FOUR CORNERS GEOLOGICAL SOCIETY

Sand Canyon Fieldtrip Guidebook

October 20th, 2018

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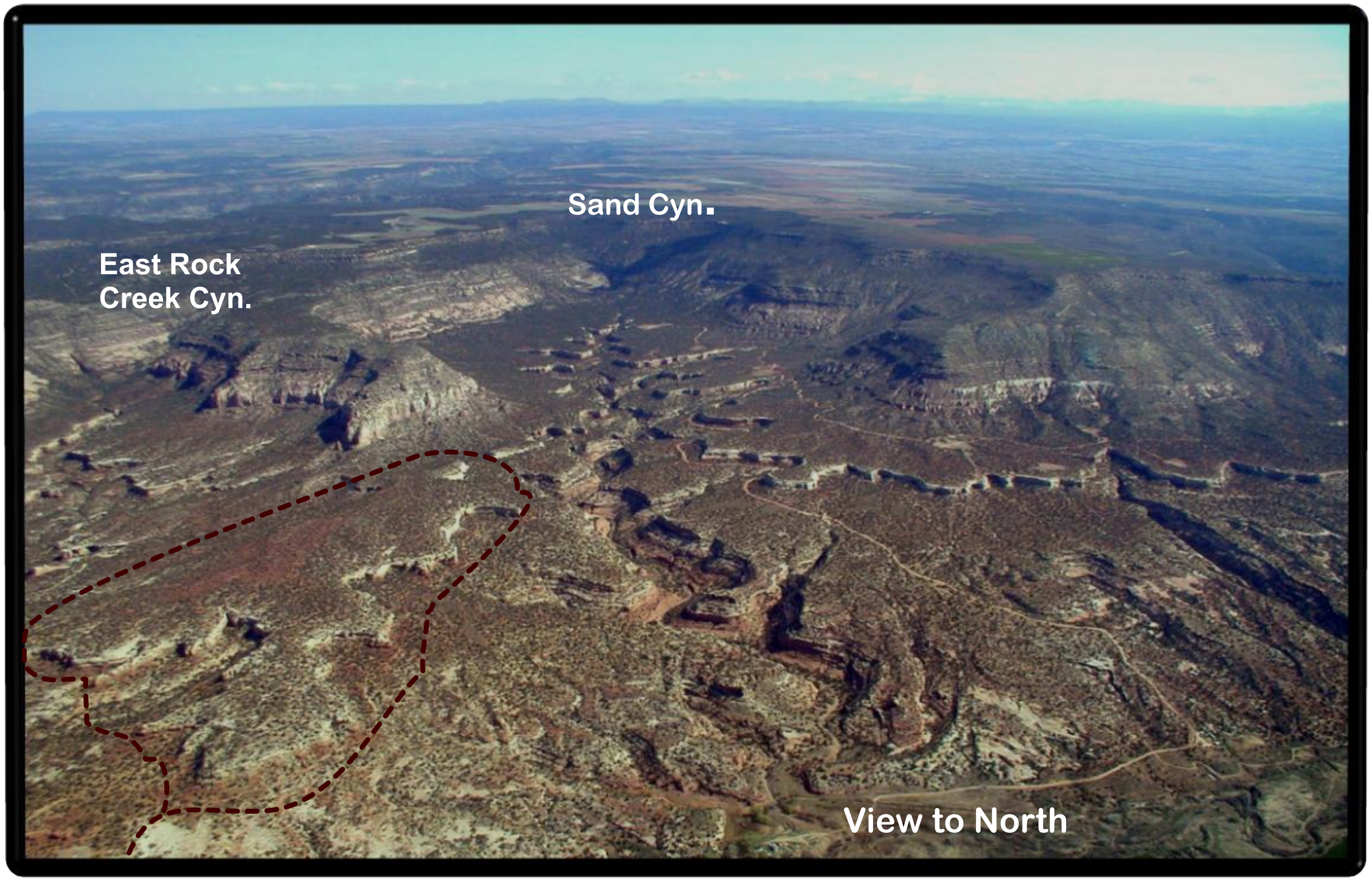


Directions: From Durango drive west on hwy 160 to intersection with 491 on west side of Cortez. Turn south and drive 2.7 miles to the intersection with County Road G (old M&M truckstop). Turn right/west onto G. Parking area is 12.4 miles on right/north side of G, just past a small sign for Sutcliffe Vineyards on the left. Parking is on an un-improved sections of dip slope of Navajo Sandstone. High clearance vehicles are easier to park here.
Drive time: Total drive is about 60 miles and takes about 1hr, 15min.
Hiking Stats: This is a 4.5mi loop ranging from 5400' to 5900' elevation on a sandy and rocky trail.

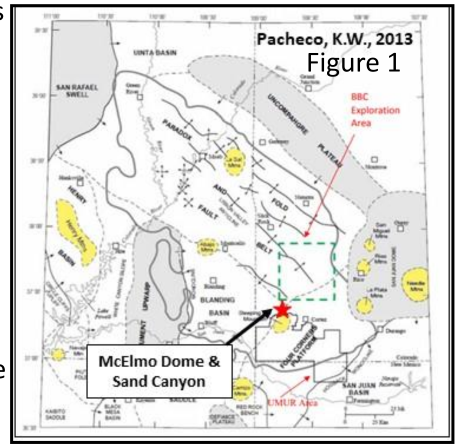
CONTENTS

All photos by Kim Miskell-Gerhardt unless otherwise credited on figure or in text.

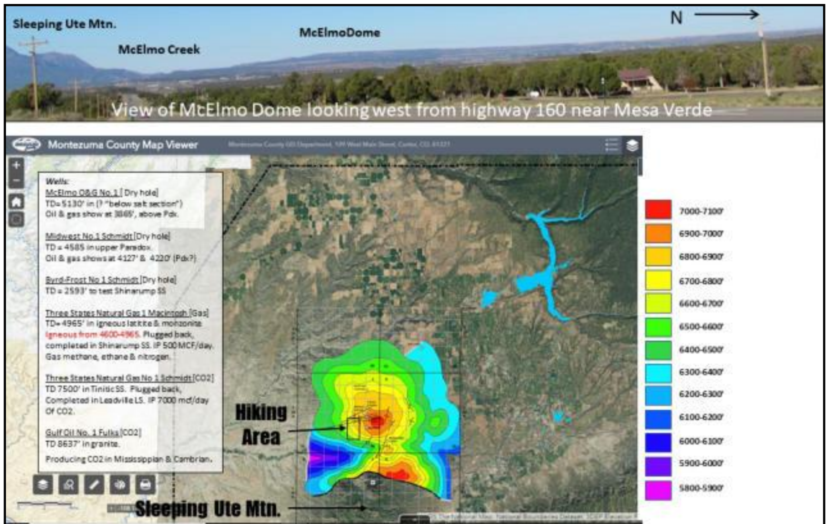
Four Corners Geological Society Hike in Sand Canyon

Overview

Sand Canyon is one of several N-S drainages cut into the southern flank of McElmo Dome in Montezuma County, Colorado which are tributaries to McElmo Creek. It is part of Canyons of the Ancients National Monument which was created by Executive Proclamation in 2000 to protect archaeological resources. The Monument is administered by the BLM from the Canyons of the Ancients Visitor Center on Lake McPhee, west of Dolores.



McElmo Dome is located in the far southeastern corner of the Paradox Basin salt embayment, structurally on the border between the basin and the Four Corners Platform (Figure 1). It is directly north of Sleeping Ute Mountain, a Laramide dioritic intrusion. The structure is asymmetric with a gentle dip to the north and steeper dip to the south (Figure 2) (Zabel, 1955). Bedding dip reverses against the northern flank of Sleeping Ute Mountain.

