyonlands National Parks (Cudlip et al., 1999).

Uranium Mining

The Paradox Basin has also been the site of uranium mining for most of the past century. The nuclear arms race spurred the first "boom" in the 1950s and early 1960s. A discovery of a large unoxidized ore deposit on the flank of Lisbon Valley anticline, southeast of the park, kindled public excitement in 1952 (Chenoweth, 1996). A second, short lived, "boom" came in the late 1970s and early 1980s as a result of interest in nuclear power plant fuel.

Although uranium ultimately comes from igneous rocks, the principal host rocks for the radium, vanadium, and uranium deposits are fluvial deposits in Mesozoic rocks. The principal host rocks are the Salt Wash member of the Jurassic Morrison Formation and the Triassic Chinle Formation. The ore bodies in the Salt Wash member consist of concentrations of uranium and vanadium minerals within the fluvial sandstones. Miners also sought fossilized logs because carnotite, a potassium-uranium vanadate, typically replaced the original organic material in the wood (Chenoweth, 1996). In the Chinle, gray, poorly sorted, fine- to coarse- grained, calcareous, arkosic, quartzose sandstone contains the uranium ore.

With decreased interest in nuclear energy, a decrease in nuclear arms proliferation, foreign competition, and excess inventories of uranium worldwide, prices for uranium ore declined and with them, the interest in uranium mining. The impacts of uranium mining, however, remain. On the northwest bank of the Colorado River, southeast of Arches Headquarters and 3 km (1.9 mi) northwest of Moab, sits the mill site and associated tailings of the now decommissioned Atlas Corporation Moab Mill Site. The site includes 400 acres (162 hectares) of processing facility, tailings pond and 10.5 million ton (9.5 million metric ton) tailings pile (Cudlip et al., 1999). Cudlip et al., 1999, outlined two concerns over the mill site: 1) an elevated ammonia level in the Colorado River downstream of the pile, and 2) potential radioactivity in the form of alpha particle levels in the primary drinking water well at Arches Headquarters. While groundwater typically flows from the northwest to the southeast towards the Colorado River, the water level within the tailings pile is above the alluvial groundwater, and hydraulic pressure variations within the pile may change the flow patterns under the mill and tailing site.

Although no official documents are known to date that identify the Atlas tailings pile as an issue, the eventual disposition of this tailings pile "will definitely affect Arches National Park, whether the pile is moved or capped" (comments from ARCH staff, July 9, 2003).

Uranium mining has also occurred elsewhere in the area, particularly in the Yellow Flat area northeast of the park.

Water Quality and Flash Flooding

Water plays a key role in defining and shaping the desert landscapes that encompass Arches National Park. The climate of Arches National Park is classified as semi- arid to arid. Typically, annual precipitation is less than 20 cm (8 in). The park has distinct winter and summer precipitation maxima (Cudlip et al., 1999). The summer rainy season in July and August results from an influx of monsoon air from the south. During the winter, infrequent intrusions of Pacific air bring snow. Potential evaporation can equal 101 cm/yr (40 in/yr).

Because of the low precipitation and high evaporation rates, recharge rates to groundwater are low. The Entrada, Navajo and Wingate sandstones serve as aquifers and are underlain by relatively impermeable strata. The groundwater may be Pleistocene in age and if so, the groundwater system is vulnerable to permanent drawdown (Cudlip et al, 1999). Groundwater mining for park operations, therefore, must be carefully managed.

Because many of the formations underlying Arches National Park were deposited in marine environments, the natural dissolved solids content in groundwater is high and affects water quality. The water well for the park headquarters, for example, is in the Navajo Sandstone and is relatively high in both dissolved solids content and high specific electrical conductance (see Cudlip et al., 1999, for water quality data). Since current flows in ionized or mineralized water, high specific conductance translates into high mineral content.

Springs and seeps in Arches are not large but provide a vital source of water for wildlife, aquatic organisms, vegetation, and visitors. Discharge is typically low from these seeps and springs. In Arches, the seep line between the Moab member of the Curtis Formation and the Slick Rock member of the Entrada Sandstone supports hanging gardens containing a myriad of endemic plants and invertebrates (Cudlip et al., 1999). Groundwater removal from slowly recharged sandstone aquifers may impact these organisms.

Flash flooding occurs in Arches National Park as a result of summer thunderstorms rather than spring snowmelt. During storm events, large amounts of water, debris, and sediment flow through channels and canyons cut by fluvial processes. Perennial streams in Salt Wash and Courthouse Wash drain into the Colorado River.

After the storms pass, the streambeds again go dry; however, rainwater can still be found in the natural potholes that form in this slickrock country. Sculptured in the soft sandstone, these small catchment basins vary in size and carry water for a time after a storm depending on the intensity and duration of the storm, the size of the pothole, and the rate of evaporation.

Water management is critical to Arches National Park. Water quality is affected by a number of sources including:

- Salinity from salt dissolution by meteoric groundwater
- Naturally high dissolved solids from geologic formations deposited in marine environments
- Selenium from Mancos shale
- Potential external threats such as increased impacts from irrigated agriculture, oil and gas development, and leaching from uranium mine spoil material

All of these concerns are addressed in the Water Resources Management Plan: Arches National Park & Canyonlands National Park, Utah (Cudlip et al., 1999).

Preservation of Fossils

A detailed description of the paleontology and biostratigraphy of Arches National Park is beyond the scope of this report. A summary of some of the fossil discoveries within and near Arches may be found in A Survey of Paleontologic Resources from the National Parks and Monuments in Utah by Vincent Santucci (2000) and from the following references:

Duffy, S., 1993, Synopsis of the dinosaur megatrack site in Arches National Park, *in* V. L. Santucci, ed., National Park Service Natural Resources Technical Report NPS/NRPO/NRTR- 93/11:4

Engelmann, G. F. and Hasiotis, S. T., 1999, Deep dinosaur tracks in the Morrison Formation: sole marks that are really sole marks, *in* D. D. Gillette, ed., Vertebrate Paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99- 1, p. 179- 183.

Lockley, M. G., 1990, Tracking the Rise of Dinosaurs in Eastern Utah: Canyon Legacy 2: 2- 8.

Lockley, M.C., Kirkland, J.I., DeCourten, F.L., Britt, B.B., and Hasiotis, S.T., 1999, Dinosaur tracks from the Cedar Mountain Formation of eastern Utah – a preliminary report, *in* D.D. Gillette, ed., Vertebrate Paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99- 1, p. 253- 257.

Mead, J. I., Sharp, S. E., and Agenbroad, L. D., 1991, Holocene Bison from Arches National Park, southeastern Utah: Great Basin Naturalist 51 (4), p. 336- 342.

Molenaar, C. M., and Cobban, W. A., 1991, Middle Cretaceous stratigraphy on the south and east sides of the Uinta Basin, northeastern Utah and northwestern Colorado: U.S.G.S. Bulletin 1787, 34 p

Other Geological Issues

The Southeast Utah Group (SEUG) Geologic Resources Inventory (GRI) Workshop held in 1999 identified the following potential geological issues related to the SEUG parks (Arches NP, Canyonlands NP, Hovenweep NM, and Natural Bridges NM) (SEUG, 1999).

- Landslide and rockfall potential. These occasionally cause road problems, including road closures. The main road in Arches, just inside the Visitor's Center, is of special concern. Rockfalls also occur in other areas of the park. Several large sandstone pieces fell from the bottom side of the span of Landscape Arch several years ago, the event was recorded by a tourist.

- Swelling soils associated with bentonitic shale in the Chinle, Morrison, and Mancos formations.

- Radon potential associated with mine openings.

- Earthquake potential along the Moab Fault.

In addition, a 1990 management report for Arches identified the following external threats that could cause damage to the geological resources in the park (Statement of Management, 1990):

- Low flying military jet aircraft often cause sonic booms that could affect geological features.

- Livestock grazing impacts springs, seeps, streams, and cryptobiotic soils in the park, in areas where there is no fencing.

- Potential impact on geological features from a toxic waste incinerator proposed for Green River, Utah. Green River is on the northwest side of the park and the prevailing winds in Arches are from that direction.

- Aesthetic impacts as a result of reduced visibility from dust and other particulate matter with increased potash mining and intrusions on the viewshed from regional oil and gas development.

- Increased acid deposition from harmful chemicals and particulates produced by the Navajo Power Plant, 240 km (150 mi) to the southwest; the Four Corners Plant, 178 km (111 mi) to the southeast; and Emery and Huntington Plants, 150 km (94 mi) to the northwest.

- Destruction of cryptobiotic soils by humans and livestock.

Research Projects

The SEUG/GRI workshop (1999) listed the following potential research topics:

- The affect of acid rain on the deterioration of the sandstone arches

- A study of the connections between gypsiferous rocks and cryptobiotic soils and crusts addressing why the crusts are healthier on gypsum- bearing rocks.

- Erosion and weathering process study to determine how long Delicate Arch will stand.

- Engineering studies of landslides and mass movements using a strain meter to assess hazards to visitors.

- A project to measure and detect moving, swelling, and collapse of rock strata in areas of the park using high resolution Geographic Positioning System (GPS).

- Studies focused on rock color. For example, some red rocks are the result of diagenetic processes and are not the result of oxidation while exposed at or near the surface of Earth.

- Locate and map the unconformity between the Entrada Moab Tongue and adjacent formations.

Additional geologic studies might focus on the following topics:

- Identifying unconformity- bounded stratigraphic packages in order to better define the depositional systems in the past. The studies using the Book Cliffs outcrops, north of the park, could be used as models.

- Detailed sedimentological analysis of the Cutler Formation in the region as well as geochemical and diagenesis analyses to study why the lower sandstones are mottled.

- Hydrogeologic studies to define subsurface flow patterns, regional and local flow systems, and the conductivity and transmissivity of the various aquifers especially in relation to abandoned or operating mines within and adjacent to the park.

- Paleontological resources need to be inventoried, monitored, and protected, especially in the Dalton Wells area.

Interpretive Needs

Two interpretive needs were addressed by the SEUG/GRI workshop (1999):

- The development of more graphics and brochures emphasizing geology. These should target the average park enthusiast.

- The possibility of hiring a full- time geologist to handle geologic issues for the SEUG.

Geologic Features and Processes

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

Arches, fins, salt structures, balanced rocks, folds, faults, and joints are displayed in Arches National Park. The greatest concentration of natural rock arches anywhere in the world grace the landscape of Arches National Park. In addition, few other areas in the world display the salt- tectonic and salt- dissolution features that are so magnificently displayed in Salt and Cache Valleys. The features are enhanced by colorful Mesozoic strata. Balanced rocks in the park are striking examples of features shaped by both wind erosion and solution. The arid climate discourages heavy vegetation and deep soils that would otherwise mask these features.

The arches and fins at Arches National Park are the result of the dry climate, the massive brittle sandstones and their susceptibility to weathering, the vertical joints in the sandstones produced by folding, and the proximity of the sandstones to salt- cored anticlines undergoing dissolution. Most of the arches and fins are associated with the Entrada Sandstone and form where the formation overlies an anticline on which closely spaced parallel fractures developed. Good examples of solution- induced anticlines and Entrada Sandstone arches can be found at Klondike bluffs, Devils Garden, Fiery Furnace, and Herdina Park. Elephant Butte, in the Windows section of Arches National Park, is a remnant of Entrada Sandstone that arched over an anticline that was probably not formed by dissolution (Doelling, 1985).

Because the Entrada Sandstone is a massive crossbedded sandstone, it is highly susceptible to a style of weathering called exfoliation wherein slabs of sandstone peel from the bedrock in a series of concentric layers (Harris et al., 1997). The Slick Rock member of the Entrada Sandstone also is composed primarily of quartz grains that are cemented together by calcium carbonate ($CaCO_3$). Rain water, charged with atmospheric carbon dioxide (CO_2), forms weak carbonic acid that is very effective at dissolving $CaCO_3$. When the cement dissolves, the individual sand grains accumulate on the surface of the parent Entrada Sandstone.

Wind and water erosion focuses along the large joints, widening the gaps between the linear cracks, and carves fin- like structures in the large slabs of rock (figure 2). Further erosion of the fins creates large holes and arches out of the fins. The fins are assumed to have formed in response to the compressional tectonic forces during the Laramide Orogeny (Doelling, 2000). A discussion of the jointing in Arches National Park is found in Dyer (1983), Cruikshank (1993), and in Cruikshank and Aydin (1993).

Water also seeps into fractures in the Entrada Sandstone and along the contacts with the Moab member of the Curtis Formation or the Dewey Bridge member of the Carmel Formation. Thin openings form along these partings (diagram A of figure 3). Fractures, created by tensional stresses in the rock, propagate upward into the overlying rock (diagram B of figure 3). Groundwater further dissolves the cement along these fractures until the roof of the opening collapses forming the typical stable arch form, neutralizing the stress, and inhibiting further collapse (diagram C of figure 3). Delicate Arch is an example of an arch formed by the contact of the Moab member with the Slick Rock member while Skyline Arch formed along a parting entirely within the Slick Rock member. The Windows Arch formed along the Dewey Bridge- Slick Rock contact. This arch enlarges with the erosion of the soft Dewey Bridge member (Doelling, 1985).

Salt- cored anticlines (salt walls) trend northwest-southeast through Arches National Park. The Salt Valley and the Moab Valley salt walls lie directly under anticlinal salt- cored axes. The salt walls that underlie Salt Valley, Cache Valley, and the Moab anticline in Arches are 3.2 km (2 mi) high, as much as 4.8- 6.4 km (3 to 4 mi) wide, and 112 km (70 mi) long (Doelling, 2000). The Moab anticline plunges to the north and gradually dies out about 10 km (6 mi) northwest of Moab Valley. The Courthouse syncline borders the Moab anticline to the northeast.

Abundant normal faults and joints parallel the trends of the Moab anticline, the Elephant Butte anticline, and the salt- cored anticlines in Salt Valley and Cache Valley (Doelling, 1985, 2000).

The tilted and broken blocks of strata that parallel the salt valleys in ARCH are structural features resulting from the dissolution of subsurface salt. Development of salt dissolution structures mentioned above is illustrated in a series of diagrams in figure 4. In the first diagram, sandstones and shales bury the salt- rich, Pennsylvanian Period Paradox Formation. The layers are parallel until pressure change at depth causes the relatively plastic, buoyant salt to begin to flow upward through the rock column. The sedimentary strata above the salt are deformed into an anticline. Extensional fractures and normal faults develop along the crest and limbs of the anticline and allow water to seep downward through the cracks. When groundwater comes into contact with the salt, the salt dissolves. With dissolution, the overlying strata collapse and a graben valley is formed bounded by a normal fault. The Moab anticline, north of the Colorado River, is a good example of the collapse of the crestal part of a salt- cored anticline (Doelling, 1985). The strata in the hinge zone of the collapsed structure roll over into the graben, and large joints form to accommodate the movement. This process is illustrated along parts of Salt Valley, especially in the area of Fiery Furnace.

Salt dissolution and salt flowage continue today. Unequal loading on the salt beds will cause salt to flow. Salt flowage may seal fractures, "heal" fault planes, fill in voids created by previous salt dissolution, and cause bulges to form at the surface. Because salt movement is slow, groundwater usually dissolves the salt before it reaches the surface. Today, the Colorado River controls salt dissolution by controlling the depth to which it allows fresh water to reach the salt, which, in turn, is controlled, by the depth to which the river has cut its canyon.

Delicate Arch

The Slick Rock member of the Entrada Sandstone forms the base and pedestals of this world- famous, free-standing arch while the Moab member of the Curtis Formation forms the bridge. The contact between the two is a plane of weakness along an unconformity. Delicate Arch has a horizontal span of about 10 m (32 ft) and a vertical span of 14 m (46 ft). The top of the arch is about 16 m (52 ft) over the base.

Landscape Arch

With an opening of 93 m (306 ft) wide and more than 27 m (88 ft) high, Landscape Arch is the longest span in the park (figure 5) (Doelling, 2000). One end of the arch is only 1.8 m (6 ft) thick while in the center of the arch, the hump spreads 6 m (20 ft) wide and weighs thousands of tons. Originally, Landscape Arch began as a cliff- wall arch but is now classified as a free- standing arch. The arch is entirely encased within a fin of the Slick Rock member.

The Windows Section

Mostly free- standing arches, the Windows are massive arches formed in a wall of the Slick Rock member underlain by the Dewey Bridge member. Well known arches in this area include: the Parade of Elephants, North Window, South Window, and Turret Arch. This area is also a good place to see alcoves (Cove of Caves) and the erosional expression of the softer Dewey Bridge member of the Carmel Formation (Garden of Eden) (Doelling, 2000).

Balanced Rock

Balanced Rock (figure 6) is perched precariously near the Windows and is an excellent example of a feature shaped by wind and water (Harris et al., 1997). Weathered in place, the resistant block of Slick Rock sandstone "balances" on top of the Dewey Bridge member of the Carmel Formation that rests above the Navajo Sandstone.

Park Avenue

The bust of Queen Nefertiti and Popsicle Rock, two other balanced rocks, can be seen on the short, 1.3 km (0.8 mile) trail in the area of the Courthouse Towers. Two high monoliths of the Slick Rock member of the Entrada Sandstone underlain with the Dewey Bridge member of the Carmel Formation guard the entrance to the trail. The Three Gossips and the Organ can also be seen along the trail. Baby Arch, an opening in its developing stage, is at the end of the trail.

Devils Garden

A walk through the Devils Garden from the Fiery Furnace northward to Dark Angel along the northeast rim of Salt Valley reveals 123 arches, most of which are free standing or cliff- wall arches. Sand Dune Arch, Broken Arch, Tunnel Arch, Pine Tree Arch, Navajo Arch, Double O Arch, Landscape Arch (figure 5), and Skyline Arch (figure 7) are some of the more well- known arches along this 11.5 km (7.2 mi) round trip trail.

The Great Wall

A wall of Entrada Sandstone stretches for about 6.4 km (4 mi) along the highway from about a mile north of the Tower of Babel to Balanced Rock. Hidden along this wall are several arches, especially pothole arches (Doelling, 2000).

Klondike Bluffs

Tower Arch is the most famous arch at Klondike Bluffs, an area of fins and exposures of the Entrada Sandstone on the southeast rim of the Salt Valley anticline. The Marching Men, another unique erosional feature, is also located in the Klondike Bluffs area (Doelling, 2000).

Moab Fault

The Moab fault is a major fault that parallels the Moab anticline just south of the Visitor's Center. Drill holes have shown that this fault cuts through and parallels the middle of the 3.2 km (2 mile) wide Moab Valley salt wall. The block of rock on the northeast side of the Moab fault has dropped down relative to the block on the southwest side. At the Visitor's Center, the Pennsylvanian Honaker Trail Formation rests against the Jurassic Entrada Sandstone, or in terms of ages, rocks deposited about 295 million years ago (Pennsylvanian) rest against rocks deposited about 150 million years ago (Jurassic). For such a situation to occur, displacement across the Moab fault was at least 732 m (2,400 ft) (Doelling, 2000). From the Visitor's Center, two branches of the fault can be seen. Like the Moab fault, the primary movement along the swarm of normal faults located on the Moab anticline is down to the northeast relative to the southwest blocks (Doelling, 1985, 2000).

The northern block has dropped down relative to the southern block on the normal fault located on the crest of the Elephant Butte anticline, also. Along the borders of Salt Valley and Cache Valley, normal faults are mapped on the surface with their down- dropped blocks on the valley side of the fault. Major normal faults, with displacements down to the northeast, have also been interpreted to exist in the subsurface along the crest of the salt- cored anticlines in Moab and Salt Valleys (Doelling, 1985, 2000). Where the normal fault in Salt Valley is exposed at the surface, isolated protrusions of

Paradox Formation caprock, covered by the upper Chinle Formation, form the southwest block of the fault, and these strata are juxtaposed against collapsed Mesozoic rocks on the northeast side of the fault (Doelling, 1985, 2000). Salt dissolution events have deformed Triassic through Cretaceous strata on the northeast side of the fault so displacement caused only by this fault cannot be accurately determined.

Fiery Furnace

The Fiery Furnace (figure 8) is a maze- like labyrinth between Entrada Sandstone fins at the south end of Devils Garden. Because the maze is so complex, first-time visitors are recommended to accompany a ranger on a guided walk or obtain a printed trail guide. Former arches that have collapsed are also present in the maze (Doelling, 2000).

Cache Valley

The same salt wall extends under both Salt Valley and Cache Valley although the wall trends northwest under Salt Valley and east- west under Cache Valley (Doelling, 2000). Cache Valley extends east of the park boundary and is the best place to view and study the effects of dissolution collapse. Unlike Salt Valley where the collapsed rocks are covered with unconsolidated Quaternary deposits, the collapsed rocks in Cache Valley are not buried.

