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GEOLOGY AND OIL POSSIBILITIES OF THE MOAB DISTRICT, GRAND AND SAN JUAN COUNTIES, UTAH

BY

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GEOLOGY AND OIL POSSIBILITIES OF THE MOAB DISTRICT, GRAND AND SAN JUAN COUNTIES, UTAH

By Arthur A. Baker

ABSTRACT

The Moab district is part of the Colorado Plateau and includes an area of about 1,000 square miles east of the Colorado River in Grand and San Juan Counties, southeastern Utah. The study of the geology presented here was made in 1926 and 1927, after drilled wells had encountered showings of oil and gas and had disclosed the presence of thick beds of salt.

The Paradox formation, which contains the salt, is the oldest exposed formation and has been tentatively assigned to the lower Pennsylvanian. Most of the information concerning the Paradox has been obtained from wells, for its surface outcrops are limited to small masses of gypsum. Younger rocks that crop out include the Hermosa formation, of Pennsylvanian age; the Rico and Cutler formations, of Permian age; the Moenkopi, Shinarump, and Chinle formations, of Triassic age; the Wingate sandstone, Kayenta formation, and Navajo sandstone, tentatively assigned to the Jurassic; the Carmel formation, Entrada sandstone, and Summerville formation, of Jurassic age; the Morrison formation, tentatively assigned to the Cretaceous; and the Dakota (?) sandstone and Mancos shale of Upper Cretaceous age. This area is a critical one in the study of Permian stratigraphy, because there is rapid lateral change in the Cutler sediments from the red arkosic facies typical of southeastern Utah and southwestern Colorado to a massive white quartz sandstone to which the name Coconino sandstone has been applied in the past but which in this report is called the Cedar Mesa sandstone member of the Cutler formation.

The beds have been folded into low anticlines and shallow synclines as a result of several periods of deformation—one at the end of the Permian, a second at the end of the Lower Triassic, and a third at the end of the Cretaceous. The uplifting of the neighboring La Sal and Abajo Mountains resulting from the intrusion of laccoliths and other bodies of igneous rocks probably took place early in the Tertiary and was accompanied by some disturbance of preexisting folds in the Moab district. The beds are cut by numerous small normal faults, some of which bound grabens (dropped blocks).

None of the anticlines within this area are considered to be true salt domes, as there is no evidence that a salt plug has intruded the overlying beds except at one locality—in the Castle Creek Valley, where the salt plug, which is associated with an intrusive plug of igneous rock, appears to be related in origin to the igneous plug. At a few places in the district, however, the flowage of the relatively plastic salt and gypsum has arched or ruptured the thinner portions of the overlying rock cover. One of these places is an area near the junction of the Green and Colorado Rivers, from which the salt has presumably flowed into an adjoining arch, and the rocks above the salt in that area are broken by graben faulting as a result of their settling. Another place is Moab Valley, where the

rocks at the crest of an anticline have been arched and ruptured by flowage of the salt, and the removal by solution of the extruded salt has resulted in the settling and normal faulting of the overlying rocks.

The deep wells, some of which were drilled on the crests of the anticlines, have shown the presence of oil and gas in the Paradox formation but have not developed commercial production. Because none of the anticlines are considered to be true salt domes, further drilling on the flanks of the anticlines does not seem to offer much hope for the discovery of commercial quantities of oil.

Disseminated deposits of uranium and vanadium minerals are irregularly distributed in the Salt Wash sandstone member of the Morrison formation, but they are of too low grade to be mined profitably under present conditions. Potassium salts have been found in the Paradox formation in deep wells, but the available information concerning them is not adequate for determining whether or not they are of commercial value.

INTRODUCTION

SEARCH FOR OIL IN THE REGION

There has been a persistent search for oil in that part of the United States between the Rocky Mountains on the east and the Sierra Nevada on the west. Small production has been obtained at a dozen or more widely separated localities in western Wyoming, western Colorado, northwestern New Mexico, and southern Utah, but at the present time the bulk of the petroleum products consumed in the intermontane States is derived from oil produced either in California fields or fields that lie east of the Rocky Mountains. In recent years the Moab district, which is described in this report, has been the scene of much drilling. Showings of oil and gas have been found in a number of wells, but no commercial production has been obtained.

LOCATION AND EXTENT OF AREA

The Moab district is located in Grand and San Juan Counties in southeastern Utah, west of the La Sal Mountains, north of the Abajo Mountains, and east of the Colorado River. As thus defined it includes about 1,000 square miles (fig. 1).

PURPOSE AND SCOPE OF WORK

As a result of the showings of oil obtained in the early wells drilled in and near the Moab district, many applications were received for permits to prospect for oil and gas on Government-owned land. The field work in this district was undertaken by the United States Geological Survey primarily to obtain the information necessary for the administration of these applications. The following report is based on the information acquired during the field examination and includes a discussion of the stratigraphy, the geologic structure, and the possibilities of oil production.

FIELD WORK

The greater part of the field work was done in 1926 and 1927. During four months in the summer of 1926 approximately the northern half of the area was mapped by the writer, assisted by G. H. Hansen and Charles Brewer, jr., and during five months in the summer of

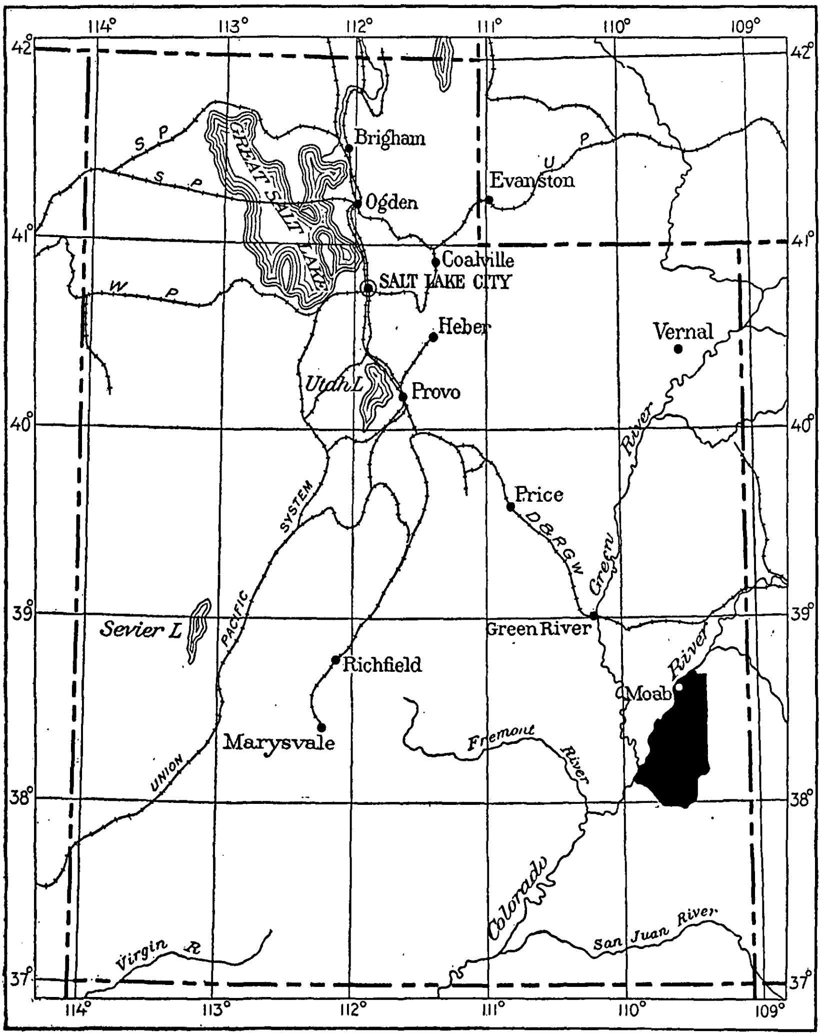


FIGURE 1.—Index map of Utah showing location of the Moab district

1927 the southern half of the area was mapped, with the assistance of M. I. Goldman, C. V. Theis, and L. W. Clark. Although the work was done under the supervision of the writer, each man worked independently. No attempt is made to indicate the portions of this area for which individuals are responsible, as it is "checkerboarded" by the work of all six. The upper part of Castle Creek Valley, in the northeast corner of the area, was mapped in July, 1929, by C. B. Hunt, under the direction of C. H. Dane. A narrow strip of the area west of the Colorado River, mapped in 1926 and 1927 by E. T. McKnight and C. H. Dane, is included in this report in order to show on a single map the geology on both sides of the river.

Almost all the mapping of geology, culture, and drainage and the establishment of altitudes, was done by triangulation, using the plane table and telescopic alidade. A triangulation net was established from a measured base line, and closely spaced locations to control sketching and to establish altitudes were made by the three-point method or by intersection from two or more points. The relation of the triangulation system to the land surveys made by the United States General Land Office was determined by locating many of the iron pins or stones used to mark the land corners. The altitudes determined on known geologic horizons and used to construct the structure contour map represent, within certain limits of error, actual height above sea level. The sea-level datum was established by E. T. McKnight by triangulation from a United States Geological Survey bench mark near the Denver & Rio Grande Western Railroad at Crescent. The method of mapping by triangulation was supplemented by stadia traverses along the canyon of Salt Creek, along the lower portion of Indian Creek, and in The Needles, and such traverses were also used in mapping part of the Cane Creek anticline and the Shafer dome. The field work along the Colorado River was facilitated by the use of the Geological Survey's maps that show the topography in narrow belts on each side of the river.[1] The La Sal map, published by the United States Geological Survey in 1885, is the only topographic map that includes the Moab district. This map was not found to be useful during the present investigation, because of its reconnaissance character and also because of its small scale and large contour interval.

Owing to the character of the topography of the Moab district, automobiles can not be used to reach all parts of the area. Automobiles were used to establish a few main camps, from which saddle horses were used for transportation. The more inaccessible parts of the area were mapped from camps established by transporting camp equipment and supplies on pack animals. A small boat equipped with an outboard motor was used while mapping the canyon of the Colorado River.

[1] Profile surveys in the Colorado River Basin in Wyoming, Utah, Colorado, and New Mexico: U. S. Geol. Survey Water-Supply Paper 396, 1917.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance and cooperation of several persons during the field and office work. To his assistants, Messrs. Hansen, Brewer, Goldman, Theis, and Clark, for their excellent work, industry, and unfailing interest in the progress of the work, he expresses his appreciation. To H. W. C. Prommel, consulting geologist, of Denver, Colo., the writer is especially indebted for his generosity in permitting the examination of unpublished reports and maps. The results obtained by the writer's colleagues J. B. Reeside, jr., and C. E. Dobbin, who studied many details of the stratigraphy of the region, have been freely used in the preparation of this report. Mr. Dobbin gave valuable assistance with fiscal matters involved in the organization of the field parties. The writer takes this opportunity to thank many residents of the region for their generous cooperation. He is indebted to Profs. C. R. Longwell and C. O. Dunbar, of Yale University, and to Messrs. H. D. Miser and C. H. Dane, of the Geological Survey, who have read and criticized the manuscript for this report. He wishes also to express his appreciation to the Director of the Geological Survey for permission to submit this report, in essentially its present form, to Yale University as a dissertation for the degree of doctor of philosophy.

GEOGRAPHY

TOPOGRAPHY

The Moab district is part of the Colorado Plateaus, a large physiographic province lying in southern Utah, northern Arizona, southwestern Colorado, and northwestern New Mexico. The surface of the province is an upland plateau of moderate relief except for a few mountain masses rising high above it and the numerous deep canyons by which it is dissected. The Colorado River is the master stream draining the province and has cut a deep canyon across it. The part of the plateau adjacent to the river is dissected by numerous deep canyons, which become shallower toward their heads. Many of the small tributaries flow in broad, open valleys on the plateau before they plunge into the canyons on their course toward the river.

The maximum relief in the Moab district is about 3,900 feet. The Colorado River, which bounds it on the west, is 3,870 feet above sea level about 3 miles below its junction with the Green River, and the surface rises to its maximum altitude of 7,800 feet near the south rim of Castle Creek Valley in the northeast corner of T. 26 S., R. 23 E. Because of the deep canyons that have been cut by the streams there is strong local relief. Many of the canyons tributary to the river are narrow and as much as 1,500 feet deep near their mouths. Three miles northeast of the mouth of Lockhart Canyon the rim of the upland surface known as Hatch Point is 2,000 feet above the level of the river.

The rocks that crop out in the Moab district include many thick resistant formations separated by less resistant formations. As the formations are relatively flat lying, the characteristic topographic form is a series of steps with the less resistant formations making the lower part of the risers and the resistant formations making the upper part of the risers and the tread. The nearly flat treads are produced by the stripping of softer rocks from the top of the resistant stratum. The most conspicuous single step in the series rising from the Colorado River toward the La Sal and Abajo Mountains is the one controlled by the resistant basal part of the Kayenta formation and the underlying vertical cliff of Wingate sandstone. These formations form impressive vertical cliffs several hundred feet high, extending for miles without interruption. The rims of the canyons are produced by these formations in a large part of the area. Above them are the areas of moderate relief on which stand many buttes, small mesas, and nubs of bare rock, many of which have been carved by erosion into odd shapes and are commonly named from their likeness, or imagined likeness, to certain objects. In the southwestern part of the area the cliffs that are made by these formations have been eroded far back from the river and rise above a broad plaza that is floored by a lower massive sandstone (the Cedar Mesa sandstone member of the Cutler formation). This lower sandstone is carved into innumerable canyons and odd erosion features. A local group of such features is appropriately called "The Needles." Where this sandstone forms the surface rock the topography usually is so rough that it is almost impossible to cross the area, even on foot, except along the stream courses or along fault zones.

Moab and Spanish Valleys form one continuous valley, which extends 14 miles southeast from the Colorado River at Moab. Its broad floor, steep high wall on the southwest side, and low wall on the northeast side give it a different appearance from the rest of the valleys in the area. The precipitous southwest wall of Spanish Valley rises about 1,500 feet above the valley floor, whereas the surface on the northeast side rises more gradually to the rim of Wilson Mesa, which is nearly 2,000 feet above the southeast end of the valley. Wilson Mesa is a broad bench formed by the stripping of soft sediments from the top of a resistant sandstone.

Two isolated mountain masses rise above the general level of the Colorado Plateau adjacent to the Moab district. The La Sal Mountains, east of the district, rise to an altitude of 13,089 feet above sea level and the Abajo Mountains, south of the district, to an altitude of 11,445 feet.