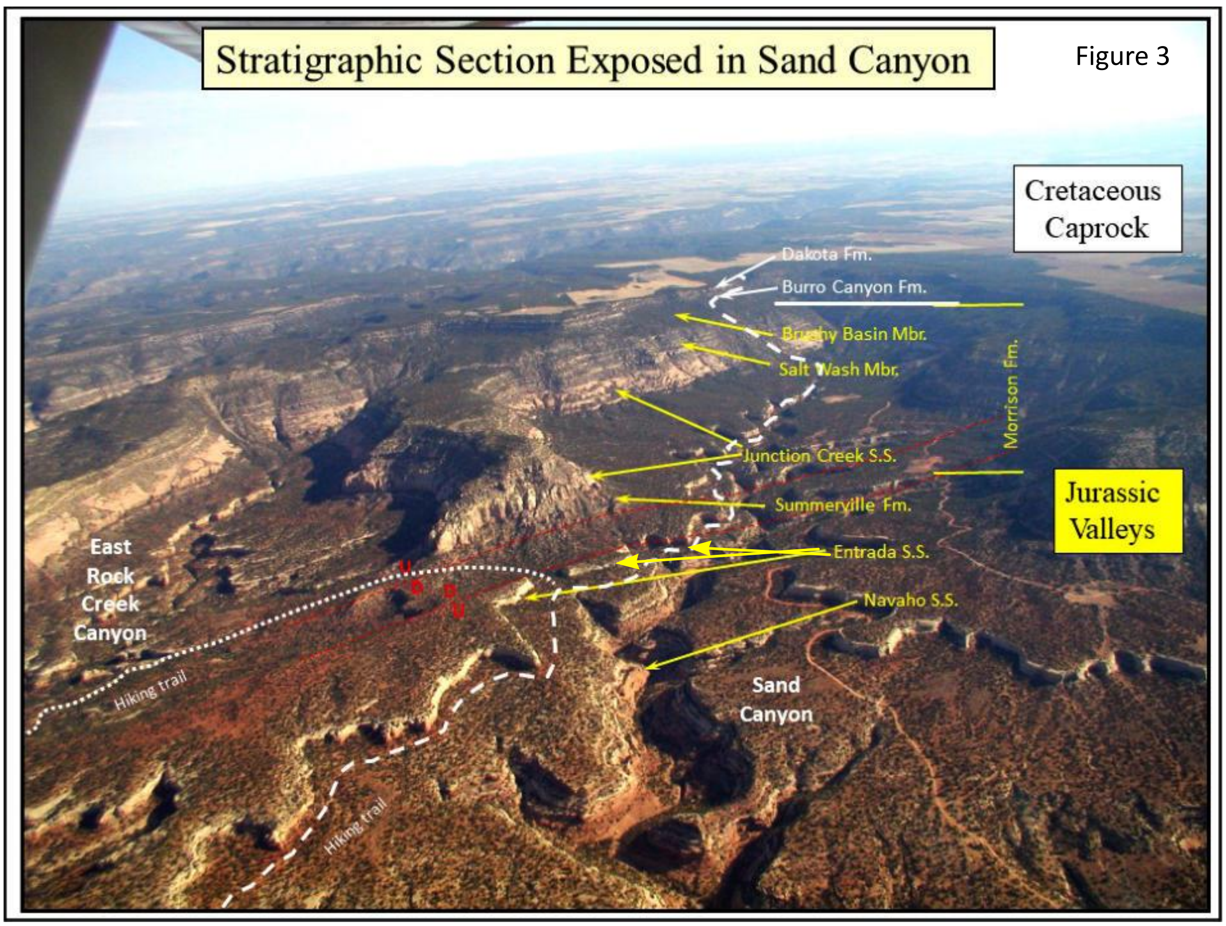


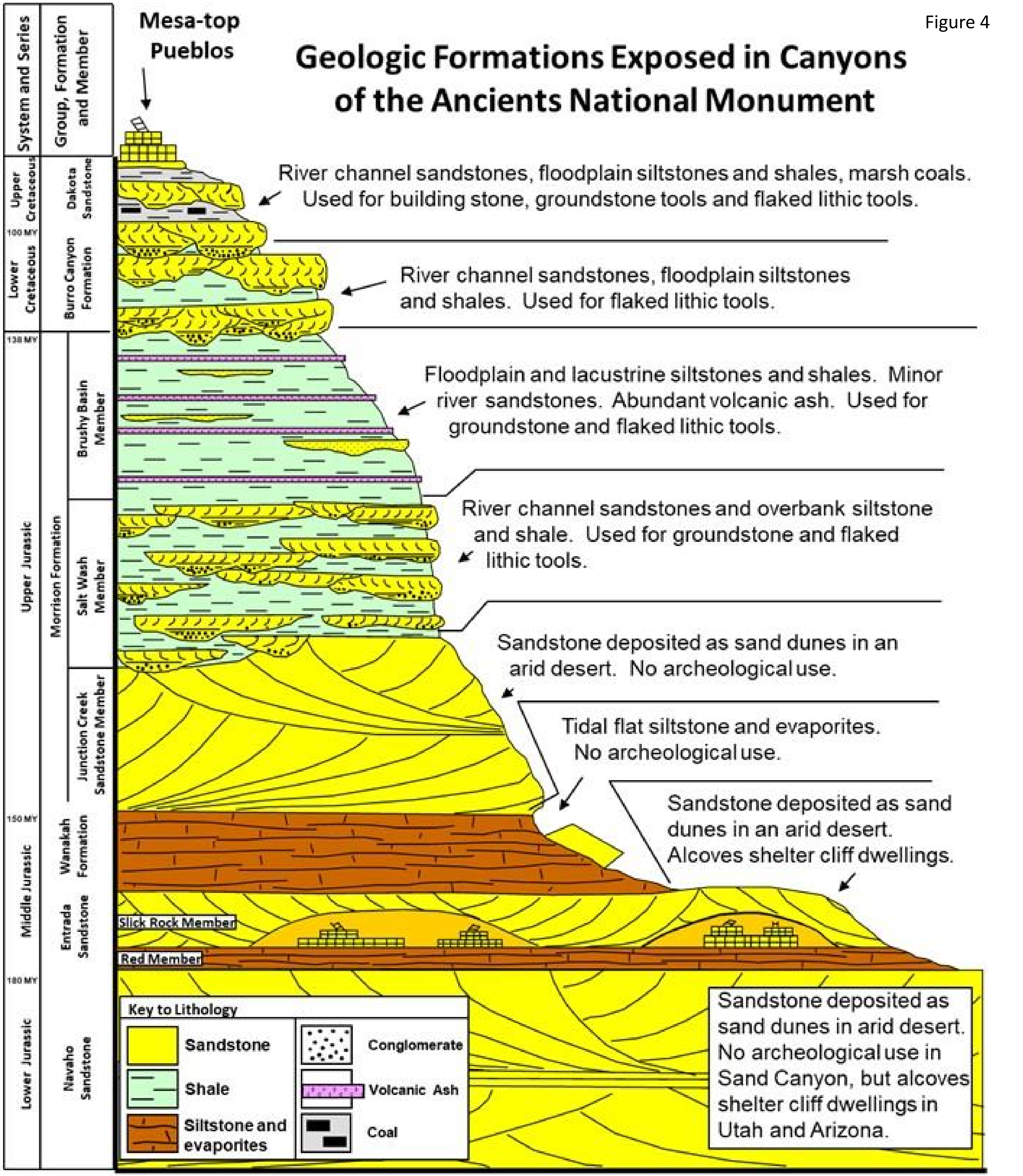
Zabel, V.H., 1955, Geology of McElmo Dome, Montezuma County, Colorado. Four Corners Geological Society Guidebook. Geology of Parts of Paradox, Black Mesa & San Juan Basins, Four Corners Field Conference, 1955, pp. 132-136.

Structure of McElmo Dome mapped in 1955 on the base of the Dakota Fm. Figure 2

Stratigraphy

Sand Canyon, near the crest of McElmo Dome, cuts more deeply into the underlying strata than any other canyon in the Monument. The exposed section extends from the Upper Cretaceous Dakota Fm. down to the Lower Jurassic Navajo Sandstone (Figure 3). The stratigraphic column and interpreted EOD's are summarized in Figures 4 & 5, reproduced from a Canyons of the Ancients Visitor's Center handout.