Elephant Butte Folds

Several paralleling anticlines and synclines have developed on the southwest and south sides of Salt Valley and Cache Valley as dissolution collapse has begun on the crest of the Salt Valley- Cache Valley salt-cored anticline (Doelling, 2000). The V- shaped synclines lie between sharp, linear anticlines. Eventually, the fold areas will become part of the Salt Valley- Cache Valley graben. Numerous talus piles of Morrison and Cedar Mountain Formation rocks line the axial areas of the synclines. These rocks once formed the cliffs that outlined the valley rims, but now, the cliffs have been eroded back several miles. The main paved road traverses the folds between Balanced Rock and Panorama Point.

Petrified Dunes

The Jurassic age sand dunes of the Navajo Sandstone are preserved in the area east of the Great Wall. The Navajo desert rivaled today's Sahara Desert in size. Exposed on the bare- rock outcrops of the Navajo are sweeping high- angle crossbeds truncated by crossbed set boundaries. These ancient dunes were cemented into solid rock and when exposed on the surface, have been eroded into rounded domes called petrified dunes or frozen dunes (Doelling, 2000)

Figure 2: Entrada Sandstone fins. Joints at rollovers open and form fins along Salt Valley graben rims. Weakly cemented partings in fins can then weather into arches. From Doelling, 2000

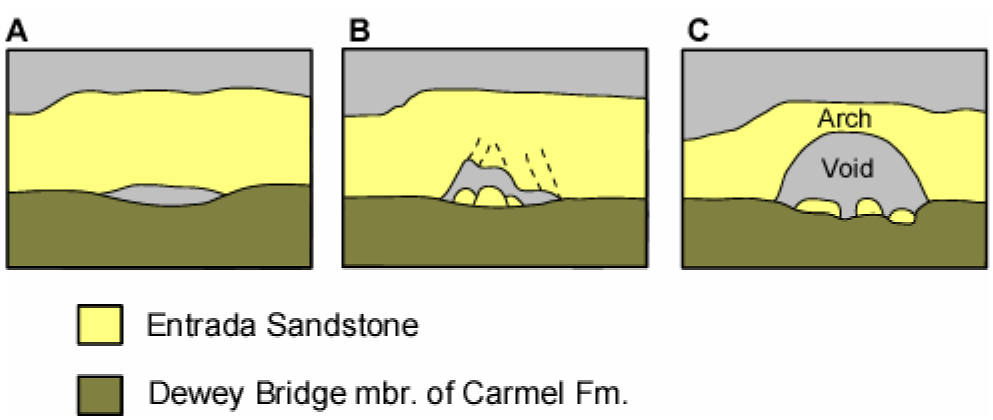


Figure 3: Diagrams illustrating the formation of an arch from a parting developing between the Entrada Sandstone and the Dewey Bridge member of the Carmel Formation. An explanation is in the text. Modified from Doelling, 1985.

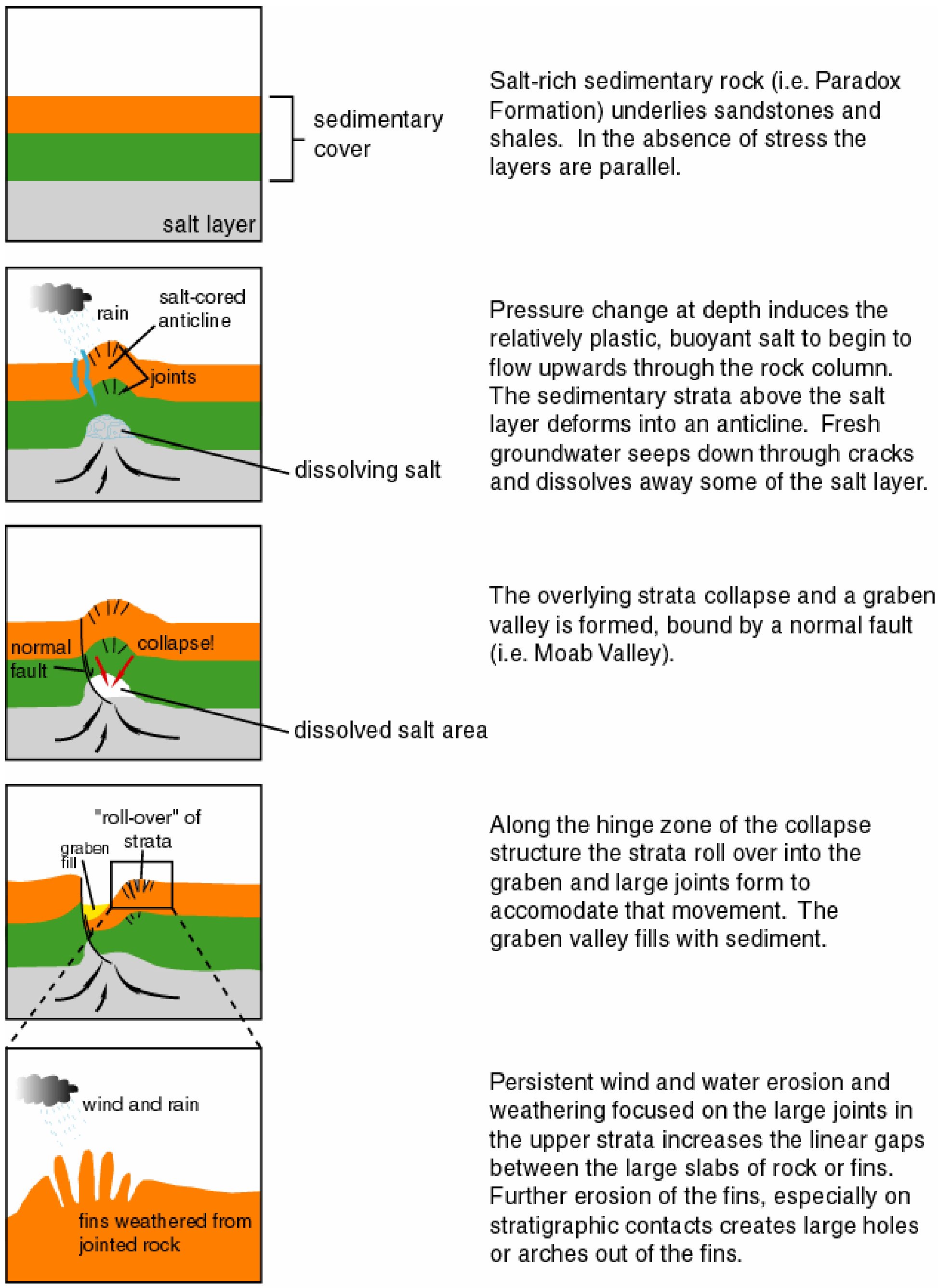


Figure 4: Schematic diagrams illustrating the formation of salt anticlines and salt dissolution structures. See text for further explanation

Figure 5: Landscape Arch with a span of 93 m (306 ft) is the longest span in the park. From Doelling (2000).

Figure 6: Balanced Rock. Well-known and a central landmark in Arches National Park, balanced rock is a huge orange-brown bulb of the Slick Rock member resting on a narrow dark-brown pedestal of the Dewey Bridge member. From Doelling (2000).

Figure 7: Skyline Arch. The opening is 22 m (71 ft) wide and 10 m (33.5 ft) high. The arch is formed along a parting in the Slick Rock member of the Entrada Sandstone. From Doelling, 2000.

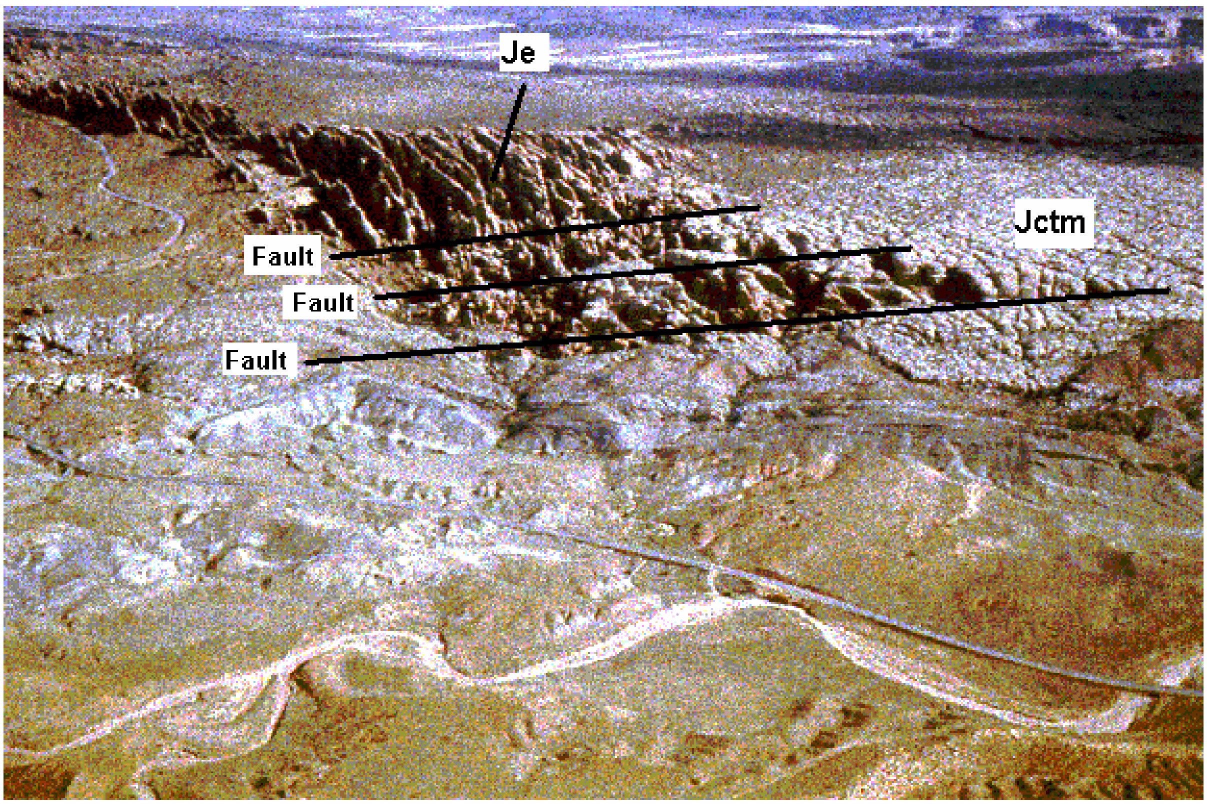


Figure 8: Aerial view toward the Fiery Furnace. Notice how the joints in the Entrada Sandstone (Je) terminate against collapsed rock as Salt Valley turns to trend east-west and join with Cache Valley. The light biscuit board surface areas are the Moab member of the Curtis Formation (Jctm). From Doelling, 2000.

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Arches National Park. Unit descriptions are highly generalized and are provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this section. 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.

Middle Pennsylvanian to Late Cretaceous- age sedimentary rock formations are exposed within Arches National Park (figure 9) (Doelling, 1985, 2000). Although these rocks cover a time period from 300 to 85 million years ago (Ma), they do not represent a period of continuous deposition. Rather, the contacts between the layers are unconformities that represent large gaps in time (figure 10).

The rock formations represent both marine and nonmarine depositional environments. Some of the environments represented include warm, shallow seas, deep ocean basins, beach and tidal- flat areas, sand dunes, and fluvial channel and overbank deposits. The formations are identified on figure 9.

In some places, unconsolidated deposits of sand, silt, gravel, and clay overlie the consolidated rock layers. Mixtures of these sediments are products of recent weathering and erosion processes and are only temporary deposits. Wind, water, and gravity have generated eolian (wind) and alluvial (river) deposits, terrace deposit, and landslides (Doelling, 1985, 2000).

Paleozoic Era:

Middle Pennsylvanian Period -
Paradox Formation

The Paradox Formation within the Pennsylvanian Period (286- 320 Ma) comprises the oldest rocks exposed in Arches National Park (figure 2; figure 9; Appendix A). In general, the Paradox Formation is made up of a series of cyclic deposits containing anhydrite (found in evaporite deposits), silty dolomite, black shale, and halite (table salt) (Rueger, 1996). Groundwater dissolves salt near the surface so that the Paradox Formation exposed in Arches consists of a cap rock of contorted gray shale, carbonaceous shale, some gypsum beds, and thin limestone beds that have remained in place following the dissolution of interbedded salts. This cap rock overlies thick salt deposits of anhydrite, halite, and other types of salt that have not been exposed to intense groundwater leaching.

The Paradox Formation is more than 3,048 m (10,000 ft) thick in some areas of the park such as under Salt Valley, Cache Valley, and Moab Valley (Doelling, 2000). Individual salt beds can be more than 274 m (900 ft) thick in areas where the Paradox Formation is very extensive. While the Paradox Formation salt underlies large areas of Arches, only the cap rock is exposed at the surface. In the middle of Salt Valley, west of Devils Garden, cap rock crops out along the Klondike Bluffs access road. Contorted thin limestone, gray shale, and other insoluble rock are well displayed along the sides of the Salt Valley Wash.

Upper Pennsylvanian Period -
Honaker Trail Formation

Overlying the Paradox Formation is the Honaker Trail Formation (figure 9). The most common rock types in the Honaker Trail Formation at ARCH are limestone and sandstone (Doelling, 2000). Both limestone and sandstone are resistant to weathering and form ledges and cliffs in ARCH. The gray, thin to medium bedded limestone is cherty, argillaceous (containing clay minerals), and fossiliferous. The beds commonly weather to hackly surfaces and to nodular shapes. The fossils include normal marine invertebrate fauna such as brachiopods, horn corals, bryozoa, and crinoids. Paleontologists have used trilobites and numerous fusulinids to date the uppermost beds in ARCH as latest Pennsylvanian in age (Doelling, 2000).

The white, yellow gray, red, maroon, and lavender sandstones are fine to medium grained, mostly well sorted, and are found in beds that range from medium to massive (homogeneous beds containing no internal structures) (Doelling, 2000). The sandstones are subarkosic or micaceous, containing high percentages of feldspar and mica. Like the limestones, the sandstones form resistant ledges and cliffs. Minor beds of shale and siltstone are interlayered with the limestones and sandstones in the Honaker Trail Formation.

The thickness of the Honaker Trail Formation varies between 0 and 671 m (2,200 ft) in Arches National Park (Doelling, 2000). In areas where the underlying Paradox Formation is very thick, the Honaker Trail Formation is thin or missing. On the other hand, where the Paradox Formation is thin, perhaps due to the dissolution or non- deposition of salt, the Honaker Trail Formation is exceptionally thick. The Honaker Trail Formation is only exposed near the Visitor's Center in Arches (Doelling, 1985, 2000). Southwest of the Visitor's Center, however, more than 182 m (600 ft) of the Honaker Trail

Formation is visible on a bench above U.S. Highway 191 and the railroad (Doelling, 2000).

Permian Period - Cutler Formation

The contact between the Cutler Formation and the Honaker Trail Formation is an unconformity, but the contact and the Cutler Formation are buried beneath younger formations in the park (figure 9). On the walls of Poison Spider Mesa, the mesa directly southwest of the Visitor's Center and Highway 191, the Cutler Formation consists primarily of interbedded sandstone and conglomerate.

The red- brown to orange brown sandstone is mostly fine- to medium- grained and is classified as a subarkosic (95% to 75% quartz) to quartzose (100% to 95% quartz) sandstone. The sandstones are moderately well- sorted but contain fragments of mica. Sedimentary structures include tabular- planar crossbedding and horizontal bedding (Doelling, 2000). The subarkose and quartzose sandstones are well indurated and generally more resistant than the red- purple arkosic sandstones and conglomeratic sandstones that are also found in the Cutler Formation.

As the feldspar content increases, the sandstone becomes red- purple in color and is an arkosic sandstone, a sandstone that contains from 100% to 75% feldspar grains and less than 25% quartz grains along with some minor (< 10%) rock fragments. As with the subarkosic sandstones of the Honaker Trail Formation, the subarkose and arkose of the Cutler indicate that the sediment was deposited a relatively short distance from its source. Because they are deposited near the source area and rapidly buried by additional sediment, the arkosic rocks have not been severely weathered, the grains haven't been rounded, and the more unstable minerals like feldspar have not been removed. Thus, the arkosic rocks are poorly sorted and medium- to coarse-grained. Sedimentary structures in the arkosic sandstones include trough crossbedding and cut- and-fill structures where fluvial channels were cut in the underlying sediment and backfilled with arkosic sediments.

The conglomeratic sandstones are also poorly sorted but the size of the grains suggests either high energy or deposition close to the source or both. The pebbles and cobbles, commonly as much as 5 cm (2 in) in diameter, are composed of the igneous rock, granite, and gneiss eroded from the Uncompahgre Highlands that rose to the east of ARCH during the Pennsylvanian and Permian Periods (Doelling, 2000).

In the lower part of the Cutler Formation, the sandstone beds are mottled, a nearly white color, and are interbedded with a few siltstone and limestone beds. The thinly- bedded, slope- forming siltstones are generally purple, red, or green. The light gray, bioclastic limestone is more resistant than the interbedded siltstone and forms ledges of thin to medium thick beds (Doelling, 2000). Because of the unique nature of the lower Cutler relative to the upper Cutler, the limestone, mottled sandstone, and siltstone beds were formerly divided into a separate geologic unit known as the Rico Formation (McKnight, 1940). Now, the informal lower Cutler beds are being applied to the Upper Pennsylvanian and Lower Permian strata and the Rico Formation name is being abandoned (Condon, 1997; Dubiel et al., 1996; Loope et al., 1990; Sanderson et al., 1990).

The Cutler Formation is missing over the thick Paradox Formation salt that underlies Salt and Cache valleys in the park and Moab Valley south of the park. The Honaker Trail Formation is also thin or missing over the thick Paradox Formation. The formations may have been eroded from the area when the salt began to flow upward and the strata bowed into an anticline. The most accessible location of exposed Cutler Formation rocks lies outside of the park, northwest of the Visitor's Center on Poison Spider Mesa. At the head of Little Valley, on the southwest side of U.S. Highway 191, the Cutler is 335 m (1,100 ft) thick, but it pinches out at the southwest margin of Moab Valley, just a little south of the covered tailings pond southeast of the Visitor's Center (Doelling, 1985, 2000). The Cutler Formation probably ranges in thickness from 0 to 457 m (1,500 ft) or more beneath the park (Doelling, 2000).

Mesozoic Era

Triassic Period - Moenkopi Formation

The chocolate- brown, sedimentary rocks of the Moenkopi Formation are separated from the underlying red- brown, orange- brown, or red- purple sedimentary rocks of the Cutler Formation by a slightly angular unconformity (figure 9) (Doelling, 2000). In the area of Arches National Park, the Moenkopi Formation can be subdivided into three members. In ascending order these are: the Tenderfoot member, the Ali Baba member, and the Sewemup member (pronounced sew- em- up). A thin basal conglomerate containing quartz, feldspar, and chert is present at the base of the formation.

The Tenderfoot member of the Moenkopi Formation forms a steep, lower slope and consists of medium-chocolate- brown, silty sandstone interbedded with sandy mudstone, fissile (flaky) siltstone, and shale (Doelling, 2000). Although relatively continuous across Arches National Park, the bedding is thin and indistinct. The sandstone and siltstone are micaceous. The thin bedded, fine- grained sandstone beds commonly contain ripple marks. The thin beds of the lower steep slope become progressively thicker upsection and eventually form distinct ledges (Doelling, 2000).

The Ali Baba member forms a ledge- forming unit that contains similar sedimentary rocks as the Tenderfoot member. The Ali Baba member is distinguished from the upper and lower units because of its thicker bedding and ledge- forming characteristics. The change from the Ali Baba ledges to the Sewemup member is abrupt. The Sewemup member forms an upper steep slope with thin to fissile beds and is a lighter brown rather than the medium- chocolate- brown of the underlying members (Doelling, 2000). In the Big Bend area along the Colorado River just south of Mat Martin Point, the Moenkopi has a thin, ledge- forming member known as the Pariott member. Red- brown to lavender, fine- to medium- grained sandstone is interbedded with chocolate- brown, orange- brown, and red siltstone, mudstone, and shale. Some of the beds in the overlying Chinle Formation resemble those in the Pariott member beds.

Exposures of the Moenkopi Formation are found at the Big Bend of the Colorado River and in scattered outcrops along the south margin of Salt Valley extending from Salt Wash eastward for about four miles. A complete outcrop of the formation is present on the cliff wall below Poison Spider Mesa. The Moenkopi below Poison Spider Mesa is about 104 m (340 ft) thick but thins southeastward until it pinches out adjacent to Moab Valley (Doelling, 2000). Where Paradox salt accumulated, the Moenkopi, like the Cutler Formation, is thin or missing. From drill holes in and adjacent to the park, the Moenkopi Formation is estimated to be zero to 396 m (1,300 ft) thick in the park area.

