PRELIMINARY GEOLOGICAL REPORT

ARCHES NATIONAL MONUMENT

by
Ross A. Maxwell
Regional Geologist
National Park Service
Region Three

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INTRODUCTION

Date of Geological Study

The field investigation reported herein was made during the period June 6 to 21, inclusive, 1941. Custodian Schmidt accompanied the writer into the field and placed the facilities of the monument at his disposal.

Purpose

The purpose of the investigation was to obtain geological data that could be used by the Interpretive Staff, Southwestern National Monuments, when preparing exhibits for the monument museum and by the Custodian when telling the geological story to monument visitors.

Maps

The topographic sheet, the La Sal quadrangle, 1885 edition, was the only topographic base map available to the writer. This map was of little value for detailed work because of the small scale and inaccuracies in the features shown. The Park Service vicinity map of the monument, Drawing No. NM-ARC 5304, shows the monument boundary, principal drainage, and location of some of the more important physical features. The geological map accompanying Dane's report, U.S. Geol. Survey Bull. 863, includes about three-fourths of the northern part of the monument. This is a good map and was especially helpful during the field study. With only a few minor changes the monument portion of Dane's map has been reproduced for

this report. The remainder of the monument area was mapped during the field investigations. The geologic structure map also accompanying Dane's report was a valuable reference. The geological map accompanying Baker's report, U.S. Geol. Survey Bull. 841, shows some of the geological details in the vicinity of Moab, south of the Colorado River and a portion of it was also reproduced for this report.

Thoroughness of Investigation

It would require at least one field season to obtain sufficient data to prepare a comprehensive geological report on the Arches National Monument. Much of the field study should be outside the monument area because there lies the key to some of the problems. The investigation reported herein is solely a reconnaissance study. It is believed, however, that the report contains sufficient information to be of help in formulating plans for the museum exhibit and also support the future interpretive program.

Acknowledgments

Appreciation is expressed to Custodian Schmidt for his cooperation throughout the field investigation and also during the preparation of the report. He arranged the details for the pack train trip, took the supplies to our base camp, and proved his value as a manager for the field excursions. Schmidt also has practical ideas on the geology and furnished technical information regarding certain problems.

Dr. J. LeRoy Kay, Curator of Vertebrate Paleontology, Carnegie Museum, spent several days with us in the field. To him is accredited the information contained in this report regarding the dinosaur remains, as well as helpful suggestions on stratigraphic problems.

GEOLOGICAL SETTING

Arches National Monument lies near the northern boundary of Fenneman's (1931 Map), Canyon Lands Section of the Colorado Plateau. The general area is characterized by a rolling plateau surface of moderate relief that has been trenched by numerous canyons. Scattered groups of mountains rise above the general level of the plateau and frequently near the mountains there are extensive badland areas.

About 14 miles north of the northern end of Arches National Monument rises the sinuous southward-facing Book Cliffs, beyond which is the Uinta Basin. South of the Book Cliffs is a strip of land, 10 to 12 miles in width, with gently rolling surface broken only by the drainage channels from the cliff and a few gravel capped ridges. As these drainage courses wind southward they develop canyons and side canyons, some of which, although small, are reasonably characteristic of those of the canyon lands.

East of the monument there is a stretch of rolling land trenched by the Colorado River and its tributaries. The general surface elevation increases from the monument eastward toward the Uncompahgre Plateau which extends northwest, for about 80 miles, from the northern end of the San Juan Mountains, in southwestern Colorado, and has an altitude of 8,500 to 9,000 feet. From the Colorado River, where it borders the monument on the southeast, the land surface rises irregularly toward the La Sal Mountains. Here Mount Waas reaches an altitude of more than 12,000

feet and Mount Peale has an altitude of more than 13,000 feet.

Southwest of the monument is the proposed Escalante National Recreational Area. The area extends in a southwesterly direction from the approximate latitude of Moab, Utah, to the Utah-Arizona line. It includes the spectacular canyons along the Colorado River from Moab to the State line, as well as the canyons near the mouths of the Green and San Juan Rivers. Farther south in Utah and extending southwestward into Arizona is Monument Valley.

Southwest of the Arches and north of the Colorado River are the Henry Mountains. These were made geologically famous by G. K. Gilbert (1880), because of the type of igneous intrusions and various physiographic processes exposed there.

The Colorado River, the master stream of the canyon lands including the Arches National Monument area, has its source far to the east in the Rocky Mountains. Much of its water supply is derived from the spring melting of snow in the mountains. Its maximum discharge is usually reached in late May and early June and diminishes to a minimum during the winter. Its headwater supply, however, is sufficient to insure perennial flow across the less humid plateau region. The altitude at the river surface where it enters Utah is about 4,325 feet and near Moab its altitude is about 3,950 feet. The largest tributary of the Colorado in this vicinity is the Dolores River. Its source is in the San Juan Mountains to the south of the monument. No permanent streams traverse

the Arches area to empty into the Colorado from the north or northwest. Salt Wash, which normally flows only following a rain, is adjacent to the area on the northeast. Salt Valley, Cache Valley, Court House Wash, and their tributary channels are the chief drainage channel in the monument. These are also intermittent.

There is a striking relationship between the topographic forms and the formational outcrops. The harder and more resistant the rocks, the steeper the cliffs. Soft layers weather to form slopes of varying inclination. In some instances, they may be stripped for a mile or so back from the outcropping cliff of the underlying hard stratum. These slopes may correspond with the dip of the harder strata and the frequently interruptions of the general topographic slope are due to cross-bedding in the underlying formation.

The sparsity of residual "soil" is impressive. It is doubtful if the soil profile is typically developed at any place in the monument. Bare rock surfaces are everywhere; examples are sheer cliffs, smooth rounded hills or ridges, and broad dissected slopes or benches, locally called "slick rock". Even the softer formations are covered only by a thin mantle of mechanically disintegrated debris through which ledges of the harder rock project. The "slick rock" surfaces are windswept and the sand derived from them is piled into dunes or distributed as a thin mantle over other formations. Only in small local areas such as "stream bottoms", or a protected flat surface, is there sufficient soil to

support a grass sod.

Although the character of the underlying bed rock is in the main responsible for the location of the smaller washes and drainage channels, the larger drainage courses are not structurally controlled. Thus the general direction and local wanderings in the course of the Colorado River is not controlled by the hardness or local structures in the bed rock, but by other factors such as erosion cycles, and periods of uplift that took place many, many years ago. The Colorado River thus traverses rocks variable in their degree of resistance to erosion, frequently differing in structural attitude and, as a result, a large variety of topographic forms are exposed along its course.

STRATIGRAPHY

The rocks exposed within the monument area and vicinity range in age from the Pennsylvanian to Upper Cretaceous. They include the common kinds of sedmentary rock and their general distribution is shown on the accompanying geologic map. The geological age, stratigraphic relationships, and thickness of these formations is summarized in the following table.

GENERAL SECTION OF ROCK FORMATIONS IN ARCHES NATIONAL MONUMENT AND VICINITY

Modified from Dane (1935)

System	Series	Group	Formation	Thickness in Feet
			Alluvium	
Cretaceous	Upper Cretaceous		Mesa Verde? group	0-20
			Mancos shale	410+
			Dakota sandstone	20-110
Jurassic	Upper Jurassic	San Rafael	Morrison formation	682-900
			Summerville formation	37-58
			Entrada sandstone with Moab member	227-300
			Carmel formation	0-150
Jurassic?		Glen Canyon	Navajo sandstone	0-300
			Kayenta formation	150-320
			Wingate sandstone	250-373
Triassic	Upper Triassic		Chinle formation	107-408
			Shinarump conglomerate	
	Lower Triassic		Moenkopi formation	0-855
Carboniferous	Pennsylvanian		Hermosa formation	0-855+
			Paradox formation	0-1000+

PALEOZOIC ERA

Pennsylvanian Rocks

Paradox Formation: (Dane (1935, pp. 25-33) in his report has described the Paradox formation as a thick series of shale, sandstone, limestone, and gypsum of Pennsylvanian age which is exposed along the crest of the Salt Valley anticline, in two very small areas in the southeast end of Cache Valley, and along Onion Creek. Dane states:

> "All outcrops of the formation have been so complexly folded, faulted, and brecciated that no complete section is exposed and no partial section of more than a few hundred feet in thickness. The base of the formation is no where exposed, unless possibly in the vicinity of the outcrops of unnamed conglomerate in Salt Valley, believed to be probably the next underlying formation or the basal part of the Paradox formation. The confused structural relationships and inadequate exposures around these outcrops inhibit observation of stratigraphic relationships."

The best exposures of the Paradox are along Onion Creek, about 12 to 15 miles east of the monument. Here, black shales are the most abundant rock type. These may be paper-thin beds or layers several feet thick; or they may alternate with beds of gray sandstone. Dense gray and yellow-gray limestone and sandy limestone are common. Much of the shale and sandy shale is gypsiferous and salty. Rock gypsum in thick beds is abundant. It is dark blue, banded with lighter and darker gray tones, and crystalline. Some exposures are white with porous, sugar-like or powdery texture. Bedded sodium and potash salts are reported by Dane (1935, p. 31) from the Paradox formation. Wells drilled deeply into the formation report great thickness of pure salt and of salt alternated with gypsum.

Fossils collected by Dane (1935, pp. 27-28), and others, in the Onion Creek area, Mesa County, Colorado, and from drill cuttings on the Crane Creek anticline, 9 miles southwest of Moab, indicate Pennsylvanian age for the formation.

The writer has given a summary of Dane's discussion of the Paradox formation as well as a quotation from his report. For further information, it is suggested that the reader study Dane's entire description of the Paradox, as well as his discussion of the structure which will be referred to in a later section of this report. This is important because one exposure of the Paradox, according to Dane's map, is adjacent to the monument area. The writer is not convinced that this exposure is Paradox.

The exposure in question crops out in portions of secs. 3, 4, 5, 9, 10, and 11, T. 24 S., R. 21 E, and secs. 28, 29, 32, and 33, T. 23 S., R. 21 E. Small portions of it are exposed within the monument boundary. Bed rock exposures are rare, at least 90 percent of the area being covered with alluvium. The exposures visited consist chiefly of shale, gypsiferous shale, some sandy shale, and a few beds of what appeared to be fresh water limestone. The gypsum is gray with bands of white and grayish-blue. The gypsum has been deformed but similar deformation was not seen in the adjacent shales. This suggests that the deformation is due to reasons other than crustal disturbances. The shale and

gypsiferous shales are very similar in physical appearance to the Mancos shale and only slightly different from many of the shales in the Morrison. Unfortunately, fossils were not found. The exposures are small and scattered which makes it difficult to determine the stratigraphic relationships. The formation contains more gypsum than is normally found in the Mancos and old drill cores on the surface near where potash test wells were drilled (see map), support the conclusion that it is Paradox, but even then the physical characteristics of the surface strata are more similar to the Morrison or Mancos than to Pennsylvanian strata.

Hermosa Formation: The Hermosa formation was named and defined by Spencer (1900, p. 48), from its exposures along Hermosa Creek in the San Juan Mountain region. The formation includes limestone, shale, and sandstone and the invertebrate fauna establish the Pennsylvanian age.