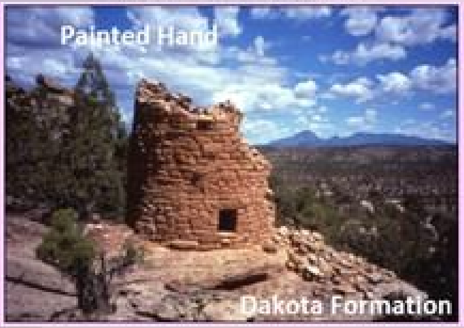


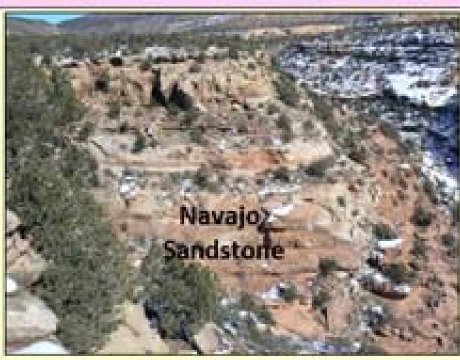


REFERENCES: Blakey, Ron, 2012, Colorado Plateau Geosystems, Inc. www.cpgeosystems.com. *(Paleogeographic maps and age dates)* / Ekren, E.B. and F.N. Houser, 1965, Geology and Petrology of the Ute Mountains Area, Colorado, Geological Survey Professional Paper 481. *(Stratigraphic column, lithology)* / Ortman, S.G., 2000, Artifacts, in: The Archeology of Castle Rock Pueblo: A Thirteenth-Century Village in Southwestern Colorado K.K. Kuckelman, ed., Available: http:// www.crowcanyon.org/castlerock, 30 July 2001. *(Archeological use of local lithologies)* / O'Sullivan, R.B., 1997, Correlation of the Middle Jurassic San Rafael Group from Bluff, Utah to Cortez, Colorado, USGS Geologic Investigation Series I-2616. *(Stratigraphic column, lithology)*. Stratigraphic section and photo column by Kim Miskell Gerhardt.

Figure 5

Photo Column

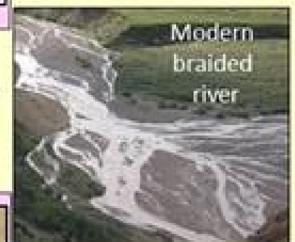




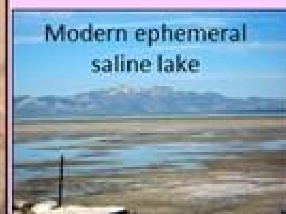
Paleogeography and Depositional Setting

★ = Location of Canyons of the Ancients National Monument

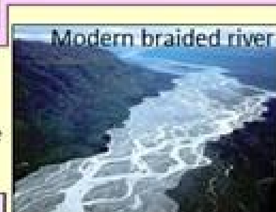
The Dakota Sandstone is made of river sands, coaly swamps and beaches adjacent to the rising Western Interior Seaway.



The Burro Canyon Formation is made of river channel sands that drained the newly-uplifted Sevier Mountains.



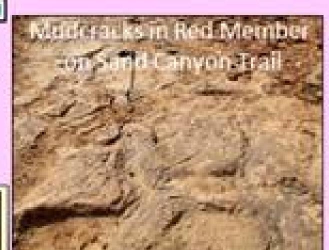
The Brushy Basin Member of the Morrison Formation is formed of clays and silts that settled to the bottom of an ephemeral saline lake.

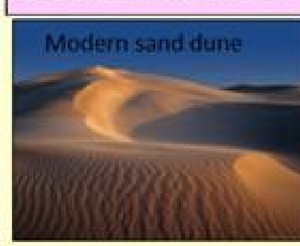


The Saltwash Member of the Morrison Formation is formed of river channel sands that were deposited by braided streams.

Similar to the Navajo Sandstone, the Slickrock Member of the Entrada and the Junction Creek Sandstone Member of the Morrison were desert sand dunes.

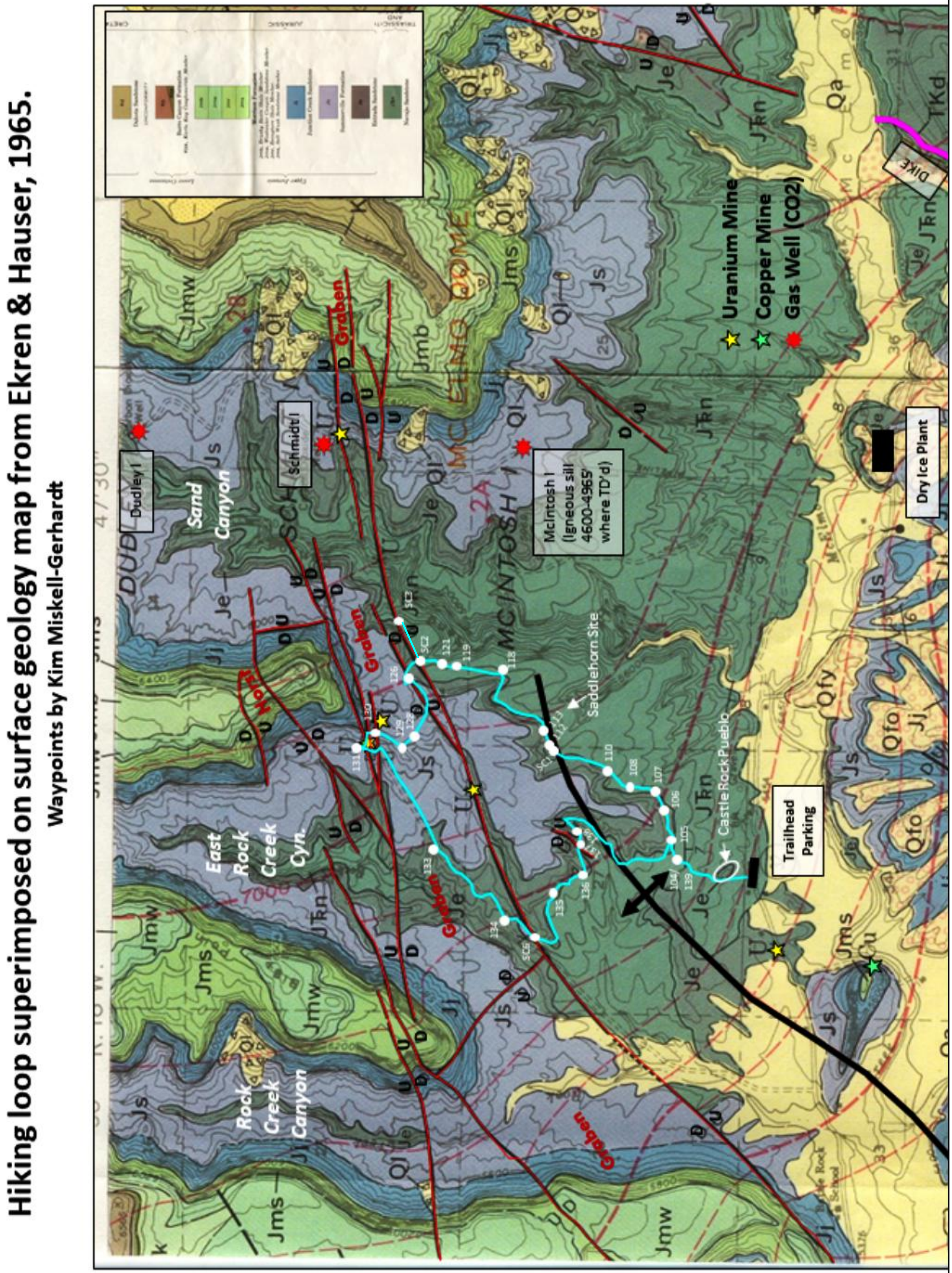
The Red Member of the Entrada Sandstone is red sandstone, mudstone and gypsum deposited near the southern end of a marine embayment.





The Navajo Sandstone was formed from a vast sand sea that covered western North America.