Chinle Formation

About 5 million years is missing between the end of the Lower Triassic, Moenkopi Formation and the beginning of the Upper Triassic, Chinle Formation (figure 9) (Dubiel, 1994; Doelling, 2000). The unconformable contact is marked by the change from the steep, light- chocolate- brown slope of the upper Moenkopi to the red and commonly ledgy slopes of the Chinle Formation (Doelling, 2000). Chinle beds may form a disconformity or a more easily recognizable angular unconformity with the underlying Moenkopi beds. A thin white or light- pink- gray ledge of sandstone is commonly found at the base of the Chinle and is a marker that is easily seen on most cliff faces (Doelling, 2000). A varicolored sandstone and conglomerate overlie the white ledge and is designated the lower Chinle.

The light- green- gray, orange- pink, and pale- red- brown, interbedded sandstone, conglomerate, siltstone, and mudstone that make up the lower Chinle are commonly discolored with white, light gray, red, purple, yellow, orange, and red brown mottles (Doelling, 2000). Thin to massive ledges and cliffs of sandstone are separated from one another by narrow steep slopes of mudstone and siltstone. The quartz grains in the fine- to coarse- grained sandstone and conglomerate are poorly sorted and subrounded to round. Chert and feldspar grains are present, as well.

Doelling (2000) recognizes another unconformity separating the upper Chinle from the lower Chinle in ARCH, but no unconformity is recognized within the Chinle of southwest Utah by Dubiel (1994). A lower slope- forming unit, a middle ledge- forming unit, and an upper slope- forming unit characterize the upper member on a local scale (Doelling, 2000). The lower slope is formed by gray- red and green- gray interbedded siltstone, mudstone, and sandstone. The siltstone and mudstone are commonly micaceous and weather into rectangular fragments. The medium- grained sandstone and brown conglomeratic sandstone form thin, discontinuous ledges in the lower slope. Ripple laminations and small- scale crossbeds are sedimentary structures found within the sandstone. Calcareous, conglomeratic sandstones contain intraformational clasts (clasts formed from Chinle strata) and form lenses with scoured bases (Doelling, 2000).

In the middle ledge, brown- gray, green gray, and red- brown conglomeratic sandstone and non- conglomeratic sandstone are interbedded with red- brown siltstone and mudstone. Thick to massive ledges of sandstone are separated by thin slopes of siltstone and mudstone in the middle unit. Petrified wood is commonly found in the conglomeratic sandstone. Some of the ledges in the middle ledge- forming unit are not well developed and are not discernible east of the Park.

The upper slope- forming unit in the upper Chinle is similar to the lower except for 0.3 to 11 m (3 to 35 ft) of light- brown to red- orange, very fine to fine- grained sandstones near the top of the unit (Doelling, 2000). The thick- bedded sandstones are mostly horizontally laminated but faint crossbedding is locally present. Interbedded with these sandstones are pale- red to red- brown siltstones and mudstones.

Exposures of the Chinle Formation are found both within the park and on the cliff below Poison Spider Mesa southwest of Moab Valley along U.S. Highway 191 (Doelling, 2000). On the geologic map (Appendix A), the Chinle Formation is mapped along the south and southwest margins of Salt Valley and in the Colorado River canyon below Mat Martin Point and around the Big Bend, and extending downstream for a few miles (Doelling, 2000).

The thickness of the entire Chinle is variable. Like the Moenkopi, Cutler, and Honaker Trail Formations, the Chinle thins in areas where the Paradox Formation contains thick salt units and thickens in areas where the Paradox Formation lacks salt. In the Arches area, the Chinle Formation probably ranges from 61 to 274 m (200 to 900 ft) in thickness (Doelling, 2000). The lower Chinle is 116 m (380 ft) thick opposite Mat Martin Point and the upper Chinle is nearly 122 m (400 ft).

The Upper Triassic was a time of extensive fluvial valley systems in Utah (Dubiel, 1994) and it's the first time during the Mesozoic that the continental interior experienced abundant volcanic ash deposits (Christiansen et al., 1994).

Jurassic Period - Wingate Sandstone

An unconformity separates the Chinle Formation from the Wingate Sandstone. The Wingate forms a red-brown, vertical, massive cliff stained with desert varnish that abruptly overlies the Chinle's red slope. Desert varnish is one of the more common desert coatings and forms a lustrous, shiny, and smooth surface coating on rock surfaces of all sizes from mere pebbles to massive cliffs.

Except where underlying units have dissolved and collapsed the unit, the Wingate Sandstone is one of the easiest formations to recognize in the Arches area (Doelling, 2000). The massive sandstone is very resistant, with very few partings or bedding planes. Because the underlying Chinle is less resistant than the Wingate sandstone, the supporting material for the Wingate cliff is gradually removed by erosion and the Wingate is undercut. When this happens, slabs of sandstone separate from the main cliff along vertical fractures that extend through the formation and fall onto the Chinle and Moenkopi slope (Doelling, 2000). Wingate rock- fall events occur regularly in ARCH (Doelling 2000).

The upper surface of the Wingate forms a broad plateau. Dry washes and shallow swales on the surface fill with water after torrential summer rainstorms. Water flowing in the normally dry washes flows over the edge of the Wingate cliffs and forms waterfalls on the slopes below. Along the flanks of many parts of the salt valleys, the Wingate doesn't form a massive cliff but rather, is shattered into a very ledgy and blocky, orange- brown cliff (Doelling, 2000).

The gray- orange to gray- orange- pink and moderate-orange- pink to pale- red- brown sandstone of the Wingate is mostly composed of quartz grains. In addition to quartz, the sandstone also contains some feldspar, traces of chert, and accessory minerals. The moderately to well- sorted, subangular to rounded quartz grains often have surfaces that appeared pitted, or frosted. Frosted grains are often the result of grains colliding with each other during eolian (wind) transport. The sandstone is cemented by calcium carbonate and silica that has precipitated between grains and is commonly stained with iron oxides. Red, dark- brown and black stains of desert varnish commonly cover the reddish-brown weathering exposures. Up close, flat beds and high- angle crossbedding can be seen on the cliff surface (Doelling, 2000). Fossils are rarely found in the Wingate Sandstone.

Kayenta Formation

The Kayenta Formation caps the Wingate cliffs. On Poison Spider Mesa, the Kayenta forms a bench, and in places, local drainages have incised through these Kayenta benches to expose the Wingate. About 61 to 91 m (200 to 300 ft) of Kayenta crops out in the Arches area (Doelling, 2000). The contact between the Wingate and overlying Kayenta Formation is placed where the thick ledges of the Kayenta Formation overlie the vertical cliff of the Wingate.

Kayenta strata are more red or pale purple and lithologically more heterogeneous than Wingate strata . Although the unit is primarily reddish, individual lenses and beds vary considerably from purple, lavender, red, tan, orange, and white depending on the mineral content and on what trace minerals are found within the cement. Grain size and mineralogy apparently influence the color with most of the sandstone lenses being moderate orange pink whereas the finer grained siltstone and shale deposits are dark red brown to gray red (Doelling, 2000).

Quartz is the primary constituent in the sandstones, but mica and lesser quantities of feldspar and dark minerals such as hornblende and augite are commonly present. Most Kayenta sandstones are fine to medium grained. Sedimentary features suggestive of fluvial depositional environments in the Kayenta include channeling, current ripple marks, rare slump features and high- angle and low- angle crossbedding. Subordinate to the fluvial sandstone are interbeds of eolian sandstone, intraformational conglomerate, siltstone, and shale (Doelling, 2000).

Navajo Sandstone

The Kayenta Formation intertongues with the Navajo Sandstone so the contact can be difficult to place. Thick sandstones near the top of the Kayenta are similar to sandstone in the Navajo (Doelling, 2000). The contact is more recognizable where light- brown or light- gray rocks of the Navajo Sandstone replace the dominantly red or lavender rocks of the Kayenta.

High- angle crossbedding is the trademark of the Navajo Sandstone (figure 9). Weathering processes etch out the crossbeds that form the basis for the Petrified Dunes area of the park. Crossbed sets, generally 5 to 8 m (15 to 25 ft) thick, are stacked within the sandstone beds. The crossbedding dips up to 35 degrees between set boundaries. Above the deep canyons of the Colorado River and its tributaries, however, the Navajo is generally exposed as a bare rock bench. Some of the hollows on this surface have been filled by unconsolidated sand that is locally eroded from other Navajo sandstone beds (Doelling, 2000).

For the most part, the orange to light- gray sandstone in the Navajo Sandstone is fine- grained, generally well-sorted, and massive. Along the crossbed laminae, however, medium to coarse grains of sand accumulate. The sandstone is cemented with both calcite and quartz. While it appears to be a well- cemented cliff former, the sandstone is somewhat friable in hand specimen. Locally, gray to pink- gray, thin, hard, lenticular limestones grade laterally into calcareous reddish siltstones that eventually become boundaries between crossbed sets. Small nodules of authigenic (grown in place) jasper (red quartz) can be found in the limestone. Petrified wood has been found in the vicinity of the limestone deposits. Like the sandstone lenses, the limestone outcrops commonly form a resistant bench. This bench is covered with a dark sandy or rubbly soil that developed in situ from the Navajo Sandstone.

The Navajo Sandstone forms the bench on much of the area east and northeast of Moab Valley. In the Park, the Navajo Sandstone is found between the Great Wall and the Big Bend of the Colorado River between Cache Valley and the Colorado River. The upper surface of the Navajo is a regional unconformity extending throughout the Colorado Plateau so that the thickness of the Navajo will be variable. The thickness of the Navajo varies in the Arches area from 61 to 168 m (200 to 550 ft) (Doelling, 2000).

Carmel Formation

Dewey Bridge Member

According to Doelling (2000), the contact between the Navajo Sandstone and the Dewey Bridge member outlines a surface of broad, topographic relief that formed on the Navajo Sandstone prior to deposition of the Dewey Bridge member. The contact is a regional unconformity called the J- 2 regional unconformity (figure 9, figure 10) (Pipiringos and O'Sullivan, 1978; Blakey, 1994).

The Dewey Bridge member may be divided into lower and upper subunits in the Arches National Park area (not divided in Appendix A or figure 9). Medium to thick beds of resistant, yellow- gray, planar- bedded, fine-grained sandstone characterizes the lower unit. In some areas, the unit is banded with pink to red- brown sandstones layered between the dominantly yellow- gray beds. The lower part of the Dewey Bridge member fills low areas in the Navajo Sandstone, and planar or flat-bedded sandstones of the Dewey Bridge cover the surface of the high- angled crossbedded Navajo. The lower Dewey Bridge weathers to the same color as that of the Navajo Sandstone. Angular white chert clasts, however, are common in the Dewey Bridge member immediately above the contact with the Navajo (Doelling, 2000).

The upper unit is a red- brown, muddy- looking, mostly fine- grained, silty sandstone that forms a slope or a red-brown to chocolate- brown recess between the lower unit and the overlying, cliff- forming Slick Rock member of the Entrada Sandstone (Doelling, 2000). This upper unit contains irregular, contorted bedding.

The Dewey Bridge member, overall, thins to the east and is anywhere from 21 to 61 m (70 to 200 ft) thick. In the Arches area, the thickness of the lower unit varies from 5 to 26 m (15 to 85 ft) and the upper unit varies from 18 to 48 m (60 to 157 ft). At the Garden of Eden, the member is about 27 m (90 ft) thick. In the northwest corner of the park, at Klondike Bluffs, the member is 42 m (139 ft) thick and near the Visitor's Center, about 32 m (104 ft) of Dewey Bridge is exposed. Where the Navajo Sandstone is thick, the Dewey Bridge member is thin (Doelling, 2000).

Exposures of the Dewey Bridge member can be seen along the park highway to Courthouse Towers, along the base of The Great Wall, and northward from the Fiery Furnace (Doelling, 2000). The Dewey Bridge member helps form some of the more unusual scenery in the Park including the pedestal of Balanced Rock and the base of The Windows arches.

Slick Rock Member

The Slick Rock member of the Entrada Sandstone is a massive, well- indurated, red- orange or brown, color banded, sandstone. The sandstone is primarily very fine to fine- grained but contains sparse and scattered medium to coarse sand grains. Calcite and iron oxide cement hold the sand grains together. Commonly, the Slick Rock weathers to form smooth cliffs and bare- rock slopes. The sandstone is both planar bedded and cross-stratified (crossbedded) with small holes commonly aligned along crossbed laminae. The Slick Rock member intertongues with the Dewey Bridge in some areas while in others, the contact is sharp (Doelling, 2000).

The Slick Rock member of the Entrada Sandstone is perhaps the most impressive geologic unit in Arches National Park. Most of the arches in the park are found along the lower and upper contacts of the Slick Rock and along the indentures in the middle of the unit (figure 7). The vertical cliffs of The Courthouse Towers and The Great Wall are Slick Rock sandstone above the red-brown or chocolate- brown marker beds of the Dewey Bridge member. The fins of the Fiery Furnace and the area northeast of Salt Valley where it is cut by numerous closely spaced joints are carved out of Slick Rock sandstone (figure 2). Large irregular fields of self-derived wind- blown sand cover or partly cover the Slick Rock where it is not exposed as a cliff, fin, or arch (Doelling, 1985, 2000). Where exposed in the park, the Slick Rock member is normally 61 to 107 m (200 to 350 ft) thick (Doelling, 2000).

Curtis Formation

Moab Member

The resistant sandstone of the Moab member forms an obvious cap on many of the Entrada Sandstone cliffs. The massive, cliff- forming sandstone is mostly a pale-orange, gray- orange, pale- yellow- brown, or light- gray on a fresh surface but weathers white or light gray. Calcium carbonate cements the fine to medium quartz grains and forms well- indurated sandstone. Low angle cross- stratification and many joints are seen in outcrop (Doelling, 2000).

About 18 to 36 m (60 to 120 ft) of the Moab member is exposed in the park (Doelling, 2000). The Moab member crops out on the hike to Delicate Arch and culminates in the upper part of the Arch, supported on pedestals of the Slick Rock member of the Entrada Sandstone. Bare- rock outcrops of the Moab member form sloping, jointed benches on each side of Salt Valley.

Summerville Formation and Morrison Formation (Tidwell Member) Undifferentiated

Because the Middle Jurassic Summerville Formation is generally less than 3 m (10 ft) thick in the park, it has been mapped as one unit with the Tidwell member of the Upper Jurassic Morrison Formation on the geologic map (Appendix A) (Doelling, 1985, 2000). This thin, redbed marker unit overlying the Moab member of the Curtis Formation was interpreted as Summerville Formation by Dane (1935) and McKnight (1940) who correlated it with reddish beds of sandstone and siltstone present in the San Rafael Swell to the west (figure 10). Later work revealed that the redbed unit actually contained two rock packages that were separated by the J- 5 regional unconformity (figure 9, figure 10) (Pipiringos and O'Sullivan, 1978; O'Sullivan, 1980, 1981; Peterson, 1994).

The lower part of this thin redbed marker unit correlates with the Summerville Formation while the upper and dominant part of the marker in the Arches area is the Tidwell member of the Morrison Formation (Doelling, 2000). Although mapped as one unit, the Summerville and Tidwell are easily divisible by field geologists who have worked with the two units.

The Summerville Formation consists of non- calcareous, light- tan to brown sandstone and red sandy siltstone. The sandstone forms thin- to medium- bedded ledges, and the siltstone forms steep slopes (Doelling, 2000). The base of the Summerville is marked by a zone of yellow- gray sandstone that contains dinosaur footprints (Lockley, 1991). The top of the formation is identified by a prominent thin- to medium- bedded, blocky to thin or platy, ripple- marked sandstone ledge (Doelling, 2000).

The contact between the Summerville Formation and the Tidwell member of the Morrison Formation is placed at the base of thin gray limestone beds or maroon to lavender, calcareous siltstone of the Tidwell member. For the most part, the Tidwell consists or red, maroon, lavender, or light- gray weathering siltstone, but discontinuous beds of light- gray limestone are interspersed throughout the siltstone. The limestone beds are more common at the base and top of the unit. White chert concretions (localized nodules that are harder than the enclosing rock), some as much as 1.8 m (5.4 ft) in diameter, may be found immediately above the lowermost limestone bed of the Tidwell member in Arches (Doelling, 2000). The origin of these concretions is still puzzling.

Only about 2 to 6 m (6 to 20 ft) of Summerville Formation is exposed in the park. The Summerville thins southward, but it thickens in all other directions. From 7.5- 15 m (25 to 50 ft) of Tidwell is exposed far down on each side of the Salt Valley salt anticline, near the axis of the Moab anticline, and in down- faulted blocks on the north side of Cache Valley on both sides of Salt Wash (Doelling, 1985, 2000).

Morrison Formation

Salt Wash Member

The gradational contact between the Tidwell member and the overlying Salt Wash member is generally placed below the first significantly thick, light- gray, yellow- gray, or light- brown sandstone lens or bed of the Salt Wash member. Six or seven thick, vertically stacked, sandstone lenses make up about 25% to 40% of the Salt Wash member and alternate with 60% to 75% red, green- gray, maroon, and lavender muddy siltstone. Locally, the Salt Wash member also contains limestone beds and nodules in the muddy siltstones (Doelling, 2000). The sandstone lenses form ledges that range from 0.6 to 6.1 m (2 to 20 ft) thick although most are 0.6 to 1.2 m (2 to 4 ft) thick (Doelling, 2000). The fine- to coarse- grained, moderately to poorly sorted quartz sandstone is crossbedded and calcareous. Fragments of petrified wood and dinosaur bones have been found in the Salt Wash member. Large pieces of sandstone litter the base of the outcrop. As the softer siltstones between the lenses of sandstone erode , the more resistant sandstone becomes unstable and unsupported and eventually falls onto the slopes of siltstones.

The Salt Wash member is exposed along the western and northeastern boundaries of the Park, in Cache Valley, and in eastern Salt Valley. In Cache and Salt valleys, outcrops of Salt Wash are exposed in fault slices (Doelling, 1985, 2000). Total thickness of the Salt Wash member ranges from 40 to 91 m (130 to 300 ft) thick in the park, and averages about 55 m (180 ft) (Doelling, 2000).

Brushy Basin Member

Dark- colored conglomeratic sandstone lenses, brightly colored- banded mudstone, or bright- green mudstone overlie the light- gray sandstone lenses of the Salt Wash member of the Morrison (figure 9). The upper contact of the Salt Wash member is placed at the top of the interval dominated by the sandstone lenses. The Brushy Basin member is a premier Upper Jurassic volcanic ash- bearing unit and consists largely of bentonitic mudstones (Christiansen et al., 1994). Whereas the Salt Wash sandstones are mostly quartzose, the Brushy Basin sandstone or conglomeratic sandstone lenses are lithic, that is, they are composed of fragments of other rocks. Sandstone is more common in Brushy Basin mudstone than in Salt Wash mudstone.

The Brushy Basin forms smooth, variegated or green slopes with few ledges. The bentonite clay in the Brushy

Basin member adds to its landslide and slump potential because bentonite is a type of clay whose crystalline structure expands when wet and shrinks upon drying. Constant expanding and contracting weaken the unit and cause overlying strata to move downslope. The silty and clayey mudstone and muddy sandstone are interbedded with a few thin units of local conglomeratic sandstone lenses. Bands of various shades of maroon, green, gray, and lavender color the steep- sloped, indistinctly bedded outcrops. The slopes are a bright green to the southeast. The shrinking and swelling of the bentonitic clay causes the surface of the Brushy Basin member to weather to a popcorn- like texture. Locally, dinosaur bone and petrified wood are found in the member (Doelling, 2000).

Seventy- five percent of the member is mudstone. The other 25% of the member is crossbedded, coarse-grained sandstone. Locally, conglomerate lenses are present with clasts the size of pebbles. Overall, the unit decreases in sandstone upsection with both the sandstone and conglomerate lenses generally found near the base of the Brushy Basin (Doelling, 2000). Approximately 91 to 137 m (300 to 450 ft) of Brushy Basin has been measured in the park (Doelling, 2000).

Cretaceous Period -
Cedar Mountain Formation and Dakota Sandstone

Approximately 30 million years is missing between the last bed of the Morrison Formation and the first bed of the Lower Cretaceous, Cedar Mountain Formation (figure 9). The unconformity is placed at the base of a persistent cliff- forming sandstone about 3 to 9 m (10 to 30 ft) thick above the top of the brightly banded or green slope of the Brushy Basin member of the Morrison Formation. Although separated by a large gap in time, the Cedar Mountain Formation weathers like the Brushy Basin member and is composed of silty and clayey mudstone with sandstone lenses much like the Brushy Basin member (figure 9). The slope of the Cedar Mountain, however, has a more pastel or dull coloration (Doelling, 2000).

