GEOLOGY OF THE MOAB REGION
(Arches, Dead Horse Point and Canyonlands)

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Introduction

The geology of Arches National Park, Dead Horse Point State Park and the "Island in the Sky" section of Canyonlands National Park is very similar. They occur in the Canyonlands section of the Colorado Plateau, in the vicinity of the confluence between the Green and Colorado Rivers. The same stratigraphic units outcrop in all three parks (figure 1) plus salt tectonic features can be found in both Arches and Canyonlands. While in the Moab region you will become familiar with some of the stratigraphic units we will see throughout the Colorado Plateau, observe salt tectonic features, arch formation and in the distance you can view the La Sal Mountains.

Cryptogamic Soils

While in these three parks (and throughout this trip) you will be required to **STAY ON THE DESIGNATED TRAILS.** This rule is especially important at these parks in order to preserve the fragile cryptogamic soils (figure 2). Cryptogamic soils are a complex of lichens, algae, moss and fungus that occurs as a black coating on the ground surface and as small mounds where it is well developed. It plays an extremely important role in the desert ecology. It binds the soil together and inhibits wind erosion and erosion by sheet wash. It absorbs moisture and converts atmospheric nitrogen into a form that can be used by higher plants. However this cryptogamic soil is so fragile that light grazing or even a single footstep can destroy tens of years of growth. One of the reasons why it is so well developed in this region is due to the lack of past grazing. You will most likely see other tourist straying from the trail, that does not make it right. Those people just don't know better.

La Sal Mountains

The large mountains, over 12,000 feet in elevation, located southeast of Arches are the La Sal Mountains. These mountains are a diorite porphyry laccolith that was intruded during the Oligocene, 30 million years ago and experienced glaciation during the Pleistocene. Melting snow which accumulates in the mountains during winter months, replenishes streams and recharges bedrock aquifers providing a valuable source of fresh water to this region. (Doelling and others, 1987)

Figure 2. Well developed cryptogamic soils along the Mesa Arch Trail, Canyonlands National Park.

Age	Thick. (ft)		Description
Quaternary		**Q**	Unconsolidated alluvium and terrace gravel (**Qal**), dune sand (**Qd**) and landslide deposits (**Qs**)
Tertiary		**Tkdp**	Quartz diorite porphyry
Cretaceous	**200-1200**	**Km**	**Mancos Shale** Dark-gray to black fissile even-bedded shale containing fossiliferous sandy limestone in the lower part of unit. Forms a slope.
Cretaceous	**50-200**	**Kdp**	**Dakota Sandstone** Brown massive to cross-bedded conglomerate and conglomeratic sandstone, locally contains green claystone lenses at base and dark-gray carbonaceous shale seams at top. Forms a cliff.
	Unconformity		
Jurassic	**600-700**	**Jm**	**Morrison Formation** Varicolored shales and fine-grained sandstones, massive sandstones and shales. Forms a slope with scattered sandstone ledges.
	Unconformity		
Jurassic			**Entrada Sandstone** Consist of the following three members:
	60-120	**Jem**	**Moab Tongue** Reddish-brown, thin-bedded, ripple-laminated muddy sandstones and siltstones. Forms a slope and short cliff
	200-500	**Je**	**Slick Rock** Pale orange, fine-grained massive, cross-bedded friable sandstone. Forms cliffs.
	40-235	**Jed**	**Dewey Bridge** Interbedded red siltstone and muddy sandstone.
Jurassic	**250-550**	**JTrn**	**Navajo Sandstone** Pale orange, well sorted, fine- to medium-grained, massive, sandstone. Forms a cliff and hummocky knobs.
Triassic	**200-300**	**Trk**	**Kayenta Formation** Reddish-brown to lavender, fine- to medium-grained sandstone with subordinate siltstone, limestone, and shale interbeds. Divided into a lower cliff-forming and an upper slope-forming unit.
Triassic	**250-450**	**Trw**	**Wingate Sandstone** reddish-brown, massive, cross-bedded fine-grained, well-sorted sandstone. Forms a prominent cliff.
Triassic	**200-900**	**Trc**	**Chinle Formation** Variegated red, purple, green and yellow bentonitic clayey sandstones and siltstones. Locally contains scattered ledges of conglomeratic sandstones. Generally forms a slope.
	Unconformity		

Figure 1. Description of Stratigraphic Units of the Moab Region (modified from Huntoon, Billingsley and Breed, 1982)

Age	Thick. (ft)		Description
Triassic	**0-1300**	**Trm**	**Moenkopi Formation** Reddish-brown, evenly-bedded, ripple-marked, cross-laminated siltstones and fine-grained sandstones. Forms a slope with a few scattered sandstone ledges.
	Unconformity		
Permian	**1800-2200**	**Pu**	**Cutler Group Undivided** Fluvial, red, arkosic sandstones and white marine sandstones, with interbedded red shales. Forms a series of alternating slopes and ledges. Contains the following Formations:
	0-250	**Pw**	**White Rim Sandstone**, Light gray to yellowish gray, fine grained cross-bedded sandstone. Forms overhanging and vertical cliffs.
	250-400	**Po**	**Organ Rock Shale**, Reddish-brown siltstone and shales. Forms a slope.
	200-1200	**Pc**	**Cedar Mesa Sandstone**, White to pale-reddish-brown, salmon, massive, cross-bedded sandstones interbedded with lenses of red, gray, green and brown sandstones. Forms a cliff.
	400-1500	**Pe**	**Elephant Canyon Formation**, Gray, cherty, chalky limestones and dolomites interbedded with pale-red sandstones, blue-gray siltstones, and thin beds of anhydrite. Forms a cliff with some slopes.
	Unconformity		
Pennsylvanian	**300-1500**	**Pht**	**Honker Trail Formation** Dark-gray, thick-bedded limestones, interbedded with gray cherty limestones, and also blue, red, and gray shales and sandstones. Forms ledges and slopes.
Pennsylvanian	**500-5000**	**Pp**	**Paradox Formation**, salt, anhydrite, and gypsum interbedded with euxinic black shales and limestones. Forms a slope.

Figure 1. (cont.) Description of Stratigraphic Units of the Moab Region (modified from Huntoon, Billingsley and Breed, 1982)

Arches National Park

Introduction

We will be observing salt deformation structures and arch formation at Arches National Park. On our drive through Arches we will stop to view the Moab Fault, La Sal Mountains, Court House Towers, Balanced Rock, Double Arch, the Garden of Eden, Pothole Arch, and Fiery Furnace (figure 3). We will hike the Windows and Devils Garden trails. If time (and energy) allow we will hike to Delicate Arch. Figure 4 shows the geology of Arches and the surrounding region.

Stratigraphy

The rocks at Arches range in age from Pennsylvanian (Paradox Formation) through Cretaceous (Mancos Shale), however the Jurassic units are the most prominent. The other stratigraphic units are found mostly as scattered blocks within the collapsed salt anticline of Salt Valley.

The prominent units we will be observing are the Jurassic Entrada Sandstone and Navajo Sandstone (Figure 5). The Entrada Sandstone is divided into three members, the Moab Tongue, Slick Rock and Dewey Bridge Members. The Moab Tongue is a thin bedded, reddish-brown, muddy sandstone and siltstone with ripple laminations. It is the stratigraphic equivalent to the Summerville Formation, found elsewhere on the Colorado Plateau. The Slick Rock Member, a massive, reddish-brown sandstone, occurs below the Moab Tongue. This unit is somewhat friable and rubbing it easily dislodges the sand grains. It tends to form cliffs that may be stained by black streaks of desert varnish. Many of the arches in the Devils Garden area occur within the Slick Rock unit. The Slick Rock was deposited in a coastal dune environment by wind and streams. Below the Slick Rock is the Dewey Bridge Member which consist of red, interbedded, muddy sandstone and siltstone. It is the stratigraphic equivalent to the Carmel Formation and was deposited in a tidal flat environment on the margin of a seaway that occurred to the west. The Dewey Bridge member is more susceptible to erosion so it occurs at the base of overhangs and arches. Bedding in the Dewey Bridge is contorted and wavy, which is unusual considering the units above and below it are undeformed. There are two possible explanations for this feature. The sediments may have been deformed prior to lithification and deposition of the overlying Slick Rock Sandstone, possibly due to slumping. An alternate explanation is that deformation occurred long after deposition and lithification of this unit. Structurally the Dewey Bridge is a relatively ductile unit confined between two resistant brittle units. During deformation the Dewey Bridge Member behaved plastically and was folded, whereas the units above and below behaved brittlely and were fractured. Below the Dewey Bridge Member is the Navajo Sandstone. This tan, massive, cross-bedded sandstone was deposited by wind in a vast desert which covered most of the Colorado Plateau. It forms both cliffs and hummocky knobs. It outcrops in the area of the park known as the “frozen dunes.” Arches also form within the Navajo sandstone.