Figure 6


Hiking loop superimposed on surface geology map from Ekren & Hauser, 1965.
Waypoints by Kim Miskell-Gerhardt
Uranium Mine
Copper Mine
Gas Well (CO2)
Dry Ice Plant
Trailhead Parking
Castle Rock Pueblo
Saddlehorn Site
Mcintosh I (igneous sill 4600-4965' where TD'd)
Schmidt I
Dudley I
Sand Canyon
East Rock Creek Cyn.
Rock Creek Canyon
Graben
Horst
DIKE
MC ELMO DOME

Although there is an extensive trail system here, we will be hiking the Sand Canyon – East Rock Creek loop which is about 4.5 miles (Figure 6). We will look at archaeological sites, the mid-Jurassic to early Cretaceous sedimentary section, a horst-graben fault system, uranium mines in the Summerville & Junction Creek Formations and CO_2 wells tapping the subsurface Mississippian Leadville Limestone. See pp 10-11 for more on CO_2 geology and pp 12-13 for more on uranium mining.

Part 1. Parking area to start of Sand Canyon Trail (Wpt 104), 0.3mi

The stops along the trail are noted by waypoint number. See the waypoint list on page 14 for locations.

Castle rock: Trailhead parking is on the Jurassic Navajo Sandstone, the uppermost unit of the Glen Canyon trilogy (Wingate, Kayenta, Navajo). Hikers walk uphill on a dip slope of Navajo Sandstone, defining the southern flank of McElmo Dome, towards Castle Rock, an erosional remnant of the Entrada Formation. The red silty sandstone unit at the base is not the Dewey Bridge Pt. Member of the Carmel but rather the Red Member of the Entrada (O'Sullivan, 1997). The upper butte is the Slickrock Member of the Entrada Fm.

This butte is the site of the Castle Rock Pueblo ruin, excavated by Crow Canyon Archaeological Center in 1990-1991 (Varien, 1999) and more thoroughly from 1992-1994 (Kuckelman, 2000). Although the surface rooms are mostly destroyed now remnants of walls remain and the excavation uncovered additional rooms and kivas. According to Varien, 1999 "Castle Rock Pueblo covers nearly 3 acres and contains an estimated 13 to 16 kivas, 40 to 75 rooms, a plaza, a tower, a large stone enclosure believed to be public/integrative architecture, three stone rectangles, and an alignment of boulders of unknown function. … These excavations documented that Castle Rock Pueblo was a habitation site used year round. Structures dated by tree-ring analysis indicate that the major part of the occupation began in approximately A.D. 1250 and ended before A.D. 1300." See the site location and reconstruction of the pueblo in Figures 7,8,9.

Figure 7

https://www.dennisrhollowayarchitect.com/CastleRock.html

Figure 8

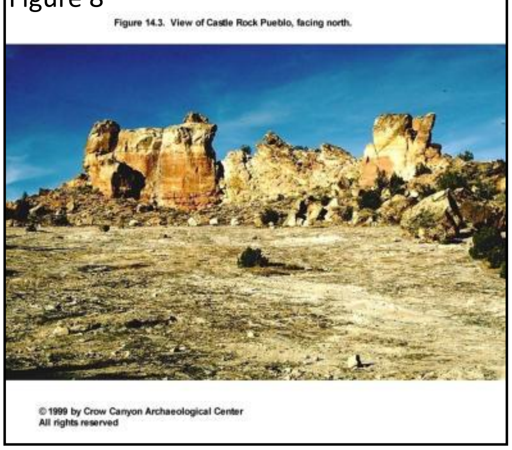
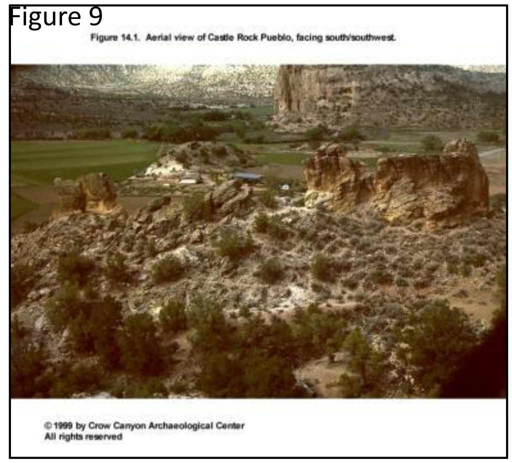


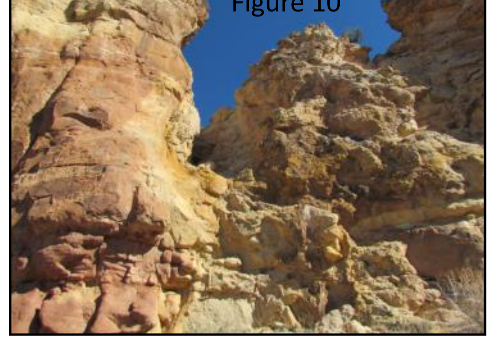
Figure 9



The Castle Rock site is only one of many in Sand Canyon that extend north to Sand Canyon Pueblo, wrapped around a spring in the Dakota Fm. rimrock at the top of the drainage. Occupation was contemporaneous in the canyon, dating to the late 1200's through tree rings and pottery.

The inhabitants of Castle Rock were the victims of a violent battle which ended habitation there. According to Kuckleman, 2000: "The occupation of the village at Castle Rock came to an abrupt and violent end. Sometime after A.D. 1274, probably in the early to mid-1280s, many of the men, women, and children in the village were killed. Human skeletal remains found during excavations at Castle Rock indicate that at least 41 of the estimated 75 to 150 inhabitants died in an attack on the village.[1] The remains of some victims lay directly on floors, and others were found in collapsed roofing material inside structures. Some, apparently, had been left on top of the butte. None was formally buried, and several concentrations of human bone included the remains of different individuals mixed together." … There is also direct evidence that physical violence occurred during the late Pueblo III period at Sand Canyon Pueblo (Lightfoot and Kuckelman 1994*2, 1995*1)".

Figure 10



Aside from the fascinating archaeological discoveries, Castle Rock is geologically more than just an erosional remnant. The center and eastern side of the butte look like mineralized fault gouge, although there is no offset. Look at the almost conglomeratic fabric and yellow stain (Figure 10) then compare this later to the Cliff House Group uranium mine that we'll see in a fault zone.

Structure & McElmo Dome CO_2 Production Discussion: After passing Castle Rock follow the rock cairns to the start of Sand Canyon Trail. Stop here to take in the view of the dip slope and Sleeping Ute Mtn. Also look beyond the road to the SW at the large, free-standing erosional remnant of eolian sandstone. This is not the Entrada but rather the Junction Creek Sandstone, a.k.a. the Bluff Sandstone, now a member of the Morrision Fm (Blakey and Ranney, 2008). This is a good location to discuss the structure of McElmo Dome, the origin of the CO_2, the Leadville Limestone reservoir and production issues.

Part 2. North on Sand Canyon Trail to Intersection with East Rock Creek connect (Wypts 104-123), 1.3mi.

Along this section of the trail we are walking on either the top of the Navajo SS or the lowermost beds of the Entrada, Red Member. The Entrada Slickrock Member forms the cliff to the left with alcoves and minor archaeological sites.

The Red Member of the Entrada is more notable for what it is not then for what it is. It is interpreted by Blakey and Ranney, 2008, as sabkhas and tidal flats adjacent to the Entrada dune field (contemporaneous Slickrock Member) and the Jurassic shoreline, then in central Utah. One might expect salt casts, salt dissolution structures, burrows, microbialites, minor interbedded sandy cross-beds, rhyzoliths, paleosols, etc. Instead it's very hard to see any sedimentary structures at all in this unit. Bedding is poorly-defined and roughly planar. There is one location on the entire hike where the Red Member appears to have a progradational bedding geometry but that is all.

The Slickrock Member of the Entrada, as well as the Navajo Sandstone, have lower angle cross-beds here than to the west in the Moab area. Here we are near the eastern edge of the ergs for both systems and deposition is more sand sheets than dunes.

The following is a list of waypoints and subjects for this section of the hike.

104 "You Are Here" sign at top of slickrock /entrance Sand Cyn trail.