The light to dark brown sandstone of the lower Cedar Mountain Formation is fine- grained, medium- grained, coarse- grained and conglomeratic. The well- indurated sandstone intervals form ledges much like the one at the base of the formation. Many of the sandstones are so strongly cemented by silica that the rock breaks across the sand grains rather than around them (Doelling, 2000). Quartzite (metamorphosed sandstone) fractures in the same manner, but the sandstone in the Cedar Mountain Formation has not been metamorphosed.

Silty mudstone is interbedded with the sandstone. In general, the clay content in the Cedar Mountain is less than in the Brushy Basin member of the Morrison. Nodular gray or brown limestone is interbedded with the mudstone and sandstone. Chert nodules can be found in the limestone (Doelling, 2000). Scattered fossils such as ostracodes (small bivalved crustaceans), protistids (one-celled organisms), and snails have been found in the Cedar Mountain Formation. White petrified wood, locally abundant in the lower cliff former, and dinosaur bones have also been found in this unit (Kirkland et al, 1999; Doelling, 2000). Abundant chalcedony (quartz with crystals too small to be seen under a light microscope) fragments weather out of the formation in local areas.

In ARCH, exposures of the Cedar Mountain Formation are mostly confined to the tilted fault blocks in Cache and Salt Valleys, especially around the Wolfe Ranch house where Salt Wash crosses Cache Valley (Doelling, 1985, 2000). More extensive Cedar Mountain outcrops are found west and north of the park boundaries (Doelling, 1985, 2000).

The unconformable contact between the Lower Cretaceous Cedar Mountain Formation and the Upper Cretaceous Dakota Sandstone is placed at the base of a white claystone or a yellow- gray to brown sandstone, conglomeratic sandstone, and conglomerate of the Dakota Sandstone (Doelling, 2000). In eastern Colorado, the Dakota Sandstone is Early Cretaceous, but the formation doesn't appear in western Colorado and Utah until the Late Cretaceous time.

The Dakota Sandstone is a heterogeneous mixture of claystone, limestone, thin coal seams, shale, conglomeratic sandstone, and yellow- gray sandstone (Doelling, 2000). The unit becomes discontinuous and is locally missing in areas west of the park. The yellow- gray conglomeratic sandstone lithology is the most obvious Dakota unit in the Arches area.

Most stratigraphic sections of Cedar Mountain Formation are only 30 to 46 m (100 to 150 ft) thick although the formation is 30.5 to 76 m (100 to 250 ft) thick in the park area (Doelling, 2000). In the park, the Dakota is only exposed in Salt and Cache Valley outcrops that are typically 6 to 24 m (20 to 80 ft) thick. A steeply dipping orange or brown Dakota hogback crops out immediately north of the highway leading to Wolfe Ranch and the parking area to the Delicate Arch overlook.

Mancos Shale

The youngest bedrock unit in Arches National Park is the slope forming, Upper Cretaceous Mancos Shale that is confined to Cache and Salt Valleys in Arches National Park (figure 9). Mancos strata is folded and perhaps attenuated by faulting. The transition from Dakota Sandstone to Mancos shale is gradational over a narrow interval.

The Mancos at Arches has been subdivided into three units: the lower Tununk member, the Ferron Sandstone member, and the Blue Gate member. Mostly medium-gray, calcareous, fissile shale from the Tununk and Blue Gate members form the soft slopes of Mancos Shale. The Tununk shales crop out as the lower part of the Mancos in Cache and Salt Valleys. The darker brown- gray

Ferron sandstone is more resistant than the surrounding shale. Erosion has exposed the Ferron as low ridges and rounded hills in Cache Valley. Most of the sandstone is platy or thin- bedded and very fine- grained (0.0625-0.125 mm). The middle of the Ferron Sandstone member consists of dark- gray and black carbonaceous shale (Doelling, 2000). Rocks in the Blue Gate member are also primarily shale. The Blue Gate overlies the Ferron Sandstone, and the shale may be slightly lighter in color than the Tununk.

The thickness of the members of the Mancos ranges from 30.5 to 122 m (100 to 400 ft) for the Tununk, 27 to 37 m (90 to 120 ft) for the thinner Ferron Sandstone member, and about 152 m (500 ft) for the relatively complete Blue Gate member (Doelling, 2000). The Mancos is fossiliferous with zones of marine pelecypods found immediately above the Dakota Sandstone and at the top of the Ferron member (Doelling, 2000).

Cenozoic Era:

Quaternary Period -
Modern Alluvium

Erosion has removed the Tertiary Period deposits from the Arches National Park area. Sedimentation during the Quaternary Period (1.6 million years to present) has resulted in thin, discontinuous, unconsolidated deposits of sand, stream gravels, and silt that cover the older rocks (Doelling, 1985).

Alluvial deposits found along the Colorado River contain cobbles of igneous rocks from the La Sal Mountains and gneiss from the Uncompahgre Plateau to the east. Qa1 represents alluvium consisting of clay, silt, sand and gravel that has been deposited along the more important active rivers, streams, and washes (Doelling, 1985). Interbedded volcanic ashes in Qa2 date these deposits at 620,000 and 740,000 years before present.

Most deposits are Holocene and most are less than 7.6 m (25 ft) thick. The alluvium in the north part of Moab Valley, however, is very thick and its lower parts may be Pleistocene in age (Doelling, 2000).
Cenozoic Era: Quaternary Period - Gravel Deposits, the larger, mappable areas of gravel deposits are of mostly alluvial origin (Qag), but terrace gravel deposits (Qat) on abandoned floodplains rise 24 m or more (80+ ft) above modern stream and dry wash channels. The alluvial deposits consist of the same materials as found in the modern channels. Gold is found on the terraces along the Colorado River but the small flakes and flour-sized particles are too fine and too sparse to be mined profitably (Doelling, 2000). Terraces in the middle of Salt Valley were laid down in an ancient stream that no longer flows in the valley. On these terraces are cobbles eroded from the Book Cliffs many miles to the north. The terrace alluvial deposits in Salt Valley are generally less than 4.6 m (15 ft) thick.

Sand Deposits

The unconsolidated sand deposits (Qeas) are mostly of eolian (wind) origin but are interbedded or mixed with various amounts of alluvial, eluvial, and colluvial sand (Doelling, 1985). Eluvial sand forms as the rock disintegrates in place while colluvium consists of a combination of alluvial sediments and angular fragments of the original rocks.

Hollows on sandstone strata, especially on the Slick Rock member of the Entrada Sandstone, are filled with wind- blown sand (Qes). Eolian sand is also trapped in protected places as the sand is blown across the area by the prevailing wind. Dunes form in some areas and in Salt Valley, long fingers of eolian sand cover mixed eolian and alluvial (Qea) deposits (Doelling, 2000).

The complex unconsolidated deposits of mixed eolian and alluvial sources form lenses of basin- fill alluvium, channel deposits, overbank deposits, and wind- blown sand sheets that are mapped in Doelling (2000), but are not differentiated in Doelling (1985) or Appendix A. Sand, silt, gravel, and clay make up most of the deposits. Well- developed caliche horizons have developed on some of the relatively old (Pleistocene?) deposits. Mostly less than 7.6 m (25 ft) thick, these mixed deposits are several hundred feet thick in Salt Valley because salt was being dissolved when the sediment accumulated. Interlayered with the unconsolidated deposits in Salt Valley is gypsum that was derived from the local outcrops of the Pennsylvanian Paradox Formation caprock as well as volcanic ash drifting into the area from the west during the Pleistocene.

The age of these mixed deposits can be determined by radiometric age- dating of the volcanic ash (Doelling, 2000). Two of the ash layers, the Bishop ash and Lava Creek B ash, have well- known ages. The Bishop ash was deposited 730,000 years ago and the Lava Creek B ash was deposited 610,000 years ago from volcanoes in California and from the current location of Yellowstone National Park (Coleman, et al., 1988). As salt beds beneath these deposits dissolved and the overlying strata collapsed, some of the thicker deposits were folded into synclines and anticlines.

Landslide Deposits

Periodically, blocks and slumps of bedrock detach from the outcrop and slide downslope, sometimes for a considerable distance (Doelling, 1985). These landslides are composed of mostly larger coherent to partly broken up masses of consolidated units. Water in this desert landscape plays an important role in generating landslides. In cycles of wet weather, fine- grained clayey bedrock outcrops collapse. The bentonite- bearing Morrison Formation, especially the Brushy Basin member, produces most landslides as the bentonite shrinks and swells with the addition and subsequent evaporation of water. Visitors to the Elephant Butte folds can see numerous small old landslides and slumps. What they can't see is the source of these slides. The closest bedrock containing the slide materials is now several miles away (Doelling, 2000).

Talus Deposits

A landslide is a general term applied to any mass movement down a slope by rock and/or soil material. One form of a landslide is a rockfall in which blocks of rock break from a cliff and fall vertically to collect in a jumbled pile of rocks called talus. The talus deposits at ARCH are a collection of rockfall blocks, boulders, and smaller angular fragments lying on slopes immediately below the parent outcrop. In Appendix A, and in the digital geologic map included with this report, the talus deposits are mapped only where they completely cover the underlying units.

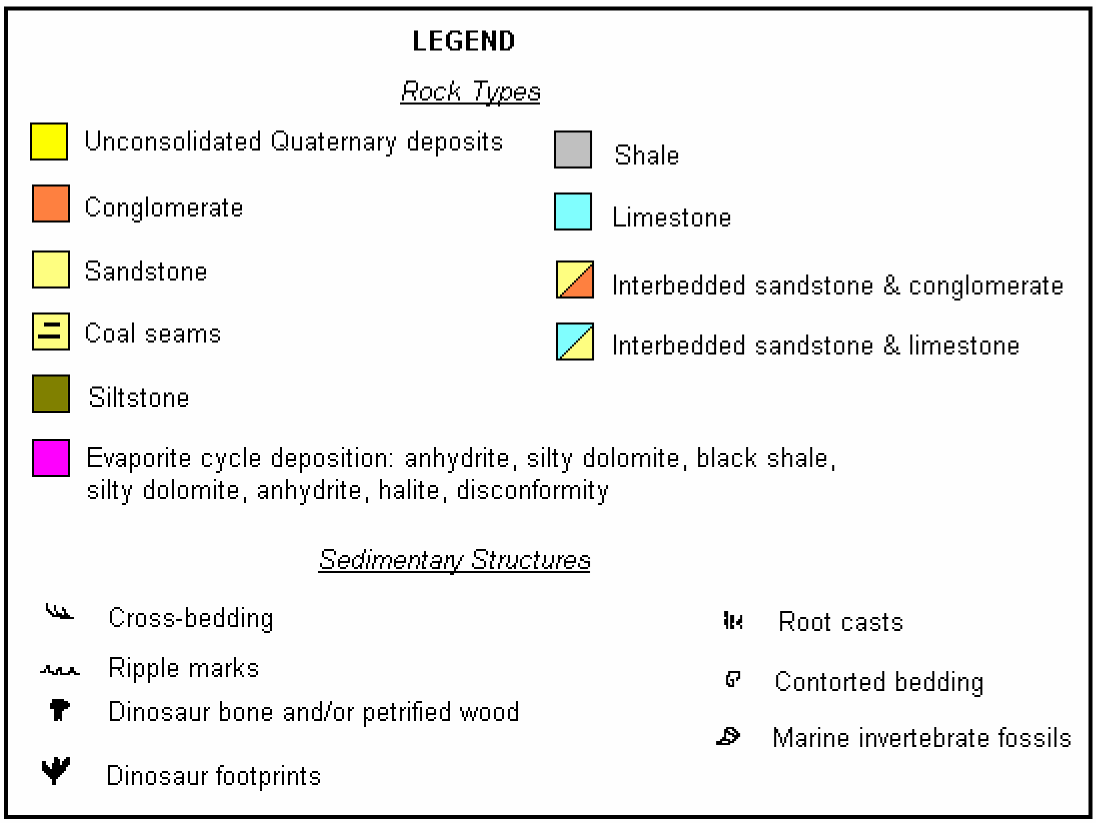
Era	Period	Epoch	Formation	Member	Thickness feet (meters)	Rock Type	Regional Unconformities
CENOZOIC	Quaternary		No Formal Formations (Alluvium, Terrace gravel, Sand, Eolian, Landslide deposits, Talus)		Variable		
	Tertiary		Missing in Arches NP				Q/T
MESOZOIC	Cretaceous	Upper	Mancos Shale	Blue Gate mbr.	500+ (150+)		K/T
				Ferron Sst. mbr.	60-120 (18-37)		
				Tununk mbr.	300-500 (90-150)		
			Dakota Sandstone		0-110 (0-34)		
		Lower	Cedar Mountain Fm.		100-250 (30-76)		K-1
	Jurassic	Upper	Morrison Fm.	Brushy Basin mbr.	300-450 (90-140)		K-0
				Salt Wash mbr.	130-300 (40-90)		
				Tidwell mbr.	40-100 (12-30)		
		Middle	Summerville Fm.		< 10 (< 3)		J-5
			Curtis Fm.	Moab mbr.	60-120 (18-37)		
			Entrada Sandstone	Slick Rock Sst.	200-500 (61-150)		J-3
			Carmel Fm.	Dewey Bridge mbr.	40-235 (12-72)		
		Lower	Navajo Sandstone		250-550 (76-170)		J-2
			Kayenta Fm.		200-300 (60-90)		
			Wingate Sandstone		250-450 (76-140)		
	Triassic	Upper	Chinle Fm.		200-900 (61-270)		J-0
		Middle	Missing in Arches NP				T-2
		Lower	Moenkopi Fm.	Sewemup mbr.	0-1300 (0-400)		T-2
				Ali Baba mbr.			
				Tenderfoot mbr.			
PALEOZOIC	Permian		Cutler Fm.		0-1500 (0-460)		T-1
	Pennsylvanian		Honaker Trail Fm.		300+ (90+)		
			Paradox Fm.		500+ (150+)		

* Millions of Years Ago

J-1 merges with the J-2 unconformity in the ARCH area.

J-4 merges with the J-5 unconformity in the ARCH area.

Figure 9: Stratigraphic column for Arches National Park including the location of regional unconformities (thick red lines) and some of the principal sedimentary structures found in the formations. See figure 9b for a legend of rock types and sedimentary features.



Legend to accompany the stratigraphic column shown in figure 9.

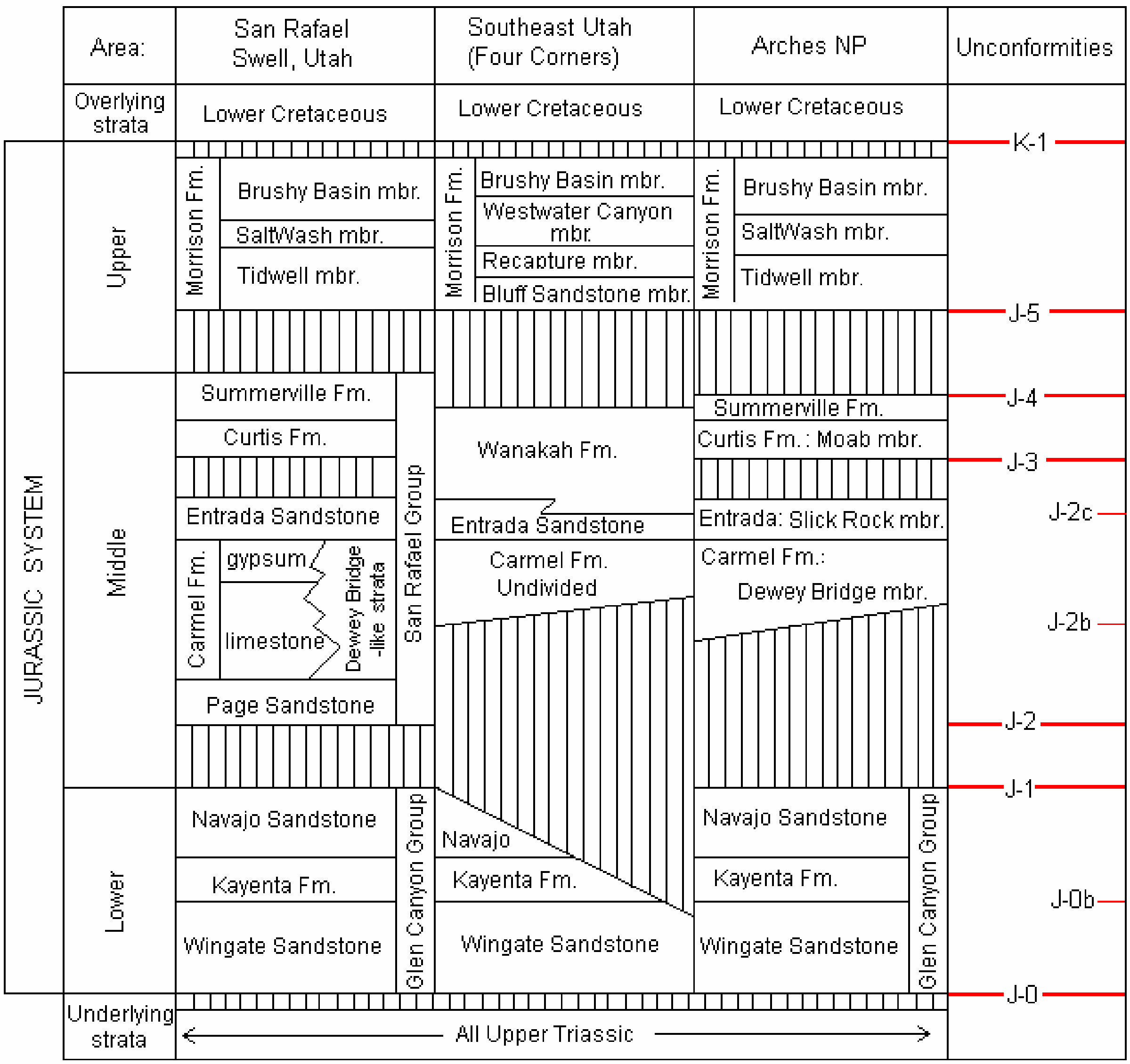


Figure 10: Correlation chart of Jurassic Period strata and unconformities in eastern Utah. Vertical lines represent times of erosion or non-deposition. Stratigraphy for Arches National Park is from Doelling (2000). Stratigraphic relationships in the San Rafael Swell and Southeast Utah are modified from Peterson, 1994.

Geologic History

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

Depositional and Tectonic History

Pennsylvanian through Cretaceous Period rocks are exposed in Arches National Park and represent marine, nearshore, and continental depositional environments. As the Paleozoic Era came to a close, the ancestral Rocky Mountains were forming and the two great landmasses, Laurasia and Gondwana were becoming sutured together in one great continent called Pangaea (figure 11). Gondwana included Australia, Antarctica, Africa, South America, and India south of the Ganges River, plus smaller islands. Laurasia, located in the northern hemisphere, is the hypothetical continent that contained the present northern continents.

The most extensive mass extinction of all recorded geologic history occurred at the end of the Permian Period. In the Mesozoic Era, Pangaea began to split apart to form the lithospheric plates that we see today sliding around the globe. This section summarizes the geologic history represented by the rocks exposed within the borders of ARCH.

Paleozoic Era

Middle Pennsylvanian Period – Paradox Formation

At this time, the continental margin of North America lay far to the west and southeast of the Colorado/Utah state line (De Voto, 1980). As Gondwana and Laurasia collided, the compression caused a northwest- southeast trending, shallow, subsiding trough called the Paradox Basin to form across the Four- Corners area (Stone, 1986). Periodic marine incursions from the south, impacted by both global tectonics and Gondwana glaciation, flooded the Paradox Basin.

A global climate shift from the warm humid environment of the Late Mississippian created a much more arid environment in the region of Utah during the Early Pennsylvanian (Rueger, 1996). During the Pennsylvanian, the Paradox Basin was located at 100 North paleolatitude (Wray, 1983). Rapid evaporation accompanied the warm climate so that the salt in the seawater became concentrated. The Middle Pennsylvanian Paradox Formation contains 29 evaporite cycles consisting of vertical sequences of organic- rich black shale, dolomite, anhydrite, sodium and potassium salts, anhydrite, dolomite and black shale (Hite, 1961; De Voto, 1980; Rueger, 1996).

With burial and the weight of accumulating sediments, the salt flowed to areas of less confining pressure in much the same way as toothpaste is squeezed from a tube. These areas of less confining pressure paralleled zones created by displacements along northwest-trending faults. The salt migrated and thickened along these zones while, at the same time, the salt thinned in adjacent areas. Rock strata arched over thickened salt zones to form aerially extensive anticlines. These anticlines trapped oil that migrated from black shale into porous limestones. Near Dead Horse Point, the salt deposits are also mined for potash salts used as fertilizer (Doelling, 1985, 2000).