DRAINAGE AND WATER SUPPLY

The streams are of three classes—perennial, intermittent, or perennial in part of their course and intermittent elsewhere. The Colorado River, the trunk stream, is perennial. In the summer it is normally shallow, but after heavy rains and in the spring it carries larger volumes of water. Boats have been used to transport passengers and freight on the river between Moab and its junction with the Green River; but on account of the shallow water, the numerous sand bars, and the braided character of its channel, it is navigable with difficulty and only by boats of shallow draft. The principal tributaries from the east are Castle, Nigger Bill, Mill, Cane, Lockhart, Indian, Salt, and Lower Red Lake Creeks. Castle and Nigger Bill Creeks are fed by numerous springs and are perennial streams. Mill Creek is perennial, but its large tributary—Pack Creek—is in part perennial and in part intermittent. These two streams receive part of their water from springs, but most of it drains from the west slopes of the La Sal Mountains. Cane Creek, with its large tributaries, is in part perennial and in part intermittent. Several springs are found in its smaller tributary canyons, but their flow soon sinks below the surface. Lockhart Canyon is fed by several springs, many of which have a high salt content, but the flow from the springs is small, and no water flows in the channel except after rains. Indian Creek, which heads in the Abajo Mountains, is the largest tributary of the Colorado River within the Moab district. It is perennial where it enters the southern part of the district; but as much of the water is used for irrigation, it carries little or no water in its lower part during the summer. Together with its large tributaries—Hart Draw, Cottonwood, Davis, and Lavender Creeks—which are intermittent streams, Indian Creek drains more than 30 per cent of the area mapped, and the rapid run-off after torrential storms sends deep, rapidly moving floods down the main channels. Salt Creek, a perennial stream, drains the northwest side of the Abajo Mountains, although its flow is very small except after rainstorms. Lower Red Lake Creek is an intermittent stream. The flow from none of the perennial streams is large, but that in Castle, Mill, and Indian Creeks is sufficient to irrigate several hundred acres of bottom land along the valleys.

Water suitable for drinking is scarce. Most of the spring water and also the water in many of the flowing streams is suitable for drinking, but large sections of the district have no springs or running water. The water from springs in the Shinarump conglomerate or any of the massive sandstone beds, such as the Cedar Mesa, Wingate, Navajo, Entrada, or Dakota (?) sandstone and the Kayenta formation, is suitable for domestic use. Springs issuing from the red strata of the Rico or Cutler formations, where they crop out along the river from the mouth of Cane Creek to the mouth of Indian Creek, are usually too salty to be suitable for drinking. The water in such running streams as Castle, Pack, and the lower parts of Mill and Indian Creeks is exposed to pollution and should not be used without boiling, but that in Nigger Bill and Cane Creeks and the upper parts of Indian and Salt Creeks can be safely used. Of great assistance to the traveler in the district is the water that accumulates in natural rock tanks after rains and furnishes a temporary supply. Except in the winter, when there is snow on the ground, the traveler in The Needles, in the southwestern part of the district, is dependent upon such natural reservoirs for a water supply.

CLIMATE

The climate of the Moab district is semiarid, with precipitation commonly less than 10 inches a year. There is somewhat more precipitation on the higher parts of the country near the mountains. The rain usually comes in hard showers that last only a few minutes, but the volume of water is so great that the water cascades in sheets over the cliffs and causes sudden floods in the streams. These floods do much damage because of their size and sudden occurrence. Most of the storms are local in extent, but all the water quickly drains from the bare rock slopes, and a rainstorm anywhere in the drainage basin sends a flood down the main drainage course. Because of the local storms and their torrential character, the same amount of rain does not fall everywhere in the district within a short period, and the rainfall for many localities may thus differ from the average for the region as compiled from records obtained at a single station. During the spring strong west winds prevail, and throughout the year more moderate winds from the same direction are normal.

The following table, compiled from the records of the United States Weather Bureau, shows the variation in temperature and precipitation at two stations. The records obtained at the Moab station may be considered typical of the greater part of the district, and the records obtained at the La Sal station, located on the upland near the base of the La Sal Mountains, a few miles east of the area, illustrate the effect on the climate of higher altitude and proximity to mountains.

Climatic data for the Moab district, Utah

[From U. S. Weather Bureau reports]

	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Year
Moab														
Temperature (°F.):														
Monthly mean	28	28.8	36.2	43.4	55.2	63.6	72.1	77.7	75.3	66.3	53.6	41.4	30.3	53.7
Highest on record	30	65	78	77	97	102	107	109	107	101	90	82	68	109
Lowest on record	30	−18	−13	8	16	27	36	43	41	29	18	9	−10	−18
Precipitation (inches):														
Monthly	30	0.91	0.69	0.91	0.64	0.74	0.33	0.85	0.66	1.01	0.91	0.66	0.93	9.24
Snowfall	24	5.4	3.3	1.6	Trace.	0.1	0	0	0	0	.2	.9	5.6	17.1
La Sal														
Temperature (°F.):														
Monthly mean	14	24.7	28.4	35.7	44.2	51.3	61.4	67.1	66.1	57.3	46.5	36.9	24.8	45.4
Highest on record	16	56	64	70	76	85	94	94	93	86	89	81	76	94
Lowest on record	16	−22	−15	−3	5	19	25	34	37	19	0	−1	−11	−22
Precipitation (inches):														
Monthly	14	0.97	1.04	0.78	0.76	0.80	0.61	1.25	1.22	1.19	0.95	0.78	0.80	11.15
Snowfall	9	10.0	8.7	3.6	1.4	1.0	0	0	0	0	.8	5.5	9.1	40.1

POPULATION

The number of inhabitants in the area here described is estimated to be about 1,200, and in 1930 the town of Moab, the business center of the district, contained 853. Large parts of the district are without permanent inhabitants. Most of the people living beyond the vicinity of Moab are located on the agricultural land in Spanish Valley and in the valleys of Castle, Pack, and Indian Creeks, and a few people owning small herds of cattle inhabit isolated parts of the district.

ACCESSIBILITY AND ROUTES OF TRAVEL

The town of Moab, in the northern part of the district, is on the east side of the Colorado River near the mouth of a wide tributary valley and is 35 miles by road south of the Denver & Rio Grande Western Railroad at Thompsons. A stage line operating on a regular schedule offers passenger and freight service between Thompsons, Moab, and Monticello. In recent years boats have been operated on the Colorado River to supply freight and passenger service between Moab and the well sites along the river. There is no boat service on the river above Moab, but a road follows the river bank through the canyon and connects with the Denver & Rio Grande Western Railroad at Cisco, Utah. The road southeast from Moab through Spanish Valley branches about 25 miles from Moab and leads to several small towns in southeastern Utah and southwestern Colorado. One branch, which is a stage road as far as Bluff, continues south through Monticello, Blanding, and Bluff to Goodridge, where a bridge across the San Juan River permits travel into Arizona.

The part of the Colorado Plateaus which is included in the Moab district is adjacent to the Colorado River and is dissected by many deep tributary canyons. Automobile travel across the area, except by the improved roads, is possible only along a few routes that have been opened to reach winter sheep camps, oil-well locations, and ranches, and these roads soon become impassable when not used. The road that made a large part of the area mapped accessible by automobile during the field work branches from the stage road near Church Rock, in Dry Valley east of the area mapped and 50 miles from Moab, and after crossing Hart Draw enters the canyon of Indian Creek near the south boundary of the area. During the summer of 1927 this road could be followed with difficulty down Indian Creek as far as the well of the Utah Petroleum Corporation and thence around the foot of the cliffs bordering Hatch Point to Lockhart Canyon and the Colorado River. Saddle-horse trails reach most points in the area, but to cross the cliffs and canyons, which may be impassable for miles, many of the trails are circuitous. The principal roads and trails are shown on Plate 1.

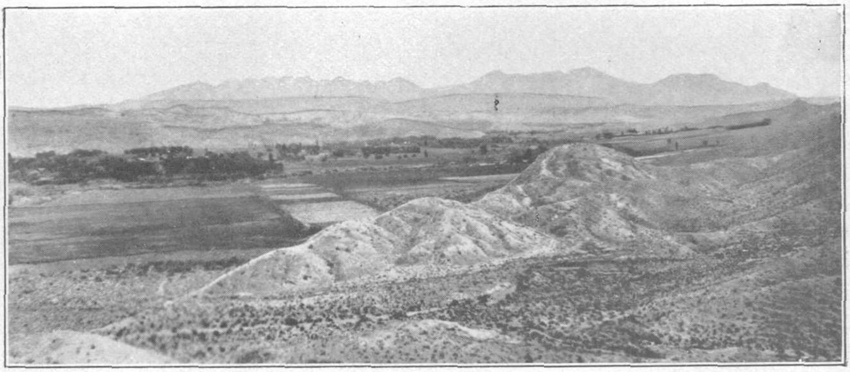
FUEL

The development of power for drilling wells in the district is expensive. Fuel for use under boilers must be shipped into the district. Coal is mined at Sego, near Thompsons, and at other points on the Denver & Rio Grande Western Railroad a few miles east and northwest of Thompsons; but to get it to the well sites, long hauls by trucks are necessary. There has been no production of crude petroleum in or near the Moab district up to the present time. If gasoline engines are used for power, gasoline must be shipped to Thompsons and, like coal, would be subject to the same long haul. The water-power plant at Moab is not at present capable of supplying much electric power in excess of that required by Moab consumers.

PREVIOUS PUBLICATIONS

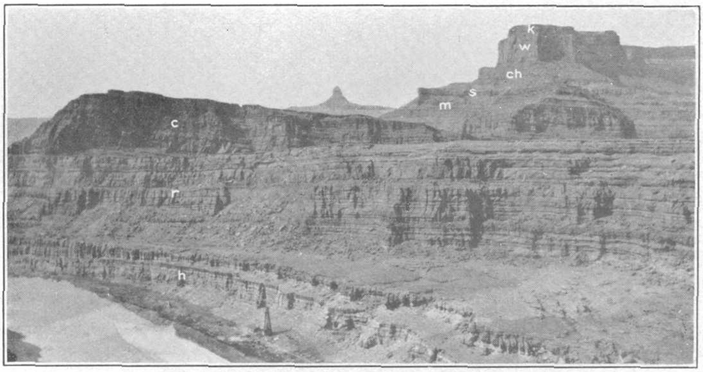
No detailed geologic reports have been published on the area here described, but the region has been visited by many geologists and reference has been made in numerous publications to special features of the geology. The first description of the geology of the district is that by Newberry,[2] who accompanied the Macomb expedition to the junction of the Green and Colorado Rivers. From the text and illustrations in his report it is obvious to a person familiar with the region that the stream referred to as Canyon Colorado is now called Indian Creek, and it appears probable that the members of the Macomb expedition did not see the junction of the Green and Colorado

[2] Newberry, J. S., Report of the exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green Rivers of the Great Colorado of the West in 1859, Engineer Dept., U. S. Army, 1876.



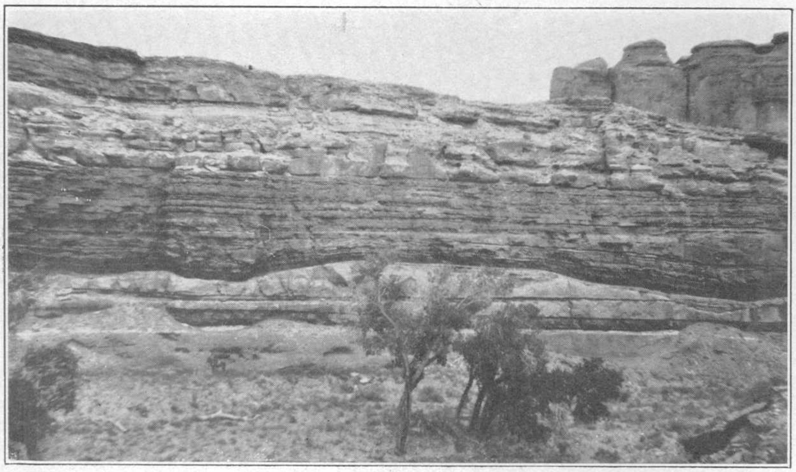
A MOAB VALLEY

Looking east from a point near the entrance to the canyon of the Colorado River below Moab. Showing exposure of gypsum in the Paradox formation on the south side of the valley. The La Sal Mountains appear in the distance.



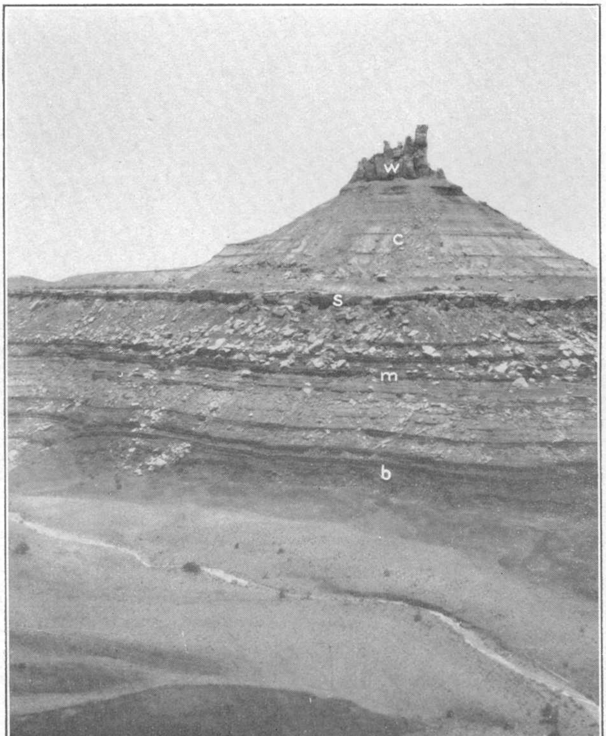
B. FORMATIONS EXPOSED WEST OF THE COLORADO RIVER AT THE CREST OF THE SHAFER DOME

The cliff formed by the Rico formation is capped by the "Shafer limestone." Drilling rig at J. H. Shafer No. 1 well appears in the foreground near river level. h, Hermosa formation; r, Rico formation; c, Cutler formation; m, Moenkopi formation; s, Shinarump conglomerate; ch, Chinle formation; w, Wingate sandstone; k, Kayenta formation.



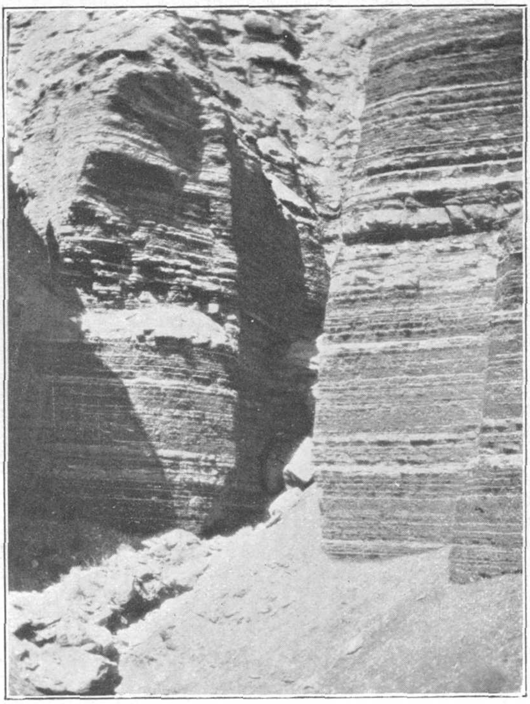
A. INTRAFORMATIONAL UNCONFORMITY IN THE RICO FORMATION IN INDIAN CREEK CANYON IN SEC. 4, T. 29½ S., R. 20 E.

Showing an erosional unconformity within the Rico formation between the marine "Shafer limestone" and the underlying fluviatile sandstone.