This formation is recognized south and west of Moab and crops out along the highway in the monument area, sec. 20, T. 25 S., R. 21 E. Here the formation consists of marine strata including limestone, argillaceous limestone, and calcareous shales. It is in fault contact with the Entrada sandstone, thus its base is not exposed. Some beds are extremely fossilferous; productus and spirifers being the most common types of brachiapods. Horn corals are abundant in certain zones, and crinoid stems cover the upper surface of many of the strata (Fig.1).



Figure 1.
Fault zone along U. S. Highway 450 near Monument Headquarters.

E. Entrada
N. Navajo
M. Moenkopi
H. Hermosa

MESOZOIC ERA

Triassic Rocks

Moenkopi Formation: The name Moenkopi was given by Ward (1905, pp. 18-19), to a series of strata exposed near the mouth of Moenkopi Wash in northeastern Arizona. This formation is composed chiefly of mudstone and fine silty sandstone that rests unconformably upon the Paleozoic rock. It is exposed in sec. 20, T. 25 S., R. 21 E., and can be seen from U. S. Highway 450 which traverses its strata. Here it consists of a rather even series of reddish-brown to chocholate-brown siltstone and silty sandstone, weathering to steep slopes which are covered with fine debris. Locally there are thin zones of conglomerate containing small pebbles of metamorphic and igneous rock. The series rest unconformabily upon the Hermosa.

The Moenkopi is difficult to distinguish from Cutler formation of Permian age, which usually underlies it. The muddy dirty sands of the Moenkopi in contast with the cleaner sands of the Cutler are the chief lithologic difference. A thin zone on conglomeratic material at the base of the Moenkopi is an aid to finding the actual contact. Fossils have been collected from this formation in other parts of Utah, but none were found in the monument area.

The Shinarump Conglomerate: The name Shinarump was proposed by Gregory (1913, pp. 424-438) for the conglomeratic unit that previously had been included by others in the base of the Chinle. This formation

is not conspicuous in the Arches area, but appears to be represented by thin discontinuous outcrops. Where recognized, the Shinarump zone is marked by a poorly cemented gray quartz sandstone and grit. It ~~is~~ scarcely more than indicates the boundary between the underlying Moenkopi and the overlying Chinle. No attempt was made to map the formation except along the Colorado River, near the mouth of Salt Wash. Baker (1933, pp. 37-38) has described one of the exposures as follows:

> "... A conglomerate 200 to 300 feet thick forms an inner gorge in the canyon.... It consists of rounded quartz pebbles 1½ to 2 inches in diameter imbedded in a matrix of buff to reddish-brown quartz sandstone, but within a short distance up the river it grades into a nondescriptive blue-gray indurated clay, which, in turn, grades into the thin gray zone at the base of the Chinle formation, at the horizon of the Shinarump conglomerate. The extent of the conglomerate is not over 2 miles along the canyon."

This unusual thickness of Shinarump is interpreted by Baker as deltaic disposition.

The Chinle Formation: The Chinle formation was named by Gregory (1917, p. 42) from exposures in the Chinle Valley of northern Arizona. It consists largely of red siltstone with which is interbedded a smaller portion of brick-red sandstone. Grit beds form a subordinate portion of the formation. The Chinle rests unconformably upon the Moenkopi when the Shinarump is absent, but is apparently conformable to the Shinarump.

The formation usually crops out as a steep slope beneath the Wingate sandstone cliffs. In general appearance it is similar to the



Figure 2.
Near where Salt Wash traverses the western side of Salt Valley.
C. Chinle W. Wingate M. Mancos
Note fault contact between Mancos and Chinle.

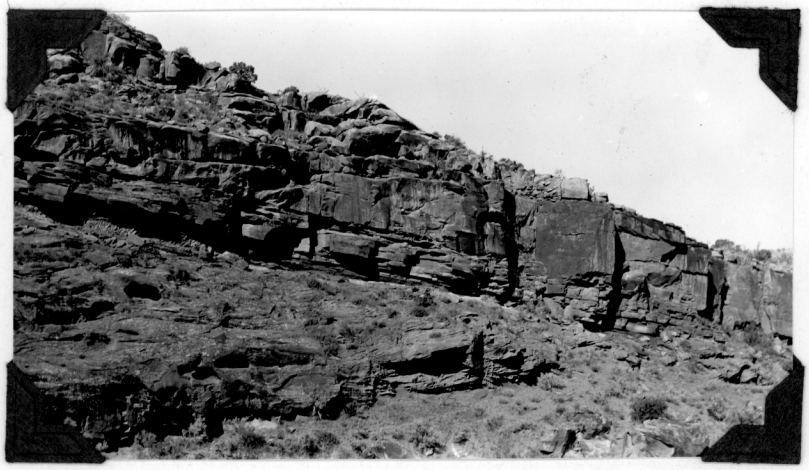


Figure 3.
Unconformity in Wingate seen in Salt Wash about midway between Salt Valley and the Colorado River.

Moenkopi, but its brighter-red shades are contrasted with the less brilliant and more yellow and brown tones in the Moenkopi. Also, the bedding in the Chinle is more irregular and many of the sandstone beds are discontinuous as contrasted with uniformly regular bedding in the Moenkopi.

Fossils are rare, but appear to be widely distributed throughout the formation exposures. The invertebrate species have been identified as fresh water forms. Fragments of petrified wood and fragmental vertebrate bones have been found within the monument. Fresh water invertebrates, silicified wood, and vertebrate bones suggest that the formation was deposited under continental conditions.

JURASSIC (?) ROCKS

Glen Canyon Group

The Wingate Sandstone: The Wingate sandstone, named by Dutton (1885, pp. 136-137), is reddish-buff in color and crops out in sheer cliffs that exposes vertical joints extending the full thickness of the formation. Surface stains frequently streak the cliff face suggesting a dark-brown and locally a black color. Fresh surfaces are light buff colored and expose rounded even-sized quartz grains. The rock is poorly cemented, crumbles under the blow of a hammer, and where weathered may be crushed to a powder in the hand. The sandstone is horizontally bedded in layers ranging from 2 to 50 feet in thickness, it usually maintains a uniform thickness latterly, and locally there is cross-bedding.

The Wingate usually forms a narrow outcrop as shown on the accompanying map, yet its cliff and canyon-forming habit make it one of the most impressive formations in the area. This is in part due to its homogeneous lithology and massiveness, partly to its greater resistance to erosion and to the rapid rate at which the underlying Chinle strata are eroded.

There is usually a sharp contact between the Wingate and the underlying Chinle. This has been interpreted by some as an unconformity, but it probably does not represent a time interval of long duration. The conditions of deposition are also controversal. Some have assumed it to be entirely of continental origin. Dinosaur tracks, the only fossils reported observed by Miser (1925, p. 13) and Gilluly (1928, p. 70), support that conclusion. Further evidence is the tangential cross-bedding, uniformly fine-grained character of the formation, and the even sorting and excellent rounding of the sand grains suggest wind deposition. On the other hand, the association of some of the ripple marks with mud-cracks indicate water currents. Some of the cross-bedding exhibits contortion and slumping which suggests saturation by water. Limestone beds are obviously water deposits, but these are thin and non-extensive. Perhaps there was a combination of wind and sheet-wash deposition on a surface of very low relief.

The Kayenta Formation: The name Kayenta was given by Baker (1936, p. 5) to beds at Comb Ridge near Kayenta, Arizona. These strata

had been previously designated as the Todilto formation that crop out in northern Arizona, southeastern Utah, and adjacent parts of Colorado. They are definitely older than the Todilto limestone of New Mexico (Baker, 1936, p. 17).

The formation consists predominantly of sandstone, ranging in color from grayish-white to brown with intermediate shades of tan, buff, and lavendar. The sandstone occurs in discontinuous beds and lenses. Cross-bedding of both tangential and angular types are common. These sandstone strata are interbedded with zones of earthy sandstone, mudstone, and shale. In addition, there are irregular lenses of conglomeratic materials.

Kayenta outcrops are characterized by alternating benches and ledges. The harder sandstone beds form the rounded ledges and in many places are responsible for overhanging recessions. The basal Kayenta appears more resistant to erosion and usually forms the cap rock on the Wingate Cliffs while the remainder of the Kayenta underlies a wide sloping bench.

The Kayenta is conformable with the Wingate. There appears to be a gradation contact between the formations. Massive sandstone of the Wingate grades upward into the thinner beds of the Kayenta. The rock series appears to have been deposited in continental environment. Mud flats, channel fillings, shale-pellet conglomerates, contortion, and slumping in the shale beds all suggest that deposition, by streams,

took place on surface of low relief. Fresh water fauna and dinosaur tracks further support the conclusions for the continental environment.

The Navajo Sandstone: This name was given by Gregory (1917, p. 57) to a series of fine to medium-grained, buff colored, quartz sandstone, tangentially cross-bedded on a large scale, and almost void of horizontal bedding. The Navajo country is Gregory's type locality but the term is now applied to strata belonging to the same stratigraphic unit which are exposed in northeastern Arizona and southeastern Utah.

This formation is composed almost exclusively of light-buff, fine-grained sand. There is some variation in color, some of the sandstone is nearly white. The rock weathers to darker shades and locally is brown. There are a few reddish-buff mudstones and Dane (1935, p. 85) has reported beds of dense gray limestone from this formation in Salt and Cache Valleys. The main mass of the rock, however, is clean sandstone cross-bedded on a large scale.

Typical exposures of the Navajo crop out as great rounded knolls rising above platforms or slopes floored by the underlying Kayenta. Less common is an outcrop in a sheer cliff where the Navajo merges with the underlying formations. The Navajo-Kayenta contact is conformable and transitional. The boundary is quite sharp and is placed at the top of the red shale and purplish sandstones of the Kayenta, but observation along the contact show that there is visible intertonguing and gradation between the two types of lithology.

The Navajo is generally considered as an eolian (windblown) deposit. Its origin being similar to that of present day sand dunes. Regarding its origin, Dane (1935, pp. 87-88) states:

> "The texture, cross-bedding, and general absence of silty beds accords with this view, and the limestone lenses found in the formation are most easily explained as deposited in local ephemeral basins within a dune-sand area. A zone of pebbles 2 or 3 inches in diameter found in the Navajo of the San Rafael Swell provides conclusive proof of eolian deposition of the sandstone associated with it, for the pebbles were quartz, highly polished and faceted-perfect examples of 'kreikanter'".

JURASSIC SYSTEM

San Rafael Group

The Carmel Formation: The Carmel formation was named by Gregory (1931, pp. 72-73) from Mount Carmel, in southwestern Utah. In the Arches area the Carmel consists of red muddy sandstone, and mudstone ranging from thin to massive beds. The bedding is frequently wavy or irregularly contorted. These irregularities extend upward into the basal layers of the overlying Entrada sandstone.

The Carmel forms a soft zone between the Navajo and the Entrada. In most cases, erosion has stripped the Carmel leaving a broad bench, occasionally more than one mile in width, on top of the Navajo. Due to the results of erosion, the Carmel is usually seen as a band with sheer face, variable in thickness, at the foot of a butte, mesa, or canyon wall where it is protected by the overlying Entrada sandstone.