Pennsylvanian rocks are not readily observable at Arches, but they play a very important role in the geology of the region. The Pennsylvanian Paradox Basin covered a large area of SE Utah and SW Colorado (figure 6). It

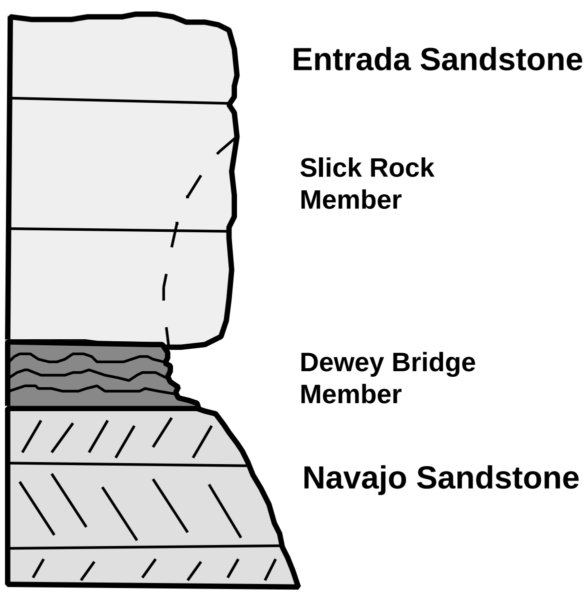

Figure 5. Sketch of the Entrada Formation and Navajo Sandstone. The curved line indicates where a cove may form by differential erosion of the Dewey Bridge Member.

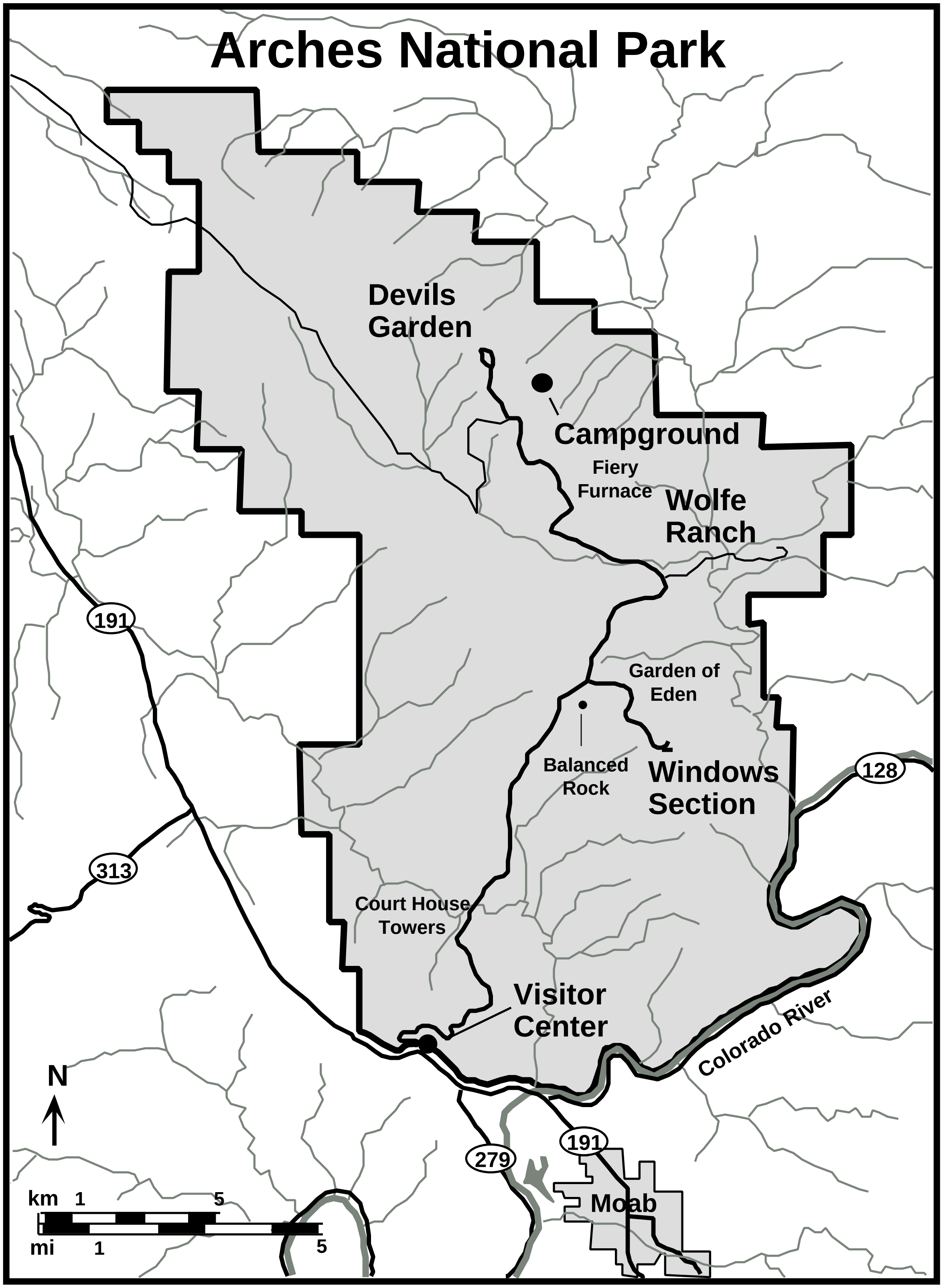

Figure 3. Map of Arches National Park (after National Park Service Map)