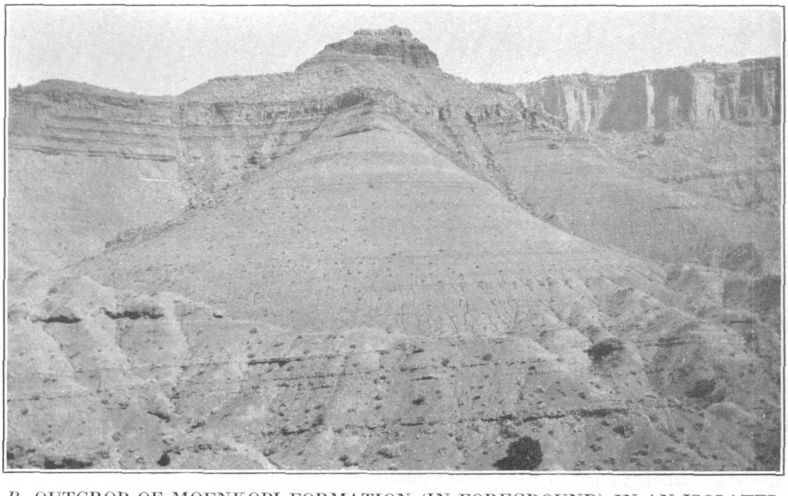
B. NORTH SIXSHOOTER PEAK, IN INDIAN CREEK VALLEY NEAR THE MOUTH OF DAVIS CANYON

b, Bogus tongue of the Cutler formation; m, Moenkopi formation; s, Shinarump conglomerate; c, Chinle formation; w, Wingate sandstone.



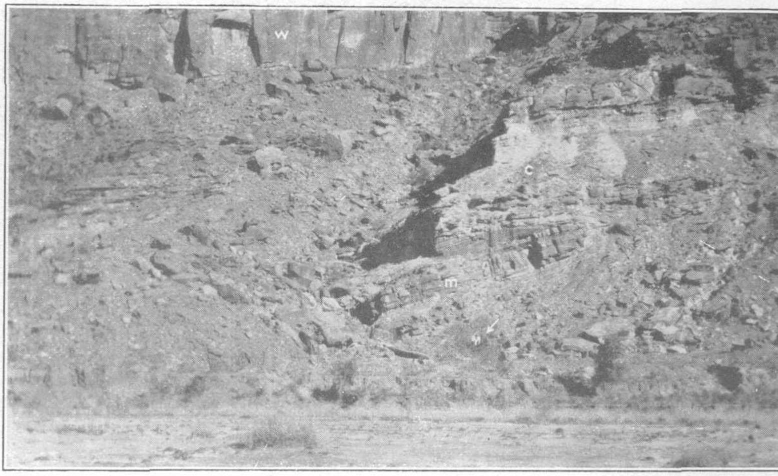
A. OUTCROP OF MOENKOPI FORMATION ON THE NORTH SIDE OF INDIAN CREEK VALLEY NEAR THE MOUTH OF HART DRAW

Showing thin regular bedding.



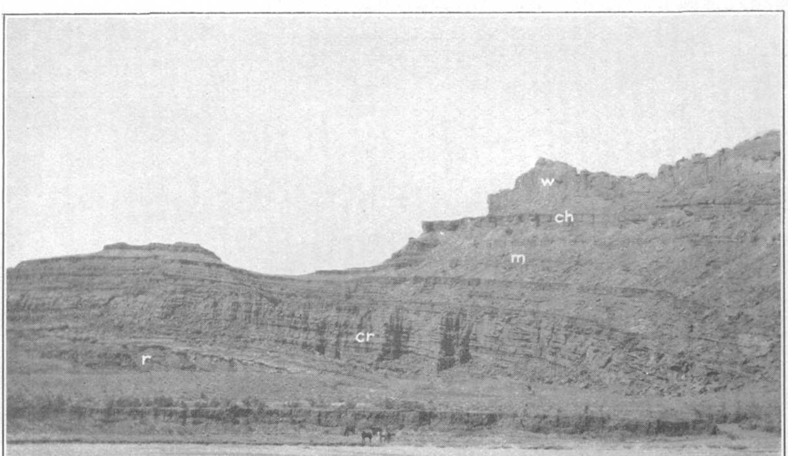
B. OUTCROP OF MOENKOPI FORMATION (IN FOREGROUND) IN AN ISOLATED BUTTE NEAR THE MOUTH OF CASTLE CREEK

Showing thin regular bedding and the smooth slopes to which the formation weathers. Ledges near top of butte are in the Chinle formation. The Shinarump conglomerate is absent. In the background are slopes formed by the Chinle formation overlain by the vertically jointed cliff of Wingate sandstone, which is capped by the Kayenta formation.



A. ANGULAR DISCORDANCE BETWEEN CHINLE AND MOENKOPI FORMATIONS ON NORTHEAST SIDE OF CANE CREEK ANTICLINE IN THE VALLEY OF CANE CREEK IN SEC. 33, T. 26 S., R. 21 E.

m, Moenkopi formation; c, Chinle formation; w, Wingate sandstone. For scale note the horseman at foot of slope (indicated by arrow).

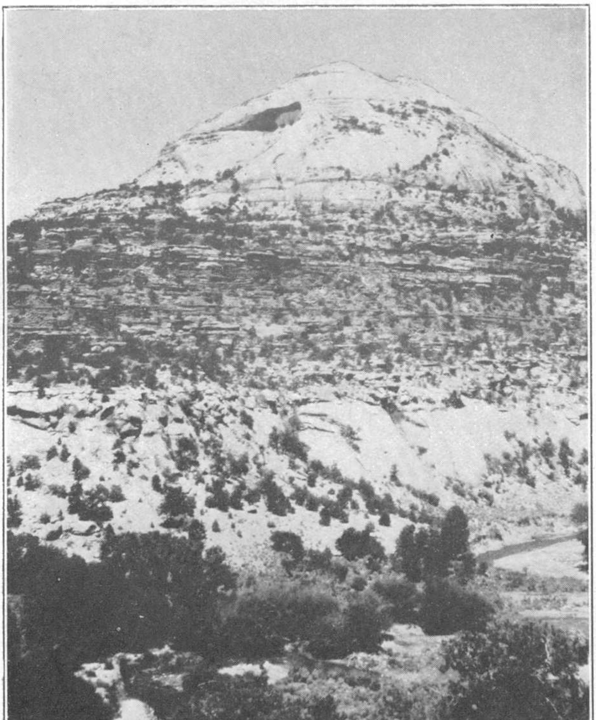


B. FORMATIONS EXPOSED AT CREST OF CANE CREEK ANTICLINE ON WEST SIDE OF CANE CREEK IN NARROW RIDGE BETWEEN IT AND THE COLORADO RIVER, IN SEC. 32, T. 26 S., R. 21 E.

r, Rico formation; cr, Cutler formation; m, Moenkopi formation; ch, Chinle formation; w, Wingate sandstone.

A. FORMATIONS EXPOSED ON EAST SIDE OF DAVIS CANYON ABOUT 1 MILE WEST OF THE SOUTHWEST CORNER OF SEC. 19, T. 31 S., R. 21 E.

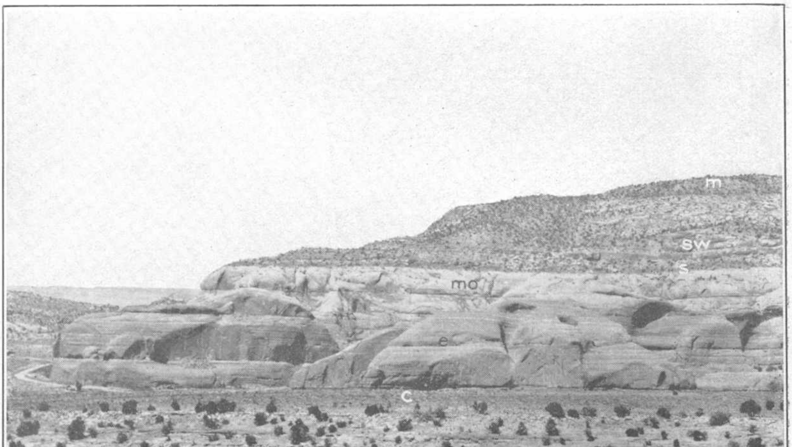
cm, Cedar Mesa sandstone member of the Cutler formation; b, Bogus tongue of the Cutler formation; m, Moenkopi formation; s, Shinarump conglomerate; ch, Chinle formation; w, Wingate sandstone; k, Kayenta formation; n, Navajo sandstone. Note the change of the lowest unit of the Bogus tongue to white sandstone near the center of the view.



B. VIEW OF SANDSTONE DOME NEAR THE UPPER ROAD CROSSING OF INDIAN CREEK IN SEC. 20, T. 32 S., R. 22 E.

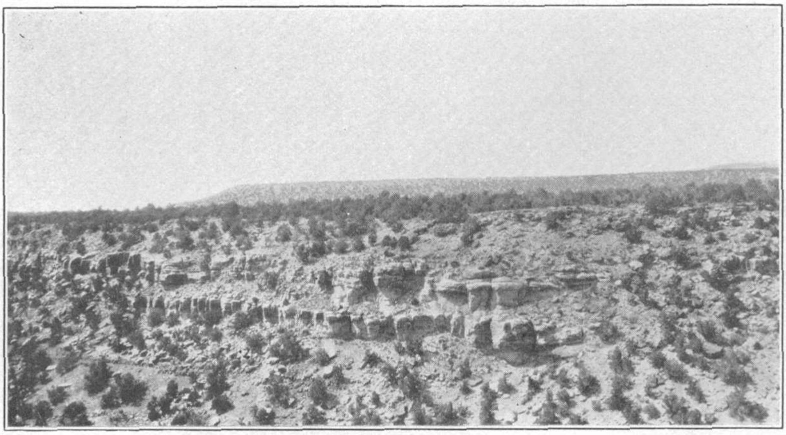
Showing the Kayenta formation forming a band of bedded sandstones between the underlying massive Wingate sandstone and the overlying massive Navajo sandstone, which forms the dome.

A. OUTCROP OF NAVAJO SANDSTONE IN MILL CREEK CANYON SHOWING TYPICAL CROSS-BEDDING



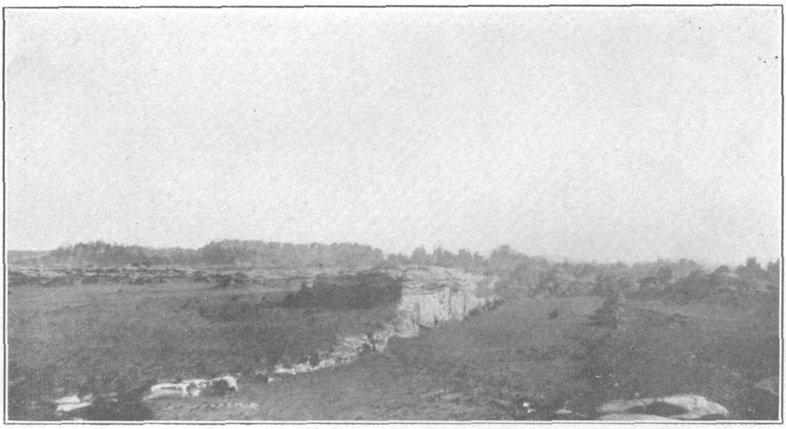
B. CLIFFS OF ENTRADA SANDSTONE AT CANE SPRINGS, IN SEC. 1, T. 28 S., R. 22 E.

Showing the upper massive Moab tongue of the Entrada sandstone and the banding and rows of cavities in the lower part. n, Navajo sandstone; c, Carmel formation; e, Entrada sandstone; mo, Moab tongue of the Entrada sandstone; s, Summerville formation; sw, Salt Wash sandstone member of the Morrison formation; m, Morrison formation.



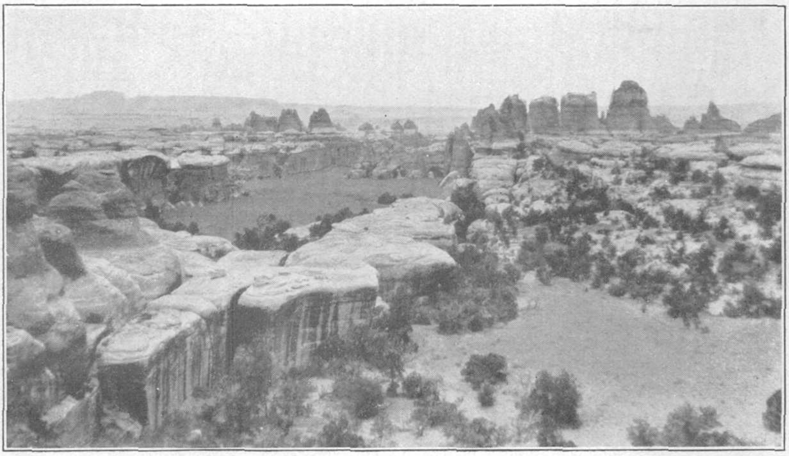
A. DAKOTA (?) SANDSTONE FORMING BENCH IN SE. ¼ SEC. 23, T. 28 S., R. 23 E., NEAR HEAD OF MULESHOE WASH

The sandstone is underlain by red shale of the Morrison formation, and the ridge in the background is formed by Mancos shale capped with gravel.



B. VIEW SOUTH ALONG TWIN VALLEY GRABEN FROM A POINT NEAR THE NORTH END

Showing alluvium-covered surface of the dropped block and the vertical fault face. In the background are the erosion forms of The Needles carved from the Cedar Mesa sandstone member of the Cutler formation.

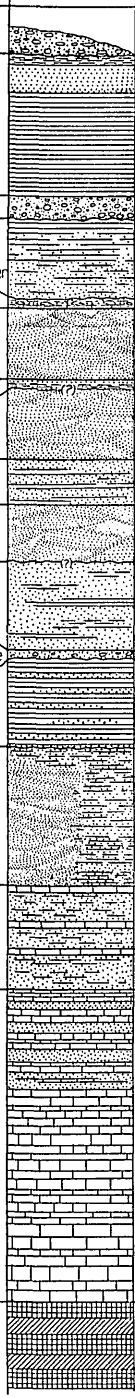


A. VIEW NORTH ALONG DEVILS POCKET GRABEN

Note subsidiary faulting within the dropped block, the alluvium-covered surface, the vertical faults, and The Needles.

B. SOUTH END OF DEVILS POCKET GRABEN

Showing parallel faulting, vertical fault face (at right), and The Needles.