Original salt thickness is believed to be about 1,500 m (5,000 ft) (Doelling, 1985). In the salt anticlines, the maximum known thickness is nearly 4,300 m (14,000 ft), and under Salt Valley in Arches National Park, the salt is at least 3,000 m (10,000 ft) thick (Doelling, 1985).

Upper Pennsylvanian Period – Honaker Trail Formation

By Late Pennsylvanian time, the Paradox Basin became more stable and filled with sediment. The region was connected to the open sea to the west and circulation prohibited salt deposition. Rather, limestone and dolomite were deposited in the open marine environment.

Clastic sediments were shed from the Uncompahgre Mountains, part of the ancestral Rocky Mountains that were rising east of the park along the Uncompahgre fault, a major thrust fault (Doelling, 2000). Large quantities of gravel, arkosic sand (sand rich in feldspar), and silt eroded from the eastern highlands and were transported by streams into the sea in which the Honaker Trail limestones were being deposited. The carbonate/clastic sequence constitutes the Honaker Trail Formation.

Permian Period – Cutler Formation

The coarse arkosic marginal- marine and continental clastic sediments of the Cutler Formation represent a complex eolian- fluvial- alluvial fan association of sediments shed from the rising Uncompahgre Mountains (Campbell, 1980; Cole et al, 1996). Near the park, the Cutler Formation rests unconformably on the Honaker Trail Formation, but regionally, the lower Cutler clastic beds represent a transitional change between the Upper Pennsylvanian and Lower Permian formations (Campbell, 1980; Dubiel et al., 1996).

While the Uncompahgre Mountains were being whittled away by erosion, buoyant salt of the Paradox Formation was rising beneath the alluvial fans. The topography changed from one of flat lowland to one of undulating hills around which streams diverted the sediments. As a result of the rising salt domes, the Cutler arkoses were only thinly deposited on top of the hills, if at all, and formed thick, complex channel deposits around the hills (Baars, 2000).

Upper Permian rocks are missing from the Arches National Park area, but from other areas around the globe, geologists have documented the third, and most severe, major mass extinction of geologic time at the close of the Permian (figure 17). Geologists think a comet, about 6- 13 km (4 to 8 mi) in diameter, collided with the Earth (Becker et. al., 2001). The heat and shock waves generated from such an impact may have triggered vast volcanic eruptions that spread lava over an area two-thirds the size of the United States. Imagine, for example, basalt flows covering the area from San Francisco to St. Louis and Seattle to New Orleans.

Powerful wind updrafts would have carried dust and grit swirling into the upper atmosphere. The particulate matter would have reflected back into space and scattered sunlight, resulting in years of global cooling with freezing temperatures even during summertime. A recent example of this type of global cooling occurred in 1816, "the year without a summer," following a volcanic explosion in Tambora, Indonesia. The sulfuric emissions from the volcanoes would have mixed with atmospheric water to produce downpours of corrosive acid rain. Thousands of species of insects, reptiles, and amphibians perished on land. In the oceans, coral formations vanished, as did snails, urchins, sea lilies, some fish, and the once- prolific trilobites. Five million years later, at the dawn of the Mesozoic Era, the oceans began to evolve into the chemistry of the modern oceans and on land, a new order arose, one that the world had never seen before and will never see again.

Mesozoic Era

Lower Triassic Period – Moenkopi Formation

Following the Permian, the Triassic Period (245- 206 Ma) opened onto a desolate scene. The atmosphere and the oceans were slowly recovering from the catastrophic extinction event. Shallow, marine water stretched from Utah to eastern Nevada over a beveled continental shelf.

In the Early Triassic, volcanic activity decreased on the western margin of the supercontinent (Christiansen et al., 1994). The sea transgressed, or overlapped, onto the continent from the northwest, pushing the shoreline into western Wyoming and northwestern Utah (figure 12). The sea then regressed off the continent and red beds were deposited. Red beds are interpreted to represent terrestrial, or continental, deposition because when exposed to air, the trace amounts of iron in the sediment oxidize to the characteristic rust color seen in the Triassic exposures across the southwest. Abundant rainfall on the Uncompahgre Highlands led to increased weathering and rapid erosion especially if vegetation had been reduced significantly by acid rain resulting from earlier volcanic activity and extraterrestrial impact.

The coarse- grained arkoses along the Colorado River and Big Bend attest to the continued erosion of the Uncompahgre as the red beds of the Lower Triassic, Moenkopi Formation were deposited in fluvial, mudflat, sabkha, and shallow marine environments (Christiansen et al., 1994; Doelling, 1985, 2000). Ripple marks and low-angle crossbeds in the Moenkopi rocks are the result of river processes that beveled the area into a relatively flat plain by eroding the higher areas and infilling the depressions with sediment. Gypsum in the lower part of the formation was a product of cyclic arid conditions (Huntoon et al., 2000), but the fossilized plants (reeds and Equiseta), trackways of reptiles and amphibians, and fossils of warm seawater invertebrates in the strata above the gypsum are evidence of a climate shift to a warm tropical setting (Stewart et al., 1972A; Huntoon et al, 2000).

Middle Triassic Period

The Middle Triassic Period (235- 240 Ma) is a mystery in Utah. No rocks that span this time range from 235- 400 Ma have been preserved in Utah. To the west, explosive volcanoes arose from the sea in the Middle Triassic and formed a north- south trending arc of islands along the border of what is now California and Nevada (Christiansen et al., 1994; Dubiel, 1994; Lawton, 1994). Eruptions from these stratovolcanoes were similar to the eruptions from Mt. Vesuvius that destroyed Pompeii in A.D. 79, only more violent (Christiansen et al., 1994).

Upper Triassic Period - Chinle Formation

Continental, Chinle Formation rocks of the Western Interior of North America form a complex assemblage of alluvial (river deposits), marsh, lacustrine (lake), playa (dried lake), and eolian (wind) deposits (Stewart et al., 1972B). Sedimentologic characteristics of the Chinle suggest that the sediments were deposited in a densely vegetated flood plain or mud flat that contained localized shallow ponds and small, shallow, sinuous streams (Scott et al., 2001). Mottling in the lower Chinle represents gleyed (bluish gray soil horizon) paleosols (ancient soils) formed by fluctuating water tables (Dubiel, 1994; Doelling, 2000; Scott et al., 2001). Vertical tubular features in the rocks are probably the remains of fossilized root systems (Doelling, 2000). Siltstone and mudstones are the consolidated result of overbank or floodplain deposits. The sandstones and conglomerates represent old stream channels. The Chinle environment was similar to today's subtropical to tropical areas of South America and Africa.

Throughout the region, layers of bentonite, montmorillinite clay, formed from the alteration of volcanic ash. The bentonite layers indicate a period of renewed volcanism to the west (Christiansen et al., 1994). Paleovalleys cut into the Moenkopi Formation (Dubiel, 1994). In the Arches region, the Moab paleovalley was a major tributary to a northwest- trending paleovalley into which many drainage networks emptied. (figure 13). Choked with sediment, braided streams, rather than meandering streams, tended to occupy these paleovalley systems.

During the final phases of Chinle deposition, lower water table conditions existed. Lacustrine mudflat siltstones and mudstones, ephemeral fluvial- channel sandstones, and eolian sand- sheet and dune deposits were deposited during extended dry periods (Dubiel, 1994).

Granitic plutons in southern California, central Nevada, on the border of Idaho and Oregon, and in central Washington, along with volcanic rocks of this age, are remnants of a magmatic arc that developed above an east- dipping subduction zone in the Mesozoic. As highlands rose above sea level to the west and the continental crust was deformed, rivers that once flowed northwesterly now reversed their direction and flowed to the south and west. Lakes formed at the base of the rising highlands (Dubiel, 1994).

Jurassic Period – Overview

Southeastern Utah during the Jurassic was a time of extensive eolian sand seas, called ergs. The region was located about 180 north latitude at the beginning of the Jurassic and about 30- 350 north latitude at the end of the Jurassic (Kocurek and Dott, 1983; Peterson, 1994). This is the latitude of today's trade wind belt where hot, dry air descends from the upper atmosphere and sweeps back to the equator in a southwesterly direction, picking up any moisture as it goes. This is the latitude, thus, of intense evaporation. Most modern hot deserts of the world occur within the trade wind belt and during the Jurassic, the climate of the Colorado Plateau appears similar to the modern Western Sahara.

In the Sahara, the world's largest desert, only 10% of the surface is sand- covered. The Arabian Desert, Earth's sandiest desert, is only 30% sand- covered. The Jurassic deserts that stormed across the Colorado Plateau for roughly 40 million years (not counting the time represented by erosion) contained sand dunes that may be the largest recorded in the rock record (Kocurek and Dott, 1983). These ergs formed on a coastal and inland dune field affecting southern Montana, eastern Utah, westernmost Colorado, southwest Colorado, northeastern Arizona, and northwestern New Mexico (Kocurek and Dott, 1983; Peterson, 1994). The volume of sand in these systems was enormous. Where did it come from? Winds in these northern latitudes blow to the west, yet the sand dunes of the Jurassic migrated to the south. Why? Answers to these questions lie with the plate tectonic setting, the climate, and the potential sediment sources.

To the south, the landmass that would become South America was splitting away from the Texas coast just as Africa and Great Britain were rifting away from the present east coast and opening up the Atlantic Ocean. The Ouachita Mountains, formed when South America collided with North America, remained a significant highland and rivers from the highland flowed to the northwest, towards the Plateau. The Uncompahgre Highlands in the west remained high in the Jurassic and also contributed sediment to the Arches area.

Lower Jurassic Period –
Wingate, Kayenta, Navajo formations

The regional depositional geometry of the Wingate, the high- angle crossbedding, well- sorted quartz grains, and frosted grains identify the Wingate Sandstone as an eolian deposit (Peterson, 1994; Doelling, 2000). Regionally, six major erg sequences have been mapped in the Wingate (Nation, 1990; Blakey, 1994). The six erg units vary in detail from one another, but in general, both the overall Wingate succession and the individual erg sequences display drying- upward depositional trends in which small eolian dunes and sandsheets of large crossbedded dunes overlie sabkha and lacustrine deposits (Blakey, 1994).

Channeling, low- angle cross- stratification, current ripple marks, and interbedded sandstone, siltstone, and shale suggest a fluvial environment for the Kayenta Formation. The rivers developed on a Wingate Sandstone surface. Adjacent to the Kayenta rivers were sand dunes with high- angled, sweeping crossbeds. These sand dunes became the Navajo Sandstone. As the rivers migrated, so did the sand dunes so that today, the fluvial deposits of the Kayenta Formation often intertongue with Navajo Sandstone (Blakey, 1994).

At Arches, however, the Kayenta separates the Navajo from the Wingate Sandstone. The crossbed sets of the Navajo Sandstone are bounded by planar surfaces thought to represent former water table surfaces. Dip directions of the dunes indicate sand transport from north to south. Gray limestones and dolomites formed in oases, playas, or interdune lakes (Doelling, 1985, 2000).

During the Lower Jurassic, the northern sea did not encroach onto the continent. At this time, erosion of Triassic and Upper Paleozoic sandstones from as far north as Montana and Alberta provided abundant quantities of sand to be transported by wind to the Colorado Plateau (Kocurek and Dott, 1983). The volcanic arc along the western margin of North America may have acted as a wall to block the southwest wind and channel it to the south (Kocurek and Dott, 1983).

Middle Jurassic Period –
Carmel, Entrada, Curtis Formations.

When the pace of collision increased off the western coast in the Middle Jurassic, the rock layers on the continent side of the collision bulged upward, and as the rocks bowed, weathering and erosion stripped away the rocks. The unconformity surface that formed on the Navajo Sandstone is called the J- 2 regional unconformity surface, see figures 9 and 10 (Pipiringos and O'Sullivan, 1978).

As plate tectonic activity increased, the sea began to onlap the continent from the north. The Dewey Bridge member of the Carmel Formation was deposited on broad tidal flats marginal to a shallow sea that lay to the west (Wright et al., 1962). The Dewey Bridge member may interfinger with the Page Sandstone member of the Carmel that has been suggested to be present in the vicinity of Ham Rock (comments from ARCH staff, July 9, 2003). The Page Sandstone is an eolian sandstone that pinches out to the east on the west flank of the Monument uplift (Peterson, 1994).

The Entrada Sandstone, lying above the Dewey Bridge member of the Carmel Formation, is the most widespread of the preserved late Paleozoic and Mesozoic eolianites and also the most important geologic unit in Arches National Park with respect to arch formation. Most of the arches in the park are associated with the lower and upper contacts of the Entrada. The cross-stratified sandstone was deposited in an extensive dune field in a back- beach area (figure 14) (Kocurek and Dott, 1983; Hintze, 1988; Doelling, 2000).

A renewed marine incursion, less extensive than the first, is recorded in the marine fossils found in the Curtis Formation to the west of the Arches area. In western and central Utah, the Curtis is separated from the Entrada by another regional unconformity, the J- 3 unconformity (Pipiringos and O'Sullivan, 1978; Doelling, 2000). In Arches National Park, the Moab member of the Curtis Formation is a resistant sandstone that caps many Entrada sandstone cliffs. The Moab sandstones have been interpreted as small eolian dune fields although specific details on the Moab depositional environment are lacking (Peterson, 1994).

Upper Jurassic Period – Summerville and Morrison Formations

As lithospheric plate collision increased on the western margin in the Upper Jurassic, a major transgression of the inland seaway forever destroyed the vast eolian sand seas that once covered the Colorado Plateau. Tidal flats covered the area as marine environments encroached from the north.

Two additional marine transgression/ regression couplets occurred in the Upper Jurassic before the seas finally receded to the north. During northward retreat of the sea, the Summerville Formation was deposited. The sandstones and siltstones of the thin Summerville Formation exposed at Arches were deposited in a delta that was marginal to a shallow sea to the west (Peterson, 1994: Doelling, 2000).

As the sea regressed to the north, the extensive Upper Jurassic, Morrison Formation was deposited across the continental Western United States. The Morrison Formation is world renowned for both its dinosaur bones and its uranium deposits (Peterson, 1994).

Morrison environments are quite varied. Sediments were deposited in mudflats, overbank floodplains, stream channels, small eolian sand fields, and scattered lakes and ponds (Peterson, 1994). Today, little vegetation grows on the banded pink, green, and gray shales of the Morrison Formation that paint a vivid landscape over parts of the Colorado Plateau.

The Tidwell member of the Morrison Formation probably represents fluvial overbank deposits and associated lake deposits. The Salt Wash member is also a fluvial deposit intertonguing with the Tidwell member. The sandstones represent channel deposits in a braided river system while the muddy siltstones are overbank flood deposits. The conglomeratic and lithic sandstones of the upper Brushy Basin member are also the products of a fluvial system that deposited channel sandstones and floodplain sediments as well as lake deposits.

Lower Cretaceous Period – Cedar Mountain Formation

Fast- flowing streams from the southwestern Mogollon Highlands incised into the softer shales and siltstones of the Upper Jurassic Morrison Formation, eroded sediment, and generated another gap in time between the Jurassic and Cretaceous Periods. Coarse- grained, Lower Cretaceous rocks form the Cedar Mountain Formation at ARCH. Paleocurrent directions show that Cedar Mountain sediments came from drainage systems coming out of central Utah (Elder and Kirkland, 1994). The sandstones, mudstones, and nodular limestones represent low- energy floodplain, fluvial, and interfluvial lacustrine deposits (Elder and Kirkland, 1994; Doelling, 2000). About 15 million years is missing between the uppermost Cedar Mountain Formation and the base of the Upper Cretaceous Dakota Formation in central Utah (Hintze, 1988).

Upper Cretaceous Period – Dakota Sandstone and Mancos Shale

As the Late Cretaceous dawned, this continental landscape experienced a dramatic change. An epicontinental sea once again inundated Utah in the Late Cretaceous. Only rising mountains in western Utah (Sevier Orogeny) limited the westward expansion of marine waters.

As the mountains rose in the west, the north- south trough that formed adjacent to the mountains subsided, and marine water began to spill into the basin from both the Gulf of Mexico and the Arctic Ocean. As the shallow sea advanced onto the continent, longshore currents flowing parallel to the shoreline redistributed the sediments deposited from river systems in much the same way sediments are redistributed along the shorelines of North America today.

The sea advanced, retreated, and readvanced many times during the Cretaceous until the most extensive interior seaway ever to cover the continent drowned much of western North America from about 95 to 65 Ma (figure 15). The advances and retreats of the Cretaceous shoreline created a myriad of environments including incised river valley systems, estuaries, coal swamps, lagoons, delta systems, beaches, and offshore marine deposits. The interfingering of these environments is very complex, and the sedimentary rocks formed from the sediments include a variety of lithologies that have been grouped together into the Dakota Sandstone on the Colorado Plateau.

In general, the Dakota represents deposition on a broad coastal plain and in lagoons shoreward of the advancing Western Interior Seaway. Coal swamps formed in the quiet backwaters of estuaries. Some of the sandstones may have been deposited in paleovalleys incised into the coastal plain during a regressive episode (Gardner and Cross, 1994). With burial and increased temperature, the organic material in the Dakota Formation began to be transformed into coal and hydrocarbons. The coarse-grained sandstone layers became reservoirs for oil, gas, and groundwater.

Only part of the Mancos Shale is exposed at Arches National Park. The Mancos Shale is the youngest bedrock unit in Arches National Park and was deposited in the advancing Cretaceous seaway. The calcareous marine mudstones that comprise the lower part of the Tununk member (figure 16) were deposited during a transgression that flooded the Dakota Sandstone environments (Gardner and Cross, 1994). The paleobathymetry over eastern Utah was approximately 328- 656 ft (100- 200 m) deep at this time (Sageman and Arthur, 1994). The lower Tununk shales represent the maximum extent of the Cretaceous Interior Sea (figure 16) (Elder and Kirkland, 1994). Pluton emplacement was quite active on the western margin of North America and volcanoes erupted great quantities of volcanic ash (Christiansen et al., 1994).

The sandstones of the Ferron Sandstone member were deposited during a regression. Although undifferentiated in ARCH, the Ferron Sandstone has been subdivided in Utah into a lower unit of shelf sandstones and an upper unit of nonmarine sandstone and mudstone (Gardner and Cross, 1994).

The fossiliferous, marine mudstones of the Blue Gate member resulted from another transgressive episode. At this time the sea lay adjacent to the Sevier thrust belt.

For roughly ten million years, clay, silt, sand, and shell debris were deposited in the Cretaceous Interior Sea. At first glance, the formation appears to be 2000+ ft (700 m) of uniform, monotonous black and gray shales with a few scattered limestone beds. Yet, the history of the Mancos on the Colorado Plateau reflects at least four major, dramatic changes in depositional systems where shoreline and near- shore environments were destroyed and new environments created as sea level rose and fell (Aubrey, 1991). In addition, fossil evidence suggests that ocean currents within the Cretaceous Interior Sea were variable. At times, the currents circulated oxygenated water throughout the water column allowing life to prosper at all levels, including within the muddy sea bottom. Conversely, at other times, the circulation in the Seaway was restricted to the upper water layer, and black, organic- rich muds accumulated in the oxygen-poor sea bottom. In those environments, the fossil material includes very few, if any, bottom fauna. As the organic- rich mud was buried, heat and pressure transformed the organic material to hydrocarbons.
In time, these hydrocarbons would flow upward, out of the buried Mancos mud and into overlying and adjacent reservoirs.

Late Cretaceous – Early Tertiary Laramide Orogeny

The onset of the Laramide Orogeny (about 70 to 35 Ma) was marked by a pronounced eastward shift in deformation throughout Utah and into Colorado. Thrust faults produced in the Laramide Orogeny cut deeply into Earth's crust, thrusting ancient plutonic and metamorphic basement rocks to the surface. In contrast, basement rocks were rarely involved in Sevier thrusting. The Sevier Orogeny (about 105 to 75 Ma) is an example of thin- skinned thrust faulting wherein just the upper sedimentary strata of Earth's crust is transported on laterally extensive thrust planes that dip at a low angle, generally 10- 15 degrees, from the horizontal surface of Earth. Thrust faults associated with the Late Cretaceous-Early Tertiary Laramide Orogeny are an example of thick- skinned deformation. The faults have steeply dipping fault planes at the surface of Earth that curve and sole out in Precambrian basement crystalline rock at depths up to 9 km (9000 m) (5.7 mi or 30,000 ft) below sea level (Gries, 1983; Erslev, 1993).

During the Laramide Orogeny, the tectonic forces that folded and faulted the entire geologic column, from Precambrian to Cretaceous age rocks, into the north-south trending Rocky Mountains and adjoining basins had seemingly little effect on the Colorado Plateau. Where the Rocky Mountains became basement- cored arches bounded by thrust faults and separated by sediment- filled basins, the Colorado Plateau, on the other hand, was primarily warped into broad anticlinal and synclinal folds with very little large- scale (kms) faulting (Dickinson and Snyder, 1978; Chapin and Cather, 1983; Hamilton, 1988; Erslev, 1993).