The contact between the Carmel and Navajo is sharp and easily

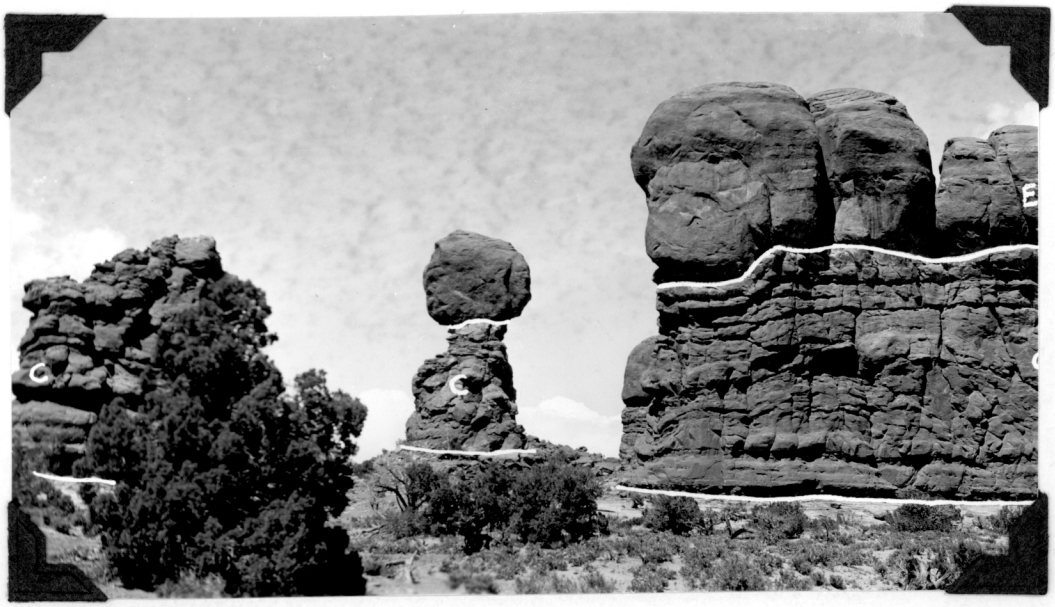


Figure 4.
Portion of the Window Section, Arches National Monument.

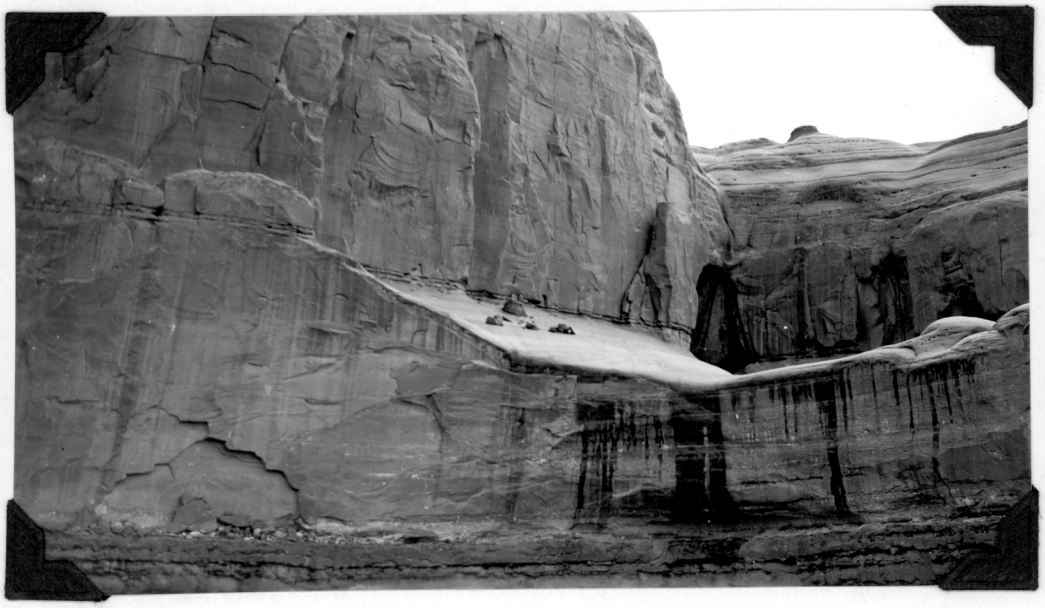


Figure 5.
The Entrada sandstone, Courthouse Towers Section of monument.

Photos by Gould.

detected because of the difference in the lithology. However, the contact is irregular. Some have postulated unconformable relations, but to the writer these irregularities appear to be due chiefly to normal deposition of the Carmel muddy sandstone upon the irregular dune sand surface of the underlying Navajo.

West of the area studied, the Carmel (Gilluly and Reeside, 1928, p. 74) is, at least in part, of marine origin as indicated by limestone containing marine fossils. Shaly layers containing anhydrite and gypsum zones in the upper part of the formation suggest deposition from evaporation probably in lagoons. The wavy, contorted bedding and irregularities in the bedding that appear to have been produced by slump suggest that the Carmel sediments of the monument area were deposited in water, but it does not prove a marine environment. Perhaps deposition was in a marginal area with the clear marine waters farther to the west.

The Entrada Sandstone: The name Entrada was given by Gilluly and Reeside (1928, p. 76) to a thick series of earthy sandstone and subordinate shales exposed on Entrada Point in the northern part of the San Rafael Swell. In the Arches area the Entrada is a massive rock in which the sand grains appear to have been well sorted. The color is orange to reddish-buff. It weathers into sheer or rounded cliffs and frequently vertical joints that extend from the base to the top of the formation are well exposed. In addition, the Entrada is the formation in which virtually all of the Arches have been carved. A discussion of the origin of the

arches appears in another section of this report.

At the top of the Entrada there is a persistently lighter-colored sandstone which was called the "Moab sandstone", by the late W. T. Lee in an unpublished report (Dane, 1935, p. 94). Dane has found this unit to be sufficiently continuous over the area, studied by him, to warrant recognition as a mapable member of the Entrada. The writer feels that, for purposes of interpretation at the monument, this member should be recognized but not emphasized, because it is not conspicuous and to emphasize its presence would probably lead to confusion of the layman.

The Moab sandstone is composed chiefly of well rounded quartz grains. Cross-bedding is common, but the cross-beds, as well as the horizontal layers are less massive than the main Entrada mass. The rock weathers to a lighter color and is usually gray instead of the orange-buff color characteristic of the Entrada. At the base of the Moab there is a zone of sandy shale. This zone is easily eroded and forms a topographic parting zone between the formations. As a result, the Moab frequently forms a cliff above a steeply sloping bench underlain by the main Entrada mass. Occasionally overhanging shelters or caves are found at this zone. The Moab is overlain by softer formations which are usually swept back from the face of the outcrop by erosion leaving a broad bench on which cross-bedded, gray colored Moab sandstone is typically exposed (Fig. 7).

The Carmel and basal Entrada exhibit extraordinary irregularities

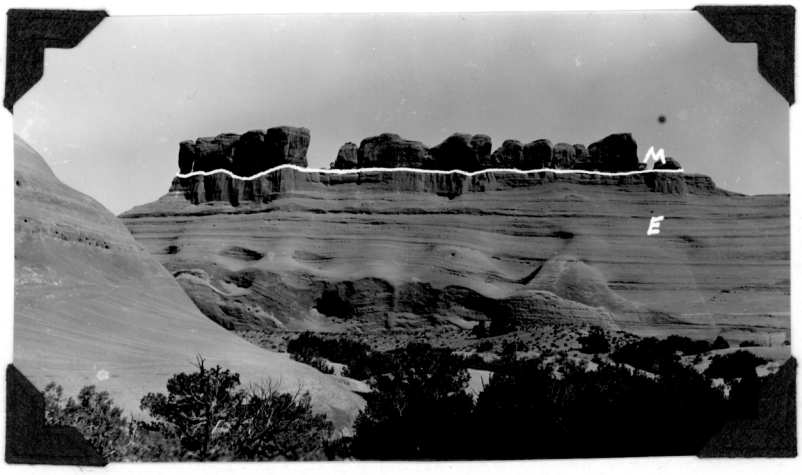


Figure 6.
Contact between the Entrada and the Moab sandstone member along the Salt Wash above Turnbow's Cabin.
M. Moab tongue E. Entrada



Figure 7.
The surface of the Moab sandstone member, Devils Garden Section.

in bedding. These appear to be due to movement in unconsolidated sediments during or soon after deposition. These irregularities are characterized by wavy crenulations, in the Carmel beds. They may decrease in intensity both up and down until they grade into horizontal beds or the intensity may increase upward until the top of the crenulation is planed off by horizontal beds in the Entrada. In other cases, masses of the Entrada appear to have been washed downward into the Carmel before it was consolidated. To the writer, these irregularities suggest extremely rapid deposition of the Entrada in a subaqueous environment while the underlying Carmel was still in a soft mushy condition.

If the above conclusions are correct, they do not prove whether it was a marine or fresh-water environment. It could have been a continuation of the marine margin facies suggested during Carmel deposition. On the other hand, the physical appearance of the Upper Entrada suggests continental deposition. The physical appearance of the upper Entrada is also different from that of the Moab member. The latter could have been deposited along the shore of the fresh-water lake that appears to have covered the area during Summerville time.

The Summerville Formation: The type locality of the Summerville formation is in the San Rafael Swell, so named from the formation exposures on Summerville Point, southeast of the head of Summerville Wash, in the northern end of the swell (Gilluly and Reeside, 1928, p. 80). In the monument area the Summerville exhibits uniform horizontal

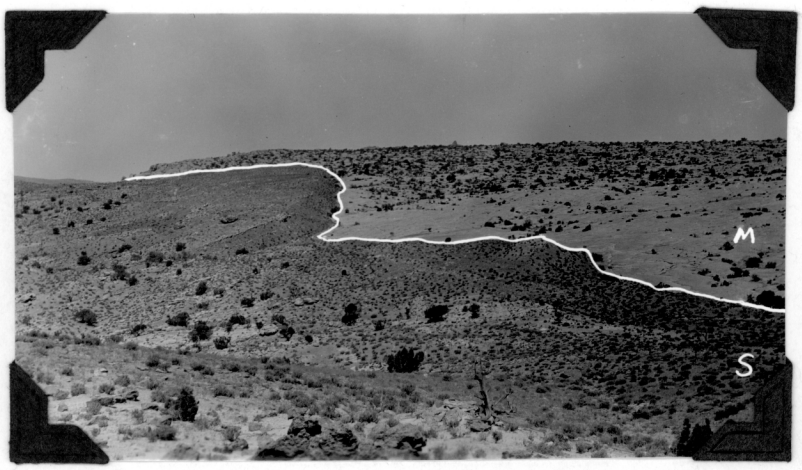


Figure 8.
Contact of the Summerville with underlying Moab sandstone member. Northeast of Turnbow Cabin.

bedding and a uniform red color which is a strong contrast to the heterogenesity and irregularities in the formations both above and below. The formation consists of current ripple-marked sandstone, sandy and silty shale, and gray to purple limestone. The formation crops out in rather steep slopes beneath a hard sandstone ledge in the base of the Morrison. This slope usually leads down to a flattish bench that is underlain by the more resistant Moab member of the Entrada. The upper contact is more difficult to distinguish because the basal Morrison also weathers to red wash-covered slopes similar to the Summerville.