System	Series	Formation	Thickness (feet)	Character of rocks
Tertiary(?)			0–300	Cemented gravel of local extent; pebbles largely composed of yellow sandstone and weathered igneous rock embedded in sandstone matrix.
Cretaceous	Upper	(Ferron sandstone member)	(160)	(Buff massive medium-grained sandstone.)
		Mancos shale	800+	Steel-gray marine shale.
		Dakota (?) sandstone	100–180	Buff and gray conglomeratic sandstone with pebbles of black and gray chert; locally contains carbonaceous shale.
Cret.(?)	Lower(?)	Morrison formation Salt Wash sandstone member	540–565	Upper part consists of variegated shale with a few siliceous conglomeratic sandstone beds containing varicolored chert pebbles; Salt Wash sandstone member in lower part consists of gray, irregularly bedded carnotite-bearing sandstone interbedded with red sandy mudstone.
Jurassic	Upper	San Rafael group: Summerville form.	25–65	Red sandy mudstone studded with large chert nodules.
		San Rafael group: (Moab tongue) Entrada sandstone	360–405	Massive cross-bedded medium-grained sandstone. Moab tongue is white; remainder of formation is banded orange and white with rows of solution cavities parallel to normal bedding.
		San Rafael group: Carmel formation	20–70	Red sandstone and mudstone with thin beds of cherty limestone.
Jurassic (?)		Glen Canyon group: Navajo sandstone	325–470	Massive cross-bedded buff to gray medium-grained sandstone locally containing red muddy, horizontally bedded sandstone and lenses of unfossiliferous gray-brown limestone.
		Glen Canyon group: Kayenta formation	230–270	Irregularly bedded fine to coarse grained gray-white, buff, lavender, and red sandstone, locally conglomeratic and with subordinate red and lavender shale; contains scattered fresh-water fossils.
		Glen Canyon group: Wingate sandstone	275–340	Massive cross-bedded buff medium-grained sandstone, which weathers into cliffs characterized by vertical joints and dull-red to purplish-black coating of desert varnish.
Triassic	Upper	Chinle formation	0–740	Irregularly bedded buff to red sandstone interbedded with quartz and limestone pebble and mud-pellet conglomerates and variegated shale.
	?	Shinarump conglomerate	0–75	Light-brown to gray sandstone and quartz-pebble conglomerate.
	Lower	Moenkopi formation	0–940	Chocolate-brown shale with numerous beds of brown to gray ripple-marked sandstone; locally seamed with gypsum.
Carboniferous	Permian	(Bogus tongue) Cutler formation (Cedar Mesa sandstone member)	0–800	Undivided Cutler formation in northern part of area is composed of buff, red, and purple arkosic sandstone and conglomerate; south of Indian Creek is the thick Cedar Mesa sandstone member (composed of massive cross-bedded white to pale-red sandstone with thin beds of cherty limestone and micaceous red sandstone) overlain by red arkosic sandstone and red mudstone, the Bogus tongue of the Cutler formation, which has a maximum thickness of about 100 feet.
		Rico formation	0–575	Buff, red, and purple arkosic sandstone and conglomerate with several thin beds of marine limestone.
	Pennsylvanian	Hermosa formation	913+	Interbedded fossiliferous bluish-gray limestone and greenish-gray sandstone.
			900	Gray limestone with some interbedded gray and blue shale and gray sandstone. Does not crop out but has been penetrated by wells.
	Penn(?)	Paradox formation		Salt, gypsum, and anhydrite with interbedded black and brown shale and some limestone. Crops out in small areas where overlying rocks were relatively thin and have been ruptured by the upward movement of the relatively plastic salt and gypsum.

GENERALIZED COLUMNAR SECTION OF THE ROCKS EXPOSED AT THE SURFACE IN THE MOAB DISTRICT

Rivers, as they supposed, but viewed instead the group of bends of the Colorado River known as "The Loop." Newberry briefly describes the rocks exposed above the top of the Rico formation. In 1869, ten years after the Macomb expedition, Powell [3] made his first trip down the canyons of the Green and Colorado Rivers, and in 1871 he made a second trip. Observations on the geology are recorded in Powell's account of these trips. In 1875 Peale [4] made a brief examination of the rocks exposed in the vicinity of the La Sal Mountains. The Moab district is not specifically included in the areas visited by Dutton in 1875–1881 and described by him,[5] but his philosophic discussions of the geology of the Grand Canyon district and of the High Plateaus are in part applicable to the Moab district. Cross in 1905 made a reconnaissance across the northeastern part of the Moab district and published a summary of his observations.[6] A paper describing the conditions of sedimentation and correlating the formations over a wide area, including the Moab district, was published by Lee.[7] Dake [8] in two papers described a pre-Moenkopi unconformity and the horizon of the marine Jurassic in a large area which includes the Moab district. After the drilling of the first wells in the Moab district in 1920 many geologists visited the Colorado Plateaus, and several papers discussing the oil possibilities, stratigraphy, or peculiar types of structure in the Moab or adjoining districts were published.[9]

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[3] Powell, J. W., Exploration of the Colorado River of the West, 1869–1872, Smithsonian Institution, 1875.

[4] Peale, A. C., Geological report on the Grand River district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., pp. 31–101, 1877.

[5] Dutton, C. E., Report on the geology of the High Plateaus of Utah, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880; The physical geology of the Grand Canyon district: U. S. Geol. Survey Second Ann. Rept., 1882; Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 1882.

[6] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 634–679, 1907.

[7] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, 1918.

[8] Dake, C. L., The pre-Moenkopi (pre-Permian?) unconformity of the Colorado Plateau: Jour. Geology, vol. 28, pp. 66–74, 1920; The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–646, 1919.

[9] Prommel, H. W. C., Geology and structure of portions of Grand and San Juan Counties, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 4, pp. 384–399, 1923. Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulation: Idem, vol. 11, No. 4, pp. 373–393, 1927; Structural history of parts of southeastern Utah from interpretations of geologic sections: Idem, vol. 11, No. 8, pp. 809–820, 1927; also published in Oil Weekly, vol. 46, No. 7, pp. 31–34, August, 1927. Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, No. 2, pp. 111–133, 1927. Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., jr., Notes on the stratigraphy of the Moab region, Utah: Idem, vol. 11, No. 8, pp. 785–808, 1927. Taber, Stephen, Fault troughs: Jour. Geology, vol. 35, pp. 577–606, 1927. Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1413–1448, 1929. Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation). Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, 1928. Lee, W. T., Boyer, W. W., and Gilluly, James, Possibility of finding oil in southeastern Utah and southwestern Colorado: U. S. Geol. Survey Press Mem. 6064, Mar 30, 1926. Powers, Sidney, Effect of salt and gypsum on the formation of Paradox and other valleys of southwestern Colorado: Geol. Soc. America Bull., vol. 37, p. 168, 1926. Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–23, 1923.

STRATIGRAPHY

GENERAL FEATURES

The exposed rocks attain a maximum thickness of nearly 7,000 feet. (See pl. 11.) The oldest rocks whose age is definitely known are part of the Hermosa formation, of Pennsylvanian age. The salt and gypsiferous series that underlies the Hermosa formation is tentatively assigned to the early Pennsylvanian. The highest rocks, with the exception of Tertiary (?) and Recent gravel deposits, are those of the Mancos shale, of Upper Cretaceous age. In the thick series of rocks between the Pennsylvanian and the Upper Cretaceous occur representatives of the Permian series and Triassic and Jurassic systems. Reconnaissance stratigraphic studies have been made in adjacent regions by the writer and other geologists, in order to determine the regional relations of the rocks of the Moab area and other areas covered by detailed mapping. Three of the papers [10] that have been prepared deal particularly with the stratigraphy of the rocks exposed in the Moab district, the regional correlation of the Permian formations and the regional correlation of the Jurassic formations. For a more extended discussion of these phases of the geology than is given in this report, the reader is referred to these three reports, particularly for correlations, discussion of nomenclature used by other writers, and discussion of the paleogeography during Permian and Jurassic time. These topics are discussed in this paper only in so far as they have special bearing on the local geology of the Moab district.

The Paleozoic and lower Mesozoic formations crop out only along the canyon of the Colorado River and its deep tributary canyons. The Wingate sandstone commonly forms the high rims of these canyons, and the Chinle, Moenkopi, Cutler, Rico, and Hermosa formations form cliffs, steep slopes, and benches below. Above the Wingate the alternating soft and resistant beds of the younger formations form the irregular treads and risers of a huge irregular stairway leading up to the outcrop of the Dakota (?) sandstone and Mancos shale on the flanks of the La Sal and Abajo Mountains.

Many of the boundaries of the formations are not clear-cut or definite, and few geologists who have worked in the district, although they may recognize and adopt the same general stratigraphic units, have accepted precisely the same formational boundaries. This leads to much confusion in comparing sections measured by the different

[10] Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., jr., Notes on the stratigraphy of the Moab region, Utah; Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 785–808, 1927. Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Idem., vol. 13, pp. 1413–1448, 1929. Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation).

workers. There may be as much as 100 feet of stratigraphic difference in the position of a boundary as selected and mapped by two workers. This is true of such boundaries as that between the Dakota (?) and Morrison, the Navajo and Kayenta, the Kayenta and Wingate, the Wingate and Chinle, the Moenkopi and Cutler, and the Cutler and Rico formations. There are no fossils to help in fixing most of these boundaries, and thus their determination is largely a matter of personal choice.

CARBONIFEROUS SYSTEM

PENNSYLVANIAN (?) SERIES

PARADOX FORMATION

The Paradox formation, which includes the oldest rocks exposed in the district, consists of interbedded salt, gypsum, anhydrite, shale, and limestone whose age has not been precisely determined but at present appears to be lower Pennsylvanian. The base of the formation is not exposed in the Moab district. There are small exposures at the crests of various anticlines in or near the Moab district, but much of the information concerning it has been obtained from the logs of numerous wells. The formation is of particular interest, because most of the oil and gas showings discovered in the region have been obtained from it, and furthermore, some potash minerals have been obtained from certain wells, suggesting that careful drilling and examination of the cores or cuttings may show extensive deposits of valuable potash minerals in the formation. Owing to the solubility of the salt and gypsum, exposures are invariably poor, and rarely can more than a few hundred feet of the formation be observed at any one locality. Although incompletely exposed in Paradox Valley, in southwestern Colorado, the exposures of the formation there are typical and are more accessible than most of the other exposures. Deep wells drilled there for oil have revealed a thickness of more than 6,000 feet without reaching the base. The formation is thus named from Paradox Valley, the name being introduced in the present paper. The definition of the Paradox formation must perforce be indefinite as to exact age, lithology, and limiting formations, as few fossils have been collected from it, outcrops are few and of slight extent, and only one of the many wells that have been drilled thousands of feet into it may have reached the base.

Within the area described in this report there are small exposures of the Paradox formation in Moab Valley (pl. 3, *A*), in Castle Creek Valley, and on the Colorado River at the mouth of Lower Red Lake Canyon, but just beyond the limits of the area other exposures have been described in Salt Valley,[11] which lies northwest of the area.

[11] Dane, C. H., Geology of the Salt Valley anticline and the northwest flank of the Uncompahgre Plateau, Grand County, Utah: U. S. Geol. Survey Bull. (in preparation).

Where exposed at the surface in the area mapped the Paradox formation is practically all gypsum, with minor amounts of greenish-gray sandstone, gray limestone, and black shale, but the lithologic elements have been so jumbled together by local folding and flowage that it is impossible to follow bedding planes more than a few feet or to determine relations within the formation. The wells drilled into it have revealed thick bodies of salt interbedded with anhydrite, gypsum, black, gray, and brown shale, and limestone.

It is impossible to determine accurately the normal thickness of the salt series, if the usual and reasonable assumption is made that the salt has been thickened at the crests of the anticlines by lateral flowage into them. All the wells have been drilled at or near the crests of the anticlines, and the only well that appears to have passed through the salt was drilled at the crest of the Shafer dome, in sec. 16, T. 27 S., R. 20 E. Consequently no figures on the normal thickness of the salt are available. The well on the Shafer dome passed through about 3,900 feet of the salt series and below the salt 290 feet of limestone and shale to the bottom of the well. Four other wells in the district and one in Lisbon Valley, just east of the area mapped, were drilled into the Paradox formation to depths ranging from 1,180 to 3,500 feet. In the five wells just mentioned the proportion of salt according to the drillers' logs ranged from 60 to 82 per cent. A smaller percentage of salt and a higher percentage of limestone are reported in the well of the Empire Gas & Fuel Co. in sec. 6, T. 30 S., R. 21 E., than in the wells drilled farther north. About 15 miles south of the area mapped a well drilled on Elk Ridge penetrated 3,500 feet of strata consisting principally of limestone and encountered only four thin beds of salt and considerable black shale intercalated in the limestone. As the evidence obtained from wells drilled within the area mapped shows a decrease of salt and an increase of limestone toward the south, and as the Elk Ridge well shows a tremendous thickness of limestone with practically no salt, the suggestion follows that the salt series in the north was deposited contemporaneously with limestone at the south. If the colored shales and limestones encountered near the base of the wells on the Shafer dome and Elk Ridge are equivalent, and if the same thickness of salt and limestone accumulated in a given length of time, the amount of limestone found in the Elk Ridge well in excess of the thickness of the part of the limestone correlated with the Hermosa formation may be a rough measure of the normal thickness of the salt series. The corollary would then follow that the thickness of salt in the well at the Shafer dome in excess of the thickness of the contemporary limestone in the Elk Ridge well is a measure of the thickening of the salt series at the Shafer dome. (See fig. 2.) The limestone series penetrated in the Elk Ridge well is approximately 3,500 feet thick, of which 1,500 feet is assumed to be equivalent to the Hermosa formation. The difference between these amounts—2,000 feet—according to the above hypothesis represents approximately the normal thickness of the salt series, and the difference between the thickness of the contemporaneous limestone in the Elk Ridge well (2,000 feet) and the thickness of the salt series in the well at the Shafer dome (3,900 feet) gives 1,900 feet as the amount of thickening of the salt series at the Shafer dome.

These calculations involve too many unknown factors to make the figures more than suggestive. The primary assumption that the variegated shales found in both wells near the bottom are equivalent may well be questioned, but it seems to be a justifiable assumption, as a thickness of 250 feet of interbedded limestone and pink to variegated shale is not known anywhere else in either well or in any of the wells drilled in the district. Pink shales are known from two high horizons in the Elk Ridge well, but they are not as thick as the shale-limestone series at the bottom of the two wells, nor do they include interbedded limestones like those in that series. According to the reasoning outlined above, the correlation of the shales at the bottom of the Shafer dome well with the upper ones in the Elk Ridge well would decrease the normal thickness of the salt series and increase the amount of thickening under the anticlines. The assumption that the limestone series included in the Hermosa formation is 1,500 feet thick in the Elk Ridge well may give too great a thickness to the Pennsylvanian limestone, but still farther south, in the canyon of the San Juan River, the Hermosa formation is nearly 1,000

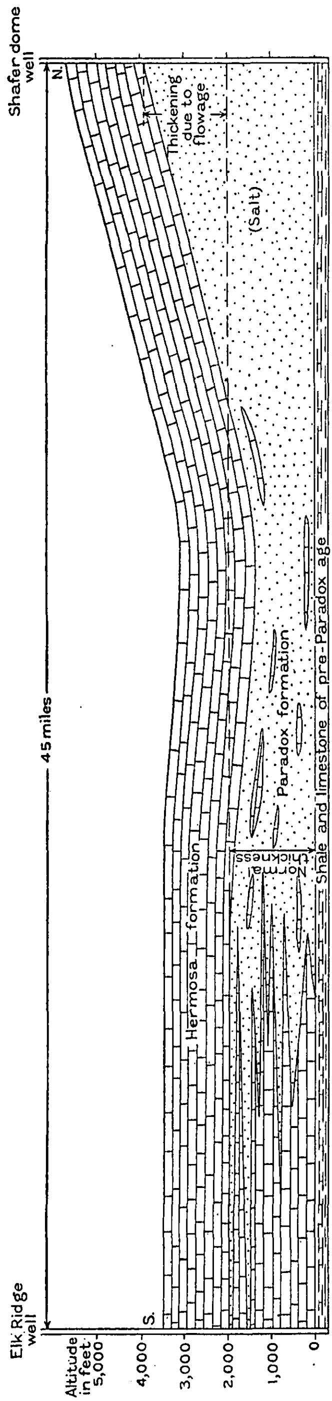

FIGURE 2.—Diagram illustrating inferred lateral changes in Paradox formation and changes in thickness resulting from movement in the salt

feet thick and the base is not exposed. It seems probable that limestones equivalent to the Hermosa are at least 1,500 feet thick between the Shafer dome and Elk Ridge.