Although not as severely deformed as rocks in the adjacent Rocky Mountains, the rocks in Arches National Park were faulted and folded during the Late Cretaceous and early Tertiary Laramide Orogeny. The regional dip of the park is 2 to 4 degrees northwards towards the Uinta Basin and away from the Monument upwarp to the south.

Tertiary Period – Overview

No Tertiary- age rocks are exposed in ARCH, but for about 35 million years during the Laramide Orogeny, the collision of the tectonic plates transformed the extensive basin of the Cretaceous Interior Seaway into smaller interior basins bordered by rocky mountains. The Colorado Plateau, as a whole, was uplifted and tilted in the latest Cretaceous- early Tertiary so that streams, flowing to the northwest, began to erode the underlying sedimentary rocks and deposit gravels and sandstones across the area (Fassett, 1985; Aubrey, 1991).

Quaternary Period – Overview

The Quaternary Period is subdivided into two epochs: 1) the Pleistocene, which ranges from about 1.6 Ma to 10,000 years before present (B.P.), and 2) the younger Holocene Epoch that extends from 10,000 years B.P. to the present. The Pleistocene Epoch is known as the Ice Age and is marked by multiple episodes of continental and alpine glaciation. Great continental glaciers, thousands of feet thick, advanced and retreated over approximately 100,000- year cycles. Huge volumes of water were stored in the glaciers during glacial periods so that sea level dropped as much as 91 m (300 ft) (Fillmore, 2000). When sea level lowered, land bridges emerged such as the Bering Land Bridge that linked North America and the Eurasian continents. During interglacial periods, Earth warmed and the glaciers retreated toward the polar regions. Sea level rose and the great land masses were once again isolated.

Geologically, the Colorado Plateau has not changed much during the Holocene, the Age of Man. The Colorado Plateau as a whole has been subjected to repeated minor uplifts and stream rejuvenation since the end of the ice age. During the cooler, more humid climates of Pleistocene time, streams cut headward into canyons, developing the drainage pattern seen today. Today, the climate is drier; yet, the intermittent streams in the canyons are still in a period of active downcutting, only at a slower rate than in the past. The prehistoric floods that once scoured the canyons are mostly an event of the past since the construction of Glen Canyon dam, Hoover dam, and the other dams on the Colorado River drainage.

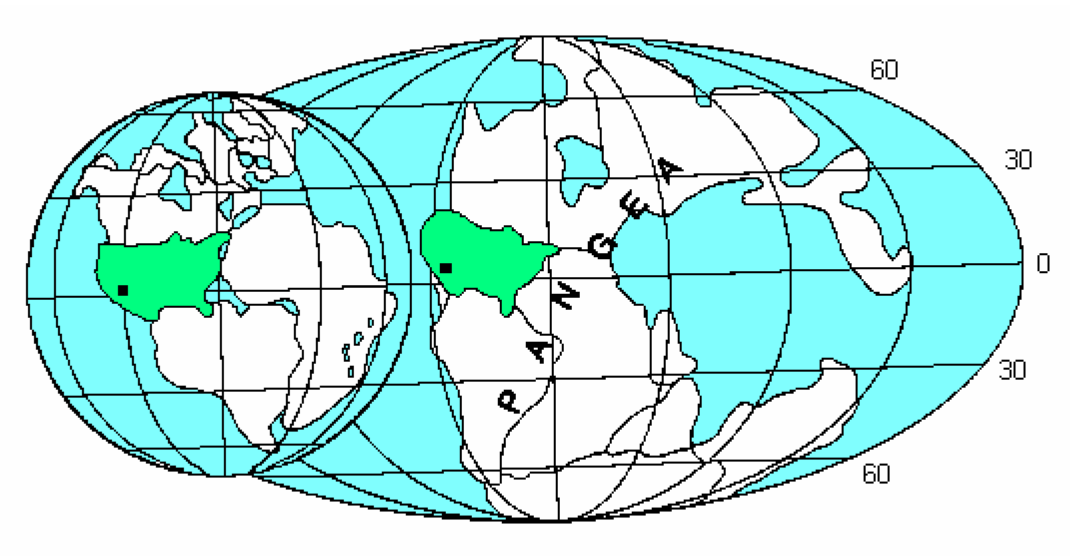


Figure 11: Schematic reconstruction of Pangaea showing the approximate Permian location of the Colorado Plateau (black box) and the United States (green). The rest of the land mass is shown in white. Round inset: Partial reconstruction of Pangaea depicting different orientation and thus rotation of the Colorado Plateau. From Dubiel et al., 1996.

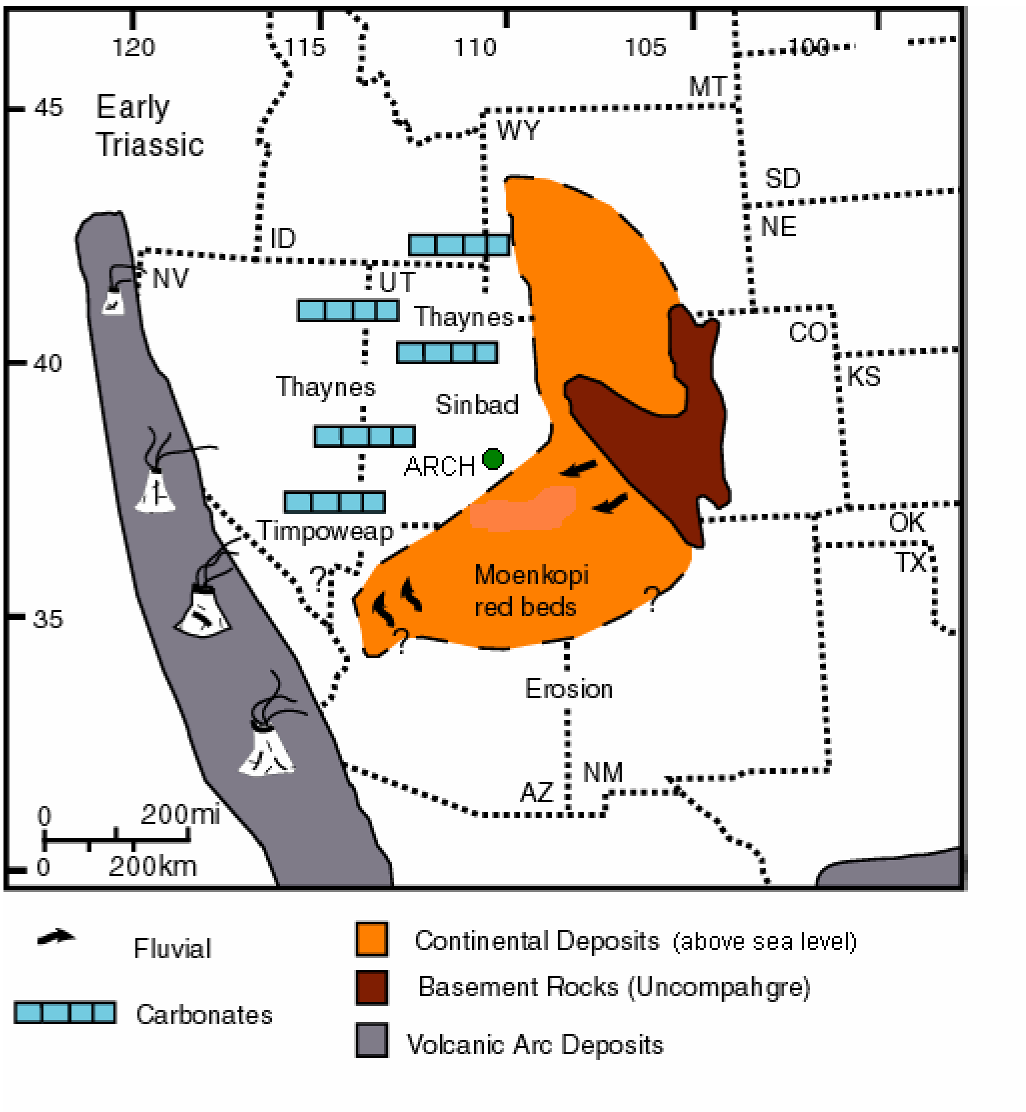


Figure 12: Lower Triassic paleogeography. Moenkopi Formation in the Four-Corners region is deposited during the second transgressive episode of the Early Triassic. Other formations include the Thaynes, Sinbad, and Timpoweap. ARCH: Arches National Park. Modified from Dubiel, 1994.

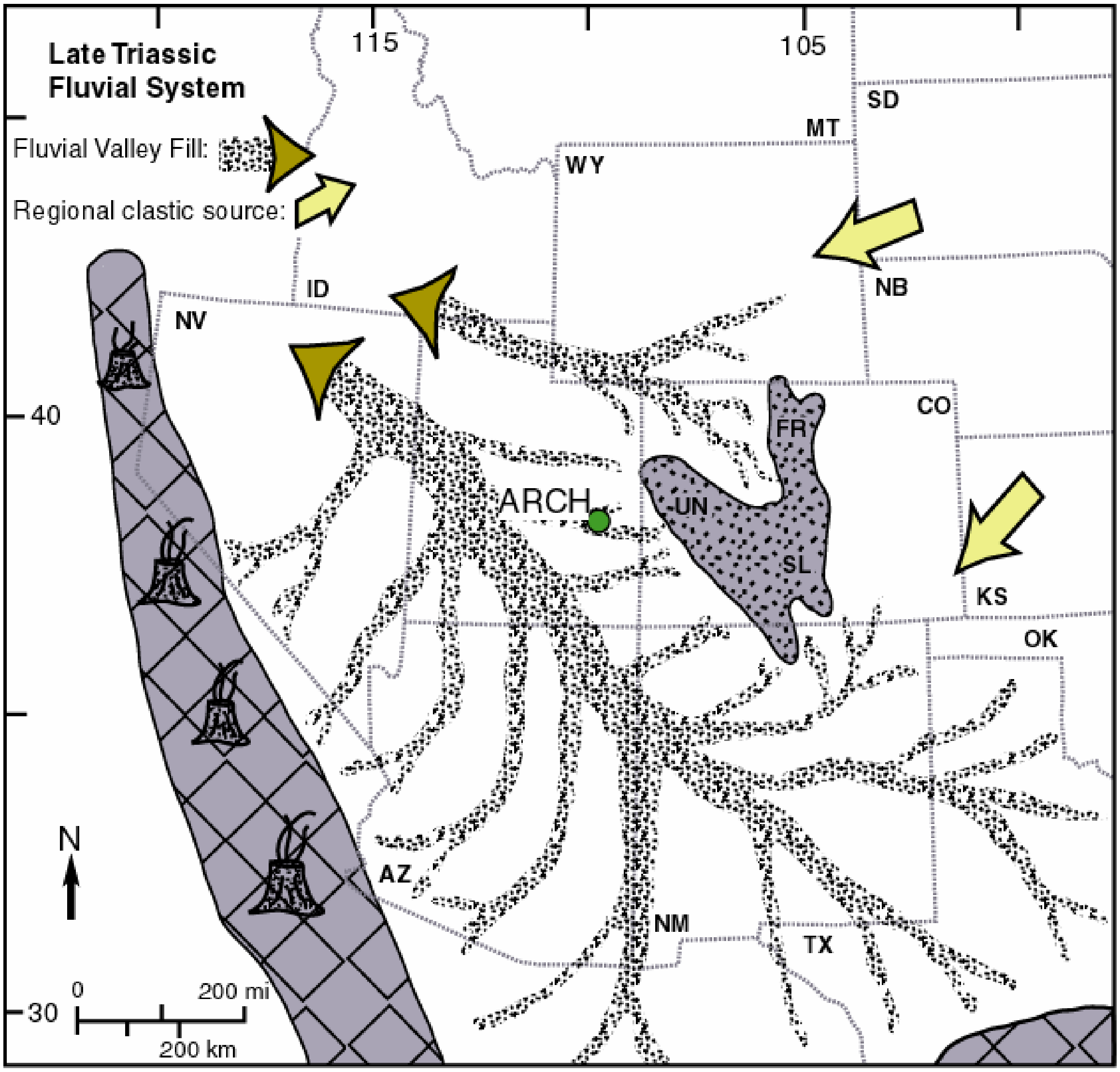


Figure 13: Paleogeographic map of the Upper Triassic. UN: Uncompahgre uplift; SL: San Luis uplift; FR: Front Range uplift. Highlands are shaded a solid gray. Modified from Dubiel, 1994.

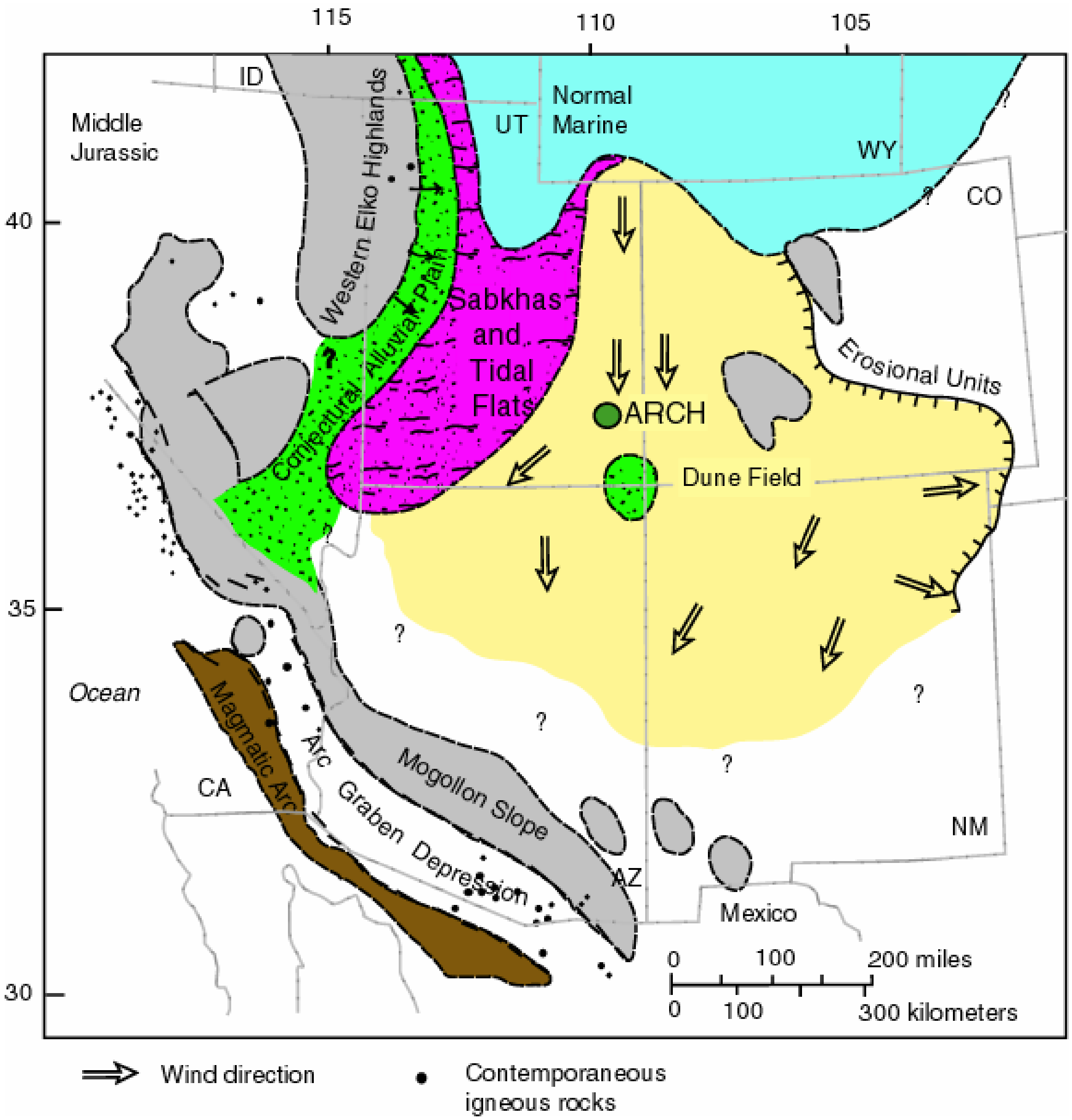


Figure 14: Middle Jurassic Period paleogeography during deposition of the Entrada Sandstone. Note that the northern marine environments have eliminated the sand source to the north, yet Entrada-age ergs are widespread. ARCH: Arches National Park. Modified from Peterson, 1994.

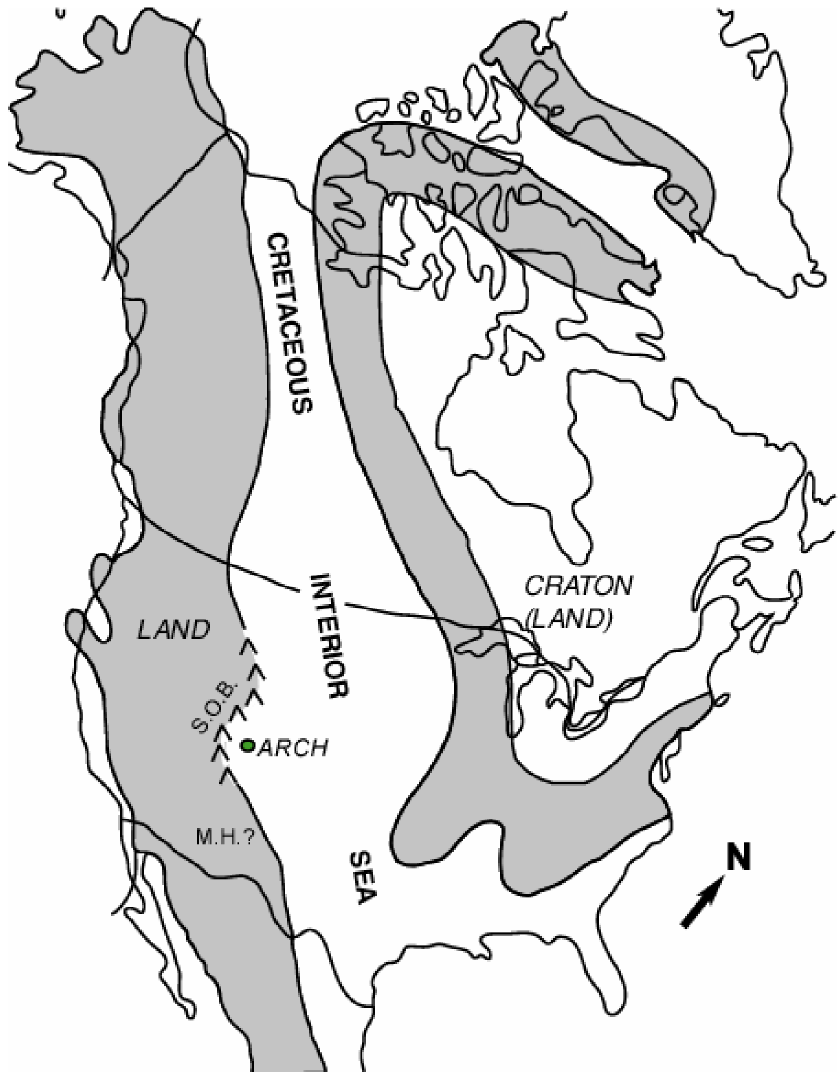


Figure 15: Location of the Cretaceous seaway. Shaded areas indicate land above sea level. "S.O.B." and inverted "V"s indicate the Sevier Orogenic belt. "M.H.?" is the Mogollon Highland in southwestern Arizona. ARCH: Arches National Park. North indicates the Cretaceous north. Modified from Rice and Shurr, 1983.