The Summerville appears to be conformable with the underlying Moab sandstone member of the Entrada, but in most cases there is an abrupt change in the lithology.

Current ripple marks, gentle cross-bedding, and regular bedding suggest deposition in shallow quiet water. Beds of dense, unfossiliferous limestone, masses of structureless red clay with occasional lenses of sandstone suggest deposition in a lake or lagoon rather than a marine environment.

The Morrison Formation: The formation consists of a varied assemblage of beds of sandstone, shale, and conglomerate, with subordinate limestone. The formation can be divided into two parts. Although they are gradational, certain features are characteristic of each. The upper part consists predominantly of silt and limy mudstones banded with a wide variety of colors including hues of green, gray, white, red, maroon,

purple, orange, and yellow. Associated with the mudstone are thin, lenticular, densely crystalline limestones with subdued colors commonly gray. There are also lenticular beds of chert-pebble conglomerate. The lower part of the formation includes about equal portions of white and light gray, cross-bedded sandstone, and gray and red mudstones. There are, in addition, a few thin gray limestones.

The Morrison-Summerville contact may be difficult to locate because of the resemblances previously mentioned. In most cases, an erosion contact is visible. Frequently, however, this angular discordance is not important as appears to be the case in the monument area, for here the angular relationships are difficult to determine, which may suggest only a brief lapse of time.

The Morrison was deposited during continental environment. The lenticular conglomerates and sandstones are stream channel fillings deposited as the streams shifted over the surface. The limestones contain fresh-water invertebrate fossils. The mudstones and similar rocks may be flood-plain deposits or lake deposits associated with fresh-water limestones. In addition, fossil wood and dinosaur remains are evidence for the continental environment.

Upper Cretaceous Rocks

The Dakota Sandstone: The Dakota sandstone of the Arches area consists of gray and buff sandstone, with beds of conglomeratic materials, and small portions of shale. Brown beds and various streaks

in the formation are usually the result of weathering. Some of the sandstone is poorly cemented, some is indurated with calcareous cement and locally it is quartzitic because of siliceous cement. This is especially true of the area near the Turnbow cabin where quartzitic ledges form topographic ridges and quartzitic float is strewn over much of the surface.

The Dakota normally crops out as a ledge, capping a steep slope, which is underlain by the softer strata belonging to the Morrison. The Dakota is likewise more resistant to erosion than the overlying Mancos shales which are usually stripped back from the crest of the Dakota ridge leaving the sandstone capping the slope of a hogback.

The Dakota crops out in many of the western States. In some localities it is fossiliferous. Fossil fern leaves, in a very fine state of preservation, have been collected from the formation. Very little fossil material has been observed in the Arches area. A few sticks and stems of fossil plants suggest deposition in a continental environment in the area studied.

The Mancos Shale: The Mancos shale is a thick formation of marine origin. It consists largely of gray to grayish-blue shale, containing subordinate amounts of earthy sandstone, and a little gray limestone. The shales are well bedded and in some localities they are slightly slatey.

The lower part of the formation is exposed in the monument area.

The upper part crops out farther north and underlies much of the Book Cliffs. In the monument area, however, the formation crops out over broad gently rolling surface with intervening wide alluvial flats. Fresh rock exposures are rare, even on the steeper slopes the shale breaks down forming a gray clay mantle. Gypsum veinlets are common in the fresher material, masses of selenite are common on weathered slopes, and alkali streaks and coatings are everywhere.

About 350 feet above the base of the Mancos is a zone of thin-bedded sandstone, 50 to 60 feet in thickness, that usually forms a hogback ridge, which parallels the more conspicuous cuesta formed by the Dakota sandstone.

Fragmental marine invertebrate shells are common in certain zones of the Arches area, but specimens suitable for museum exhibits were not seen.

The Mesa Verde (?) Group: In Cache Valley near the eastern boundary of the monument there is a series of sandstone which appear to overlie the Mancos shale. These strata are believed to belong to the Mesa Verde group, probably to the Blackhawk member described by Fisher (1936, pp. 12-14) in the Book Cliffs area. These strata are in fault contact with the Wingate and although Dane (1935, map, plate 1) has shown an exposure of Dakota sandstone near there, the writer feels that the particular outcrop in question is a small exposure of Mesa Verde strata.

STRUCTURE

Most of the strata in the Arches area have been influenced by broad structural uplifts outside the immediate area. The general inclination of the beds is northward toward the Uinta Basin. The La Sal Mountains, a laccolithic uplift to the southeast, have also influenced the dip of the strata in adjacent areas and similar conditions are true adjacent to the Uncompahgre Plateau, an anticlinal uplift in Colorado.

Although the general structure of this area is not complex, there are several minor folds and faults which add to the general structural picture. Most conspicuous of these is the long curved Salt and Cache Valleys which form a complexly faulted anticline. In addition, there is the Court House Syncline, a broad trough, which traverses the southern part of the area, the Elephant Butte folds, both anticlines and synclines in the vicinity of the Window Section, and the Moab Valley, in the extreme southern part of the area.

The Salt Valley Anticline

The Salt Valley anticline is the largest fold in the area. The flanks of the anticline stand as ridges because they are composed of resistant sandstone. Within the center of the arch the exposed rock formations are soft and have been eroded down forming a valley which is largely covered with alluvium. In addition, a series of faults on both sides of the fold's crest have allowed a block along the crest of

the anticline to sink downward forming a rift valley. This is not a typical graben in all places, however, because the faults are not continuous and in some localities the depressed segment is only a tilted fault block and in other areas there is a series of multiple faults and cross faults (see map). To add further complications, Dane (1935, pp. 121-124 and 138-153) has described a salt-gypsum plug that has been intruded into the midst of the rift valley. A summary of Dane's description of a salt-gypsum plug, a part of which is in the monument area follows:

The Paradox formation crops out in sec. 32, T. 23 S., R. 21 E., and extends southeastward for about 4 miles into sec. 11, T. 24 S., R. 21 E. This formation is separated from the Chinle shale on the southwest side by a fault or intrusive contact and the northeast side is also faulted, bringing formations ranging from the Chinle to the Mancos into contact with the Paradox. The Paradox formation consists largely of salt and gypsum, has high plasticity, and its abnormal relationships with other formations is due, in part, to the intrusion of the plastic mass into or through overlying formations as a salt plug. Along the walls of the valley the rocks are cut by numerous normal faults, with prevailing drop toward the valley which is also toward the Paradox exposure. A glance at the accompanying map shows the complex structure.

That the Paradox formation was actually forced upward as a plastic mass cutting across formational boundaries is supported by observations

at the outcrops. Dane (1935, pp. 138-139) has described these cross-bedding relations at several localities outside the area studied by this writer. Evidence supporting the above conclusions regarding the Paradox exposure in the southern part of Salt Valley, part of which is exposed in the monument, are that there are beds of gypsum exposed at the surface near the Babcock-Armstrong wells numbered 1A, 1B, and 2 (see map). Cores of gypsum and perhaps salt still remain near the wells as evidence of the kind of material encountered. Records of some of the wells drilled in Salt Valley may be seen on pages 158 to 161 and pages 175 to 176 of Dane's report.

On the other hand, the writer is not convinced that the Paradox exposure mapped by Dane in the southern part of Salt Valley is a gypsum-salt plug or even Paradox strata. In the first place, Mancos fossils were seen in the shales near the monument corner between sec. 3 and 4, T. 24 S., R. 21 E. Other exposures along the road and stream bed which traverse longer dimension of the outcrop resemble Mancos, but fossils were not seen. The gypsum beds are not as highly contorted as one would expect had they been pushed upward as a plug and, in addition, the deformation in the gypsum is more severe than that in the adjacent shales. To the writer, this was suggestive of the type of deformation that takes place when gypsum changes to anhydrite.

To the writer, this portion of Salt Valley appears more like a typical rift valley with a floor of Mancos and Morrison strata. One

difficulty in proving this theory is, a method of explaining the presence of the gypsum which is excessive to amounts normally found in either the Mancos or Morrison. Whether one supports the gypsum-salt plug or the rift valley idea there is a good alibi because the bed rock strata are covered with alluvium and it is difficult to determine what has actually happened.

The origin and economic importance of salt plugs would certainly be an interesting item for the interpretative program for it is doubtful if there is another salt plug in a Service area. On the other hand, the possibility of a salt plug should not be included in the interpretive program until its presence has been definitely proven. The writer hopes to make further studies of the problem before the museum exhibit is prepared.

The Cache Valley Graben

Extending eastward from the southern end of the Salt Valley anticline is the Cache Valley graben. It likewise is an arched area with a rift valley along the crest of the uplift. It differs from the Salt Valley anticline in that the arching of the strata is less prominent and the rift faulting is more prominent. Actually, there is a gradation between the two structures and it is difficult to determine where one ends and the other begins. Salt Wash is usually taken as the geographical boundary. The term "graben" is not strictly applicable to the entire structure because of the overlapping faults, branching faults,

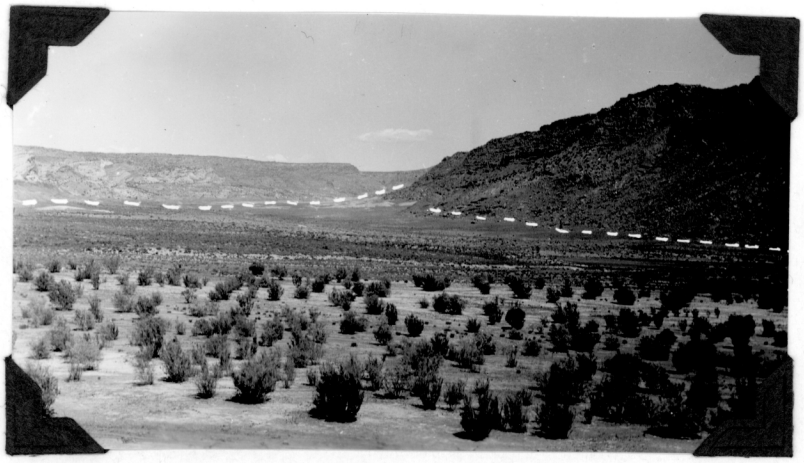


Figure 9.

Looking eastward up Cache Valley from near the Turnbow Cabin. The dashed lines show the approximate location of the faults. The floor of the valley between the faults is underlain by the Mancos. The cliffs on either side are underlain by Triassic and Jurassic strata.



Figure 10.

Looking down the Moab Valley. Here erosion along the crest of a faulted anticline has produced topography simulating a rift valley.

cross faults, and down folding.