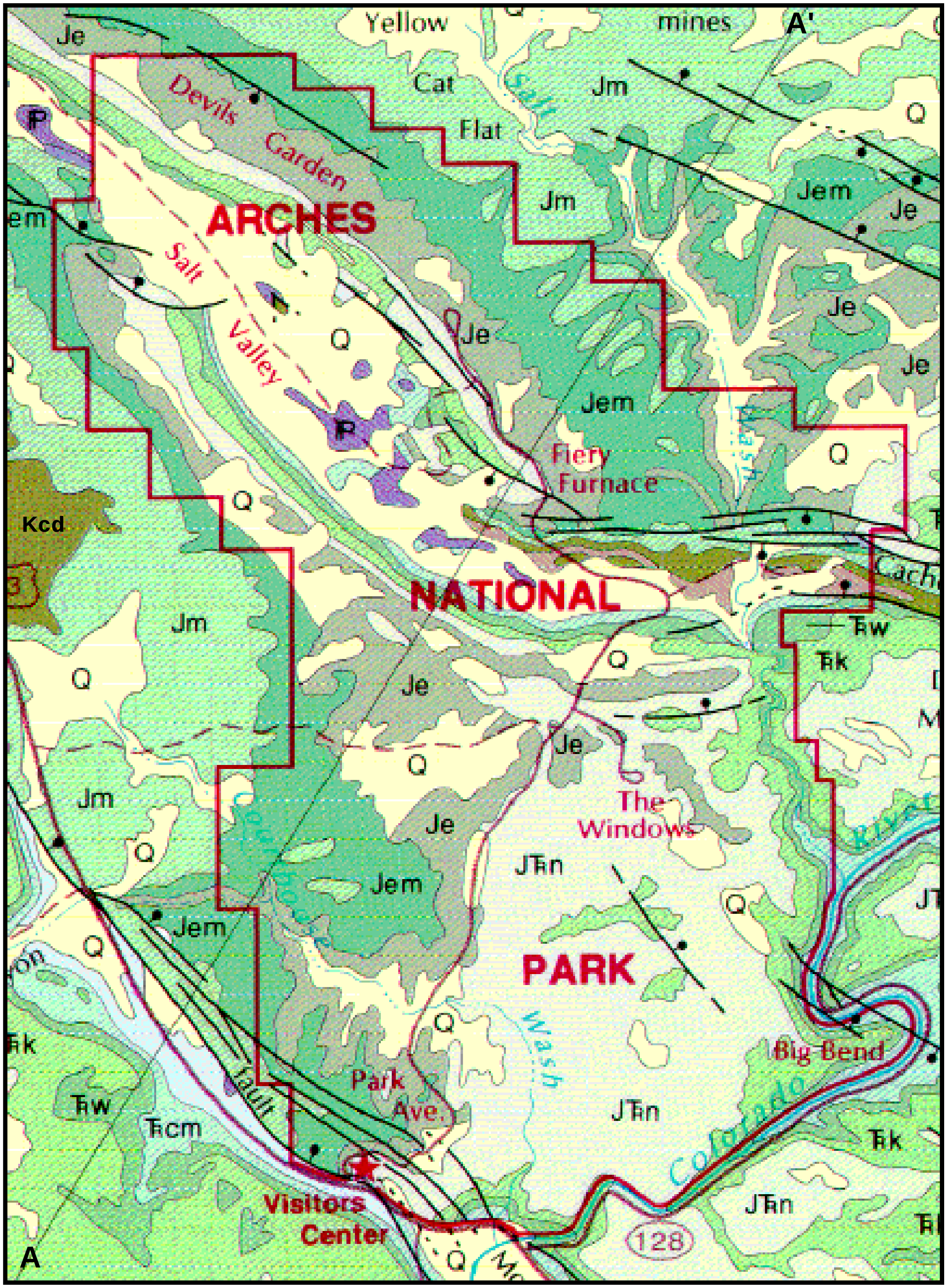

Figure 4. Geologic map of Arches National Park (Doelling, 1987)

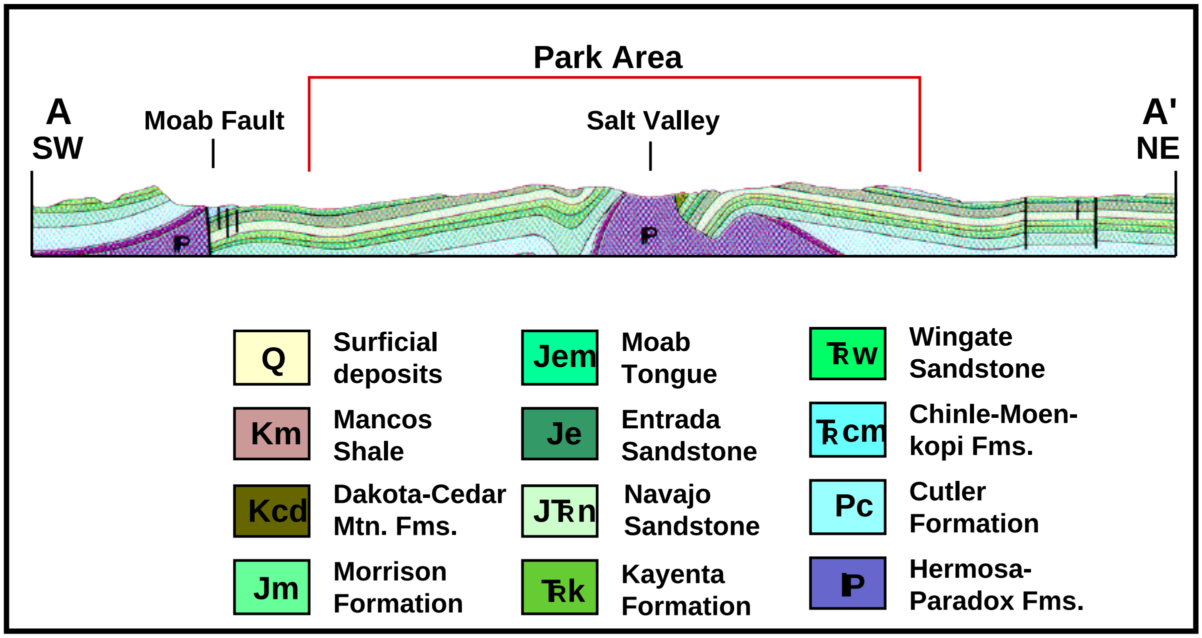

Figure 4 (cont.). Geologic map of Arches National Park (Doelling, 1987)

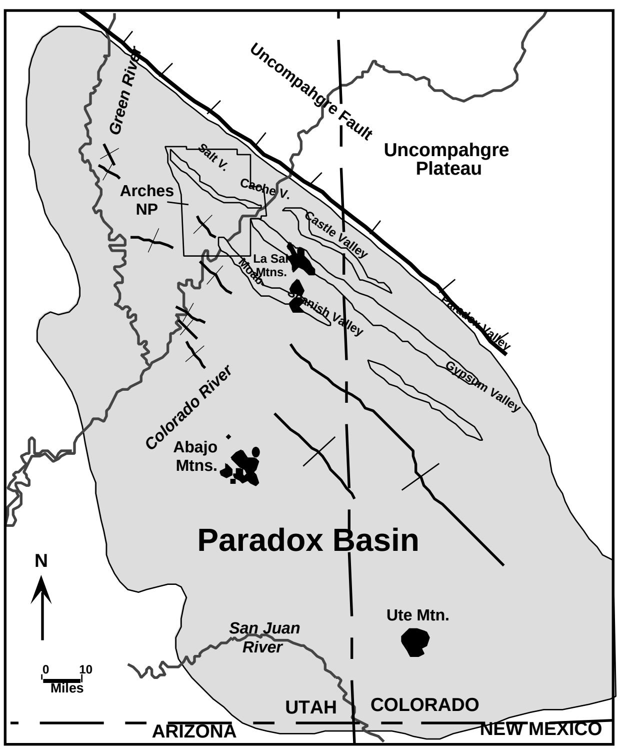

Figure 6. Map of the Paradox Basin showing salt anticlines, and salt valleys formed by collapse of salt anticlines (stippled pattern). Also shown is the location of major laccoliths and volcanic centers, La Sal, Abajo and Ute Mountains. (After Doelling, 1985)

is a down faulted basin formed by reactivation of deep seated Precambrian faults (Baars, 1993). Circulation in this sea was restricted which allowed for the accumulation salt deposits that had an original thickness ranging from 4,000 to 8,000 feet. The sedimentary basin was asymmetrical so the salt deposits are thickest in the NE part of the basin which corresponds to the area below Arches National Park. Overlying the salt deposits are Pennsylvanian and Permian aged sediments which were eroded from the adjacent Uncompahgre Uplift which formed at the same time as the Basin.

Salt Tectonics

Salt tectonic features can be found in both Arches and Canyonlands National Parks. Salt Valley and Moab Valley, both collapsed salt anticlines, are examples of salt deformation features. An illustration of the geology beneath one of these salt valleys is given in figure 7. Salt deposits composed primarily of the mineral halite (NaCl) deform plastically and have a low density relative to sandstones, shales and limestones. The load of overlying sediments will cause the plastic salt deposits to flow upwards into salt diapirs. The major salt structures occur along the trend of the thickest

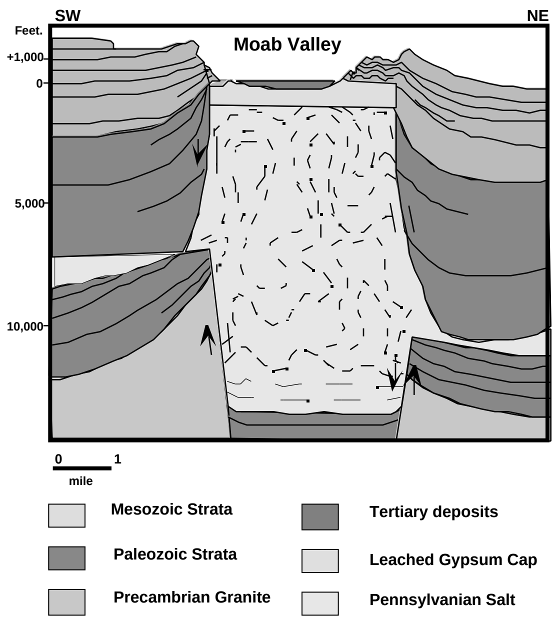

Figure 7. General structure of rocks beneath the Moab salt-intruded anticline (after Baars and Doelling, 1987)

salt deposits in the Paradox Basin. It is also believed that deep seated Precambrian faults may be controlling the location of salt tectonic features. Changes in the thickness of sedimentary units and the presence of angular unconformities indicate that the salt began to rise upwards at the end of the Pennsylvanian and continued during most of the Mesozoic Era (Baars and Doelling, 1987). As the salt moved upwards it deformed overlying sediments to form either salt anticlines or salt domes. Compressional forces during the Laramide orogeny downfolded the rocks between the salt anticlines into broad synclines and reactivated the basement faults. The sedimentary rocks were fractured at this time, with north-northwest joint sets developed parallel to the axis of the salt anticlines and major faults. During the Tertiary groundwater percolating through fractures and along faults dissolved the underlying salt deposits. A residual "leached gypsum cap" formed from gypsum ($CaSO_4$) within the salt deposits that is less soluble than halite. Eventually the rocks collapsed into the resultant void producing a salt valley. The Colorado River established it's course prior to collapse and maintained it's position after the valley formed. As a result the major drainage flows across, rather than running parallel to, or down the valley. The early settlers observed this "paradox" and named one of the salt valleys Paradox Valley (Baars and Doelling, 1987).