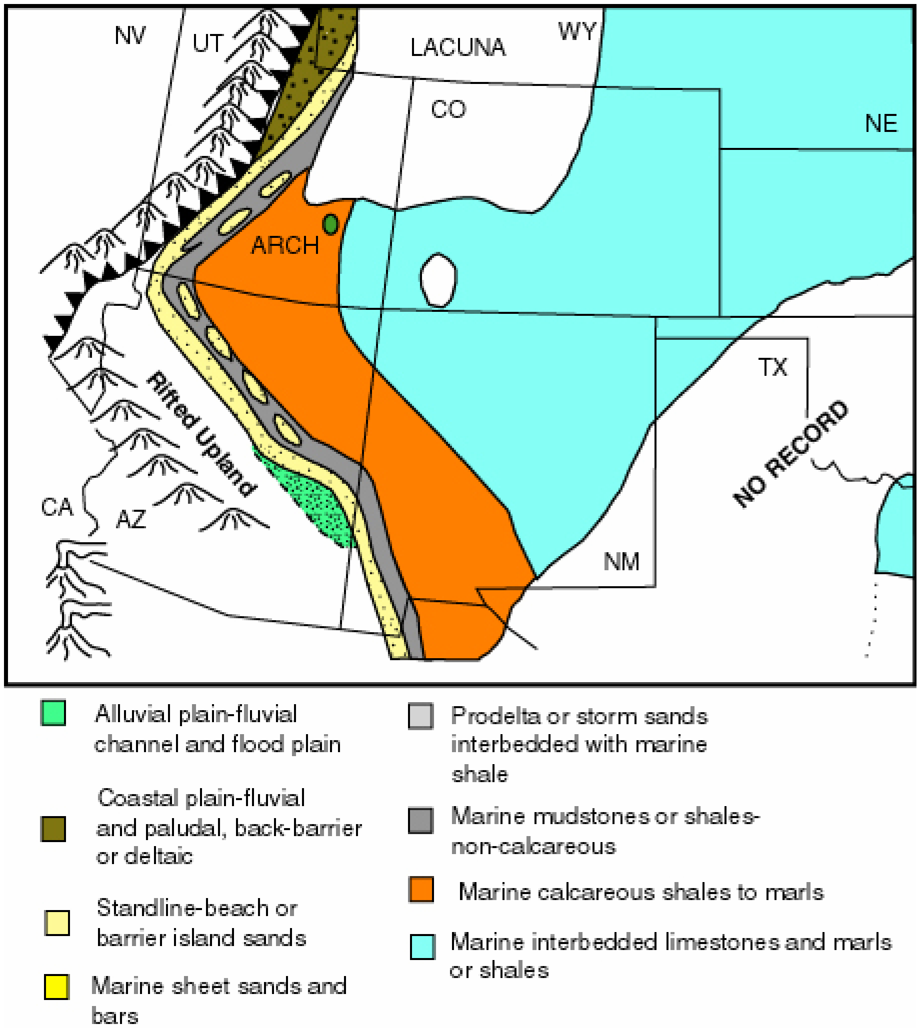


Figure 16: Upper Cretaceous paleogeography at the time of Tununk Shale member, Mancos Shale, deposition. Solid triangles mark the leading edge of thrust faulting with the triangles on the overriding plate. A lacuna is an unrecorded stratigraphic record at an erosion surface caused by either erosion or non-deposition. ARCH: Arches National Park. Diagram modified from Elder and Kirkland, 1994.

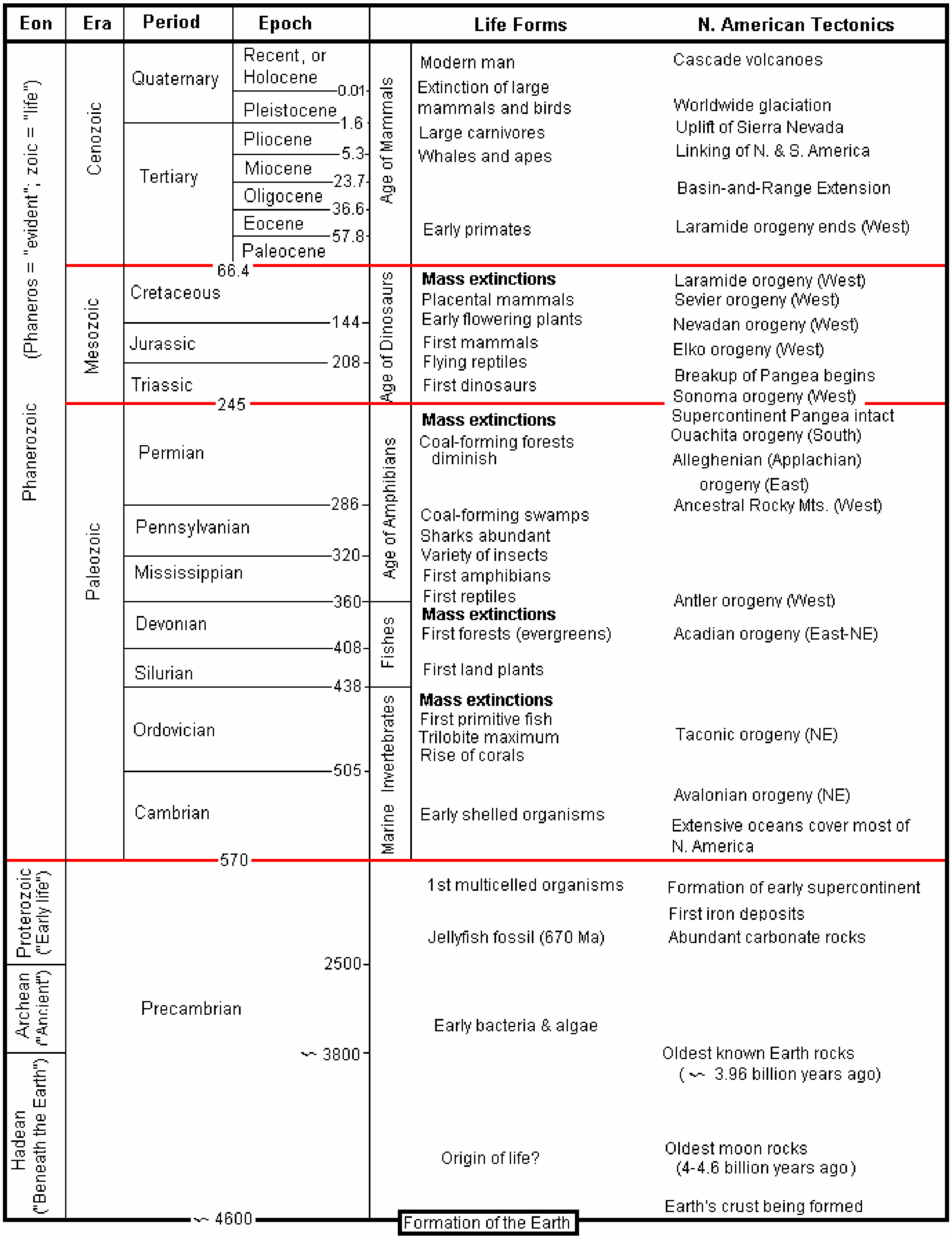


Figure 17: Geologic time scale. Red lines indicate major unconformities between eras. Absolute ages shown are in millions of years. Scale is from the U.S.G.S.

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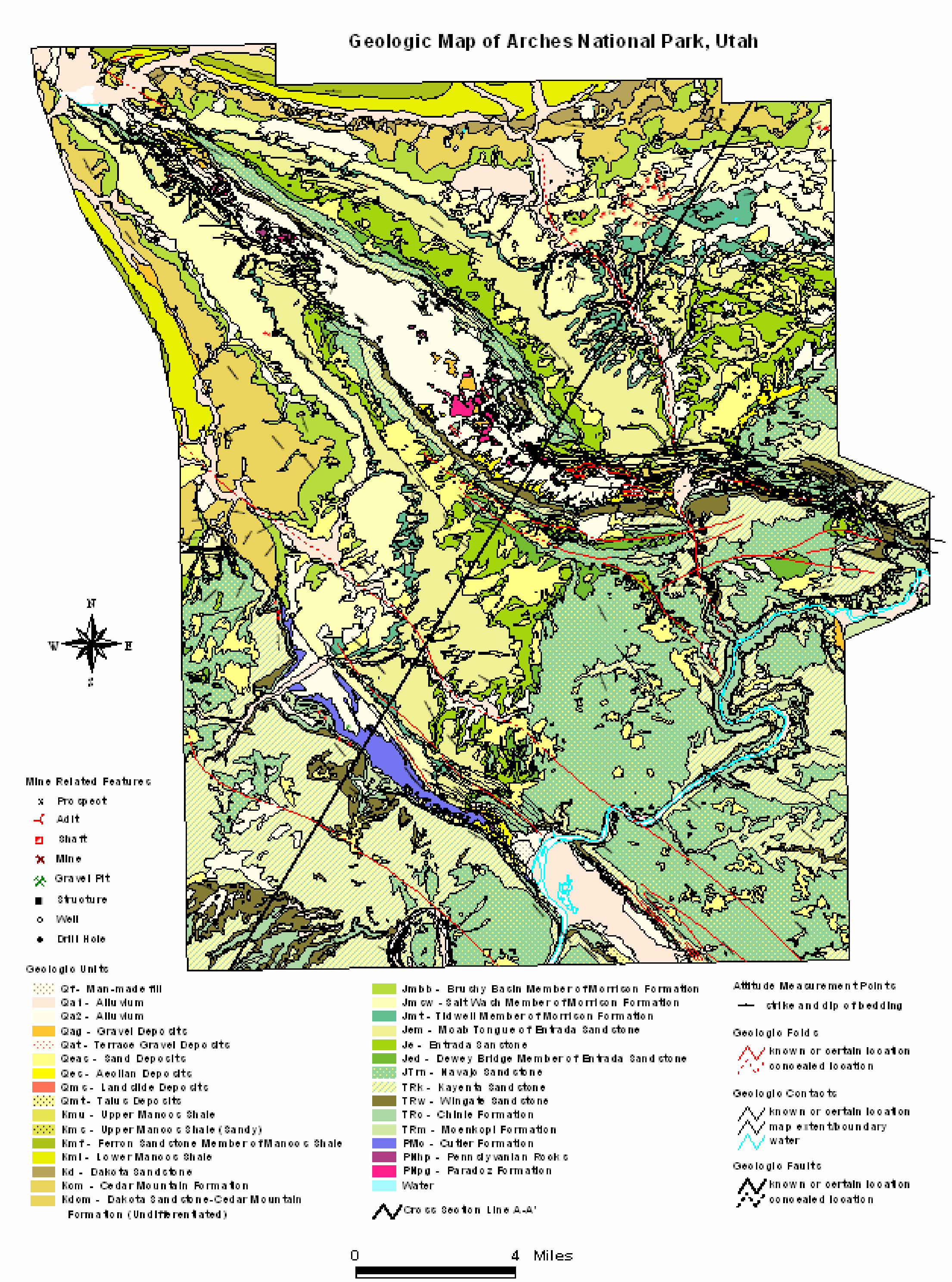
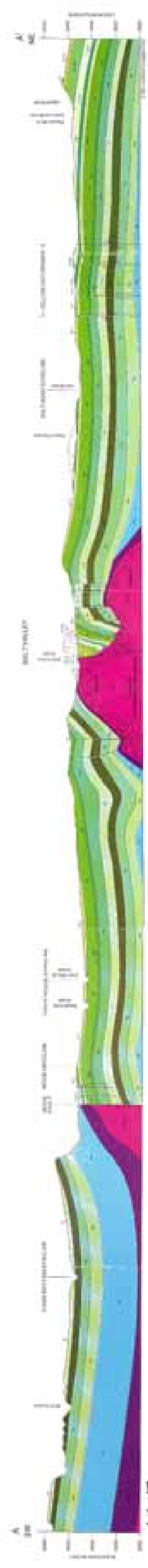
Appendix A: Geologic Map and Cross Section Graphics

This image provides a preview or "snapshot" of the geologic map and cross section for Arches National Park. For a detailed digital geologic map, see included CD.



The original maps digitized by NPS staff to create this product was: Doelling, D.M., 1985, Geologic map of the Arches National Park and vicinity, Grand County, Utah, Utah Geological Survey, UGS 74, 1:50000 scale. For a detailed digital geologic map and cross sections, see included CD.



Arches NP
Map 74: Geological Cross Section A-A'
Geologic Map of Arches NP and Vicinity, Grand County, Utah
by Hellmut H. Doelling
Utah Geological and Mineral Survey, 1985

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Arches National Park and other parks located in southeastern Utah. The scoping meeting occurred May 24- 27, 1999; therefore, the contact information and Web addresses referred to herein may be outdated. At the time of this meeting the GRE program was known as the Geologic Resources Inventory (GRI).Please contact to the Geologic Resources Division for current information.

Executive Summary

An inventory workshop was held for national park service units in the Southeast Utah Group (Arches NP, Canyonlands NP, Hovenweep NM, and Natural Bridges NM) from May 24- 27, 1999 to view and discuss the geologic resources, to address the status of geologic mapping by the Utah Geological Survey (UGS) for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Natural Resources Information Division (NRID), Southeast Utah Group NPS staff (interpretation, natural resources, deputy superintendents), UGS, United States Geological Survey (USGS), and Utah Geological Association (UGA) were present for the two day workshop.

- Monday May 24th involved a field trip to Natural Bridges NM (NABR) led by Red Rocks College geologist Jack Stanesco with additions from Christine Turner and Pete Peterson (both of the USGS).

- Tuesday May 25th involved a field trip to Canyonlands NP (CANY) led by USGS geologist George Billingsley, again with additions from Christine Turner and Pete Peterson also of the USGS.

- Wednesday May 26th involved a field trip to Arches NP (arch) led by UGS geologist Hellmut Doelling with additions from Grant Willis (UGS) and Vince Santucci (NPS- GRD).

An on- line slide show of the highlights of these field trips can be found at http://www.nature.nps.gov/grd/geology/gri/ut/seug/field_trip_seug

- Thursday May 27th involved a scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the Geologic Resources Division, and the ongoing Geologic Resources Inventory (GRI) for Colorado and Utah. Round table discussions involving geologic issues for the Southeast Utah Group included interpretation, the UGA Millennium 2000 guidebook featuring the geology of Utah's National and State parks, paleontological resources, the status of cooperative geologic mapping efforts, sources of available data, geologic hazards, potential future research topics, and action items generated from this meeting. Brief summaries of each follows.

Overview of Geologic Resources Inventory

After introductions by the participants, Joe Gregson (NPS- NRID) presented an overview of the NPS I&M Program, the status of the natural resource inventories, and the geological resources inventory.

He also presented a demonstration of some of the main features of the digital geologic map for the Black Canyon of the Gunnison NM and Curecanti NRA areas in Colorado. This has become the prototype for the NPS digital geologic map model as it ideally reproduces all aspects of a paper map (i.e. it incorporates the map notes, cross sections, legend etc.) with the added benefit of being a GIS component. It is displayed in ESRI ArcView shape files and features a built- in help file system to identify the map units. It can also display scanned JPG or GIF images of the geologic cross sections supplied with the map. The cross section lines (ex. A- A') are subsequently digitized as a shape file and are hyperlinked to the scanned images.

For a recap on this process, go to: http://www.nature.nps.gov/grd/geology/gri/blca_cure/ and view the various files in the directory.

The geologists at the workshop familiar with GIS methods were quite impressed with this method of displaying geologic maps digitally; Gregson is to be commended for his accomplishments.

Bruce Heise (NPS- GRD) followed with an introduction to the NPS GRD group.

Interpretation

The GRI also aims to help promote geologic resource interpretation within the parks and GRD has staff and technology to assist in preparation of useful materials including developing site bulletins and resource management proposal (RMP) statements appropriate to promoting geology. Jim Wood (GRD) and Melanie Moreno (USGS- Menlo Park, CA) have worked with several other NPS units in developing web- based geology interpretation themes, and should be considered as a source of assistance should the park desire.

Along the lines of interpretation of geology for the SEUG, it was suggested that they consider hiring a full-time geologist to be on staff to evaluate research proposals and generally assist all interpretive areas within the SEUG to find out what issues should be addressed. A geologist could add greatly to NABR, CANY, and ARCH because the primary theme of these parks is geologic; there would be no bridges, arches, or canyon (lands) without the underlying influence of geology and geologic processes upon this part of the world. A geologist would also certainly be active in establishing the most effective wayside exhibits aimed at informing the public about the geologic wonders of the area. A geologist can certainly assist in the presentation and interpretation of paleontologic resources and issues also.

Such a position could act as a liaison among various tour groups, researchers, field camps and professional organizations that visit the area because of the spectacular geology. Geologic hazards would also be able to be more fully understood. Obviously, effective communication skills are a highly desirable quality for any applicant.

In the absence of such a position, the GRD is most willing to assist the SEUG in any geologic matters and issues should they desire. Please contact Bruce Heise or Tim Connors to discuss further matters regarding geologic resources.

UGA Guidebook on Utah's National and State Park Areas

Doug Sprinkel of the UGA announced that a guidebook treating the geology of 27 of Utah's national and state parks and monuments will be compiled for publication in September 2000. This compilation will be a snapshot into the geology of each park and covers most facets of what the GRI is trying to develop for each park for a final report (i.e. cross sections, simplified geologic map, general discussions of rocks, structure, unique aspects of park geology, classic viewing localities). Each author will be encouraged to get with NPS staff interpreters to develop a product that aims at a wide audience (the common visitor, the technical audience and the teaching community). Authors for SEUG parks are as follows:

- Arches NP: Hellmut Doelling (UGS)
- Canyonlands NP: Donald Baars
- Natural Bridges NM: Jackie Huntoon, Russell Dubiel, Jack Stanesco

Also, a CD- ROM will be distributed with the publication featuring road and trail logs for specific parks as well as a photo glossary and gallery. Park authors are strongly encouraged to get with NPS staff to make sure that any trail logs do follow maintained trails and do not take visitors into unauthorized areas, or places where resources are fragile and would be disturbed by increased visitation (i.e. areas with crytptogamic soils).

The photo glossary will describe certain geologic features (i.e. what is crossbedding?). These will also be available as web- downloadable Adobe Acrobat PDF files. The UGA cannot copyright this material because it is funded with state money, so it can be distributed widely and freely, which will also benefit the purposes of the GRI. Additional reprints are not a problem because of the digital nature of the publication and the UGA board is committed to additional printings as needed. UGA normally prints 1000 copies of their publications because they become dated after about five years; that will probably not be an issue for this publication. Prices for the full- color guidebook are estimated to be approximately $25/copy, and sales are expected to be high (exact estimates for Capitol Reef NM were 125 copies/year). A website for the guidebook is forthcoming in October 1999.

Field Trips will be held in September 2000. Currently, four field trips are scheduled:

1. Arches NP, Canyonlands NP, Dead Horse Point State Park (SP)
2. type of project could serve as a model for other states to follow to bolster Antelope Island SP and Wasatch Mountain SP
3. Southeast Utah Group NP, Cedar Breaks NM, Snow Canyon SP and Quail Creek SP
4. Dinosaur NM, Flaming Gorge NRA, and Red Fleet SP

Note: Trips 1 and 2 will run concurrently and Trips 3 and 4 will also run concurrently.

Many other benefits are anticipated from this publication and are enumerated below:

- This tourism and book sales promoting their state and its geologic features.
- Sandy Eldredge (UGS) will be targeting teaching communities for involvement in the field trips; hopefully teachers will pass on what they have learned to their young audience.
- The language is intended to appeal to someone with a moderate background in geology and yet will be very informative to the educated geologist.
- The publication may be able to serve as a textbook to colleges teaching Geology of National Parks (in Utah).
- A welcomed by- product could be roadlogs between parks in Utah for those visiting multiple parks, perhaps with a regional synthesis summarizing how the overall picture of Utah geology has developed.

Disturbed Lands

GRD's John Burghardt has done work in Lathrop Canyon on reclaiming abandoned mineral lands (AML). His reports should be studied as a significant source of data for this area to determine if additional work needs to be performed. Dave Steensen (GRD) heads the AML program and can also be contacted.

Paleontological Resources

The field trip at Arches NP provided glimpses into the paleontological resources (dinosaur bones) near Delicate Arch. It has been suggested to keep this location low profile to minimize disturbances and potential theft or vandalism.

During the scoping session, the importance of a paleontological resource inventory for the Cedar Mountain and Morrison Formations near the Dalton Wells Quarry was discussed as being a priority. The important resources are likely to be dinosaur bones. A staff geologist or paleontologist would surely be useful for this purpose.

Vince Santucci (NPS- GRD Paleontologist) will be co-authoring a "Paleontological Survey of Arches National Park" and detailing findings of resources within the park. Plants, invertebrates, and vertebrate tracksites are among the recognized paleontological resources within the Southeast Utah Group area parks.

Similar surveys have been done for Yellowstone and Death Valley NP's and have shed valuable new information on previously unrecognized resources. These surveys involve a literature review/bibliography and recognition of type specimens, species lists, and maps (which are unpublished to protect locality information), and also make park specific recommendations for protecting and preserving the resources.

The Death Valley Survey will be available soon. The Yellowstone Survey is already available on- line at:
http://www.nature.nps.gov/grd/geology/paleo/yell_survey/index.htm
and is also available as a downloadable PDF at
http://www.nature.nps.gov/grd/geology/paleo/yell.pdf

Paleontological resource management plans should be produced for Southeast Utah Group involving some inventory and monitoring to identify human and natural threats to these resources. Perhaps someone on the park staff could be assigned to coordinate paleontological resource management and incorporate any findings or suggestions into the parks general management plan (GMP). It would be useful to train park staff (including interpreters and law enforcement) in resource protection, as the fossil trade "black market" has become quite lucrative for sellers and often results in illegal collecting from federal lands.