105 Pinstripe laminations in tops of x-beds of Navajo SS underfoot.

106 Small concretions, or insect burrows? In top of Navajo SS underfoot.


Figure 11

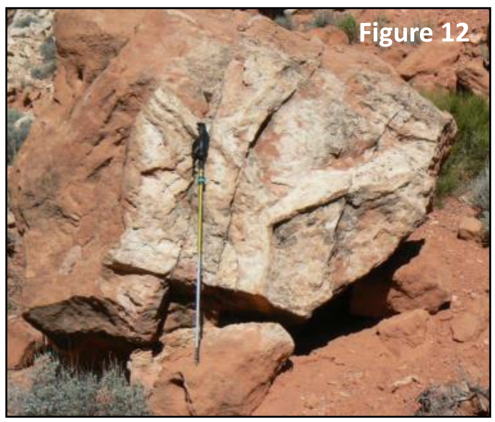


Figure 12

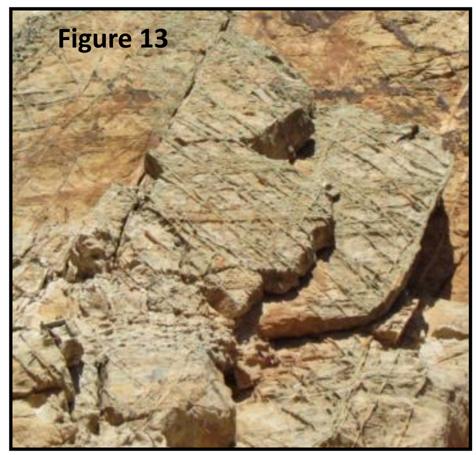


Figure 13

107 Entrada Slickrock is fractured. Look at the cemented fall blocks. Also see minor fault in Red Mbr.

108 Large mudcracks (~1m) in top of Navajo SS in trail (Figure 11). Also see some on undersides of float blocks of the Entrada Red Mbr. (Figure 12).

110 Just past this WP Entrada Slickrock is fractured & cemented (Figure 13).

SC1 Axis of anticline mapped by Ekren & Houser, '65 (see Figure 6).

111 Can go right for view of canyon and Navajo SS section. (But better views ahead.)

112 Entrada Slickrock Mbr. Has higher angle x-beds at top of cliff than seen so far. Still very small dunes

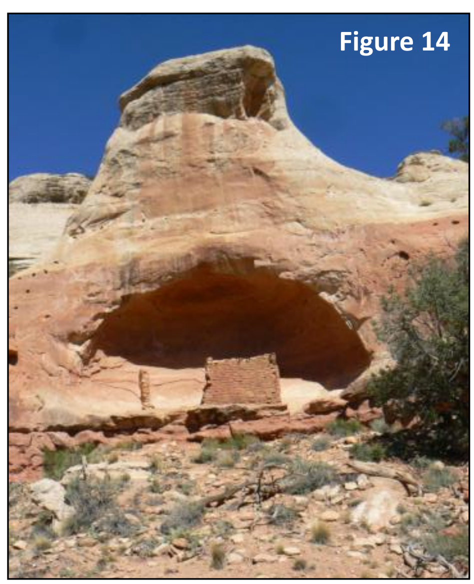


Figure 14

Figure 15

compared to Moab.

113 Spur to Saddlehorn ruin. Turn left to look (Figure 14). There are two dry wall structures inside the alcove (interpreted as towers) and the base of an isolated third wall. Crow Canyon Archaeological Center excavated the ground at the base of the alcove and and found a buried kiva (Figure 15) with a burned roof and few artifacts. Tree ring dates range from 1229-1232, the latest date is 1256. CCAC suggests that the inhabitants took their possessions, ritually burned the kiva and left the area before the general abandonment of the entire Mesa Verde region around 1300 (Varien, 1999).

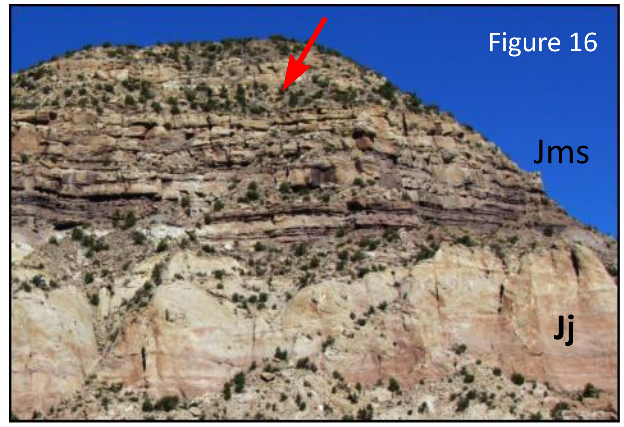


Figure 16

118 Turn right off main trail and walk to edge of canyon. View of Sleeping Ute Mtn. to the south, the Navajo SS in the cut below and the entire section from Entrada to Dakota SS in the far eastern wall. Ahead to north is first view of the long E-W face of the graben fault system and also the Summerville – Junction Creek SS – Morrison Saltwash Mbr section. Contact of Jms on Jj looks highly erosional but this face is also faulted & fractured enhancing this perception. Note the high angle cross-beds in the Jj, typical of eolian dune deposits. We also see a possible reverse fault (Figure 16). This interpretation changes as we walk to the west.


Figure 17

119 Spur to right to canyon overlook. Could be a good spot for lunch. See all of above again.

121 Rhyzolith in top of Navajo SS (Figure 17). Cement is calcareous.

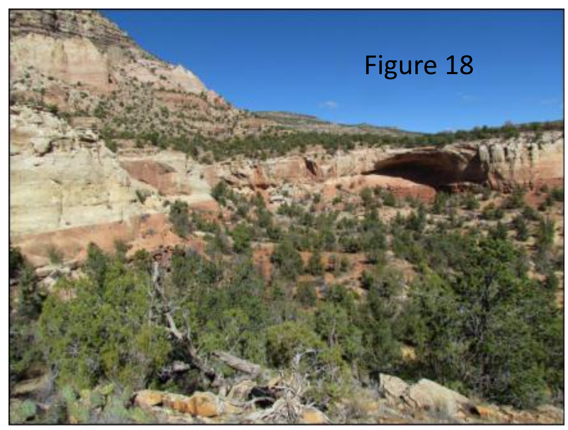


Figure 18

123 =SC2 “You Are Here” sign at intersection SC trail with connector trail to East Rock Creek. Continuing on SC trail a little farther then will backtrack and take this. We also cross a fault here from Up to Down. Now the <u>top</u> of the Entrada Slickrock Mbr. is to our left rather than the base of it.

124=SC3 At top of a section of switchbacks which is also a fault. Standing on or near the top of the Entrada Fm. Looking down at down-dropped Entrada with Summerville on top (Figure 18). Notice several alcoves with cliff dwellings in Entrada alcoves below. Looking N/NW beyond the rim of Entrada see a fault in the Summerville dropping it down towards us. This must be the other side of the graben system.

123= SC2 Retrace route to trail intersection (WP 123 above). Turn onto connector trail. Are hiking uphill into Summerville Fm., tidal, sabkha & eolian deposits marginal to the Jurassic Sea (Curtis Fm. in central Utah). Underfoot seeing loose red siltstone and maybe caliche nodules.