The above interpretation of the stratigraphic relations existing between the Shafer dome and the well on Elk Ridge does not accord with the commonly accepted theory of the accumulation of great thicknesses of saliferous beds, and the following alternative interpretation of the stratigraphic relations is perhaps the more logical one. Thick series of saliferous beds are believed to accumulate in a nearly landlocked basin in which salts are deposited from sea water because of concentration by evaporation. The amount of water lost by evaporation is constantly replenished by sea water entering the basin, but the concentrated salt solution in the basin is retained because free circulation does not exist between the basin and the open sea. Under such conditions it is improbable that great thicknesses of limestone would accumulate in one part of the basin while a comparable thickness of saliferous beds accumulated in another part of the same basin. It can be inferred, therefore, that the red beds at the bottom of the well at the Shafer dome are not equivalent to the lower red beds in the well at Elk Ridge and that the limestone below the salt beds at Elk Ridge is not contemporaneous in origin with the greater part of the Paradox formation but that this limestone is older than the Paradox formation and forms the floor of the basin upon which the Paradox beds were deposited and against which they overlap near the margin of the basin. The salt beds found in the Elk Ridge well would thus represent a thin marginal facies of the Paradox formation. Under this interpretation of the conditions it is impossible to determine the normal thickness of the saliferous beds.

The age of the Paradox formation is not definitely known. It underlies the Hermosa formation, of Pennsylvanian age, but there may have been continuous deposition from the Paradox to the Hermosa formation. The rocks that underlie the Paradox formation do not crop out in the Moab district, and little information concerning them can be obtained from the logs of wells. The lower part of the so-called Weber formation, which crops out near Glenwood Springs, Colo., and consists of gray to buff sandstone and light-gray to black shale, changing laterally into massive gypsum, may be equivalent to the Paradox formation. The Weber (?) formation, which contains Pennsylvanian fossils, rests upon the Leadville limestone, of Mississippian age. In the vicinity of Glenwood Springs the gypsiferous phase of the Weber (?) formation is overlain by red sandstones of undetermined age, and the Hermosa formation can not be recognized. Beds of gypsum are present locally in the lower part of the Hermosa formation above limestones containing Hermosa fossils where that formation crops out in the Rico Mountains.[12] The individual gyp-

[12] Cross, Whitman, and Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

sum beds in the Hermosa formation of the Rico Mountains are of local extent, but the thin gypsum of the Rico Mountains may be the marginal phase of the thick Paradox formation. Below the Hermosa formation in the Rico Mountains is the thin Molas formation, of Pennsylvanian age, consisting of red calcareous or sandy beds with chert pebbles, which is underlain by the Leadville limestone, of Mississippian age. West or southwest of the Moab district no rocks older than the Hermosa crop out until the Grand Canyon is reached. There rocks of Pennsylvanian age are very thin or absent and the Supai formation, of Permian age, rests upon the Redwall limestone, of Mississippian age. The only well drilled into the Paradox formation within the district that may have passed through it is the well drilled on the Shafer dome in sec. 16, T. 27 S., R. 20 E., and from the log of that well alone can an idea of the strata underlying the salt basin be obtained. Beneath 3,900 feet of salt and gypsum the well penetrated 120 feet of gray shale and black lime between 5,570 and 5,690 feet, which was underlain by 170 feet of variegated shale extending to the bottom of the well at a depth of 5,860 feet. No such thickness of variegated shale or variegated and gray shale without salt or gypsum has been encountered in the Paradox formation in any of the other wells, so it seems probable that these clastic beds mark the base of the formation. This inference is supported by the fact that fresh water was found at the bottom of the hole, indicating that the shale beds form an impervious layer between salt beds above and nonsalt-bearing beds below.

As it is impossible to trace the Paradox formation from the Moab district to areas where the age of equivalent rocks has been determined, its age determination must rest upon evidence collected from its scanty outcrops or from chance fossils obtained from well cuttings. Thus far few fossils have been obtained that are diagnostic or sufficiently well preserved to be of value.

Samples of cuttings from the Frank Shafer No. 1 well from depths of 3,250 to 3,350 feet (about 1,750 to 1,850 feet below the top of the Paradox formation) contained conodonts which were described by P. V. Roundy as follows:

All cuttings are of a fine-grained black shale. Eight of the samples contained conodonts; two (3,270–3,280 and 3,340–3,350) contained no fossils. The cuttings from 3,320 to 3,330 feet contained 44 specimens. In all 105 specimens were picked out; all were incomplete, but seven genera were recognized.

Of these, two genera, *Hindeodella* and *Lonchodus*, range from Devonian to lower Permian. The species of *Hindeodella*, however, is distinct from the Devonian type. As the anterior end of all specimens was missing, a specific identification is not possible. *Lonchodus* is an indeterminate genus and has no stratigraphic value.

The Carboniferous genus *Gnathodus* is represented, and the type in these cuttings ranges, so far as I know, from the middle or upper part of the lower Mississippian to the upper Pennsylvanian. It is, however, I believe, a Pennsylvanian rather than a Mississippian species.

Another genus, undescribed but nearer to *Gnathodus* than *Polygnathus*, occurs only so far as I know in the Pennsylvanian and Permian. The two species of this form are very abundant in the cuttings, and I believe they are probably the Pennsylvanian type.

The other three genera are represented only by such imperfect specimens that their identification is not at all sure, but they do not offer any objection to the Pennsylvanian age of the cuttings.

The conodont evidence indicates that the shale from 3,250 to 3,340 feet in the well is a single unit and that in age it probably belongs in the lower half of the Pennsylvanian. It can not be Devonian and probably is not Mississippian unless these conodonts range lower than present knowledge would indicate. However, if other information indicated a location in the upper Pennsylvanian the conodont evidence would offer but little objection to such a position.

On the basis of poorly preserved invertebrate fossils collected from the Paradox formation in Sinbad Valley, Colo., and in Onion Creek, Utah, a few miles north of the area here described, and poorly preserved plant remains collected from the outcrop in Sinbad Valley by C. H. Dane, H. D. Miser, and J. B. Reeside, jr., an early Pennsylvanian age is tentatively assigned to the formation by G. H. Girty and David White. Thus the three lines of evidence supplied by conodonts, invertebrate fossils, and fossil plants are in agreement as indicating an early Pennsylvanian age for the formation. It is possible that additional collections of fossils will alter this conclusion, as the fossils upon which it is based are not well preserved. As a working hypothesis it is suggested that the variegated shale beds encountered in the base of the well on the Shafer dome are early Pennsylvanian and equivalent to the Molas formation of southwestern Colorado, that the Paradox formation is early Pennsylvanian and either is unrepresented between the Molas formation and the Hermosa formation or is equivalent to the basal part of the Hermosa formation in southwestern Colorado, and that in the Grand Canyon district the Pennsylvanian Molas, Paradox, and Hermosa formations either were not deposited or were removed by erosion prior to the deposition of the Permian Supai formation. These suggested correlations are illustrated graphically in Figure 3.

PENNSYLVANIAN SERIES

HERMOSA FORMATION

The Hermosa formation, of Pennsylvanian age, crops out in Moab Valley and along the Colorado River. In Moab Valley the formation crops out west of the river, southwest of a fault, and east of the river grayish-lavender unfossiliferous brecciated limestone that is correlated with the Hermosa formation crops out at the edge of the alluvium on both sides of Moab Valley. South of Moab the formation again rises to the surface for a short distance along the river near the southwest corner of T. 26 S., R. 21 E., where 300 feet of the top of the formation is exposed. Near the center of T. 27 S., R. 20 E., 8 miles farther down the river, there is a similar outcrop of the Hermosa formation. From a point about 3 miles below the mouth of Indian Creek the formation again appears above the level of the river and continues to rise to the south.

A complete section of the Hermosa formation is not exposed in or near the Moab district, but the logs of several wells give some information about the buried strata. The most complete exposure of the Hermosa is in the canyons of the Green and Colorado Rivers near their junction and between the junction and the head of Cataract Canyon, where the upper 900 feet or more of the formation crops

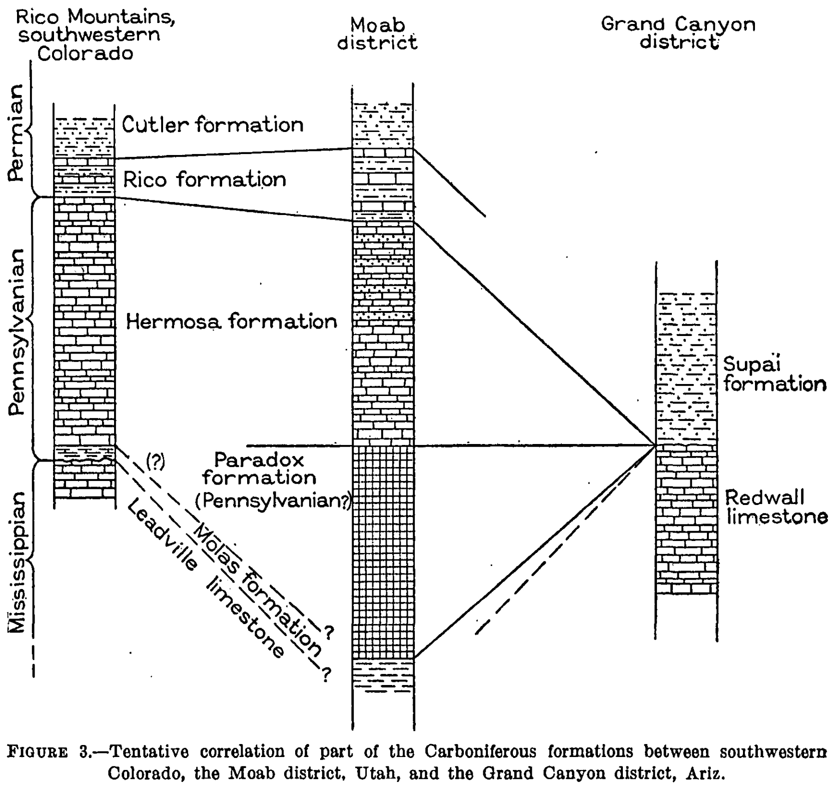

FIGURE 3.—Tentative correlation of part of the Carboniferous formations between southwestern Colorado, the Moab district, Utah, and the Grand Canyon district, Ariz.

out. It consists of interbedded thin to massively bedded fossiliferous gray limestone and massively bedded gray to greenish-gray sandstone and shale. Logs of five deep wells show an additional 600 to 900 feet of limestone above the top of the salt series. The total thickness of the rocks included in the Hermosa formation is therefore 1,500 to 1,800 feet. This figure corresponds closely with the thickness of the Hermosa in the San Juan Mountains, Colo., near its type locality, where it is reported to be from 1,800 to 2,000 feet thick.[13] In most

[13] Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 48–49, 1900.

of the wells that have been drilled the boundary between the limestone and salt is not sharp, as there is a transition from massive limestone through limestone interbedded with thin beds of salt to beds predominantly salt.

The following section of the part of the Hermosa formation exposed at The Slide, about 1½ miles above the junction of the Colorado and Green Rivers, was measured by J. B. Reeside, jr.:

Section of the Hermosa formation at The Slide

	Feet
Rico formation.	
Hermosa formation:	
1. Shale, calcareous, gray	20
2. Limestone, dense, massive, dove-gray to blue-gray, cliff-forming; contains echinoid spines and crinoid stems	18
3. Mudstone, gray, calcareous	4
4. Limestone, thin bedded, dove-gray, dense	10
5. Limestone, dense, massive, cliff-forming, dove-gray to blue-gray	10
6. Sandstone, massive, calcareous, gray-white when fresh but weathering brown	10
7. Shale, blue-gray	3
8. Limestone, dense, massive, dark gray	5
9. Sandstone, massive, cross-bedded, greenish gray to gray-white on a fresh surface but weathers buff	75
10. Shale, greenish gray, calcareous, interbedded with layers of gray sandy limestone and limestone conglomerate in beds up to 6 feet thick	75
11. Sandstone, massive, calcareous, fine grained, cliff-forming; contains abundant silicified fossils	10
12. Limestone, dark gray, coarsely crystalline; abundant fossils	5
13. Sandstone, like No. 9	30
14. Limestone, dense, massive, dove-gray, weathering brown; contains scattered fossils and a few masses of brown chert 18 inches long	40
15. Sandstone, like No. 9	30
16. Limestone, dense, slaty, sandy, dark gray	5
17. Sandstone, like No. 9	35
18. Limestone, like No. 16	10
19. Shale, greenish gray, calcareous; scattered fossils	20
20. Limestone, dense in some layers, soft and shaly in others, massive, dark gray; dense layers contain nodules of black chert up to 12 inches long	15
21. Sandstone, like No. 9	15
22. Limestone, like No. 20	25
23. Shale, greenish gray, calcareous, fossiliferous	10
24. Limestone, massive, gray, hard; weathers brown and hackly; contains a few chert nodules	4
25. Sandstone, like No. 9	70
26. Shale, purplish, sandy	7
27. Sandstone, greenish gray, coarse grained	2

Hermosa formation—Continued.	Feet
28. Limestone, like No. 24	12
29. Sandstone, gray streaked with red, cross-bedded	25
30. Shale, dark red, sandy	8
31. Sandstone, thin bedded, calcareous, fine grained, gray and purple	5
32. Limestone, thin bedded, gray, interbedded with shale, red chert common	10
33. Limestone, massive, gray, hard; weathers brown and hackly; contains few fossils	18
34. Shale, green	8
35. Limestone, massive, gray, hard	2
36. Sandstone, massive, cross-bedded, medium grained, greenish gray to light gray, weathering buff	40
37. Limestone, massive, dark gray, much crystalline calcite	2
38. Sandstone, like No. 36	30
39. Shale, light gray, sandy	15
40. Limestone, massive, dark gray, weathering brown	10
41. Shale, like No. 39	15
42. Limestone, dense, light gray, sandy; shale in minor amount, fossils on surface of beds	40
43. Shale, like No. 39	10
44. Sandstone, like No. 36	50
45. Limestone, dense, light gray, sandy, weathers platy	40
46. Sandstone, like No. 36	10
Alluvium to river level, about 20 feet.	
	913

Several collections of invertebrate fossils from the Hermosa formation clearly show that it is of Pennsylvanian age, although it has not been possible to determine how much of Pennsylvanian time is represented. The top of an apparent lithologic transition zone about 25 feet thick between the Hermosa and Rico formations is reported by G. H. Girty to coincide with a change in fauna between these formations. The fossils listed below have been described by Mr. Girty.