Collections taken from this area that now reside in outside repositories should be tracked down for inventory purposes. Fossils offer many interpretive themes and combine a geology/biology link and should be utilized as much as possible in interpretive programs.

Status of Geologic Mapping Efforts for the SEUG

Status of Existing Maps

It should be noted that the following paper geologic maps exist:

- Arches NP ("Geologic Map of Arches National Park and vicinity, Grand County, Utah" by Hellmut H. Doelling, 1985) at 1:50,000. The area was mapped at 1:24,000 scale, but compiled at 1:50,000 scale.

- Canyonlands NP ("Geologic Map of Canyonlands National Park and Vicinity, Utah" by George Billingsley, Peter Huntoon, and William J. Breed, 1982) at 1:62,500

- Canyonlands NP ("Bedrock Geologic Map of Upheaval Dome, Canyonlands NP, Utah" by Gene Shoemaker, Herkenhoff and Kriens, 1997); scale unknown.

George Billingsley noted that when he worked on the Canyonlands map, he mostly compiled previous material. He thought several additions to the Quaternary deposits and the placement of joints/fractures on the maps would improve the quality of the 1982 Canyonlands map. There are also some issues regarding assignment of the Page Sandstone, and the controversy of the Dewey Bridge Member of the Entrada versus the Carmel Formation being within the map area. He thinks eventually, the entire area should be compiled at 1:24,000 to better enhance features and add to resource management.

Jackie Huntoon has told Bruce Heise that she is working on a digital coverage for Natural Bridges, but needs the hypsography (contour lines) to complete her work. Desired quadrangles that NRID has this coverage for are the following:

- The Cheesebox

- Woodenshoe Buttes

- Kane Gulch

- It is not sure if the coverage exists for the Moss Back Butte quadrangle; Joe Gregson will look into it.

Digitized Maps

The 1985 Arches map has been digitized into an ArcInfo coverage by SEUG staff. The attribute quality is unknown however, and will be researched. NPS- GRI folks will work with SEUG GIS Specialist Gery Wakefield to learn more about this coverage

The 1982 Canyonlands map is not known to have been digitized at this point and hopefully can be done by the SEUG GIS staff. George Billingsley says that the Canyonlands Natural History Association has the original line work and mylars; Diane Allen said she will contact them to see if they still have this work.

The 1997 Upheaval Dome map is digitized as an ArcInfo coverage and a copy was given to Craig Hauke (CANY) from George Billingsley. It also contains cross sections and a report. A website exists for this work at: http://www.seismo.unr.edu/ftp/pub/louie/dome/98seismo/index.html

UGS Mapping Activities in SEUG area

Currently, the UGS is mapping in Utah at three different scales:

- 1:24,000 for high priority areas (i.e. National and State parks)
- 1:100,000 for the rest of the state
- 1:500,000 for a compiled state geologic map

The UGS plans to complete mapping for the entire state of Utah within 10- 15 years at 1:100,000 scale. For 1:100,000 scale maps, their goal is to produce both paper and digital maps; for 1:24,000 scale maps, the only digital products will be from "special interest" areas (i.e. areas such as Southeast Utah Group and growing metropolitan St. George). Grant Willis mentioned that the UGS simply does not have enough manpower and resources to do more areas at this scale. He also reiterated that UGS mapping goals are coincident with those of the National Geologic Mapping Program.

Grant Willis talked about the status of UGS mapping activities within the Southeast Utah Group area. 30 x 60 sheets (at 1:100,000) for the area include the La Sal (greater Canyonlands area) and Moab (Arches NP) sheets, which are currently in progress (paper and digital format).

Below is a brief summary of various mapping projects for SEUG parks from the UGS:

Park	Quadrangle	Status
Arches NP	Klondike Bluffs	UGS (Doelling) mapping in Progress
	Mollie Hogans	UGS (Doelling) mapping in Progress
	Cisco SW	Slated for future work
	Big Bend	Paper map published 1998; not digitized
	The Windows Section	UGS (Doelling) mapping in Progress
	Merrimac Butte	In publication
	Gold Bar Canyon	Published
	Moab- 16	Ready for press
	Moab (30x60)	Digital and printed map in progress
Canyonlands NP	Hanksville	Nothing currently; hopefully in a few years
	La Sal	Digital and printed map in progress
Natural Bridges NM	Hite Crossing	Nothing slated at this time
	Blanding	

Other Sources of Natural Resources Data for SEUG

- The UGS has a significant quadrangle database that they have furnished to NRID for the entire state of Utah.
- NRID has compiled a geologic bibliography for numerous parks and monuments, including all parks in the Southeast Utah Group. Visit the website at: http://165.83.36.151/biblios/geobib.nsf; user id is "geobib read", password is "anybody".
- SEUG GIS specialist showed a digitized version of Hellmut Doelling's 1985 map as and ArcInfo coverage; attribution needs to be checked; other coverage's should be sought that may exist from the previous GIS specialist.
- GRD has several entries regarding abandoned mineral land (AML) sites in their database that should be checked for data validity and compared with park records; John Burghardt (GRD) should be contacted regarding this
- The Arches NP visitor center sells a publication that has an inventory of all the arches of Arches
- The UGS has compiled a CD- ROM with well locations, pipelines, etc. for the state of Utah; GRD should obtain a copy of this. Parks may also desire copies too.

Geologic Hazards

There are numerous issues related to geologic hazards in and around the Southeast Utah Group parks. Below is a brief list of some mentioned during the scoping session:

- Landslide and rockfall potential along all roads that occasionally cause road closures; of special note was the problem with the main road in Arches, just above the visitor center
- Landscape Arch (arch) collapsed in a few places several years ago and was recorded by a tourist
- Swelling soils associated with bentonitic shale's of the Chinle, Morrison, and Mancos formations
- Radon potential associated with mine closures
- Earthquake potential along the Moab Fault

Potential Research Topics for SEUG NP

A list of potential research topics includes studies of the following:

- What are the connections between gypsiferous rocks and cryptobiotic soils/crusts?; why were the crust healthier on the gypsum- bearing rocks?
- How long will Delicate Arch stand?
- Engineering studies to determine hazards to visitors; use strain meter
- Use High resolution GPS to detect moving, swelling, and collapse in areas of the parks
- Rock color studies
- Subsurface seismic work for voids in the Needles around synclines and salt dome structures
- Locate real unconformity between Entrada Moab Tongue and abutting formations

Action Items

Many follow- up items were discussed during the course of the scoping session and are reiterated by category for quick reference.

Interpretation

- More graphics and brochures emphasizing geology and targeting the average enthusiast should be developed. If Southeast Utah Group NP needs assistance with these, please consult GRD's Jim Wood (jim_f._wood@nps.gov) or Melanie Moreno at the USGS- Menlo Park, CA (mmoreno@usgs.gov).
- Consider the possibility of hiring a full- time geologist to handle geologic issues for the SEUG; in the absence of this consult with GRD for assistance in geologic matters

UGA Guidebook

- Attempt to plant the seeds of this concept to other states for similar publications involving local area geology. Such publications are especially useful for the GRI
- Have authors prepare logs that are "sensitive" to delicate areas in the park (i.e. where less user impact is desired)

Paleontological Resources

- For now, try to minimize location disclosure of vertebrate sites to minimize disturbances and the potential for theft or vandalism
- Develop an in- house plan to inventory, monitor and protect significant paleontological resources from threats; assign staff to oversee especially in regard to the Dalton Wells area
- Locate collections taken from the park residing in outside repositories

Geologic Mapping

- Attempt to complete digital coverage for the entire SEUG area from existing maps
- Locate already existing digital coverage's (like that of Doelling's 1985 Arches map)
- Work closely with UGS to finish paper and digital coverage of SEUG area where maps are lacking
- Work with cooperators (NABR- Jackie Huntoon) to ensure there work could be incorporated into the master plan of the GRI.

Natural Resource Data Sources

- Examine GRD databases for AML and disturbed lands for data validity
- Attempt to locate other digital coverage's from the previous SEUG GIS specialist (Eric) for Gery Wakefield's (current SEUG GIS specialist) inventory

Miscellaneous

- Review proposed research topics for future studies within Southeast Utah Group NP
- Promote sensitivity to delicate resources (crusts, etc.) to researchers, and visiting park groups

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Overview of Geologic Resources Inventory

The NPS Geologic Inventory is a collaborative effort of the NPS Geologic Resources Division (GRD) and Inventory and Monitoring Program (I&M) with assistance from the U.S. Geological Survey (USGS), American Association of State Geologists (AASG), and numerous individual volunteers and cooperators at NPS units, colleges, and universities.

From the perspective of the servicewide I&M Program, the primary focus (Level 1) of the geological inventory is

1. to assemble a bibliography of associated geological resources for NPS units with significant natural resources,

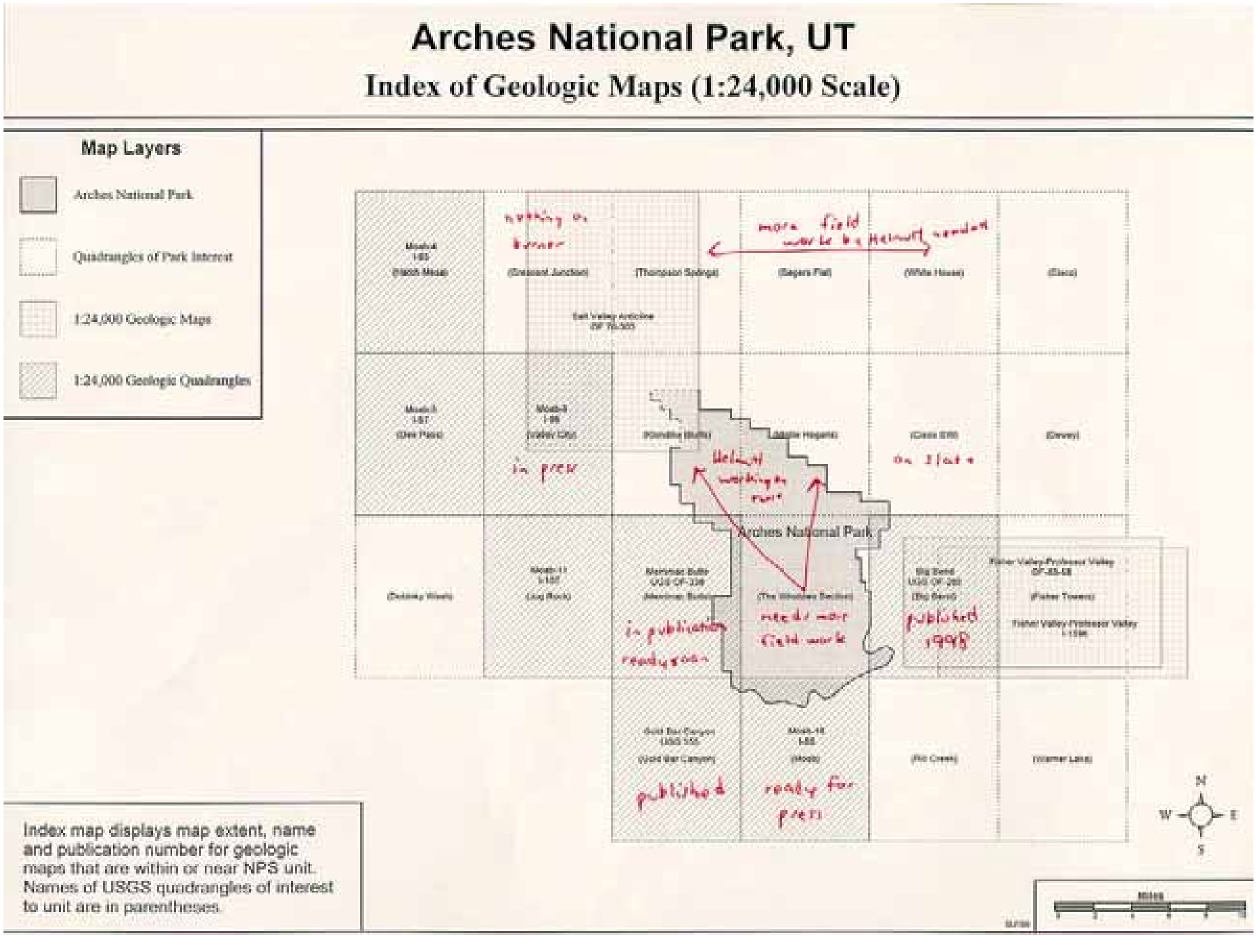
2. to compile and evaluate a list of existing geologic maps for each unit,

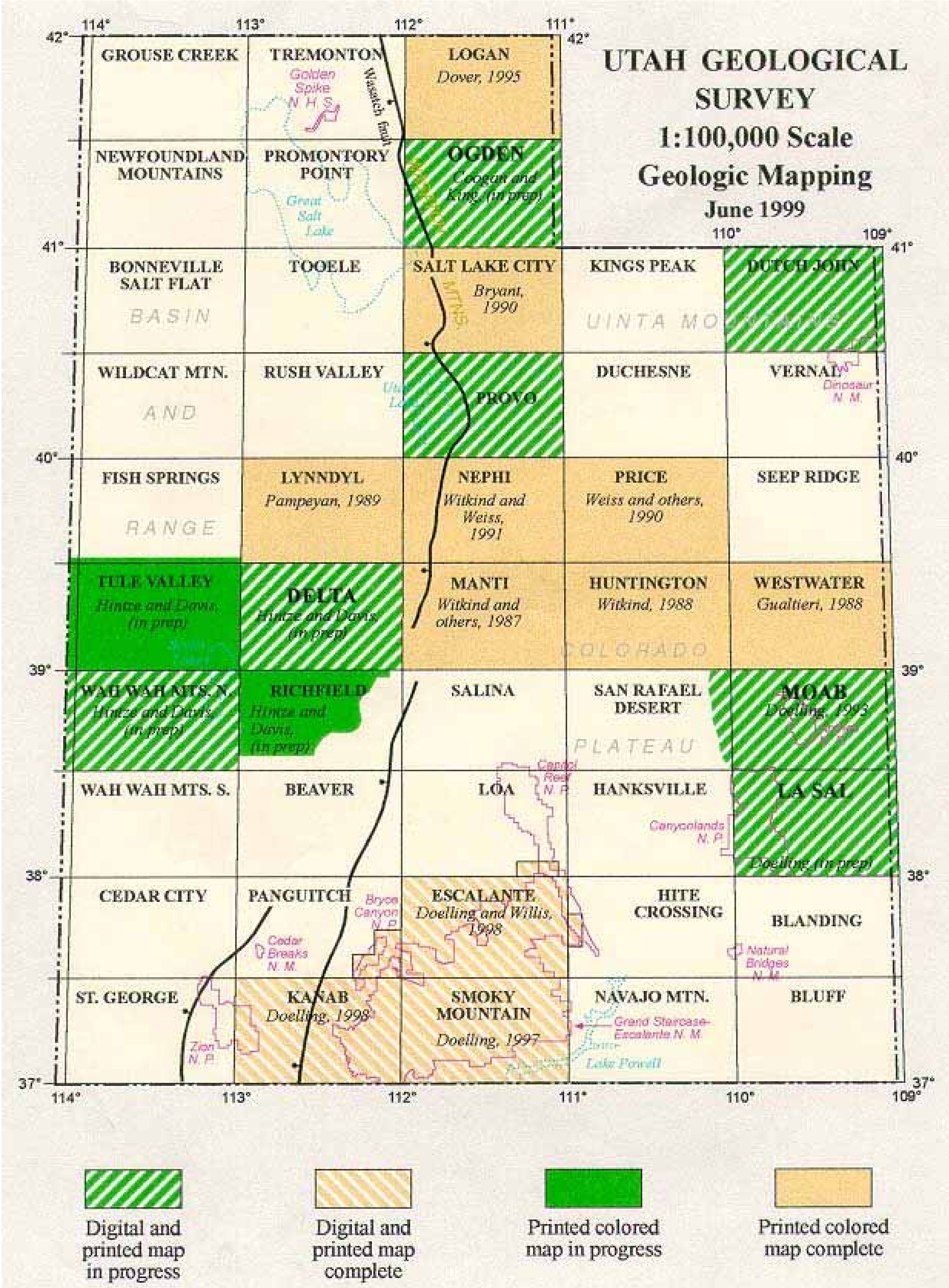
3. to develop digital geologic map products, and

4. to complete a geological report that synthesizes much of the existing geologic knowledge about each park. The emphasis of the inventory is not to routinely initiate new geologic mapping projects, but to aggregate existing information and identify where serious geologic data needs and issues exist in the National Park System.

The NPS Geologic Resources Division is an active participant in the I&M Program and has provided guidance and funding in the development of inventory goals and activities. GRD administers the Abandoned Mine Lands (AML) and Geologists In Parks (GIP) programs which contribute to the inventory. NPS paleontologists, geologists, and other natural resource professionals also contribute to inventory planning and data. A major goal of the collaborative effort is to provide a broad baseline of geologic data and scientific support to assist park managers with earth resource issues that may arise.

For each NPS unit, a cooperative group of geologists and NPS personnel (the Park Team) will be assembled to advise and assist with the inventory. Park Teams will meet at the each NPS unit to discuss and scope the geologic resources and inventory, which is the subject of this report. If needed, a second meeting will be held at a central office to evaluate available geologic maps for digital production. After the two meetings, digital geologic map products and a geologic report will be produced. The report will summarize the geologic inventory activities and basic geology topics for each park unit. Due to the variety of geologic settings throughout the NPS, each report will vary in subject matter covered, and section topics will be adapted as needed to describe the geologic resources of each unit. Whenever possible the scientific sections of the report will be written by knowledgeable cooperators and peer reviewed for accuracy and validity.


Arches National Park, UT
Index of Geologic Maps (1:24,000 Scale)
Map Layers
Arches National Park
Quadrangles of Park Interest
1:24,000 Geologic Maps
1:24,000 Geologic Quadrangles
(Thompson Springs)
(Sagers Flat)
(White House)
(Cisco)
Salt Valley Anticline
(Dewey)
Arches National Park
(Fisher Towers)
(Moab)
(Rill Creek)
(Warner Lake)
in press
more field work by Helmut needed
on slate
needs more field work
published 1998
in publication ready soon
published
ready for press
N
W
E
S
Miles
Index map displays map extent, name and publication number for geologic maps that are within or near NPS unit. Names of USGS quadrangles of interest to unit are in parentheses.


UTAH GEOLOGICAL SURVEY
1:100,000 Scale
Geologic Mapping
June 1999
GROUSE CREEK
TREMONTON
Golden Spike N. H. S.
Wasatch fault
LOGAN
Dover, 1995
NEWFOUNDLAND MOUNTAINS
PROMONTORY POINT
Great Salt Lake
OGDEN
Coogan and King, (in prep)
BONNEVILLE SALT FLAT
BASIN
TOOELE
SALT LAKE CITY
Bryant, 1990
KINGS PEAK
UINTA MO
DUTCH JOHN
WILDCAT MTN.
AND
RUSH VALLEY
PROVO
DUCHESNE
VERNAL
Dinosaur N. M.
FISH SPRINGS
RANGE
LYNNDYL
Pampeyan, 1989
NEPHI
Witkind and Weiss, 1991
PRICE
Weiss and others, 1990
SEEP RIDGE
TULE VALLEY
Hintze and Davis, (in prep)
DELTA
Hintze and Davis, (in prep)
MANTI
Witkind and others, 1987
HUNTINGTON
Witkind, 1988
WESTWATER
Gualtieri, 1988
COLORADO
WAH WAH MTS. N.
Hintze and Davis, (in prep)
RICHFIELD
Hintze and Davis, (in prep)
SALINA
SAN RAFAEL DESERT
PLATEAU
MOAB
Doelling, 1993
WAH WAH MTS. S.
BEAVER
LOA
Capitol Reef N. P.
HANKSVILLE
Canyonlands N. P.
LA SAL
Doelling (in prep)
CEDAR CITY
PANGUITCH
Bryce Canyon N. P.
Cedar Breaks N. M.
ESCALANTE
Doelling and Willis, 1998
HITE CROSSING
BLANDING
Natural Bridges N. M.
ST. GEORGE
Zion N. P.
KANAB
Doelling, 1998
SMOKY MOUNTAIN
Doelling, 1997
NAVAJO MTN.
Grand Staircase-Escalante N. M.
Lake Powell
BLUFF
114°
113°
112°
111°
110°
109°
42°
41°
40°
39°
38°
37°
Digital and printed map in progress
Digital and printed map complete
Printed colored map in progress
Printed colored map complete

Arches National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2004/005
NPS D-197, November 2004

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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