Moab Fault

The Moab Fault is a near vertical, normal fault that is oriented parallel to the Moab salt valley. Along this fault the older Pennsylvanian and Permian Honaker Trail and Cutler Formations are in contact with Jurassic Entrada and Morrison Formations. The average thickness of the missing units can be used to determine the relative displacement along the fault which is believed to be up to 2600 feet.

Arch Formation

Unsupported spans of rock fall under two main categories, natural bridges and arches, both of which are well represented on the Colorado Plateau. Natural bridges form by stream erosion and span either an active or an abandoned water course. Excellent examples of natural bridges can be observed at Natural Bridges and Rainbow Bridge National Monuments. Hickman Bridge located at Capitol Reef National Park is also a natural bridge. In contrast to natural bridges, arches form by weathering processes and are unrelated to stream erosion. Arches National Park has an unusually high number of natural arches with more than 500 arches reported within the park. A third type of unsupported span of rock forms in response to karst processes (dissolution of limestone by ground water). Angels Window which can be observed at the North Rim of the Grand Canyon formed in this manner.

There are two fundamental requirements for arch formation, a narrow wall of rock, known as a fin, and rocks that are strong enough to support the roof of the arch. These requirements are most often met within the Slick Rock Member of the Entrada Sandstone and the Navajo Sandstone. Both these units are strong competent units which tend to undergo brittle deformation (fracturing) rather than plastic deformation (folding). Deformation during formation of the Salt Valley Anticline caused the sandstones to be fractured and jointed. The Devils Garden section, where numerous closely spaced, parallel, fractures occur, is located on the axis of the Salt Valley anticline. Water percolating through these fractures enlarges them, leaving behind a thin wall of rock.

Arch formation often begins at the contact between the Dewey Bridge and Slick Rock Members of the Entrada Sandstone. The Dewey Bridge Member, which contains shale interbeds, is preferentially eroded producing a notch or overhang. The unsupported roof of the notch spalls off forming a concave cove. Eventually as the cove enlarges it breaks through the fin to form a window which can become enlarged to form an arch. Sometimes arch formation is initiated at a small seam of clay within the Slick Rock Member. Recent studies by (Cruikshank and Aydin, 1994) suggest that the distribution of minor fractures play an important role in arch formation.

There are three major stages of arch formation (figure 8): 1) Development Stage; characterized by a small window relative to the mass of enclosing rock. 2) Growth Stage; characterized by thinner more delicate arches with dwindling supports. 3) Destructive Stage; collapsed arches, with only closely spaced pinnacles remaining.

Pothole arches can form on the edge of vertical cliffs in the absence of a fin. Potholes form in slight depressions on the surface of exposed rocks. Water accumulates in these depressions which increases their susceptibility to weathering and causes the depressions to be enlarged. Excellent examples of potholes, locally known as waterpockets, can be observed at Capitol Reef National Park. If a pothole forms near the edge of a vertical cliff, it could eventually breach the side of the cliff and become enlarged to form a pothole arch. Many of the arches in the Windows section and Mesa Arch of Canyonlands formed in this manner.

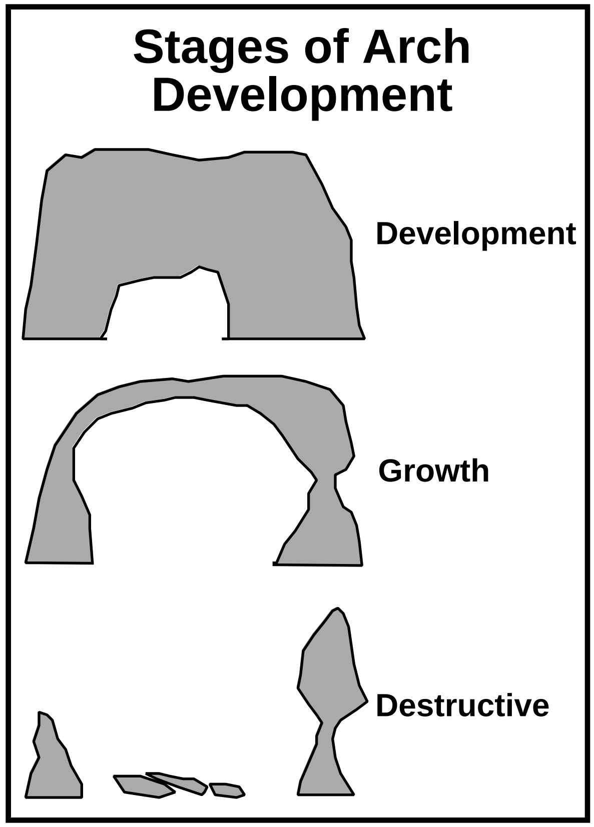

Figure 8. Stages of Arch development.

Dead Horse Point State Park

Dead Horse Point is a rock promontory surrounded by steep cliffs (figure 9). Before the turn of the century, the point was used as a natural corral for wild mustangs. Legend has it that a band of horses became stranded on the point and died of thirst within sight of the river below. The topography of this area, with broad flat mesas and steep sided cliffs is typical of flat lying strata that weathers in an arid environment. Humid climates are characterized by well developed soils and a dominance of mass wasting processes such as slump and creep, resulting in a smooth, rounded topography (figure 10). Under arid conditions, soils are either very poorly developed or lacking, and rock fall is the major mass wasting process. Resistant sandstones and limestones form vertical cliffs and the less resistant shales form gentle slopes. Erosion of valley walls is by vertical scarp retreat. Shales are eroded by sheet wash on barren rock after the infrequent but intense rainfalls. Undercutting of the shales, leaves the resistant beds (sandstones and limestones) unsupported. Eventually large blocks break free leaving behind a vertical cliff.

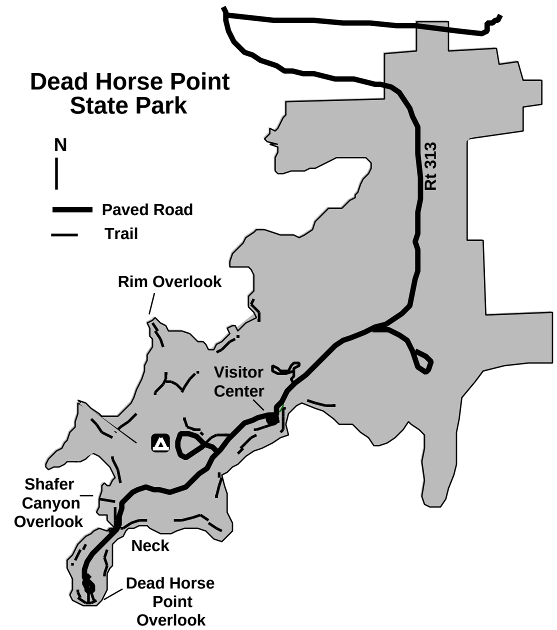

Figure 9. Map of Dead Horse Point State Park

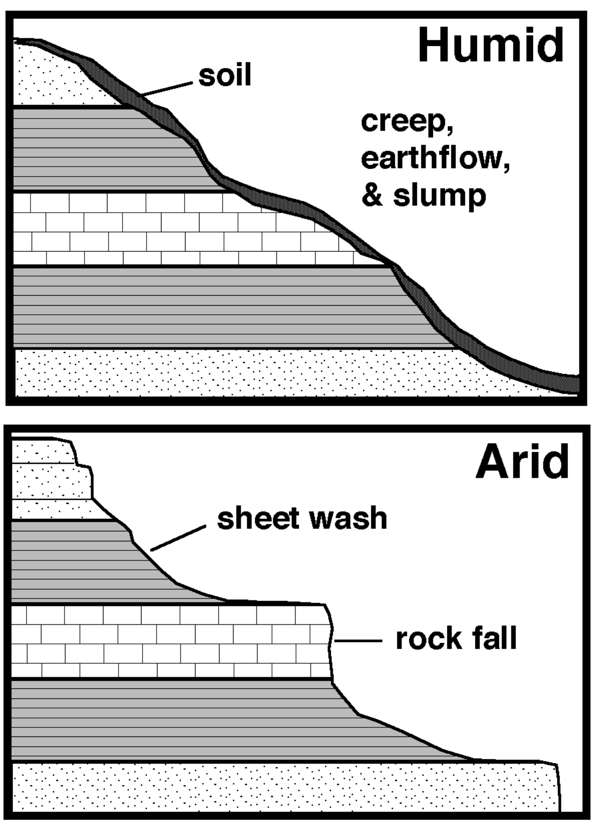

Figure 10. Comparison of mass wasting processes in arid and humid climates.