Fossils of the Hermosa formation

	5947g	5947f	5947e	5947d	5949	5883	5883a	5883b	5883c	5883d
Fusulina secalica					×					
Sponges several		×					×		×	
Campophyllum torquium						×		×	×	×
Campophyllum kansasense					?			×		×
Campophyllum sp				×				?		
Triplophyllum sp								×		×
Axophyllum rude										?
Clisiophyllum? sp					×					
Lophophyllum profundum	?	?			×				×	
Syringopora multattenuata						×				
Lithostrotion? sp						×				
Echinocrinus coloradoensis?						?		×		
Echinocrinus sp					×		×			
Delocrinus aff. D. texanus								×		
Erisocrinus propinquus?		?								
Eupachycrinus? sp		×								
Fistulipora sp					×			×		
Stenopora carbonaria					?			×	×	
Stenopora sp	×	×			×					
Cyclotrypa barberi					×			?	×	
Fenestella sp	×	×	×		×			×	×	
Polypora sp	×	×	×		×	×		×	×	
Pinnatopora sp	×							×		
Thamniscus aff. T. guadalupensis		×								
Chainodictyon sp	×	×								
Rhombopora lepidodendroides					×	×		×	×	
Rhombopora sp	×	×								
Cystodictya sp		×								
Orbiculoidea sp		×								
Rhipidomella carbonaria	×									
Derbya crassa					×					
Derbya bennetti					×					
Derbya sp	×							?		
Chonetes granulifer					×			×	×	
Chonetes geinitzianus		×								
Productus semireticulatus	×	×			×				×	×
Productus cora		×			×	×	×	×		
Productus pertenuis					×			×		
Productus aff. P. guadalupensis	×	×								
Pustula nebraskensis	×				×			×		
Pustula symmetrica					×			×		
Pustula semipunctata	×				×			×	×	
Pustula aff. P. porrecta	×	×								
Pustula n. sp					×			×		
Marginifera splendens	×	?						×	×	
Marginifera wabashensis					?			×		
Marginifera lasallensis					?			?		
Rhynchopora aff. R. taylori		×								
Rhynchopora illinoisensis					×			×		
Pugnoides osagensis					×			×		
Pugnoides sp							?			
Dielasma sp					×					
Spirifer triplicatus	×	×		×	×			×	×	
Spiriferina kentuckyensis	×	×			×			×		
Spiriferina gonionotus?	?	?								
Squamularia perplexa					×			×		
Squamularia aff. S. guadalupensis		×								
Brachythyris n. sp		×								
Composita subtilita	×	×	×			×		×		×
Hustedia mormoni	×	×	×							
Edmondia gibbosa								?		
Allerisma terminale?					×					
Pinna peracuta								×		
Acanthopecten carboniferus	?	?	?							
Myalina sp			×							
Schizostoma catilloides					×					
Naticopsis? sp							×			
Euomphalus? sp							×			
Platyceras occidentale	×									
Griffithides sp		×								

5947g. The Slide, on the west side of the Colorado River about 1½ miles above the mouth of the Green River; 790 feet below top.

5947f. Same as 5947g; 475 feet below top.

5947e. Same as 5947g; 400 feet below top.

5947d. Same as 5947g; 220 feet below top.

5949. West side of the Colorado River at the southwest corner of T. 26 S., R. 21 E., from bed of massive limestone just below thin series of transition beds at top of Hermosa formation.

5883. Near road from Moab to Thompsons, about 5 miles northwest of Moab; 180 feet below top.

5883a. Same as 5883; 120 feet below top.

5883b. Same as 5883; 18 feet below top.

5883c. Same as 5883; 10 feet below top.

5883d. Same as 5883; upper 5 feet.

It is probable that the outcrops of Hermosa formation in Moab Valley represent mostly the lower part of the formation. Cross [14] suggested this possibility because of differences in the fauna collected near Moab by his party and that previously collected by Powell and Newberry near the junction of the Green and Colorado Rivers. Unconformities displayed in the cliff west of the river at Moab cut out locally all the formations between the Chinle and the Hermosa, and the Chinle formation was deposited with angular discordance upon beveled limestone beds of the Hermosa formation.[15] It is not possible at the present time to say how much of the Hermosa formation was removed during the two periods of erosion that occurred before the deposition of the Chinle formation protected it from further erosion. The greater part of the formation may have been removed in the vicinity of Moab.

The Hermosa formation is definitely correlated with the massive limestone and sandstone beds of the lower part of the "Goodridge formation" exposed in the San Juan oil field in southern Utah.[16] There is not a sharp lithologic boundary between the massive limestone beds and the overlying interbedded limestone and red sandstone and shale beds of the "Goodridge formation," but the lower massive beds, of which about 1,000 feet is exposed, contain the same fauna as that found in the Hermosa formation, and the upper beds, about 465 feet thick, contain the Permian Rico fauna. A deep well drilled in 1926 and 1927 by the Utah Southern Oil Co. about 5 miles northwest of the San Juan field penetrated 2,850 feet of limestone that contains no salt. This well perhaps passed through the Hermosa formation and entered an older series of limestones, possibly equivalent to the Paradox formation.

PERMIAN SERIES

RICO FORMATION

The Rico formation is the lowest one of a thick series commonly included under the general term "Red Beds." Its outcrop is almost continuous along the Colorado River from a point near the southwest corner of T. 26 S., R. 21 E., to the southern limit of the area, with small exposures along the tributary streams. An outcrop of the Rico formation on the west side of the river is shown in Plate 3, *B*. The formation is a bedded series of sandstone with some red to lavender shale and several thin layers of limestone. The sandstones are of varying hardness and coarseness of grain and are commonly mas-

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[14] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 675, 1907.

[15] Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., jr., Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 793, 1927.

[16] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 76–104, 1912. Baker, A. A., Geology of the Monument Valley-Navajo Mountain region, Utah: U. S. Geol. Survey Bull. (in preparation).

sive but are in some places cross-bedded and irregularly bedded and may pinch out within a short distance along the outcrop. Many of them are coarse grained to conglomeratic arkosic sandstones, containing many fresh feldspar crystals and fragments of mica in addition to the quartz. Toward the south the sandstones become finer grained. In color the beds are maroon in a distant view, but red, purple, pink, and brown are the common colors of individual beds. The limestone beds are thin, usually sandy, and gray to green, and some carry a rich marine fauna. Springs issuing from the Rico formation are commonly very salty, but no salt was observed at the surface. The formation may contain bedded salt locally or disseminated salts, but it is of course possible that the water containing the salt has risen along fissures from the salt beds of the Paradox formation. The normal thickness of the Rico formation is 575 feet as measured in the southwest corner of T. 26 S., R. 21 E., and near the junction of the Green and Colorado Rivers. The Rico formation is absent locally near Moab, where it has been cut out by a post-Cutler unconformity.

The following section of the Rico formation was measured by J. B. Reeside, jr., near "The Slide" on the Colorado River, about 1½ miles above its junction with the Green River:

Section of the Rico formation at The Slide

Cutler formation:	
Sandstone, massive, cross-bedded, medium to coarse grained, buff to gray; forms rim rock of canyon.	
Rico formation:	Feet
Shale, maroon interbedded with purple arkosic sandstone	10
Limestone, thin bedded, gray to purple, sandy; good fossils rare, but crinoid fragments and broken shells abundant ("Shafer limestone"?)	25
Sandstone, calcareous, blue-gray	8
Sandstone, massive, cross-bedded, salmon-red, medium to coarse grained	30
Arkose, coarse grained, with pebbles of feldspar and quartz as much as one-half inch in diameter interbedded with purple sandy limestone	20
Limestone, massive, gray, sandy, with vermilion jasper in upper part; few cross sections of brachiopods on surface	30
Mudstone, sandy, purple and maroon, and 2-foot layers of gray sandy limestone interbedded; fossils in limestone	30
Shale, red, calcareous, poorly exposed	25
Sandstone, massive, cross-bedded, deep red, locally mottled with gray-white; layer of limy nodules 10 feet above base	75
Arkose, thin bedded, fine grained	18

	Feet
Rico formation—Continued.	
Limestone, olive-green, coarsely crystalline, fossiliferous	½
Shale and sandstone, deep red; sandstone, feldspathic, medium to coarse grained in beds 3 to 8 feet thick; shale in beds 3 to 10 feet thick	55
Arkose, massive, cliff-forming, deep red to purple, medium to coarse grained; upper 5 feet limy and contains fragments of fossils	40
Shale, vermilion-red, sandy	20
Sandstone, deep red, weathers into bosses	25
Sandstone, shaly, vermilion-red to deep maroon	20
Sandstone and shale, brownish red, interbedded	63
Sandstone, hard, brownish red, banded with gray	25
Limestone, greenish gray, coarsely crystalline	1
Shale, light gray, sandy	10
Limestone, sandy, olive-green to brown on weathered surface, fossiliferous	4
Arkose, deep red to purple, coarse grained	40
Hermosa formation.	
	574½

The Rico formation is conformable on the Hermosa formation—in fact, the lithology of the upper 25 feet of the Hermosa at the Cane Creek anticline, near the southwest corner of T. 26 S., R. 21 E., suggests a gradation between the two formations, as it is composed of thin-bedded red sandstone and shale varying along the outcrop to massive coarse-grained red arkosic sandstone resembling the sediments of the overlying Rico formation, rather than the Hermosa formation. G. H. Girty reports a definite faunal break at the top of the gradational series, however, so it is included in the Hermosa formation. On the map the upper limit of the Rico formation is arbitrarily placed at the top of the "Shafer limestone," which is the highest fossiliferous limestone in a large part of the district. The presence or absence of fossiliferous limestones is the only means by which the Rico and Cutler formations can be separated in the northern part of the district, where the lithology of the overlying Cutler closely resembles that of the Rico formation. At the type locality, in the Rico Mountains, Colo.,[17] the boundary between the Rico and Cutler formations is placed at the top of the highest fossiliferous limestone. The "Shafer limestone," which is bench-forming, is readily traceable over most of its length of outcrop and usually marks the highest fossiliferous horizon. It thins toward the northeast and can not be recognized at the northern limit of the outcrop of the Rico formation along the Colorado River except by the stratigraphic relations of the adjacent beds. Northwest of Moab it has not been possible to differentiate the Rico and Cutler formations. In the southwest corner of T. 26 S., R. 21 E., and along Cane Creek a limestone 45 feet lower in the section is the highest bed in which

[17] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

fossils could be found. Furthermore, in the southern part of the district a limestone 65 to 72 feet above the "Shafer limestone" contains fossils. This upper limestone should be considered the top of the Rico formation in the southern part of the area, for it marks a change in lithology as well as the uppermost fossiliferous horizon. The overlying red beds of the Cutler formation have there changed to the massive Cedar Mesa sandstone member, and the limestone above the "Shafer" is the lower limit of the lithologic change. Below it the typical lithology of the Rico formation persists. The upper limestone is not shown on the map, and the "Shafer limestone" is considered to mark the top of the Rico formation in order to maintain uniformity throughout the map. In many places the upper limestone and the "Shafer limestone" crop out in the same vertical cliff, so that the same outcrop line would answer for both, but where the limestones cross stream courses the upper limestone extends farther up the streams and some confusion may result.

Several limestones in the Rico formation contain marine invertebrate fossils. G. H. Girty reports them to be of Permian age and to correlate in a general way with the Permian of Kansas and the Mississippi Valley. The fauna of the Rico formation includes a large proportion of pelecypods, in contrast with the brachiopod fauna of the underlying Hermosa. On the basis of fossils Mr. Girty correlates the Rico formation in the Moab district with the Rico formation at the type locality in Colorado and also with the interbedded red beds and limestones forming the upper 465 feet of the "Goodridge formation" [18] in the San Juan oil field. The stratigraphic evidence supports this correlation.[19] Prommel and Crum [20] and Harrison [21] believed the Rico formation of the Moab district to be equivalent to the Supai formation of the Grand Canyon region, but the Supai is now considered to be equivalent to the Rico formation plus the lower part of the Cutler formation.[22]

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[18] Woodruff, E. G., Geology of the San Juan oil field: U. S. Geol. Survey Bull. 471, p. 82, 1912. Baker, A. A., Geology of the Monument Valley-Navajo Mountain region, Utah: U. S. Geol. Survey Bull. (in preparation).

[19] Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1413–1448, 1929.

[20] Prommel, H. W. C., and Crum, H. E., Structural history of parts of southeastern Utah: Oil Weekly, vol. 46, pp. 31–34, 42, 1927.

[21] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 115, 1927.

[22] Baker, A. A., and Reeside, J. B. jr., op. cit., p. 1445.

The following fossils have been described by G. H. Girty:

Fossils from the Rico formation

	6013a	5949e	5949a	5919b	5919d	5949c	6011	6012	5947c	5947b	5883e	5883f	5883g	5950	5951	5883i	5947	5947a	5947h	5948	5946	6411	6411a	6411b	6113	6415	5948a	6412	6415a	6416
Fusulina secalica			X																											
Lophophyllum profundum																						X								
Hydreionocrinus? sp																							X							
Stenopora aff. S. carbonaria																	X			X	X									
Stenopora sp					X															X					X					
Fenestella sp											X									X										
Meekopora? sp																									X					
Septopora biserialis?																									X					
Septopora sp																				X										
Dichotrypa n. sp																				X										
Fistulipora sp				X					X		X																			
Polypora sp		X				X					X						?					X								
Rhombopora lepidodendroides						X					X														X					
Rhombopora sp				X													X			X										
Streblotrypa prisca											X																			
Orbiculoidea capuliformis									?																					
Orbiculoidea sp					X						X																			
Derbya bennetti			X		?						X																			
Chonetes granulifer	X																													
Chonetes sp		X																												
Productus cora	X	X		X	X	X					X	X					X			X	X		X	X	X					
Productus pertenuis			X			X					X																			
Pustula nebraskensis		X	X		X	X			X		X						X	X		X	X	X			X					
Pustula symmetrica					X																									
Pustula semipunctata																									X					
Dielasma n. sp																						X								
Marginifera lasallensis					?																									
Spirifer triplicatus					X	X					X									X	X	X			X	X				
Spiriferina kentuckyensis										X															?					
Composita subtilita	X	X		X			X				X						X	X		X	X	X	X	X	X	X				X
Edmondia glabra							?											?												
Edmondia gibbosa					X				X		X									X										
Edmondia aspinwallensis											X																			
Edmondia subtruncata																									X					
Edmondia sp	?					X					?													?						
Allerisma terminale	X	X		X	X	X					X		?		X					X				X	X					
Sanguinolites costatus											?									X										
Sanguinolites n. sp					X																									
Chaenomya? sp											X																			
Nucula levatiformis																	X			X										
Nucula sp		X																												
Yoldia sp							X										X													
Leda arata											X																			
Leda sp		X									?																			
Parallelodon sp		?									X				X					X							X			
Schizodus curtiformis						X														X										
Schizodus curtus							X				?																			
Schizodus meekanus						?																								
Schizodus compressus																		X												
Schizodus wheeleri																				X										
Schizodus sp		?		X												X	X							X			X			
Deltopecten occidentalis	X				X	X					X				X	?	X			X				X	X					
Aviculipecten sp		?			X						X							X		X										
Acanthopecten carboniferus									X		X																			
Pinna peracuta															X					X										
Myalina perattenuata																				X		X								
Myalina subquadrata						?			X									?		X				X						
Myalina recurvirostris																				X										
Myalina wyomingensis																	X													
Myalina permiana																				X										
Myalina kansasensis											X												?							
Myalina swallowi											X														?					
Myalina aviculoides															?															
Myalina sp			X		X					X																				X
Lima retifera	X																													
Lima sp											X																			
Limatula fasciculata	?																													
Pseudomonotis equistriata											X																			
Pseudomonotis kansasensis											X																			
Pseudomonotis subleris											?																			
Pseudomonotis? sp					X																				X					
Pteria longa						X					X																			
Pteria sp																			X											
Monopteria marian?									X																					
Monopteria n. sp.?									X																					
Monopteria sp																				X										
Modiola subelliptica	?																													
Posidoniella? sp											X																			
Pleurophorus aff. P. oblongus																	X													

See reference at end of table.