In this area the rim of the arch is also high because it is composed of resistant sandstone and the floor of the rift valley is underlain by soft rock which is easily eroded. The greatest displacement is in the southern side of the valley where the Mancos is in contact with the Chinle. On the opposite side the Morrison is in contact with rocks that range from Summerville to Wingate.

Moab Valley

The broad valley, including the Moab valley, which extends southeastward from the southern end of the monument, is also a structural valley. In general, it appears similar to a rift valley, but that appearance is, in part, due to erosion. The structure is variable in type. From the south end of the monument and extending southeastward to the vicinity of Moab the structure is a faulted anticline. Farther southeast, near the Grand-San Juan County line, the structure is a faulted syncline, and still farther southeast the structure is a synclinal graben.

Northwest of the Colorado River is a fault zone which extends southeastward from the Green River, and is continuous with the fault zone along the southern border of the monument and the zone along the southern side of the Moab Valley. About 5 miles west of the river the fault has a displacement of approximately 2600 feet. The displacement decreases southeastward and passes into a faulted monocline in the

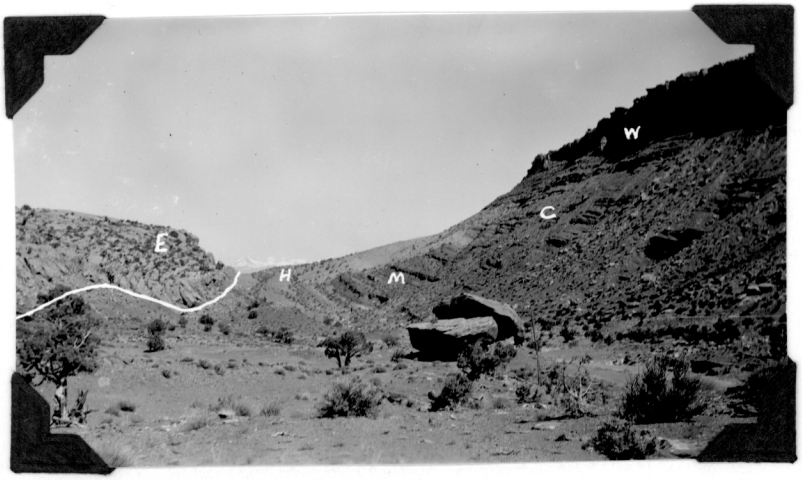


Figure 11.
Fault zone seen from U.S. Highway 450 near southwest corner of monument.
H. Hermosa M. Moenkopi C. Chinle
W. Wingate E. Entrada



Figure 12.
Morrison faulted against Chinle and Wingate seen from highway about 8 miles north of monument headquarters.
C. Chinle W. Wingate M. Morrison

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vicinity of the southwest corner of the monument. Here the Entrada is in fault contact with Moenkopi and Hermosa. Farther south, in the vicinity of Moab, the valley is a faulted anticline.

The Moab anticline is an elliptical-shaped arch. The northeast flank of the anticline has a maximum dip of 9 degrees toward the Court House syncline, and the southwest flank has a dip of about 16 degrees toward the Kings Bottom syncline. Both flanks are faulted near the margin of the valleys and steep dips are present in or near the fault zones. The walls of the valley are capped by resistant sandstone ledges which outline both the valley and the arched structure. The floor of the valley is underlain by soft materials covered with alluvium. Exposures of gypsum along the sides of the valley and larger masses of gypsum and salt encountered in wells drilled in the valley suggest that the floor of the valley is underlain by the Paradox formation.

The Court House Syncline

The Court House syncline traverses the monument southwest of the Window Section. Its axis crosses the Colorado River in sec. 24, T. 25 S., R. 21 E. The fold extends for several miles northwest of the river and also southeastward along the drainage of Nigger Bill Creek. It is a symmetrical trough with dips of about 6 degrees on each flank. The southwestern side of the structure is terminated by the faults and local folds along the northwestern side of the Moab Valley. The northeast side of the fold, west of the Colorado River, is modified by local

folding in the Windows Section.

The Elephant Butte Folds

In the Window Section, and between that area and the Salt Valley, are several anticlines and synclines. They are small, some of them being not more than one mile in length. Suggestions of their location, size, and trends can best be obtained from the accompanying geologic map.

PALEONTOLOGY

Fossil remains are not widely distributed in the Arches area. There are a few localities, however, where fossils have been found. The Hermosa strata, exposed along the highway in sec. 20, T. 25 S., R. 21 E., and also along the sides of the Moab Valley, are fossiliferous. Here the most abundant types of invertebrates are brachiopods, horn corals, and crinoid stems. Most of the forms are well preserved and many of them are suitable for museum exhibits. Dane (1935, p. 35) has listed 34 species collected from the Hermosa.

The Mancos shale is also fossiliferous and much fragmental material was found in the Mancos exposures within the monument. There were only a few good specimens seen, but it is believed that suitable museum material can be obtained by careful search. The fossils are chiefly pelecypods or the clam-oyster type of invertebrate.

Fresh-water snails and clams have been collected from some of the other formations, but they are not abundant and probably are not important for museum exhibit purposes.

Fragmental dinosaur bones are found associated with the Morrison strata in most of the exposures in the monument and surrounding area. Dr. LeRoy Kay reports that several genera and species are indicated by the bone fragments. Also that both herbiverous and carnivorous types are present. Dinosaur bones were found in place in sec. 7, T. 24 S., R. 22 E., about one mile west of the Turnbow Cabin. In

addition, there is a zone, with bones in place, about one-fourth of a mile north of the Dalton Wells CCC Camp, on U.S. Highway 450, north of Moab. Dr. Kay reports that this appears to be one of the most promising areas for collecting dinosaur bones that he has seen in the Morrison formation.

Vertebrate bone fragments are also present in certain conglomeratic beds in the Chinle shale. Although the bone fragments were found in place, in several localities, we did not find a locality that would warrant extensive prospecting.

Fossil wood is found at many places in the Morrison formation and to a lesser extent in the Chinle shale. It is usually found as fragmental material that has been scattered by the normal processes of erosion. The pieces range in size from an inch or so in diameter to blocks one foot in length. The best exhibit now known in the monument is from the Morrison about 1½ miles west of the Turnbow Cabin. Here there is one log about 39 inches in diameter at the base and 42 feet long. It is in place and more than half covered. Another log, also partly covered, appears to be larger. Partial remains of an old stump was also seen. This wood is silicified and banded. Colors range from gray to almost black, with some bands of yellow and brick-red. It is nice coloring but in general not so highly colored as the wood at Petrified Forest National Monument. All logs seen were badly fractured.

ECONOMIC GEOLOGY

Oil and Gas

Dane (1935, pp. 158 to 174) has given a summary of the history of drilling and the possibilities of obtaining oil and gas in the area studied by him. This included most of the monument area as well as considerable area to the north and east. It appears that drilling has failed to obtain commercial production and that the shows of oil and gas have not been sufficient to warrant further drilling. This should not condemn the area, for perhaps all possibilities for commercial production have not been tested. On the other hand, past results are not encouraging and commercial production does not appear likely in the monument area.

Gypsum Salt and Potash

Irregular lenses of gypsum crop out in Salt Valley. Well records show that salt is present at shallow depths. Soluble potash salts are also present. The commercial exploitation of these mineral resources appears dubious as compared with deposits in other areas that are more regularly bedded and more advantageously situated.

Uranium and Vanadium

The occurrence of uranium and vanadium ores have been known for southeastern Utah since the beginning of the century. They usually occur in the sandstones of the basal Morrison. Frequently the ore is

seen in streaks or lenticular masses embedded in the sandstone. Occasionally it has been seen in veinlets along joints or fractures.

Two uranium-vanadium prospects were seen in the monument area. One is in sec. 7, T. 24 S., R. 22 E., about 1/2 mile northwest of the Turnbow Cabin. Here there is a lense of black sandy ore probably 12 inches thick and 250 feet in length. The mass appears to pinch out on each end, and, although it parallels the bedding of the basal Morrison, it is doubtful if the deposit extends far beneath the surface. What may be a larger deposit was seen about 1¼ miles west of the Turnbow Cabin.

Although the two prospects mentioned above are the best deposits now known, there are several small deposits in the basal Morrison at other localities in the monument. All deposits are believed to be small, the most of the ore low grade, and when the ore is of fair to good quality, the quantity appears to be limited.

Manganese

Manganese ore was seen in several localities in the Chinle shale exposed along the western side of Salt and Cache Valleys. Locally small nodules up to one foot in diameter appear to be rich ore, but in general the majority of the deposits are low grade.

Other Metallic Minerals

Old prospect pits seen along the western side of Cache Valley are said to have been dug in search of silver and copper. They have been

abandoned for years.

At the time of the field investigation, a company was dredging for placer gold in the gravels of the Colorado River. Several similar claims were seen at other points. One placer mining claim was seen on an alluvial fan near the Court House Towers.

During recent months Magnesium Chloride has been extracted from the brines found in wells near Crescent Junction, about 30 miles north of Moab. The wells are about 4,000 feet deep. Water is pumped into the well which dissolves the magnesium salts. It is then pumped out and evaporated, leaving magnesium chloride crystals. It is reported that plans for drilling additional wells and erection of a large plant have been formulated. The cost of obtaining an ample water supply appears to be the chief obstacle. There is reason to believe that similar magnesium minerals might be obtained from the subsurface salt and gypsum deposits known to exist along the Salt Valley anticline.

ARCHEOLOGY

The writer does not intend to discuss the archeology of Arches National Monument but only to call attention to some observations. The canyon walls along Salt Wash range from 50 to about 200 feet high. Most of the walls are composed of Entrada sandstone capped by the Moab sandstone member. The Moab sandstone is more resistant to erosion than the adjacent portion of the underlying Entrada, consequently there are numerous overhanging cliffs and shallow caves.

One cave, probably located in the W. 1/2 sec. 24, T. 23 S., R. 21 E., has some archeological interest (fig. 13). The cave is crescent shaped. It is about 300 feet in length, 100 to 150 feet deep in the central portion with the depth decreasing to zero at the ends. The floor is flat, the light good, and it is dry except for a small spring of clear cool water at the back of the cave. There are remains of one or more ruins in the cave. Partial walls two to four tiers of stone in height are exposed. Judging from the mound of debris, the ruin covered a considerable portion of the floor but it may not have been more than a single story in height. About half a dozen pits have been dug in the cave litter, but there does not appear to have been much vandalism.

The writer entered another cave in the Entrada sandstone on the eastern side of Salt Wash, about 2 miles north of the Turnbow Cabin (fig. 14). Custodian Schmidt had previously reported this cave and I am sure information regarding it is available. Chief interest to



Figure 13.

Cave that contains evidence of early human occupation; probably in the W½, Sec. 24, T. 23 S., R. 21 E., on a tributary to Salt Wash.



Figure 14.

Cave along Salt Wash about 2 miles above Turnbow Cabin. Contains evidence of early human occupation.

me are the 16 storage cists made of adobe. In addition to the caves, several campgrounds, littered with flint chippings and broken tools, were seen.

In addition to these two caves mentioned, there are perhaps a dozen or more other caves that appear promising as possible sites of human culture. The writer entered only the two mentioned, but would recommend that a trained archeologist investigate these to determine if they contain sufficient values to justify further study or protection by the Service, possibly by including them in the Arches National Monument.