<u>Part 3. Connection Trail between Sand Canyon and East Rock Creek (Wypts 123-131), 0.7mi.</u>

126 Turn left off the climbing trail to an overlook here. During hike from switchbacks to here have another chance to evaluate the “reverse” fault seen at wp 118. Now can look more parallel to the E-W face and see three places where the lower Jj and Js are down-dropped into the valley along an E-W fault trend (Figure 19). Light yellow talus above the faulted

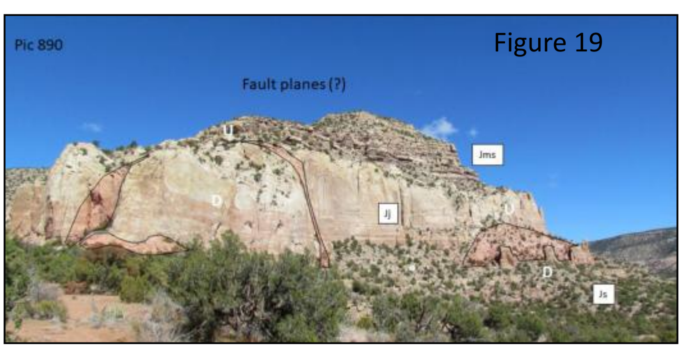


Figure 19

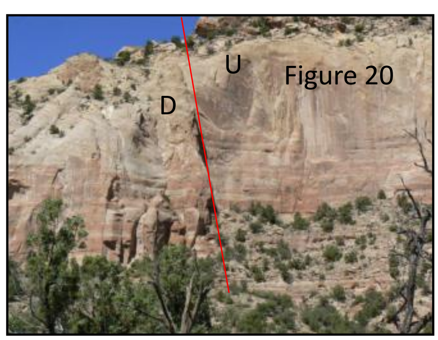


Figure 20

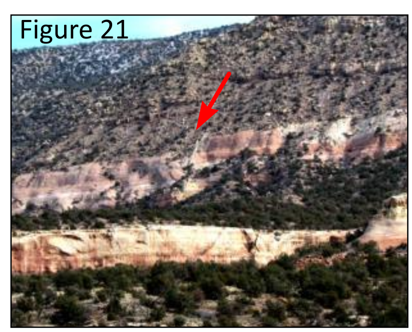


Figure 21

block may be gouge. To left (west) see other segments of this fault including offset in the Jj section on the far left with a cemented fault zone in between (Figure 20). In the eastern wall of Sand Canyon can see a normal fault offsetting the Jj down to the north (Figure 21). This must be the continuation of the fault seen in front of us.


Figure 22

128 Another view of the E-W face to north with another chance to pick out the fault trend from a bit farther west. View of Summerville section in drainage to W/SW (Figure 22). Yellow staining probably limonite, but… we are getting closer to the uranium mines.


Figure 23


Figure 24


Figure 25

129 Wooden post with directions to Spur or Trail. Go right to continue on trail. Soon get a view to NW of the Cliff House Group uranium mine in the westernmost side of the E-W face, and on trend with the fault zone we've been seeing (Figure 23).

130 & SC5 Cross fault as go downhill through Js towards mine. This is a spur of the main fault. At base of escarpment to left, below the trail, is another uranium mine, probably Cliff House #2. As walk towards the Cliff House Group mine note the fall blocks of fractured and silica-cemented Jj (Figure 24). The Cliff House Group mine is either a very small mine or a large test hole. It doesn't go very far back into the face. The mine is in yellow-stained fault gouge. The mine & discoloration line up with cemented fins of sandstone at the top of the cliff marking associated faults and fractures (Figure 25).

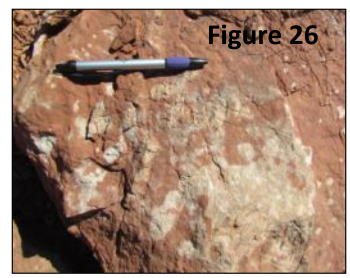


Figure 26

131 "You Are Here" sign at intersection of connector trail with the East Rock Creek sign. Turn left / south to head back towards cars. This part of the trail is an old road probably built to work the mine. As walk, keep looking back into the fault zone to see it from different perspectives. Can also see offset in the Js here. In Js float blocks see probable paleosols. Calcareous caliche nodules and maybe root mottling in red siltstones Figure 26).

Part 4. South on East Rock Creek Trail (Wypts 131-134), 1mi.

Figure 27

133 Turn off trail to right and go to rim of East Rock Creek Canyon. The high sandstone cliff walls in the canyon below are the Entrada Fm. (see the Red Mbr. at the base). NOT the Navajo SS as in the walls of Sand Canyon. Look over to the far (western) wall of East Rock Creek Canyon and note that the Jms-Jj-Js section is dropped down to the south in two places Figure 27). This is the western continuation of the fault system we just saw at the mine.

134 "You Are Here" sign at intersection of the East Rock Creek trail with a connector going back to the parking area. This is an easy turn to miss! Turn left and hike uphill. We are walking on the Summerville with the Entrada in the walls of the canyon below us to the right (west). But look up to the left and see that the Entrada also forms a cliff above us to the east & north. We will be crossing a big fault soon.

Figure 28

Part 5. East on Connector and back to Cars (Wypts 134-139), 1.6mi.

SC6 Position of fault. Crossing from down to up side. Note the cemented fractures in the Entrada re-entrant we see as we come out. We are now walking on the Red Member of the Entrada again with the Slickrock Mbr. to our left, just like before on the Sand Canyon trail. Look up on top of the cliff for the remains of a wall – probably a tower.

Figure 29

135 Alcove in the Entrada with a small ruin. Alcove to right with small tree is empty. Just past this there are progradatoinal geometries in the Red Mbr. of the Entrada (Figure 28).

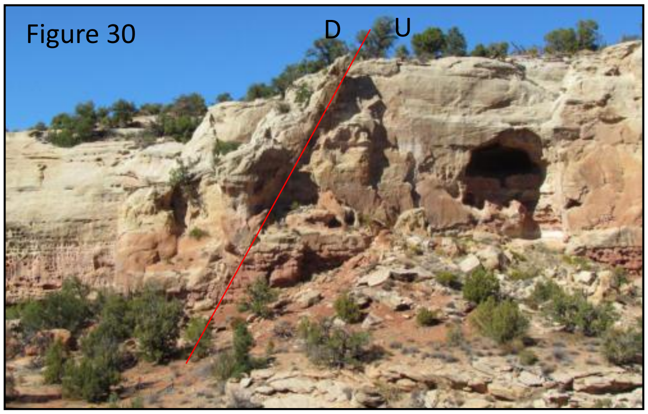


Figure 30

136 Walking on top of the Navajo SS. Bedding plane is riddled with either small concretions or insect burrows (?) (Figure 29).

137 Alcove in Enrada with small ruin. This should be a fault according to Ekren & Houser but it's a bit farther east.

138 = S7 Alcove in Entrada with a larger ruin. Walls fronting the habitation look very defensive! On left (west) side of alcove cliff face is a small fault, down to west (Figure 30). This is better seen farther along the trail from across the small wash.

139 Wooden post marks end of trail segment. Now walk down the Navajo SS dip slope following the cairns back past Castle Rock and back to the cars.

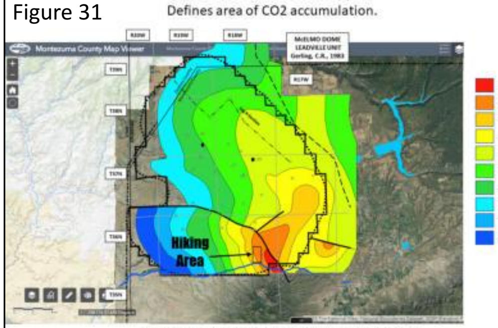
===

McElmo Dome & CO_2

The surface structure of McElmo Dome has been described as "starfish-shaped" because it has two axes, one NW-SE and a second NE-SW (Figure 2). Minor E-W faults near the crest form a horst within a graben. There is a second set of NE-SW faults on the eastern flank. One is associated with a dike extending north from Sleeping Ute Mountain and crossing Rd. G. McElmo Dome was explored for petroleum in the late 40's-50's (Aneth was discovered in 1956). However only minor natural gas was found, producing from the Triassic Shinarump Sandstone. CO_2 was discovered in the Mississippian Leadville Limestone as well as in the Cambrian (Gerling, 1983). The McElmo Dome discovery well, the Stanolind #1, was drilled in 1947, and flowed 40,000 mcf/day of CO2 from the interval of 6,805 feet to 6,965 feet (Horn, 2004). By 1949 CO_2 was piped down canyon to a dry ice plant that still exists today just east of the Sand Canyon parking area on Rd. G. The McElmo Dome CO_2 unit as mapped in 1983 by Gerling is shown in Figure 31, which is a structure map on the Leadville LS. Comparing Figure 31 to Figure 2, the surface structure of McElmo Dome mapped on the Dakota, we can see that the area of CO_2 accumulation is much larger than might have been predicted early on.