The elevation of Dead Horse Point is 6,000 feet, with a 2,000 foot drop, to the Colorado River, in a distance of approximately one mile. The Cutler Group is exposed at the base of the stratigraphic section, starting with a limestone bed of the Elephant Canyon Formation at the level of the Colorado River. The White Rock Sandstone (Cutler Group) forms the first major cliff below the broad flat bench that occurs near the top of the gooseneck. The next unit is the brown, slope forming siltstones and sandstones of the Moenkopi Formation. A thin, bench forming, white sandstone marks the contact between the Chinle and the Moenkopi Formations. The purple to red clayey sandstones and siltstones of the Chinle Formation form slopes up to the base of the Wingate Sandstone. The vertical cliffs of red, Wingate Sandstone are capped by the Kayenta Formation which we are standing on. In the distance are white, rounded hills of Navajo Sandstone.

The gooseneck is an example of an incised meander. The Colorado River established it’s coarse on a broad flat plain where it developed broad meander loops. A sudden lowering of the river’s base level either due to uplift of the Colorado Plateau or stream capture of the Colorado caused it to start rapidly down cutting, leaving the meanders incised within canyon walls.

The Cane-Creek potash mine can be observed from the visitors center. The potash ore of sylvite (KCl) and carnallite ($KMgCl_3 \cdot 6H_2O$) is mined from the Paradox Formation at a depth of approximately 2,800 feet. It was originally a conventional underground mine. Due to mining problems such as salt movement and roof failure, it was converted to a system combining solution mining and solar evaporation in 1970 (Gwynn, 1984). Fresh water from the Colorado River is pumped down where it flows through the old mine workings, dissolves the potash minerals, is pumped to the surface and allowed to concentrate in solar evaporation ponds. The potash is used in fertilizer and pharmaceutical products. (Doelling and others, 1987)

Canyonlands National Park

Introduction

We will visit the “Island in the Sky” section of Canyonlands. “Island in the Sky” is a high, (6,000-6,500 feet), broad, mesa that is connected to the "mainland" by a narrow neck of land. It occurs 2000 feet above the Green River to the west and Colorado River to the east The other sections of Canyonlands National Park include the Maze district, located southwest of the Green River, and the Needles district, located southeast of the Colorado River.

While at the park we will stop at the Grand View Point and Green River Overlooks. We will hike the Whale Rock and Upheaval Dome Overlook trails. If time allows we will hike the Mesa Arch Trail.

Stratigraphy and Geologic History

The rocks at Canyonlands range in age from Pennsylvanian through Jurassic (figure 1). During the Pennsylvanian the Ancestral Rocky Mountains, including the Uncompahgre Uplift of eastern Utah and western Colorado were uplifted. At the same time the Paradox Basin formed by subsidence. The oldest rocks of Canyonlands are the Pennsylvanian Paradox Formation, a thick accumulation of salt deposits that formed by evaporation of sea water in the restricted Paradox Basin. Although there are very few outcrops of the Paradox Formation, later movement of the salt deposits play an important role in the geology of the park. The prominent jointing in the Needles district formed as a result of salt tectonics.

Overlying the Paradox Formation is the Honaker Trail Formation which begins to outcrop along the Colorado and Green Rivers in the region just north of the Confluence. The Honaker Trail Formation consist of fossiliferous limestones with minor shales and sandstones and is evidence that this region was covered by a shallow sea during the Pennsylvanian. Glaciation on the southern continent of Gondwana caused global sea level to repeatedly rise and fall during the Pennsylvanian. These eustatic sea level fluctuations are recorded in the Honaker Trail Formation as repeated shallowing upwards cycles capped by subaerial exposure surfaces (Goldhammer, Oswald and Dunn, 1991).

Permian rocks of the Cutler Group unconformably overlie the Honaker Trail Formation. At least half of the surface outcrops at Canyonlands National Park are Permian rocks (Stokes 1988). The Permian arkosic red beds which dominate the scenery give this area its nick name “red rocks country.” The stratigraphy of the Cutler group represents a complex interfingering of facies and changes in source rock through time (Baars, 1983). Before I begin discussing the names of individual Formations picture the Uncompahgre Uplift to the northeast, an actively eroding mountain range. The climate is hot and dry. At the base of the mountains are alluvial fans which are coarse grained close to the mountains and get progressively finer grained moving toward the west. Now picture a belt of transitional environments with coastal dunes, beach deposits and submarine sand bars with a shallow sea off to the west (figure 12). To the east closest to the Uncompahgre highlands the

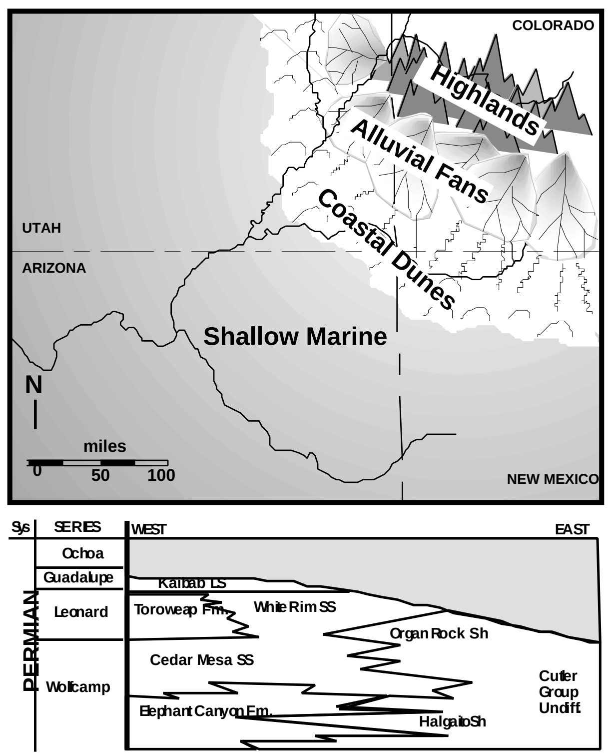

Figure 12. Paleogeography and correlation chart for the Permian of the Paradox Basin and Four Corners region. (Correlation after Stevenson and Baars, 1987)