THE ORIGIN OF CERTAIN GEOLOGICAL FEATURES

The Arches

To date, 83 arches have been reported in Arches National Monument. Of that number, 65 to 70 are in the Devil's Garden Section. In addition throughout the monument area there are 14 smaller openings locally referred to as windows. The arches are variable in size, and range from relatively small openings to those having dimensions of more than 100 feet. The dimensions of the double arch have been estimated as 157 feet in height and 305 feet in length (fig. 15). Landscape Arch is 118 feet in height and 305 feet long. From the visitors who see these unique formations frequently comes the questions-- How were these arches formed and why are there so many?

Reference was previously made to the depositional environment for the Entrada sandstone. Following the deposition there was compaction and consolidation. The results of these are manifested by the physical characteristics of the formation.

The rocks of the outer shell of the earth are frequently traversed by fractures which may vary from microscopic crevices to important breaks along which there has been large displacement. Fractures along which there has not been appreciable displacement ~~is a~~ are joints. Some joints in sedimentary rocks are the result of tension caused by contraction in beds of sediments when they were elevated from the sea floor to form land masses. Another cause is the warping and twisting experienced by

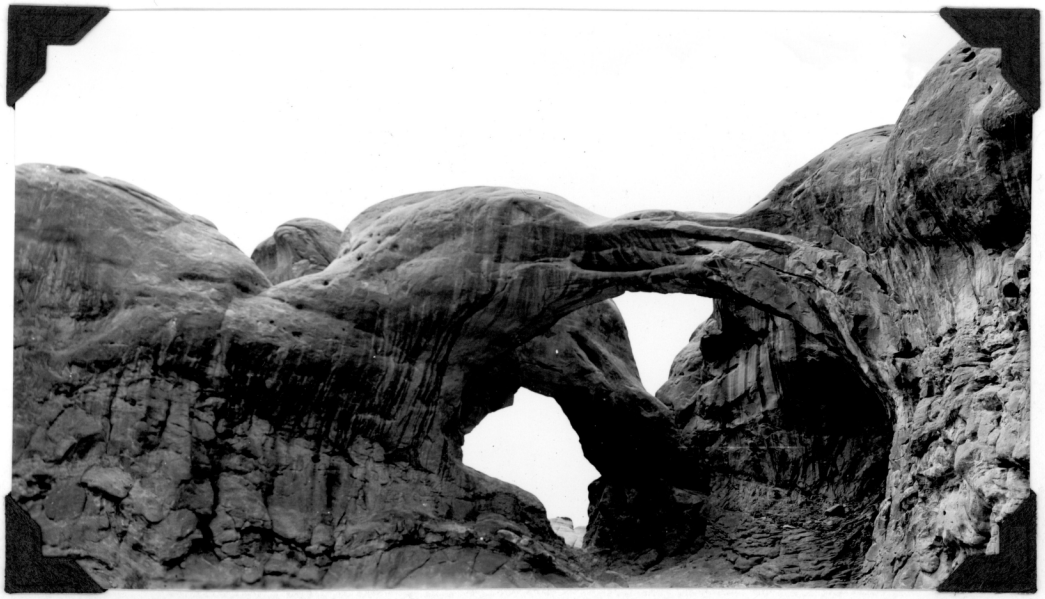


Figure 15.
The Double Arch.

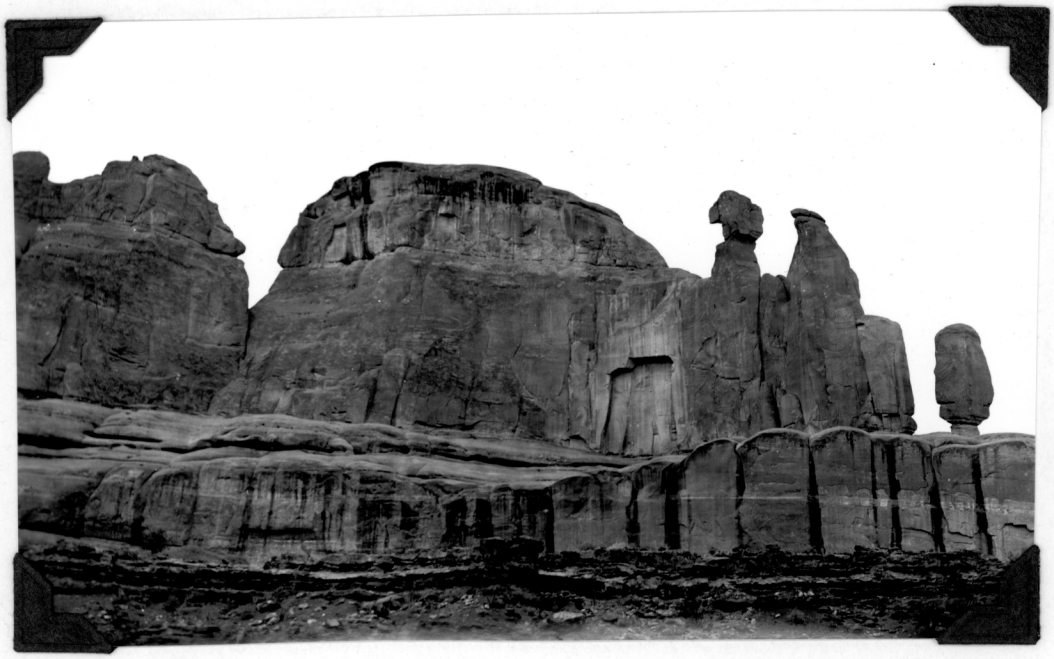


Figure 16.
"Fin" of Entrada sandstone.

Photos by Gould.

the strata during crustal movements.

In areas where joints are abundant, they are commonly arranged in more or less definite patterns; that is, the joint planes may fall in groups with sub parallel direction. This is called a set of joints. Occasionally, there are two sets of joints intersecting at a large angle. Such a combination of two or more intersecting joint sets is a joint system. As a rule, the finer the grain of the rock, the more perfect the jointing. This factor, combined with a well-defined joint system and natural bedding planes may cause the strata to be divided into a series of closely fitting blocks. Sets of joints that extend for long distances across thick series of strata are known as master joints as contrasted with minor fractures of local extent.

It is a familiar fact that bedrock underlies all parts of the land surface, although it is often concealed it can be reached by excavating to sufficient depth. Wherever it is exposed at the surface it has undergone obvious change. Even the most casual observer recognizes changes where the rock has been exposed to the weather. Thus, we say the rock has been weathered, and the complex processes which changes the rocks and leads to the breaking up and decay is called weathering.

The chief agent of weathering is the atmosphere which is responsible for vast changes on the earth. These may be brought about through oxidation, leaching, temperature changes, which cause expansion and contraction in the rock itself, freezing of water, and other less common

processes
agencies. The disintegration and decomposition of rocks, which are the results of the processes agencies of weathering are facilitated by the presence of cracks, crevices, and joints. The joints allow ready entrance of air, water, and other weathering agents into the rocks. Even some of the mineral grains have minute cracks which admit some moisture. As a result of the weathering processes, the original openings are widened and new ones formed.

The widening of joints is also augmented by the agencies of erosion. Joints can usually be distinguished by elongate depressions which range from inches to one foot or more in depth. Their length depends in a measure upon the character of the rock and the internal stress which formed the joint. Frequently, they are 100 feet or more in length. The agencies of weathering which crumble the rock prepare the way for removal of the rock particles by the agencies of erosion. In the early stages the wind is an important factor in removing the dust particles. The larger particles may be further pulverized by the wedgework of the roots of plants, or crushed beneath the feet of wild animals or domestic stock that find the partially pulverized rock along the joint trace more satisfactory for travel than the more resistant rock on either side. In time, however, running water will course along the joint trace and eventually by concentration of sufficient water, the trace that originally marked a joint may be deepended into gorge-like proportions or widened and deepened into a broad river channel (figs. 17-18).

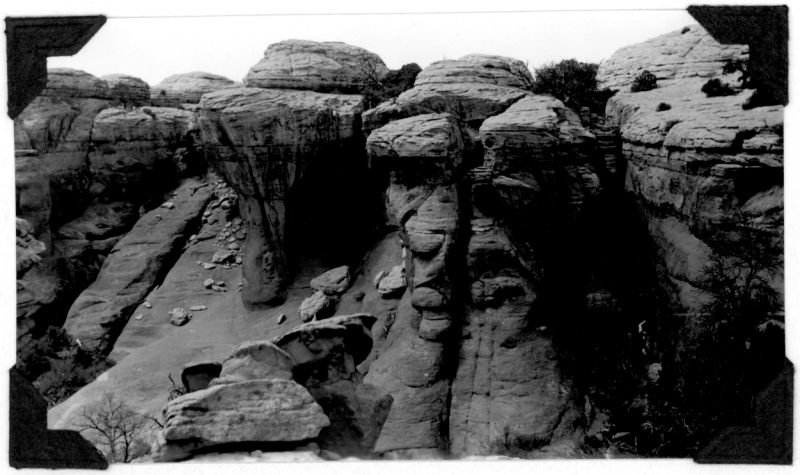


Figure 17.
Joints in the Entrada sandstone widened by weathering.

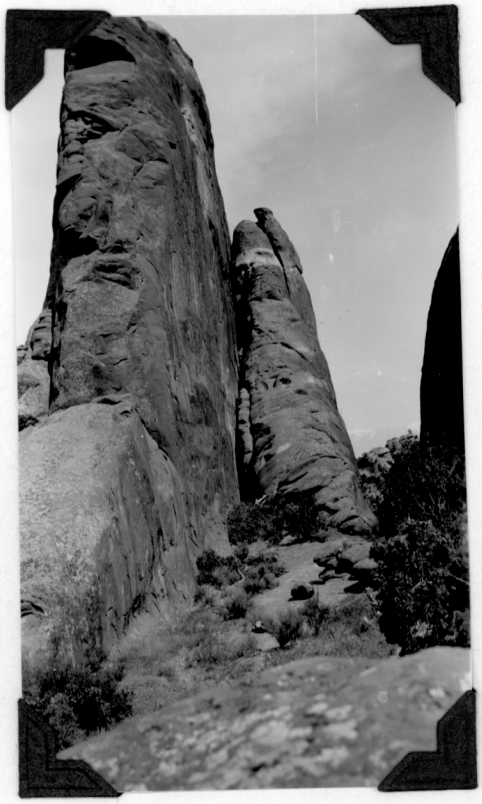


Figure 18.
Note regular surface on relatively fresh joint in Entrada sandstone.

The agencies of weathering and erosion working along the joint systems have been primarily responsible for the origin of the arches and windows in Arches National Monument. Here erosion along the master joints, in the Entrada sandstone, have formed gorge-like drainage channels subparallel in direction. These gorges are separated by elongated masses of rock that are more resistant to the agencies of weather and erosion than the rock in and adjacent to the joint planes. In some instances, the streams that flow through the gorges begin latteral cutting and eventually they break through the divide between. This will leave relatively broad valleys bordered by divides with massive steep cliffs. The above process continues until there remain great "fins" or upright slabs of rock which average 50 to 500 feet in thickness, 30 to 150 feet in height that rise abruptly above the undulating plain.