Figure 31

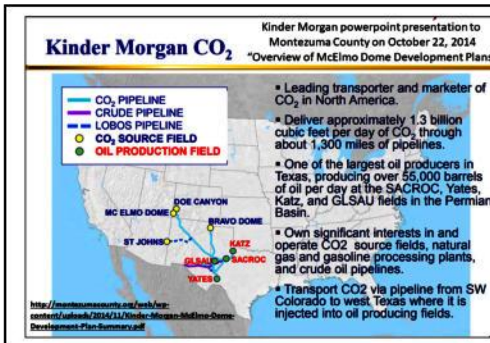
Structure of Leadville Limestone mapped in 1983. Defines area of CO2 accumulation.



Gerling, C.R., 1983, McElmo Dome Leadville Carbon Dioxide Field, Colorado. Four Corners Geological Society, Oil & Gas Fields of the Four Corners Area, Volume III, pp. 735-739.

Now Kinder Morgan owns the McElmo Dome CO_2 unit and sends the gas south to the Permian Basin through a pipeline to support enhanced oil recovery (EOR) operations. See Figures 32 - 34 from a Kinder Morgan presentation to Montezuma County officials in October 2014, now published online. One notable statistic; McElmo Dome is the largest CO_2 field in the world and has 15 TCF of recoverable CO_2. "To date" (2004), only 29 percent of the estimated reserves have been produced using current technology. Another 50 years of production, at current rates, is assured (Horn 2004). The figures included from the presentation show the pipeline route to Texas, (fairly)

Figure 32



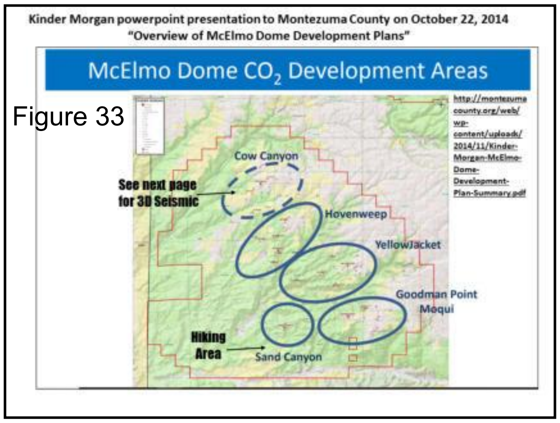


Figure 33

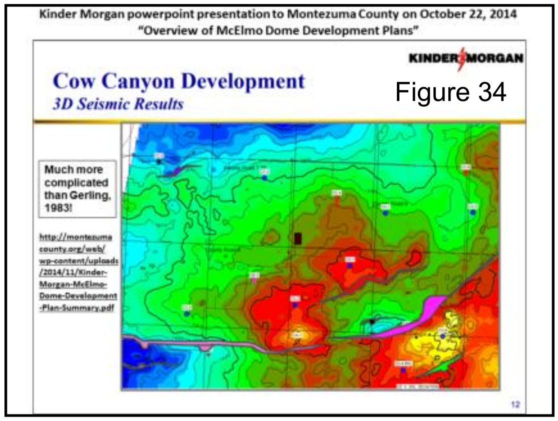


Figure 34

current well locations, expansion plans and a 3D seismic horizon slice from Cow Canyon. The structure and producibility of the Leadville is much more complex than was understood in 1983!

In addition to the CO_2 produced from the reservoir, large amounts of water and traces of oil are produced. In 2003 the operator reported that approximately 30,000 to 65,000 bbls/month of water are produced, and 480 bbls/month of oil are produced from the unit. The produced water is disposed of to a greater depth in the Leadville Formation, beneath the CO2-water contact (Horn, 2004).

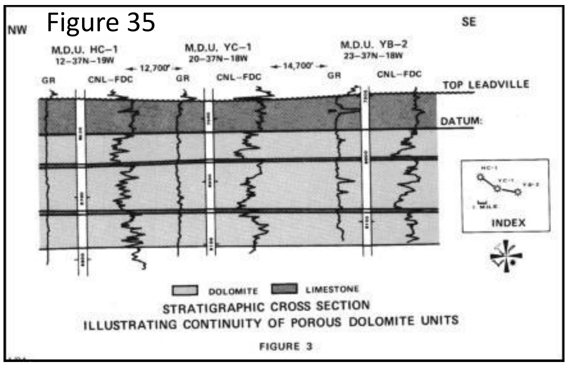


Figure 35

CO_2 accumulation and producibility is controlled by (at least) four factors. First by the extent of diagenetic alteration of the Leadville Limestone to more porous and permeable fractured dolomite, improving reservoir quality. Apparently this is not an issue here. Net pay per well ranges from 70-150’, porosity averages 11% and permeability 23 millidarcies in well tests (200md in core). See Figure 35 from Gerling, 1983, showing dolomitic vs limestone lithologies in a short well log cross section, and also the continuity of the dolomitic units. Secondly producibility is controlled by the intersection of the tilted reservoir unit with the _tilted_ water table. The water contact is tilted to the west at 0.5° or 50-60’ per mile and is controlled by hydrodynamics (see well log cross-section, Figure 36, (Gerling, 1983)) . Third by compartmentalization by faulting and fourth by compartmentalization by facies and stratal geometries. In an email to K. Gerhardt dated Oct 17, 2018,, Kevin Schmidt of KinderMorgan stated that “pressure communication is fairly widespread, although we do see compartmentalization that we believe is caused by fully and/or partially sealing faults. The internal markers we’ve traced within the Leadville seem to be reservoir baffles more than barriers. They inhibit flow on a local scale but don’t prevent broader pressure communication. Surface faults generally exhibit the same orientations as the deeper faulting, but they don’t extend through the Paradox Salt.”

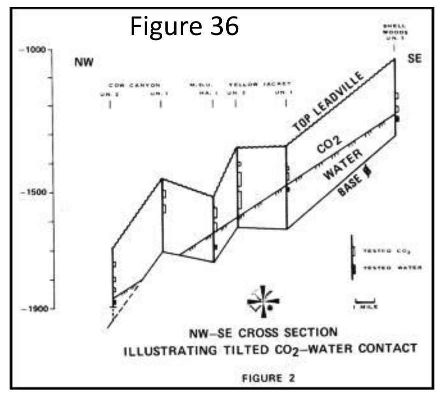


Figure 36

Professor Gary Gianniny and students at Fort Lewis college have studied facies, diagenesis and the detailed stratigraphy of the Leadville LS from McElmo Dome to Silverton (see Klink et al., 2015, Cowan et al., 2015). They believe that sequence stratigraphic partitioning explains some of the reservoir compartmentalization in the McElmo CO_2 field, but not all (GLG personal communication).

The origin of McElmo Dome is presumed to be an igneous intrusion at depth. Support for this theory is found in the proximity of Sleeping Ute Mountain, the obvious NE extending dike and the fact that one of the early wells (Three States Natural Gas No. 1 Macintosh) drilled into latite & monzonite from 4600-4965’ where it TD’d. Many geologists interpret this lithology as a sill. K.Schmidt confirms that KinderMorgan has seen igneous intrusions on seismic and in wellbores.

Other interpretations are that McElmo Dome is a salt dome, similar to the salt walls to the north, or that it’s just one of a number of enigmatic Laramide structures on the Colorado Plateau like Monument Uplift.

The origin of the CO_2 is also controversial. Earlier authors favored in-situ thermal decomposition of the Leadville LS by a nearby melt during the Laramide orogeny (Rogers, et al., 2002), coincident with formation of the dome. But one of FLC Professor David Gonzales’ students, Joshua Adams, analyzed noble gas isotopes in the CO_2 from across McElmo Dome field in 2015 and determined it was at least partially sourced by releases from Cenozoic magmatic melts, in three or more pulses of CO_2 injection (Adams et al, 2015). This theory links CO_2 emplacement with the timing of violent Oligocene eruptions in the San Juan Volcanic field. K. Schmidt of KinderMorgan confirms that they think the CO_2 is of magmatic origin.