Fossils from the Rico formation—Continued

	6013a	5949e	5949a	5949b	5949d	5949c	6011	6012	5947c	5947b	5883e	5883f	5883g	5950	5951	5883i	5947	5947a	5947h	5948	5946	6411	6411a	6411b	6413	6115	5948a	6412	6415a	6416
Pleurophorus aff. P. subcostatus																											X			
Pleurophorus subcostatus	?							?											?											
Pleurophorus aff. P. taffi											X																			
Pleurophorus sp					X										X	X									X					
Astartella concentrica																				?										
Astartella subquadrata																	X					X								
Plagioglypta canna															X					X										
Plagioglypta? sp					X																									
Bellerophon crassus											?			?	X	?														
Bellerophon aff. B. majusculus?																														X
Bellerophon sp					X											X						X								
Patellostium sp															X				?											
Pharkidonotus pericarinatus		?													X					X										
Pharkidonotus pericarinatus var. tricarinatus						?					X																			
Pharkidonotus? sp														X		X														
Bucanopsis aff. B. modesta		X																												
Bucanopsis meekana		X		?							?									X										
Bucanopsis aff. B. bella																				?										
Bucanopsis? sp																					X									
Euphemus subpapillosus															?													?		?
Euphemus sp	X													?																
Pleurotomaria sp. a																				X										
Pleurotomaria sp. b																				X										
Pleurotomaria sp	X					X					X				?		X		X			X								
Goniospira sp																											?	?		?
Schizostoma catilloides		?			?						?				?	?	?	X		X					X		?			
Schizostoma n. sp																						X								
Euconospira excelsa							X		?										X			X					?	X	X	
Euconospira? sp														X																
Euconospira missouriensis																									X					
Diaphorostoma remex																			X									X	X	?
Naticopsis deformis																				?	X									
Naticopsis sp															X												X			
Sphaerodoma hallana																				X										
Sphaerodoma aff. S. gracilis																													X	
Bulimorpha chrysalis																				X										
Holopea? sp							X																							
Aclisina sp																			X	X									?	
Euomphalus sp																													X	
Orthoceras sp											X								X											
Pseudorthoceras knoxense											X																			
Nautilus sp							?		X																					
Griffithides sp		X																		X		X			X					
Fish remains				X																										

6013a. Near northwest corner of sec. 31, T. 26 S., R. 21 E.; zone 6 feet thick at base.
5949e. SW. ¼ sec. 31, T. 26 S., R. 21 E.; 24 feet above base.
5949a. Same as 5949e; 24 feet above base.
5949b. Same as 5949e; 35 feet above base.
5949d. Same as 5949e; 160 feet above base.
5949c. Same as 5949e; 200 feet above base.
6011. SE. ¼ sec. 31, T. 26 S., R. 21 E.; 525 feet above base.
6012. SW. ¼ sec. 32, T. 26 S., R. 21 E., 525 feet above base.
5947c. The Slide, on the west side of the Colorado River about 1½ miles above the mouth of the Green River; 40 feet above base.
5947b. Same as 5947c; 303 feet above base.
5883e. Near road from Moab to Thompsons, about 5 miles northwest of Moab; 18 feet above base.
5883f. Same as 5883e; 36 feet above base.
5883g. Same as 5883e; 39 feet above base.
5950. Same as 5883e; 185 feet above base.
5951. Same as 5883e; 345 feet above base.
5883i. Same as 5883e; 345 feet above base.
5947. The Slide, on the west side of the Colorado River about 1½ miles above the mouth of the Green River; "Shafer limestone."
5947a. Same as 5947.
5947h. Same as 5947.
5948. On the Colorado River near the southwest corner of sec. 19, T. 28 S., R. 20 E.; "Shafer limestone."
5946. On the Colorado River in sec. 32, T. 27 S., R. 20 E.; "Shafer limestone."
6411. Canyon of Indian Creek in sec. 1, T. 30 S., R. 20 E.; "Shafer limestone."
6411a. Same as 6411; top bed of "Shafer limestone."
6411b. Canyon of Indian Creek in sec. 2, T. 29½ S., R. 20 E.; lower part of "Shafer limestone."
6413. Canyon of Indian Creek in sec. 4, T. 29½ S., R. 20 E.; "Shafer limestone."
6415. Canyon of Salt Creek about 1 mile above the mouth of Butler Canyon; "Shafer limestone."
5948a. On the Colorado River near the southwest corner of sec. 19, T. 28 S., R. 20 E.; a limestone bed above the "Shafer limestone."
6412. Small canyon draining into Indian Creek from north between Rustler Canyon and the Colorado River; limestone bed 72 feet above "Shafer limestone."
6415a. Canyon of Salt Creek at the mouth of Butler Canyon; limestone bed 65 feet above the "Shafer limestone."
6416. Canyon of Salt Creek about 1¼ miles south of the mouth of Horse Canyon; limestone bed 65 feet above "Shafer limestone."

The marine fossils present in the limestone beds of the Rico formation prove that these beds at least were deposited in marine water, but most of the sediments between the limestone beds are believed to be of continental origin. The source of the sediments clearly lay east of the Moab district, for the sediments become finer grained toward the west, changing from arkosic conglomerates in western Colorado and eastern Utah to predominantly fine-grained sandstone in the southwestern part of the Moab district. The source was probably the pre-Cambrian of western Colorado. The type of bedding and the character of the materials suggest a fluviatile origin and rapid deposition. Apparently there were periodic incursions of the sea upon aggraded plains that extended from the high land to the east. The contact between marine and continental sediments is illustrated in Plate 4, *A*.

CUTLER FORMATION

The Cutler formation, which conformably overlies the Rico formation, crops out in Castle Creek Valley, in Moab Valley west of the Colorado River, and along the Colorado River from the southwestern part of T. 26 S., R. 21 E., to the southern limit of the area. Abrupt changes in the lithology of the Cutler formation occur within the Moab district, making it a critical area in the study of Permian stratigraphy. On the south side of Castle Creek Valley, near its mouth, the Cutler formation is a massive pink to white conglomeratic sandstone whose pebbles consist principally of fresh feldspar. It is there 300 feet thick, with the base not exposed. Farther up Castle Creek Valley and northward along the Colorado River, beyond the limits of the area mapped, where the Cutler formation again appears at the surface, it consists of purple and red coarsely conglomeratic arkosic sandstones. Where it crops out at Moab, west of the Colorado River, it is also a purple and red conglomeratic arkosic sandstone, inseparable on the basis of lithology from the underlying Rico formation. South of Moab, where the Cutler formation first appears at the surface, near the southwest corner of T. 26 S., R. 21 E., it is composed principally of irregularly bedded reddish-brown to purple medium to coarse grained arkosic sandstones with some red shale and mudstone. (See pl. 6, *B*.) It is decidedly finer grained than farther north and weathers into fluted cliffs. Farther south the Cutler contains less conglomeratic sandstone, the purple and red colors become less pronounced, and in the lower part of the valley of Indian Creek it is composed of a series of salmon-red medium-grained sandstones, in part evenly bedded and in part irregularly bedded, with some interbedded grayish-lavender coarse-grained sandstone and in places thin discontinuous cherty limestone beds. South of lower Indian Creek the change in lithology is abrupt, and the greater part of the

Cutler formation becomes a thick, massive medium-grained cross-bedded gray-white sandstone, with a few irregular pink bands. This sandstone, named the Cedar Mesa sandstone member of the Cutler formation,[23] rests directly upon the Rico formation but is overlain by red medium-grained sandstone and mudstone about 100 feet thick (pl. 7, *A*) that is also part of the Cutler formation and immediately underlies the Moenkopi formation. This sandstone and mudstone series is here named the Bogus tongue of the Cutler formation, from its outcrop in Bogus Pocket, in the southwest corner of T. 30 S., R. 21 E. Where the white sandstone is shattered by faults near the junction of the Colorado and Green Rivers, it has weathered into a picturesque series of towers and spires appropriately named The Needles. Elsewhere it weathers in rounded domes, alcoves, arches, sheer walls, and many fantastic shapes.

The following section of the Cutler formation was measured on the north side of Lockhart Canyon in sec. 23, T. 28 S., R. 20 E.:

Section of the Cutler formation in Lockhart Canyon

Moenkopi formation.	
Unconformity.	
Cutler formation:	Feet
Sandstone, arkosic, medium to coarse grained, cross-bedded, alternating hard and soft beds, brownish lavender to brick-red	201
Sandstone, arkosic, coarse grained, cross-bedded, brownish lavender	6
Sandstone, quartzose, thin bedded, reddish brown	17
Sandstone, arkosic, medium grained, brownish lavender	25
Sandstone, quartzose, thin bedded, reddish brown	37
Sandstone, thin bedded, shaly, brownish lavender	11
Sandstone, arkosic, coarse grained, massive, grayish lavender	28
Sandstone, arkosic, thin bedded, brick-red to lavender-brown; interbedded with shaly sandstone and grit; discontinuous thin siliceous limestone at base	28
Sandstone, medium to coarse grained, with some grit, salmon-red	6
Sandstone, quartzose, evenly bedded; brown, weathering brick-red to lavender; weathers to knobby surface	3½
Sandstone, cross-bedded, medium grained, with stringers of quartz grit, salmon-red	33
Sandstone, evenly bedded in part and cross-bedded in part, fine grained to grit, brick-red; weathers with knobby irregularly bleached surface	26
Sandstone, medium grained to quartz grit, salmon-red	31
Sandstone, arkosic, evenly bedded with individual beds cross-bedded, chocolate-brown	7

[23] Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 1443, 1929.

Cutler formation—Continued.	Feet
Sandstone, arkosic, massive, cross-bedded, medium to coarse grained, with stringers of grit, brownish lavender	18
Sandstone, quartzose, medium grained, salmon-red, with irregular splotches of white	27½
Sandstone, micaceous, salmon-red, splotched with white; weathers with knobby surface	21
Sandstone, quartzose, massive, cross-bedded, medium grained, with stringers of quartz grit, salmon-red	55
Sandstone, arkosic, brownish lavender, irregular lower boundary	5½
Sandstone and sandy shale, wine-red to dark lavender-brown	13½
Sandstone, arkosic, cross-bedded, medium to coarse grained and grit, dark lavender-brown	5
Sandstone, quartzose, massive, cross-bedded, medium to coarse grained with stringers of quartz grit, salmon-red	51
Sandstone, arkosic, cross-bedded, medium to coarse grained, dark lavender-brown	10
Sandstone, quartzose, soft, coarse grained, gray	5½
Rico formation. ("Shafer limestone").	
	671½

The thickness of the Cutler formation differs considerably from place to place within the Moab district. It is thinnest at the crest of the anticlines, suggesting that folding occurred at the end of Cutler time and that the Cutler formation was eroded prior to the deposition of the Moenkopi formation. This inference is supported by the presence of an angular unconformity at the top of the Cutler formation in Moab Valley west of the Colorado River, in Castle Creek Valley, and at other places in the region outside of the area discussed in this report. Both the Cutler and the Rico formations are cut out by an unconformity at Moab. At the crest of the Cane Creek anticline, in the northwestern part of T. 27 S., R. 21 E., the Cutler formation is 390 feet thick. Its thickness is 670 feet in sec. 27, T. 29 S., R. 20 E., at the southwest corner of Hatch Point. South of Indian Creek the massive white sandstone is 700 feet thick and is overlain by red beds 100 feet thick. The Cutler formation continues to thicken toward the south, for it is 1,900 feet thick along the San Juan River west of Bluff, 55 miles south of the area.[24]

The correlation of the Cutler formation with the formations of Permian age exposed in the surrounding area has been discussed at length in another paper,[25] but a brief summary may be appropriately given here. In stratigraphic relations and lithology the Cutler of

[24] Baker, A. A., Geology of the Monument Valley-Navajo Mountain region, Utah: U. S. Geol. Survey Bull. (in preparation).

[25] Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologist Bull., vol. 13, pp. 1413–1448, 1929.

the northern part of the Moab district is clearly the Cutler of the type locality in the Rico Mountains.[26] Within the limits of the area here described there is a lateral transition from the arkosic purplish-red conglomeratic sandstones to a massive cross-bedded white quartz sandstone except for a relatively thin band of red sandstone and mudstone that persists above the top of the white sandstone. It has therefore seemed desirable to continue the use of the name Cutler formation to include both the white sandstone and the overlying red beds, recognizing the white sandstone as a member and the red beds as a tongue of the Cutler formation. The white sandstone has been commonly correlated with the Coconino sandstone of the Grand Canyon,[27] but later work has shown that the history of Permian sedimentation was complex, and the simple correlation of the white sandstone with the Coconino sandstone can not be made. The white sandstone of the Moab district is continuous with the white sandstone from which the natural bridges of the Natural Bridges National Monument in White Canyon, southwest of the Abajo Mountains, are carved and is continuous with the massive white sandstone that forms Cedar Mesa, north of the San Juan River near Mexican Hat. The name Cedar Mesa sandstone member is derived from this exposure. In the southern part of the Moab district and at Dark Canyon, west of the Abajo Mountains, the Cedar Mesa sandstone member rests directly upon fossiliferous limestone of the Rico formation, but farther south along the San Juan River more than 400 feet of red beds intervene between it and the Rico formation. These lower red beds have been named the Halgaito tongue of the Cutler formation. The red beds above the Cedar Mesa sandstone member in the Moab district, which have been named in this report the Bogus tongue of the Cutler formation, may or may not be continuous across Elk Ridge west of the Abajo Mountains with the red beds immediately above the Cedar Mesa sandstone member at the Natural Bridges National Monument and in Monument Valley. This series of beds in Monument Valley is named the Organ Rock tongue of the Cutler formation and is there overlain by a massive white sandstone that is continuous with the sandstone which crops out in Canyon De Chelly, Ariz., and which is therefore named the De Chelly sandstone member of the Cutler formation. This sandstone thins northward and disappears approximately at the San Juan River. In Monument Valley the De Chelly sandstone member is overlain by a thin series of red beds named the Hoskinini tongue of the Cutler

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[26] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

[27] Prommel, H. W. C., and Crum, H. E., Structural history of parts of southeastern Utah: Oil Weekly, vol. 46, pp. 31–34, 42, 1927. Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, 1923. Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., jr., Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 785–808, 1927.

formation. A regional study of the stratigraphy has developed the fact that the De Chelly sandstone member is continuous with the Coconino sandstone of the Grand Canyon when correlated through central Arizona, and that the Cedar Mesa sandstone member, which underlies the De Chelly sandstone in Monument Valley and is separated from it by about 500 feet of red beds in the Organ Rock member, is probably continuous with the Coconino sandstone of the Grand Canyon when correlated through southern Utah. It is therefore apparent that two massive white sandstones, which have been correlated with the Coconino sandstone and are continuous with it, were not deposited contemporaneously throughout their extent. In order to avoid confusion in nomenclature from the use of Grand Canyon formational names, all the Permian strata of the Moab district above the Rico formation are designated the Cutler formation, and the individual lithologic units are called members and tongues of the Cutler.