It is in these "fins" of Entrada sandstone that the majority of the arches occur. Moisture entering the secondary, tertiary, and less important joints and cracks, as well as the bedding planes, has dissolved the cementing materials and loosened the sand grains. When the fine material is once loosened, it may be removed by the wind. The larger particles, slabs, or even boulders may be removed by gravity. In this way, the weakened portions of the rock mass are continually being attacked by the agencies of weathering and erosion and eventually a hole is cut through the rock "fin". In many cases, only a small

opening is first carved, but when once started, the agencies of weathering aided by the wind and the force of gravity cause a sizeable arch to be formed. This process was beautifully exemplified by what has been known as the "Arch in the Making", but during the winter of 1940 the arch was made when a large boulder tumbled from the side rock "fin", completing the arch (figs. 21-22).

All stages in the development of arches can be seen in the monument. They range in size from small holes, scarcely large enough to be seen, to great openings of more than 100 feet in height. When the arch is once formed, regardless of size or shape, it continues to increase in size until the rock "fin" is so weakened that the arch falls of its own weight leaving only the end buttresses standing. These are frequently picturesque because of their odd shapes, but they too are weakened by the continuous attack of the elements and they finally disappear from the landscape.

Towers and Pinnacles

Arches are not the only common feature formed directly by weathering and erosion along joints. Frequently, the rock "fins" have been broken by a transverse set of joints. These also have been widened by the agencies of weathering and erosion until now there are numerous towers and pinnacles like those seen in the Klondike Bluffs and Fiery Furnace sections. The isolated pinnacles seen in many localities are also believed to have been produced in a similar way and are the remnants of former rock "fins" (figs. 19-20).

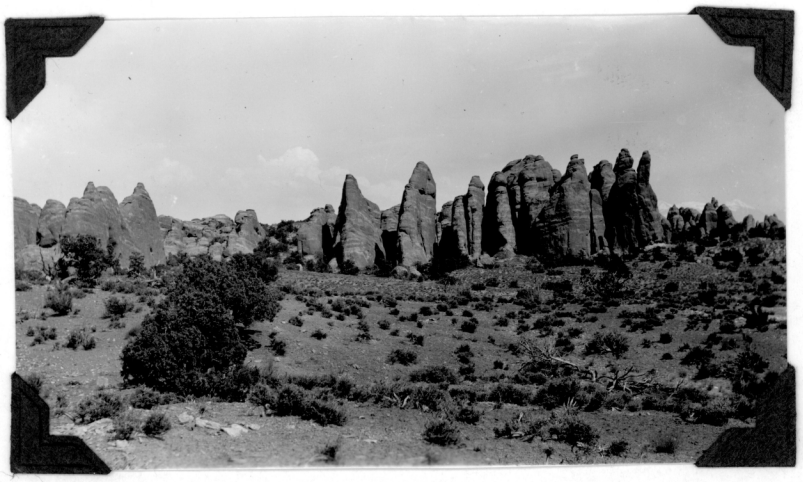


Figure 19.
Further weathering along the joint system may produce pinnacles which is an intermediate step to the origin of peculiar shaped balanced rocks.



Figure 20.
Balanced rocks are the result of differential weathering and erosion along the joints.

Photo by Gould.

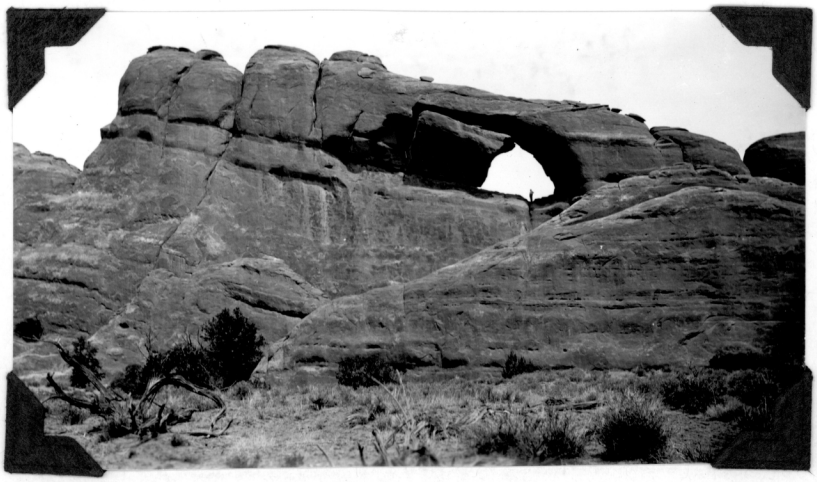


Figure 21.
The "arch-in-the making" prior to November 1940.

Photo by W. Ward Yeager

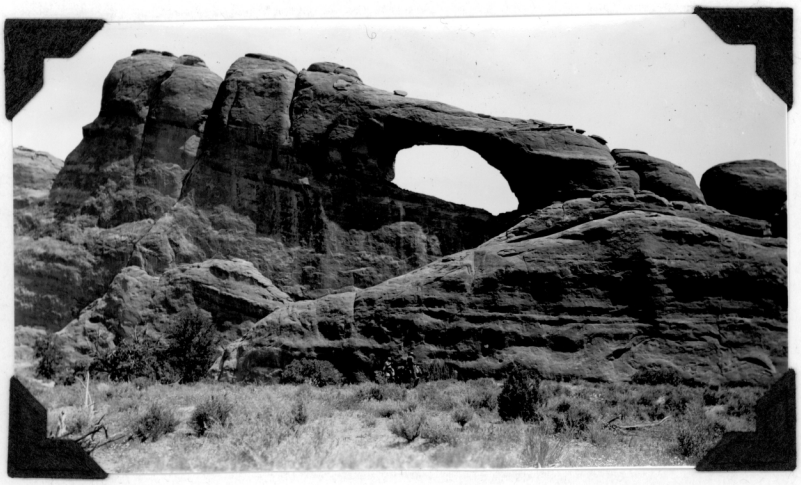


Figure 22.
The "arch-in-the-making" after it was made during November 1940.

Sand Dunes

Windblown sand accumulates to form rounded or irregular-shaped mounds known as dunes. Usually the growth of a dune is started by an obstacle such as a boulder, a bush, a clump of grass, or an irregularity on the ground surface which breaks the carrying power of the wind and allows the sand to be deposited. When the resulting heap has grown to an appreciable size, it acts as its own windbreak, causing further deposition.

In arid or semi-arid regions the lack of vegetation and the dryness of the ground produces an effective environment for sand dune development. It is absolutely necessary, however, that there be a source of fine-grained material that can be swept away by the wind and this depends chiefly upon the character of the exposed bedrock. The most favorable bedrock is sandstone which disintegrates, due to weathering, and becomes loose sand.

During the growth of a dune the sand is swept up the windward slope, falls over the crest, and rolls down the lee side. The wind tends to flatten the windward slope, but the slope of the lee side ranges from 20 to 30 degrees. This gives an asymmetric profile. Successive layers of sand are deposited parallel with the dunes external surface. The layers, therefore, are more steeply inclined on the lee than on the windward side. If there is a steady prevailing wind, the general outline of the dune and the incline of the layers of sand may

remain reasonably constant. This is usually not the case, however, for shifting winds quickly modify the shape and cause extreme irregularities. Sand dunes are, therefore, characterized by extremely irregular cross-bedding.

Sand dunes are common in the Arches National Monument area where several factors combine forming a favorable environment. In the first place, there are shifting winds that sweep across relatively barren sandstone outcrops. The climate is arid, and the ground surface has a sparse cover of vegetation. This results in the origin of numerous sand dunes that are variable in size, shape, and the degree of cross-bedding. Several fine examples may be seen from the monument road.

In addition to the recent dunes mentioned in the preceding paragraphs, there are also ancient dunes and windblown sand accumulations. No doubt the monument visitors will see the intricate cross-bedding in the Navajo sandstone. This formation is believed to have been largely deposited as windblown debris. The character of the cross-bedding suggests much shifting of the sand and modification of the dunes during deposition, thus increasing the complexity of the cross-bedding to an unusually high degree. Following this period of continental deposition, the area was, at least temporarily, submerged by water which produced a much different type of depositional environment. In time, the windblown sands of what is now Navajo were compacted and consolidated into sandstone. Today, where erosion has stripped away the overlying

formations, we see the Navajo sandstone and, except for the fact that it is now solid rock, the surface and structure in that rock is similar to that in the present dunes.

Folding in the Carmel

The upper part of the Carmel formation and the lower part of the Entrada sandstone exhibit extraordinary irregularities in bedding (fig. 23). These appear to be the result of movement in unconsolidated or only partly consolidated sediments during or shortly after deposition. The carmel is an earthy sandstone without pronounced bedding planes. The deformation in the Carmel are wavy cremulations that locally grade upward in intensity obscuring the true bedding. The contact with the overlying Entrada sandstone is charp but the irregularities in the basal Entrada conform with those in the Carmel. The relationship at the contact suggest a rolling motion in the Entrada sediments at the contact during the time of deposition. The intensity of the deformation in the basal Entrada diminish upward and grade into horizontal strata. Locally, dike-like masses of the Entrada have penetrated the Carmel (fig. 24). Occasionally, small faults flank the dike-like masses, and they extend upward into the sandstone, but soon die out or pass into small flectures.

It would appear that this deformation could be due to plastic adjustment of the water-soaked Carmel under conditions of differential loading during the rapid deposition of the Entrada.

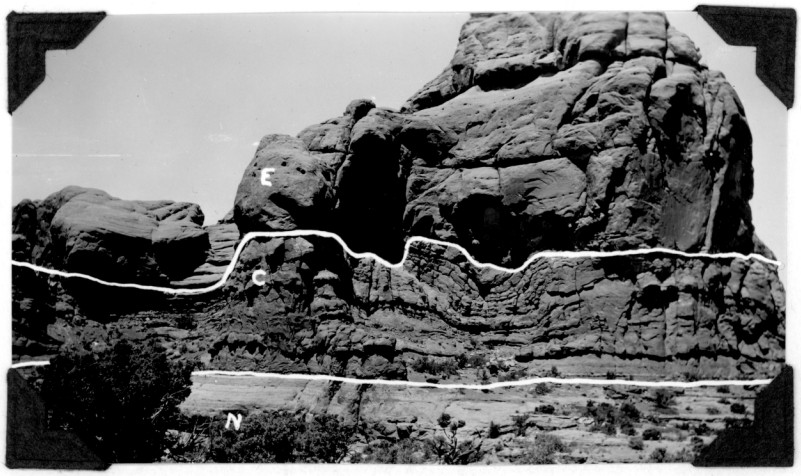


Figure 23.
Typical deformation in Carmel and basal Entrada.
N. Navajo C. Carmel E. Entrada



Figure 24.
"Sandstone dikes", from the Entrada extending downward into the Carmel.
C. Carmel E. Entrada

Faulting

Faults have been defined as a fracture along which there has been slipping so that points formerly in contact have been dislocated or displaced along the fracture. A fault is never an accident, but is the result of forces that have been in action in the earth's crust. These forces may be compressional or tensional, and the character of the fault usually gives some indication as to the nature of the forces. These forces normally act continuously but very slowly. Therefore, fault movements are normally slow, if measurable at all. An inch of displacement would probably require centuries. Near the surface, however, the dislocation may be intermittent, although the stresses are applied uniformily and continuously, because the rock does not break until its resistance has been overcome.