Mining and Uranium Exploration

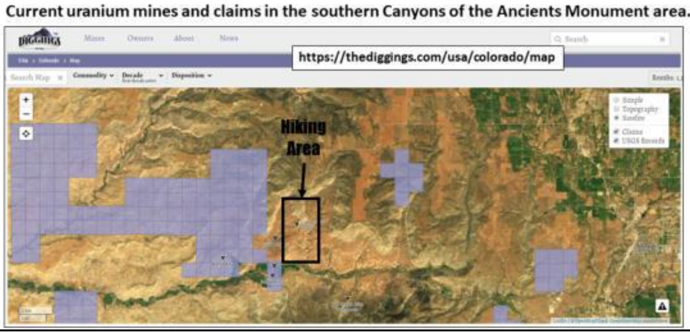
Uranium emplacement in Canyons of the Ancients National Monument is associated with both faults and stratigraphic units, particularly the Karla Kay Conglomerate of the early Cretaceous Burro Canyon Fm. There, uranium is concentrated in organic debris in a mudstone rip-up clast conglomerate which forms a sinuous “shoestring” fluvial sand (Schwochow, S.D, 1983).

On the hike we will pass the “Cliff House Group” mine(s), an example of uranium enrichment in a fault zone. This mine is described in TheDiggings.com website as follows: “Uranium and vanadium deposits are documented at "Cliff House." Uranium is present at a grade sufficient to have a strong effect on the economics of an excavation project. It may even be viable as the only commodity mined. The vanadium at this site is economically interesting but not currently recoverable. At the time this deposit was surveyed, some surface trenching, adits, shafts, drill holes, geophysics, geochemistry, or geological mapping was conducted to estimate grade and tonnage of the deposit.” The analytical report, gleaned from Schwochow, S.D, 1983 is as follows: “LIMONITIC SANDSTONE FROM CLIFF HOUSE PROSPECT CONTAINED 0.038% EQUIV U308 (RADIOMETRIC ANALYSIS) AND 0.040% U308 AND 0.16% V205 (CHEMICAL ANALYSIS). LIMONITIC SANDSTONE FROM CLIFF HOUSE NO. 4 CONTAINED 0.053% EQUIV U308 (RADIOMETRIC ANALYSIS) AND 0.028% U308 AND L.T. 0.1% V205 (CHEMICAL ANALYSIS).” The deposit is described thus: “ALL PROSPECTS LIE ON BOUNDING FAULTS OF UNNAMED GRABEN ON SW SIDE OF MCELMO DOME. MINERALIZATION AT CLIFF HOUSE PROSPECT LIMITED TO ZONE WHERE SUMMERVILLE FM MUDSTONE AND SANDSTONE DOWNDROPPED AGAINST 4-FT LIMESTONE BED IN NAVAJO SANDSTONE (TRI?-JUR). MINERALIZATION AT CLIFF HOUSE NO. 2 ASSOCIATED WITH LIMONITE-STAINED SANDSTONE IN SUMMERVILLE FM IN FAULT CONTACT WITH ENTRADA SANDSTONE (JUR). MINERALIZATION AT CLIFF HOUSE NO. 4 OCCURS IN SMALL GRABEN (SUBSIDIARY TO PRINCIPAL GRABEN) WHERE RADIOACTIVE UPPER PARTS OF SUMMERVILLE FM AND JUNCTION CREEK SANDSTONE DISPLACED AGAINST LOWER SUMMERVILLE FM. RADIOACTIVITY CLOSELY ASSOCIATED WITH UPPER SUMMERVILLE SANDSTONE BED CONTAINING CONCENTRATION OF LIMONITE, HEMATITE, BARITE, ASPHALTITE, AND CU CARBONATES, AND WITH FAULT BRECCIA ADJACENT TO BED.”

The following text, excerpted from Horn, 2004, recaps some of the history of uranium exploration in the Monument:

Figure 36

Current uranium mines and claims in the southern Canyons of the Ancients Monument area.



Mining in and around the Canyons of the Ancients National Monument was principally focused on uranium/vanadium and coal. Although prospecting for uranium and staking of claims was rampant in the Monument in the 1940s and 1950s, actual mining was quite limited. … [Current claims and mines are shown in Figure 36 from thediggings.com .]

Uranium/vanadium prospecting and mining on the Monument predominantly took place from the late 1940s to early 1960s, with some minor mining taking place into the 1970s. It is possible that some prospecting and mining of vanadium took place prior to 1923, but this is unlikely. The majority of evidence of the uranium boom in the area will be mining claim markers. Some small 45 prospect pits may also be found that were dug to comply with the requirement of doing annual assessment work to hold the claims. In a few instances, mainly in Cross Canyon, actual uranium mining took place, with values of vanadium also recovered. These were small operations that will be evidenced by an adit dug into a slope with waste rock below that has been leveled to form a working area for the mine.

In the late 1930s, the principles of radioactivity and the energy potential of nuclear chain reactions began to be understood, including its potential as a fission explosive device. Beginning in 1942, the Bureau of Mines and U.S. Geological Survey combined to conduct secretive core-drilling programs at select locations in the Salt Wash Member of the Morrison formation on the Colorado Plateau. Exploration was reported to be for vanadium, but was actually done to explore for uranium in order to acquire ore for development of the nuclear bomb under the Manhattan Project (Godfrey 1991:31; Carter and Gualtieri 1965:39). Uranium ore for the Manhattan Project was acquired as discarded material from vanadium tailings from mills in Blanding, Utah, Naturita, Durango, Slick Rock, Gateway, and Loma and from the stockpiles held by Howard Balsley (Amundson 2002:8-9). …

Following World War II, the Atomic Energy Act was passed to promote the use of nuclear energy for both domestic and defense purposes. It established that fissionable materials would be under the control of the federal government, but promoted exploration for and mining of uranium by the general public. The act also resulted in the government establishing prices for uranium ore and being the sole buyer, refiner, and producer for atomic use (Amundson 2002:19-20). … Although uranium deposits were found within the Monument, mining was of small scale. Rather extensive staking of claims took place as speculative ventures. Some of the claims seem to have been surveyed, but none ever became patented and left the public domain. … Local residents Robert and Francis Young reportedly staked 3,000 uranium claims in the Monument with Danny

Dalrymple. They mined what they called the Blue Eagle Mine in Cross Canyon from 1951 to 1960 and kept the Blue Eagle claims until about 1980, when the assessment costs became too expensive for them to keep the claims current. They mined using a Model A Ford engine to run a compressor to power a jackhammer and drill. Ore was blasted loose and taken by wheel barrow to a chute, where it was loaded one ton at a time into a Dodge Power Wagon. Initially, the government paid $3 per ton for the ore with a $3 per ton premium; vanadium sold for 23 cents per pound. If the ore had sufficient uranium content, the government would pay to have it shipped to the mill. Consequently, a large quantity of low-grade ore was disposed of. When the government ceased paying the premium, it was no longer profitable to mine the ore…

Battle Rock Copper Mine: The only non-uranium/vanadium precious metal mining known in the vicinity of the Monument was a single mine at the Black Dike near Battle Rock in McElmo Canyon, dug by Jack Kelly. The mine reportedly yielded small quantities of gold, silver, copper, zinc, lead, vanadium, uranium, and barite.

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Sand Canyon – East Rock Creek Waypoint List

Way-point	Northing, Degrees	Easting, Degrees
104	37.34510	108.81654
105	37.34535	108.81532
106	37.34575	108.81329
107	37.34627	108.81200
108	37.34757	108.81175
110	37.34878	108.81059
SC1	37.35163	108.80928
111	37.35125	108.80945
112	37.35185	108.80882
113	37.35216	108.80793
118	37.35440	108.80386
119	37.35682	108.80361
121	37.35762	108.80350
123, SC2	37.35876	108.80321
124, SC3	37.36000	108.80056
123, SC2	37.35876	108.80321
126	37.35941	108.80457
128	37.35913	108.80844
129	37.35971	108.80902
130 , SC5	37.36119	108.80808
131	37.36215	108.80906
133	37.35806	108.81588
134	37.35418	108.82066
SC6	37.35260	108.82188
135	37.35170	108.81882
136	37.35006	108.81759
137	37.35032	108.81544
138, SC7	37.35043	108.81467
139	37.34517	108.81669

Fault zone in northeastern East Rock Creek near the Cliff House Group uranium mine.