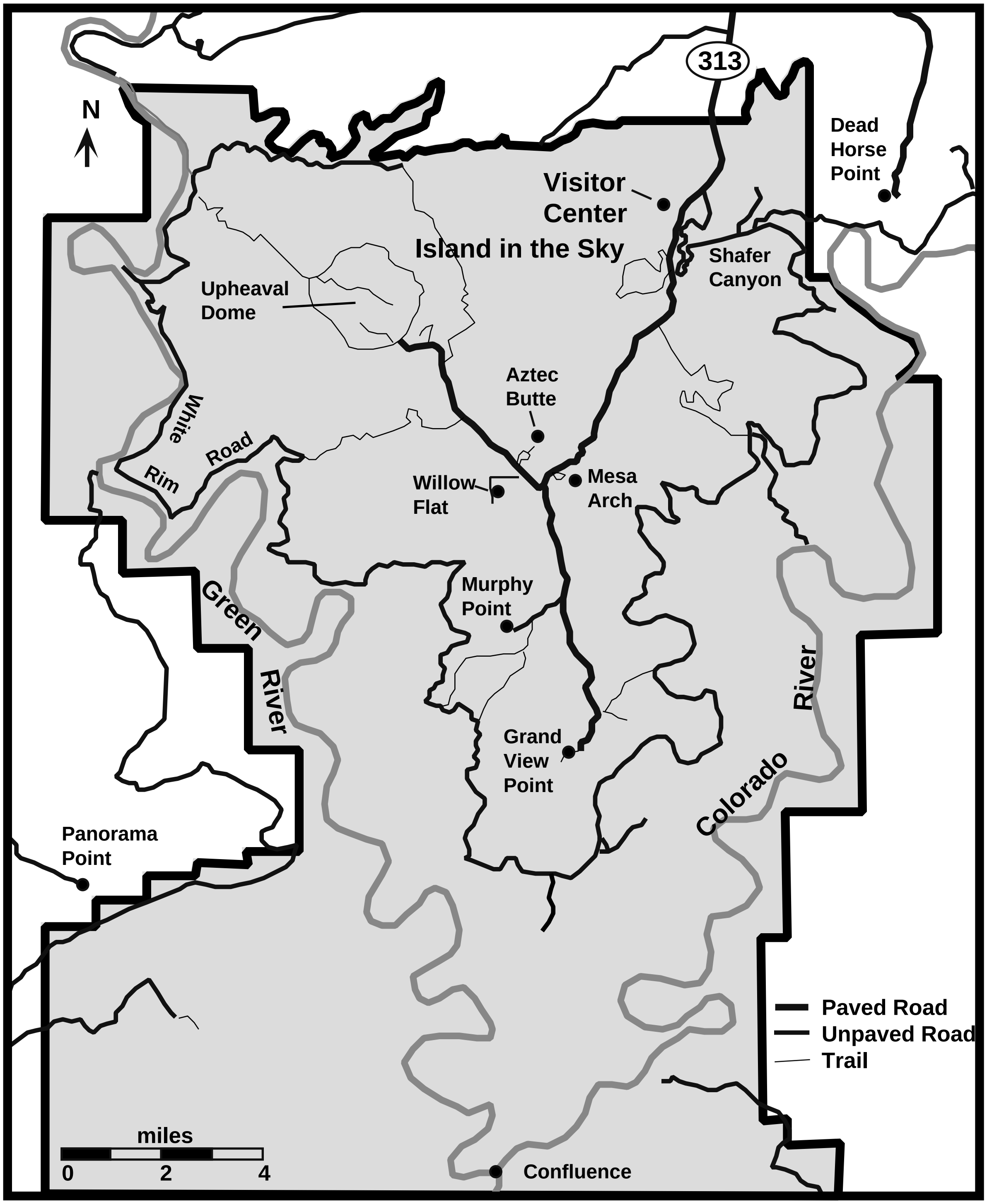

Figure 11. Map of the northern part of Canyonlands National Park (after National Park Service Map)

Cutler Formation is undifferentiated and consist of arkosic redbeds deposited on alluvial fans. Moving away from the highlands the Cutler Group is divided into distinct Formations which represent the transitional and marine facies. At the base of the section is the Elephant Canyon Formation a marine limestone that represents an embayment from the northwest. Above the

Elephant Canyon Formation is the Cedar Mesa Sandstone, a white cross-bedded sandstone. The Cedar Mesa Sandstones has been interpreted as representing both eolian coastal dunes and submarine sandbars. Paleocurrent analysis indicates that this influx of white sand had a source area somewhere to the northwest. An abrupt facies change between the red arkoses of the Cutler Formation and the white Cedar Mesa Sandstone can be observed at Grand View Point. Above the Cedar Mesa Sandstone is the Organ Rock Shale, a tongue of red siltstones and shales that were deposited in a coastal lowland to tidal flat environment. These shales are easily eroded and form the red slopes beneath the overlying White Rim Sandstone which forms a broad topographic bench. The White Rim Sandstone is cross-bedded and was primarily deposited in a shallow marine environment as large sand bars or a barrier island. In places tar seeps from the White Rim, indicating this unit was once a petroleum reservoir that is now exposed at the surface.

An unconformity separates the Triassic Moenkopi Formation from the Permian units. The Moenkopi represents a marine transgression across the Colorado Plateau with a facies transition from shallow to marginal marine deposits in the west grading into tidal flat deposits with fluvial deposits to the east (Molenaar, 1987). This unit is characterized by reddish-brown, fine grained sandstones and siltstones that form ledgy slopes. Mudcracks and ripple marks are commonly observed on bedding planes of the Moenkopi. The overlying Chinle Formation is separated from the Moenkopi by an unconformity. The Chinle tends to form slopes with a ledge forming yellowish-gray sandstone at the base, overlain by greenish-gray to reddish-brown, mudstones, shales and sandstones. It represents terrestrial stream and lake environments. The lower part of the Chinle is carboniferous and contains uranium deposits in the Canyonlands area. Overlying the Chinle Formation is the Glen Canyon Group consisting of the Wingate, Kayenta, and Navaho Formations, which represent two thick eolian (wind blown) units separated by a fluvial (stream) deposit. These units are typically unfossiliferous making biostratigraphic correlation difficult. However recent studies suggest that the Triassic-Jurassic boundary occurs at the base of the Wingate Sandstone (Molenaar, 1987). The Wingate sandstone is the orange to brown, massive, cross-bedded, cliff forming sandstone that border the edges of the mesa and plateaus in this area. The fluvial Kayenta Formation caps the cliffs of Wingate sandstone. It consist of red sandstones with interbedded red to green mudstones and lacustrine limestones. In the northern part of Canyonlands the cross-bedded eolian Navajo Sandstone forms rounded cliffs and domes.

Upheaval Dome

We will be observing upheaval dome from two vantage points, the core of the Dome can be viewed from the Upheaval Dome Trail and the outer rim from the Whale Rock Trail. The oldest rocks of Permian sandstones are exposed in the center of the dome and the rocks get progressively younger moving out of the center toward the rim ending with the Jurassic Navajo Sandstone (figure 13). Note that the stratigraphic units are all dipping away from the center of the dome. The Whale Rock trail is located on the crest of a “rim syncline” that circles the dome. Looking east at the beginning of the trail you can see progressively older strata exposed, going from Navajo, Kayenta, Wingate to Chinle. At the end of the trail looking west you can see the same sequence of strata.

Upheaval dome is an enigmatic structure that has been interpreted as a cryptovolcanic explosion, meteoric impact, fluid escape structure and salt diapir. The salt diapirism interpretation suggest that Upheaval Dome is a salt dome. Salt from the Paradox Formation flowed upwards in a circular or mushroom shaped cell, deforming the overlying strata. As the salt moved upwards it migrated from surrounding areas, forming a depression which is reflected by the rim syncline. Baars (1993) noted that there is an intersection between two basement faults beneath the dome which may have caused the salt to flow upwards at this location. The latest interpretation by Jackson and others (1998) is that a salt diapir was pinched off from it’s stem and subsequently eroded. Evidence in support of this interpretation includes the structures similarity to other salt domes such as those of the Gulf Coast region, geophysical studies that indicate there is thickened salt beneath Upheaval Dome and synsedimentary structures that indicate Jurassic growth of the dome.

An alternative interpretation is that Upheaval Dome represents a meteorite impact crater. Meteorite impacts that cause dinosaurs to go extinct are much more exciting than salt domes and as Baars (1993) puts it “Perhaps it was a meteor that just happened to hit a spot where there was plenty of salt in place and a nice pair of cooperative basement faults beneath.” In contrast, Kriens, Shoemaker, and Herkenhoff (1997) describe Upheaval dome as the “best exposed complex crater in the world.” Complex craters form when a meteorite greater than 2 km strikes the earth. The initial cavity collapses and rocks of the wall and rim subside and are transported inwards. In support of their meteorite impact interpretation, Kriens and others (1997) cite; 1) the presence of lag deposits of impactites, shatter surfaces and rare shatter cones, 2) the depth of the underlying salt horizon at least 500 m below the surface, 3) the distribution and orientation of small scale thrust and normal faults which indicate a centerward movement of material, and 4) the presence of wide spread clastic dikes.