The surface of the fracture along which the movement and dislocation has taken place is frequently referred to as the fault place. It is to be understood that departures from a mathematical plane occurs but these departures are relatively small as compared with the magnitude of the length and depth of the fault. Fault planes are also frequently curved; because of curvative, departures from the mathematical plane, and other irregularities, the term fault surface is preferred. Rather commonly fault movement occurs not upon one surface but along several adjacent breaks, and the aggregate of the various offsets comprise the total displacement, producing a fault zone.

Faults may occur in all types of rock, but they are usually the

most easily recognized in relatively hard sedementary strata. If a ridge corresponding with an outcrop of hard strata is observed and the same strata continues in an offset position, then it is usually assumed that the offset is due to faulting. Frequently, however, the actual fault trace is hidden beneath alluvium. Ordinarily a fault breaks the surface as well as the rocks beneath, then if the strata on one side of the fault are raised with respect to the strata on the opposite side, the result is a cliff or fault scarp. As erosion progresses, the original scarp will be modified and in time it may be completely removed.

As a result of faulting, the friction between the broken block may produce rock faces that are smoothed or striated and it is not uncommon for them to receive a high polish. Such polished and grooved surfaces are known as slickensides. Along many faults the grinding of the walls against each other has produced a zone of broken and crushed rock known as fault breccia. In some instances, there is a seam of clay-like material along the fault surface formed from finely powdered rock. This is fault gouge. In most cases, fault zones are tightly sealed with mineral matter that was deposited from solution following the fault movement.

There are many faults in the Arches National Monument area, some of which are conspicuous, others are not. One, which the layman should be able to recognize, is along the western side of the Moab Valley (fig. 10). Here there is a prominent scarp, not a true fault scarp but a

fault-line scarp. By that we mean that the original fault scarp has been modified and shifted by erosion. The actual fault trace is out in the valley and for the most part it is covered with alluvium. The actual fault surface is crossed by U.S. Highway 450 and can be seen from that highway as one approaches the monument headquarters from the north (fig. 11). Another fault, about 9 miles north of the monument headquarters, does not have a prominent escarpment but the rocks have distinctly different physical characteristics, including color. It can also be seen from the highway (fig. 12).

Faults are exceptionally numerous in the Cache-Salt Valley area. The Cache Valley is bordered by two fault zone escarpments. Fault zones are present on each side of the valley and the valley was formed by an elongate block that was depressed between the two fault zones. Each of the fault zones are relatively complex and erosion has shifted the fault scarp latterly producing faultline scarps. Depressed blocks of this type bordered by single faults or fault zones are called grabens or rift valleys.

The Salt Valley portion of this area is topographically similar to but structurally different than the Cache Valley. Here the rock strata were arched into an elongate fold. The trend of the fold is in a northwesterly direction. The uplift which produced it probably also produced the master joints which are the controlling structural factor in the origin of the rock "fins" from which the arches have been formed.

In addition to this folding, rift valley faulting has taken place. Now there are fault zones on both sides of the crest of the fold and the crest of the original fold has subsided forming a rift valley along what was at one time the fold's crest.

Canyons

When streams deepen their channels rapidly through hard rock so that their banks remain, steep canyons are formed. Canyon development usually takes place where extensive areas standing at high altitudes are crossed by swift flowing streams and the conditions promoting valley widening are lacking. Arid regions, traversed by streams that have their headwaters in snow capped mountains or in regions of heavier rainfall, are usually favorable to the development of canyons, especially if the stream channel cuts through rock capable of standing in steep cliffs. The canyon walls in arid regions will remain comparatively steep because there is but little wash from the sides as compared with sidewash and weathering along the side of the stream channel in humid areas.

The Colorado River heads in the Rocky Mountains far to the east of the Arches area. Its upper drainage receives ample precipitation to insure a permanent flow across the semi-arid plateau country. The river's cutting tools--silt, sand, and gravel--are more than adequate. Side wash is negligible and the rocks along its banks are reasonably firm. The general and local windings of the Colorado River are not controlled by bedrock, but the rocks do have an important bearing upon

the character of the topography. Where the rocks are hard, the canyon walls are usually sheer, where they are soft the banks are sloping, and structures have but little effect upon the river's course.

This is not the case with most of the local tributary streams for, in most cases, structural trends have aided materially with the canyon cutting. Salt Wash, for the most part, courses through a canyon with sheer walls. The location and the declivity of those walls are in a large measure controlled by the joint system. This is especially conspicuous in that portion of the drainage above Salt Valley where the walls of the canyon are composed of the Entrada sandstone. These structural controls are also present below Salt Valley, even to influencing the course of the stream at meanders. In addition, the majority of the tributaries to the Salt Wash have been carved along the traces of the joint system.

The stream in Cache Valley is also controlled by the structure. Here the chief feature is a rift valley, but local intermittent drainage has cut a small channel along the bottom of the rift valley and has also modified the fault zone scarp on either side. It must be remembered, however, that the principal valley features are due to crustal movements and deformation and not to stream erosion.

Similar conditions are present in Salt Valley. Here there was arching which undoubtedly produced longitudional fractures that would have been helpful in establishing the drainage. Since the most intense fracturing would be expected along the crest of the anticline, one

would expect drainage channels to course subparallel to the trend of the crest of the structure. In addition, the crest of the anticline is also a rift valley. These two structural controls have been chiefly responsible for concentrating the agencies of erosion to form the features now present in that vicinity.

"Slick Rock" Surfaces

There is a striking relationship between the topography and the resistance to erosion of the several formations exposed in the Arches area. The more resistant strata usually form sheer cliffs. Softer strata weather to form slopes, the inclination depending largely upon the resistance that particular formation offers to erosion. Frequently the soft formations are stripped for a mile or more back from the outcropping edge of the underlying harder formation. Bare rock is exposed everywhere and because of the sparsity or absence of a soil cover on these wind-swept slopes, they are commonly called "slick rock" (fig. 7).

The "slick rock" slopes may partly or wholly correspond to the dip of the exposed harder stratum. Frequently, isolated flat-topped buttes with steep walls rise above the "slick rock" slopes, further emphasizing the close relationship between topographic details and the kind and altitude of the underlying formation.

NEED FOR FURTHER GEOLOGICAL STUDIES

The bibliography accompanying this report might indicate that the geology of the Arches National Monument area has been studied in detail. This is not the case, for most of the reports deal with the monument area in only the most general way. On the other hand, Dane (1935) has discussed some of the features that are, in part, within the monument boundary and the geological map accompnying his report includes about three-fourths of the monument area. Further investigations by Park Service geologists or geologists collaborating with the Service can certainly be justified.

Probably the most urgent need for further studies is relative to the outcrops of the Paradox formation mapped by Dane in the Salt and Cache Valleys and the relation of this formation to salt-gypsum plugs. The writer does not question that there are salt-gypsum plugs in southeastern Utah, but he is not convinced that the Paradox crops out in Salt Valley, or that it is associated with a salt-gypsum plug. It is important that the Service be sure of these questions in order that it can give the geological story at Arches National Monument completely and correctly. In addition, if a salt plug is present, it is probably the only Service area where a plug exists and it would be the basis for a splendid museum exhibit.

It would appear that a logical method of attack would be to study the structure and stratigraphy of both the surface and subsurface in

southeastern Utah where salt-gypsum plugs are known to exist. Then make detailed studies of the possible salt-gypsum plug area in the Salt-Cache valleys. If, or when, this problem is studied, the person making the investigation should be thoroughly familiar with the stratigraphy as well as the mechanics of salt plug deformation. It would require at least one month, perhaps considerably more, to make such an investigation. The writer is not sure if he will be able to accomplish this task. He hopes to be able to visit the Salt Valley area during the coming spring or summer to check on certain phases of this problem.

Another problem which would be extremely interesting research, but of less importance for the interpretive program, is relative to the principles of sedimentation in that vicinity. The depositional environment was mentioned briefly for several of the formations. There are rapid changes in the physical characteristics of several of the formations. To date, the cause of some of these changes is not known. Perhaps the cause or causes could not be determined. Furthermore, correlating the geological formations in the monument with other formations in southeastern Utah could be expanded.

TENTATIVE SUGGESTIONS FOR GEOLOGICAL EXHIBITS

Arches National Monument was established for its geological values. Wildlife, archeological, and historical values are also represented. It is assumed that in a future museum the exhibits will be primarily geological and that wildlife, archeology, and history will be represented according to their relative importance in the area. With this thought in mind, the following suggestions are made.

Near the entrance, and preferably the first exhibit seen, should be an orientation map showing the principal highways and towns, streams, canyons, parks, monuments, proposed park or monument areas, and other physical features or historical sites and routes of travel that would be of interest to the traveling public. In addition, there should be a map of the monument area. This would include all roads, trails, principal streams, canyons, the principal arches, and other points of interest. Around the margin of the map, place suitable photographs of drawings of the arches and other principal physical features, the location of which is shown on the map. Although it is not necessary but since it is a geological area it may be advisable to include also a geological map of the monument.

The important geological story to be told is: How were the arches made? This could be done in several ways, but it appears that it might be satisfactorily accomplished by a series of three-dimensional diagrams. The story should probably begin with the deformation of the earth's crust

that formed the joint system. The next step shown would be the results of weathering and erosion along the joints and eventually the origin of the great sandstone "fins". This would be followed by the carving of the arch itself and finally the destruction of the arch, leaving only the end buttresses.

The story of faulting might be shown in a similar way. This should include single fault surfaces, fault zones, and rift valleys. The story could well be supplemented by the affect of erosion upon the fault blocks and how in some instances faults control drainage.

Other exhibits that might be included would show the origin of sand dunes, present and past, as an interpretation tool for explaining the cross-bedding in the Navajo sandstone. The origin of "slick rock" surfaces, lone pinnacles, and isolated flat-topped buttes are also worthy of a word of explanation as to their origin. Last, but not least, if it is found that salt-gypsum plugs exist in the Salt Valley area, a diagram telling the story of these plugs should occupy an important place in the museum.

The question may arise as to the preparation of exhibits telling a story regarding dinosaurs or petrified wood. The dinosaur story will be satisfactorily told at Dinosaur National Monument, and fossil wood at Petrified Forest National Monument. If these stories are included at Arches, it is the writer's belief that they should be minimized.

The preceding comments certainly do not represent a complete discussion of the museum possibilities or problems at Arches. The writer

is not a museum technician and does not want or intend to dictate the type, number, or method of presentation of the geological exhibits at Arches National Monument. It is time, however, that the problem should be given some thought. The preceding suggestions are, therefore, included for consideration by the museum technicians.

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