Upheaval Dome

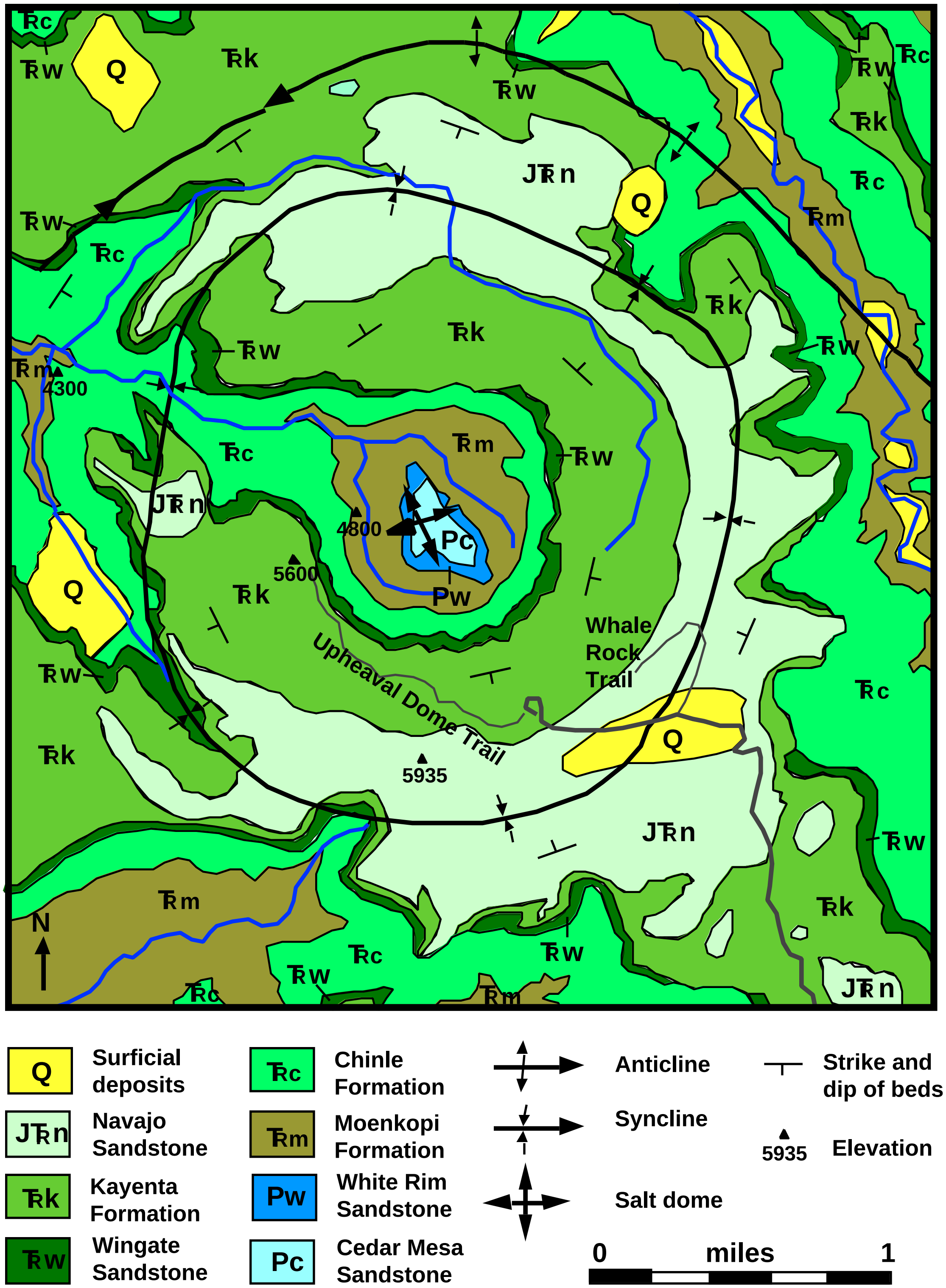

Figure 13. Geologic map of Upheaval Dome, Canyonlands National Park (after Huntoon, Billingsley and Breed, 1982).

Uranium Mining on the Colorado Plateau

Uranium and vanadium deposits occur in the Jurassic Salt Wash Member of the Morrison Formation and basal Shinarump Conglomerate of the Triassic Chinle Formation on the Colorado Plateau. Both of these units were deposited by streams and represent point bar deposits (figure 14). The uranium is concentrated with plant materials on the sides of paleochannels and in point bar deposits of ancient streams. The uranium was transported to the site of deposition by oxygen rich groundwater. Decay of organic material from the plant remains created a micro-reducing environment which caused the uranium to precipitate. Mineralization significantly postdates the deposition of the sediments, occurring during the Tertiary.

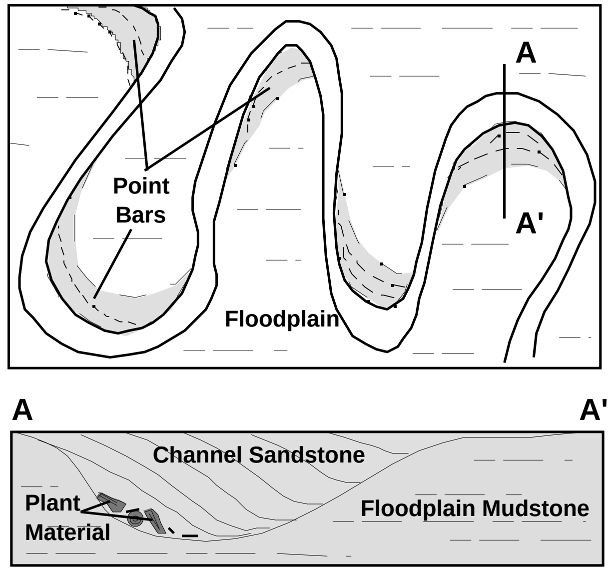

Figure 14. Depositional environment of uranium deposits of the Colorado Plateau. Uranium is associated with plant materials that accumulated in point bar deposits on the margin of paleostream channels.

Mining of these deposits dates back to 1912 when they were developed for radium. Vanadium production was initiated in 1935. During World War II a source of raw materials was needed to support the Manhattan Project (Chenoweth, 1987). The existing uranium deposits were located in the Belgium Congo and Northwest Territory of Canada. Due to the uncertainties of foreign supplies of vanadium and uranium, the war department saw a need to develop domestic supplies of these strategic mineral resources and they looked toward the uranium and vanadium deposits of the Colorado Plateau. Initially the uranium was produced from the tailings of vanadium mills. The uranium “boom” of the 1950’s led to tens of thousands of claims staked each year (Doelling and others, 1987). Many of the existing jeep trails in this area were constructed to provide access to the uranium deposits during this time. The Shinarump and Salt Wash stratigraphic units can be identified by the intensity of roads and prospecting pits (Baars, 1983). A decrease in the demand and price of uranium led to a significant decline in the mining industry by the mid 1980’s.

Tailings from the Uranium mining industry pose a significant threat to the environment (Aubrecht, 1995). The mine tailings are ground rock left over after the processing of the ore for uranium. These tailings are dangerous because they produce radium and radon gas which can be released into the atmosphere or leached into the groundwater. The tailings piles also produce dust which can be transported long distances by the wind. In the past, when the attitude toward radioactivity exposure was more casual mine tailings were used as landfill under building sites. The city of Grand Junction Colorado has hundreds of buildings where permissible exposure limits have been exceeded. On a Navajo reservation in Arizona rock waste from uranium milling was actually used for building homes. The decline of the uranium industry put most of the uranium mills out of business, resulting in abandonment of these sites and leaving cleanup the responsibility of the federal government. A site of particular concern is the uranium mill located at the north end of Moab Valley on the floodplain of the Colorado River.

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Exercises

Arches

1) Skyline Arch has the following dimensions; 47 ft high, 90 ft wide, with an opening 71 ft by 33.5 ft. On the graph paper provided make a proportional sketch of skyline arch. Include in your drawing obvious bedding planes, joints and fractures.

2) Moab Fault

a) Sketch the fault below.

b) What type of fault is the Moab Fault?

c) What formations are exposed on either side of the fault?

d) From the formation thicknesses given on the stratigraphic section, (figure 1) estimate the displacement along the fault.

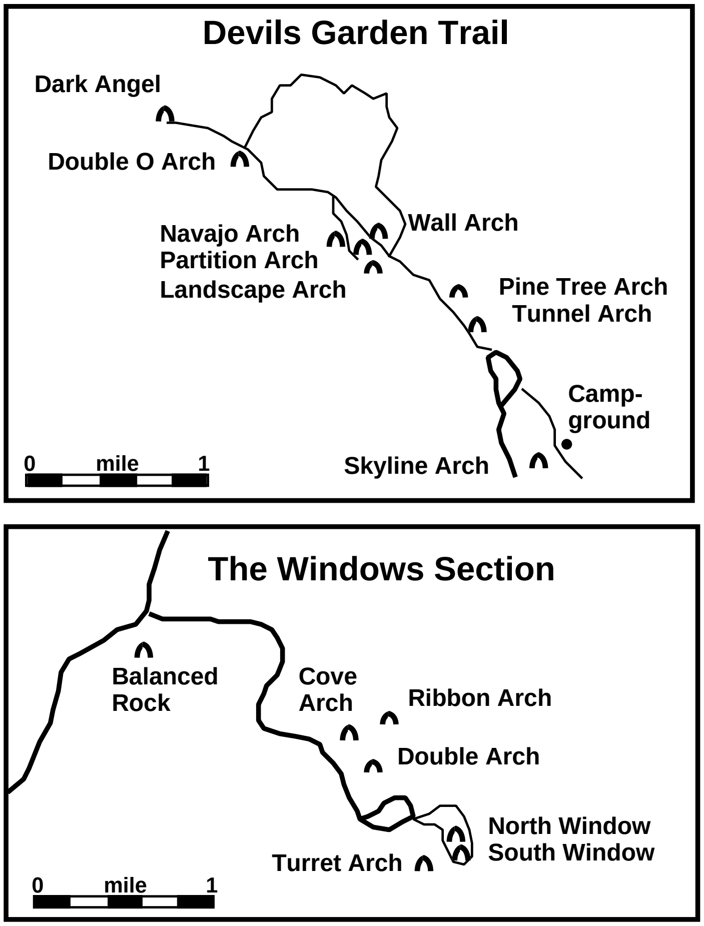


Figure 15. Devils Garden and Windows Trails.

3) List examples of the different stages of arch development.

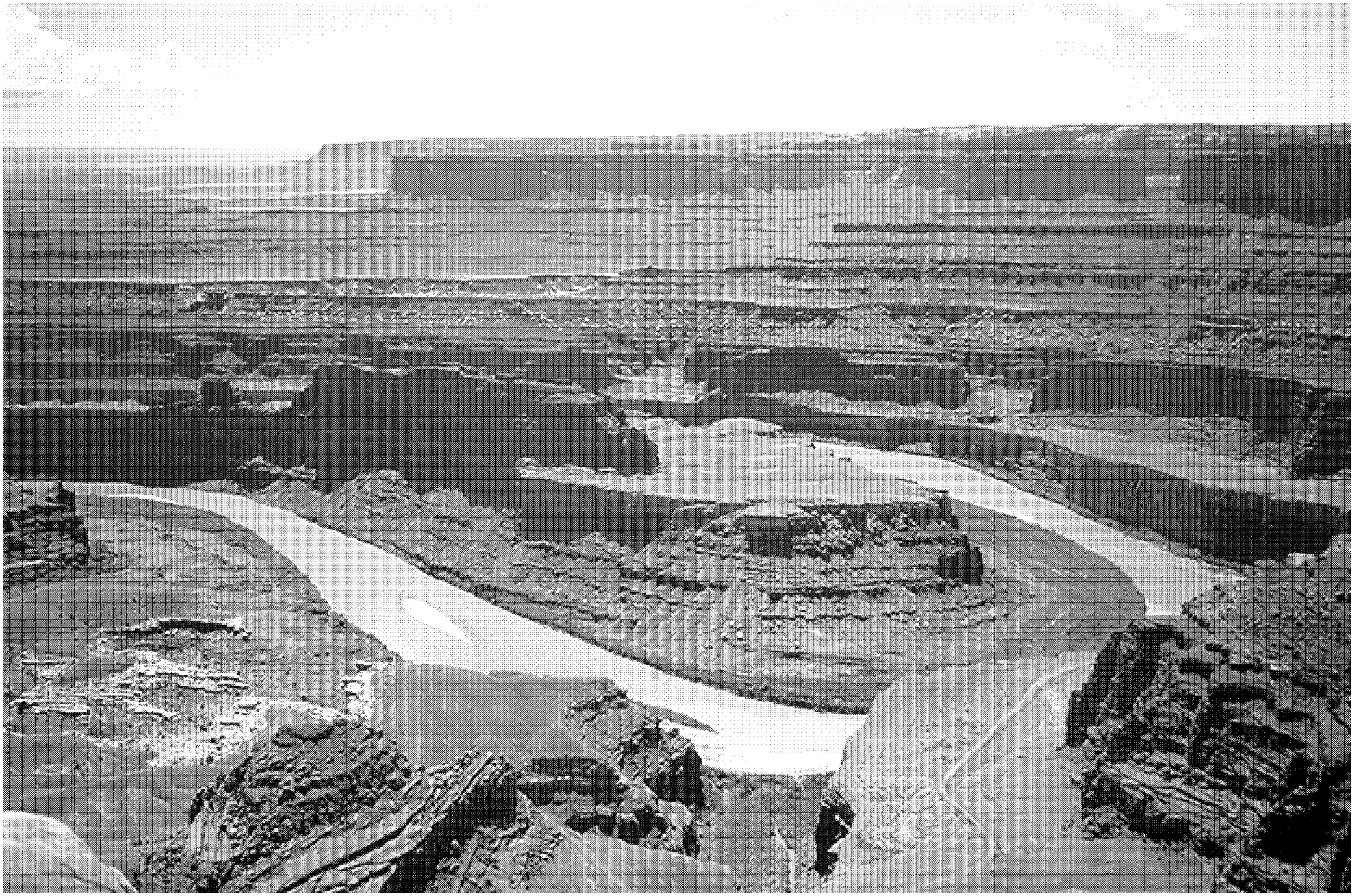
4) How do the arches in the Windows section compare with those of the Devils Garden section? Can you explain this difference with evidence from the geologic map (figure 4)?

Dead Horse Point

1) Refer to the stratigraphic column of the Moab Region (figure 1) to identify the formations you see.

2) Label the formations and contacts on the photograph from Dead Horse Point.

Dead Horse Point



Route 313 Stop

Refer to the stratigraphic column for the Moab Region (figure 1) and the geologic map to identify the formations exposed at the first view area on Rt. 313 and sketch a stratigraphic section for this location illustrating the relative resistance to erosion.

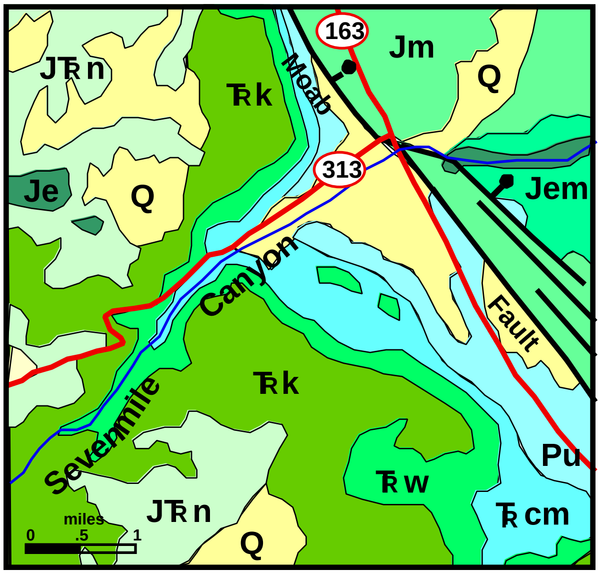


Figure 17. Geology along Rt 313

Canyonlands Exercise

Hike the Whale Rock and Upheaval Dome Overlook trails.

1) What unit is exposed along Whale Rock trail?

2) What unit is exposed along the Upheaval Dome Overlook trail?

3) Refer to the stratigraphic section (figure 1) and geologic map of Upheaval Dome (figure 13) to determine the age of the formation exposed in the center of Upheaval Dome.

4) What happens to the age of the rocks as you go from the center to the margins of Upheaval Dome?

5) Describe any features you observe that would help you determine the origin of Upheaval Dome (salt diapir or meteorite impact)

6) Sketch a cross section of Upheaval Dome.

Definitions

Define the following terms and give examples of each feature.

Anticline

Arch

Cryptogamic soil

Dome

Fin

Formation

Joint

Normal fault

Salt anticline

Salt valley