The age of the Cutler formation can be determined only by the age of the inclosing sediments, as no diagnostic fossils have been found in it. Two specimens of fossil plants collected from the lower part of the Cutler formation in Indian Creek Valley near the mouth of Hart Draw were identified by David White as *Pecopteris tenuinervis?*, a form which is common in the Permian red beds of the Southwest but is also present in the Pennsylvanian. Silicified logs were noted at one locality near the center of T. 29 S., R. 20 E. The Cutler formation conformably overlies the Rico formation, of Permian age, and west [28] and southwest [29] of the Moab district the fossiliferous Kaibab limestone of Permian age, overlies strata correlated with the Cutler formation.[30]

UNCONFORMITY BETWEEN CUTLER AND MOENKOPI FORMATIONS

The contact between the Permian and the Lower Triassic in the Moab district is the boundary between the Cutler formation, of Permian age, and the Moenkopi formation, of Lower Triassic age. Through most of the district these two formations appear to be conformable, but locally there is angular discordance, the tilted beds of the Cutler formation having been beveled by erosion before the Moenkopi formation was deposited. Near Moab, on the west side of the Colorado River, the Moenkopi formation overlies the Cutler formation with an angular discordance of 4°, and just above the mouth of the canyon below Moab both the Cutler and the underlying Rico formation are cut out so that the Moenkopi formation rests on

[28] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pp. 69–130, 1929.

[29] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, pp. 199–227, 1922.

[30] Baker, A. A., and Reeside, J. B., jr., op. cit., p. 1431.

Hermosa limestone. In Castle Creek Valley also there is angular discordance between the white conglomeratic sandstone of the Cutler formation and the overlying Moenkopi formation. McKnight[31] observed slight angular discordance at this horizon in the northeastern part of T. 26 S., R. 20 E., on the flank of the Cane Creek anticline. A decrease in thickness of the Cutler formation over the crest of the Cane Creek anticline suggests folding and erosion prior to the deposition of the Moenkopi formation, but no angular discordance was observed on the portion of the anticline east of the Colorado River. A pre-Moenkopi erosion surface has been recognized at many places in the Colorado Plateau,[32] and it probably represents an important break in the sedimentation.

TRIASSIC SYSTEM

LOWER TRIASSIC SERIES

MOENKOPI FORMATION

The Moenkopi is the lowest of the formations of Mesozoic age that crop out in the Moab district. It is one of the softer formations and is usually exposed in the lower half of the long slope extending from the top of the cliffs made by the Cutler formation to the base of the Wingate sandstone. It consists of evenly bedded shale and mudstone with numerous thin ledges of flaggy fine-grained red-brown and gray sandstone. Small seams of gypsum are common, but bedded gypsum is rare. The color and lithology are in most places distinctive, but local variations in lithology sometimes make it difficult to choose the upper and lower contacts with certainty. The color is usually a light chocolate-brown on weathered slopes as contrasted with the bright red of the overlying Chinle formation and the somber maroon of the underlying Cutler formation. Fresh exposures show a fine banding of dark reddish-brown and greenish-gray mudstone and shale with a few ledges of sandstone. (See pl. 5, *A*.) The weathered slopes of the Moenkopi formation are in some places smooth (pl. 5, *B*), but usually are studded with numerous ledges of flaggy sandstone (pl. 4, *B*). Ripple marking is one of the most conspicuous features of the formation. Fossil mud cracks are also present.

The following section of the Moenkopi formation was measured on the southwest corner of Hatch Point, in sec. 27, T. 29 S., R. 20 E.:

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31 McKnight, E. T., personal communication.

32 Dake, C. L., The pre-Moenkopi (pre-Permian?) unconformity of the Colorado Plateau: Jour. Geology, vol. 28, pp. 61–74, 1920. Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–23 1923. Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, 1928. Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1413–1448, 1929.

Section of the Moenkopi formation at the southwest corner of Hatch Point

Shinarump conglomerate.	
Unconformity.	
Moenkopi formation:	Feet
Shale and mudstone, evenly bedded, light chocolate-brown with a few ledges of reddish-brown sandstone; lower part seamed with gypsum	235
Sandstone and shale, thin and evenly bedded, light chocolate-brown; sandstone ripple marked; seams of gypsum abundant and 4-inch bed of gypsum near top	40
Grit; gray quartz grains	½
Shale, sandy, evenly bedded, light chocolate-brown with few thin beds of gray sandstone	18
Sandstone, quartzitic, soft, coarse grained, white	7
Shale and mudstone, chocolate-brown	38
Mudstone, light chocolate-brown, knobby weathering, with occasional ledges of white fine-grained quartz sandstone	120
Unconformity.	
Cutler formation.	458½

The thickness of the Moenkopi formation is variable, ranging from a knife edge to 940 feet. It attains its maximum thickness in the northern part of the area, on the north side of Castle Creek Valley. Like the underlying Cutler formation, it owes its variation in thickness in large part to folding and erosion that preceded the deposition of the overlying beds. In Moab Valley, west of the Colorado River, an unconformity above the Moenkopi formation cuts it out entirely, and it is also absent along the sides of Moab Valley east of the river. In sec. 32, T. 26 S., R. 21 E., at the crest of the Cane Creek anticline, it is only about 200 feet thick, its thinness being due to uplift and erosion prior to the deposition of the overlying beds. The unconformity is well exposed in the valley of Cane Creek in sec. 33, T. 26 S., R. 21 E. (See pl. 6, A.) South of the Cane Creek anticline the thickness is 400 feet in Lockhart Canyon and 460 feet at the southwest corner of Hatch Point.

The age determination of the Moenkopi formation is based upon marine invertebrate fossils collected by E. T. McKnight in Green River Canyon near its junction with the Colorado River and by James Gilluly [33] in the San Rafael Swell. G. H. Girty reports that the fossils collected at these localities are of Lower Triassic age. Collections at both localities were made from limestone. The Moenkopi formation of the Moab district contains no limestone but is directly traceable into the sediments that inclose the fossiliferous limestone in the Green River Canyon. Because the Moenkopi formation can be correlated over a wide area by its lithology, there can

[33] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pp. 86–87, 1929.

be no doubt of its correlation between the Moab district and the San Rafael Swell. In the San Rafael Swell the Moenkopi unconformably overlies the fossiliferous Kaibab limestone, of Permian age, and throughout the region it unconformably underlies the Shinarump conglomerate, tentatively assigned to the Upper Triassic, or the Upper Triassic Chinle formation.

The sediments of the Moenkopi formation were obviously deposited in shallow water and were frequently above water level. Ripple marks of both oscillation and current types are abundant, and fossil mud cracks are common. The remarkably even bedding of the fine-grained sediments suggests accumulation in deep water, but such evidence is overweighed by the presence of the ripple marks and mud cracks. During at least part of Moenkopi time marine limestone accumulated a short distance west of the Colorado River near its junction with the Green River, and some of the beds associated with the limestone are probably also marine, but if such beds extend into the part of the area herein described they were not recognized. It seems probable that the sediments of the Moenkopi formation are terrestrial deposits which accumulated slowly on a broad flood plain sloping very gently toward the sea from higher lands in western Colorado.

UNCONFORMITY AT THE TOP OF THE MOENKOPI FORMATION

An unconformity can be observed at the top of the Moenkopi formation at practically every place where the top is exposed in the southern part of the area and locally in the northern part of the area. Erosion of the Moenkopi formation occurred before the deposition of the overlying beds. In the southern part of the area, where the Shinarump conglomerate is present, the irregular contact between the two formations that are lithologically so different is conspicuous, but in the northern part of the area, where the Shinarump conglomerate is absent and formations somewhat similar in lithology are superposed, the unconformity is generally rather difficult to detect. The relief on the eroded surface of the Moenkopi formation was not observed to exceed 10 feet.

Locally the Moenkopi formation was folded and eroded prior to the deposition of the overlying beds. Angular discordance between the Moenkopi formation and the overlying Chinle formation is well exposed on the walls of the canyon of lower Cane Creek in sec. 33, T. 26 S., R. 21 E., where the Moenkopi dips 11° to 14° more steeply than the Chinle formation on the north flank of the Cane Creek anticline (pl. 6, *A*), and the beveling of the Moenkopi strata results in a thinning of the formation at the top of the anticline. The Cane Creek anticline obviously was raised in part at the end of Moenkopi time. West of the Colorado River at Moab the Moenkopi formation thins from 450 feet to the vanishing point in a distance of about 3 miles, and the Chinle formation rests on Hermosa limestone, of Pennsylvanian age, near the mouth of the canyon where the Colorado River leaves the valley. The thinning is apparently due to folding and erosion before the overlying beds were deposited, but it may be due in part to overlap onto folded older beds. The Moenkopi formation is absent on the northeast side of Moab Valley at the mouth of Mill Creek Canyon, where the Wingate sandstone rests upon Hermosa limestone with a discordance of about 13°. It is not possible to determine how much of the material normally intervening between these two formations was removed during the time represented by the post-Cutler unconformity or the later post-Moenkopi unconformity. The absence of the Chinle formation must of course be explained in other ways, which are discussed on page 40.

UPPER (?) TRIASSIC SERIES

SHINARUMP CONGLOMERATE

The Shinarump conglomerate is well developed in the southern part of the area but is absent or thin and discontinuous north of Lockhart Canyon. Where well developed it forms a conspicuous ledge between the Moenkopi and Chinle formations, as it is composed of resistant sandstone and conglomerate, and where the overlying beds have been stripped back by erosion it forms the flat caps of mesas or platforms above which rise the slopes of the soft Chinle formation. (See pl. 4, *B*.) The sandstone is gray and medium to coarse grained, and both it and the conglomerate are in part quartzitic and contain abundant silicified wood. No carbonized wood was observed. The pebbles of the conglomerate are quartz, basic igneous rock, chert, and sandstone, and the largest are 1½ inches in diameter. North of Lockhart Canyon the horizon of the Shinarump conglomerate is marked by a thin and discontinuous zone composed of poorly cemented gray quartz sandstone and grit. No attempt to map this gray zone was made, as it scarcely more than marks the boundary between the Moenkopi and Chinle formations. At the Big Bend of the Colorado River, about 9 miles above the bridge at Moab, a conglomerate 200 to 300 feet thick forms an inner gorge in the canyon and is shown as Shinarump conglomerate on the map. It consists of rounded quartz pebbles 1½ to 2 inches in diameter embedded in a matrix of buff to reddish-brown quartz sandstone, but within a short distance up the river it grades into a nondescript 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. Bedding in the conglomerate suggests topset and foreset bedding, as inclined beds dipping 12° or more merge with or are truncated by a nearly horizontal bed at the top. The inclined beds dip north in the southern part of the outcrop and southwest in the northern part, but these dips may be components of a uniform northwest dip. Cross[34] included the conglomerate in the Cutler formation, interpreted the beveling of the inclined strata as angular discordance at the top of the Cutler formation, and concluded that 600 to 800 feet of the upper part of the Cutler had been removed by erosion before the overlying beds were deposited. Detailed mapping by the writer has shown that the normal sequence of beds is present in the canyon both above and below this series of beds, and they are therefore interpreted as a local development of the Shinarump conglomerate, and the unusual bedding is ascribed to deltaic deposition. The maximum thickness of the Shinarump conglomerate observed in the southern part of the area is 75 feet.

The following section of the Shinarump conglomerate was measured beneath South Sixshooter Peak, in sec. 6, T. 31 S., R. 21 E.:

Section of Shinarump conglomerate beneath South Sixshooter Peak

	Feet
Chinle formation.	
Shinarump conglomerate:	
Sandstone, soft greenish gray, varying along outcrops to more massive red sandstone; weathers back from top of bench to foot of Chinle slope	16
Sandstone, massive, medium to coarse grained, gray, with streaks of pebbles	28
Conglomerate, massive, gray, with coarse-grained sandstone matrix containing pebbles of quartz, basic igneous rocks. chert, and sandstone; contains silicified logs	28
	72
Unconformity.	
Moenkopi formation.	

The Triassic age of the Shinarump conglomerate is fixed by the Lower Triassic Moenkopi formation below and the Upper Triassic Chinle formation above. It rests upon an eroded surface of the Moenkopi formation, indicating a lapse of time, but it grades upward into the Chinle formation. No fossils that aid in determining its age have been found in the formation in this area, but its relation to the inclosing sediments has led recent writers to consider it a basal conglomerate or introductory phase of the Chinle formation. It is differentiated as a separate formation principally because of its distinctive lithology and topographic expression.

UPPER TRIASSIC SERIES

CHINLE FORMATION

The Chinle formation is the topmost formation of an almost continuous section of red beds about 2,000 feet thick which include the Rico, Cutler, Moenkopi, and Chinle formations. It is exposed on the

[34] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 655, 1907.

slopes immediately below the Wingate sandstone cliffs, and its sinuous outcrop is continuous for many miles along the canyons of the Colorado River and its tributaries. In general appearance the Chinle formation is a shale slope studded with ledges of sandstone not unlike the Moenkopi formation, except that the sandstones in the Chinle formation are more abundant and are more massive and irregularly bedded in the northern part of the area and the color of the Chinle formation is bright red to variegated in tones of red and lavender, as contrasted with the nearly uniform pale chocolate-brown of the Moenkopi formation. In the northern part of the area sandstone is abundant, but it decreases in amount toward the south, and in the valley of Indian Creek the formation is largely composed of shale. (See pl. 4, *B*.)

The Chinle formation is composed of irregularly bedded, poorly assorted sandstone, shale, grit, and conglomerate. The sandstones are usually brick-red and medium to fine grained and locally micaceous. Scattered through the formation are many beds that have a sandstone matrix inclosing rounded pellets about one-fourth inch in diameter which appear to be composed of a sandy and limy mud and make up nearly 50 per cent of the bed. There are numerous beds of true conglomerate with a lime-cemented sandy matrix inclosing pebbles of limestone and quartz. The shale in the Chinle formation is variegated, ranging from dark purplish red to red, brown, and grayish green. It is possible that some of the beds described as shale are composed largely of volcanic ash reworked by water, as bentonite has been recognized in the Chinle formation at several localities.[35] Gypsum is present locally, but it is not common in the formation.

The following section of the Chinle formation was measured on the north side of Lockhart Canyon in sec. 24, T. 28 S., R. 20 E.:

Section of the Chinle formation on the north side of Lockhart Canyon

Wingate sandstone.	
Chinle formation:	Feet
1. Sandstone, fine grained, shaly in part, reddish brown, interbedded with reddish-brown shale; softer beds form smooth slopes between ledges of sandstone	144
2. Shale, pale reddish lavender	21
3. Sandstone, like No. 1	70
4. Sandstone, greenish gray, with pellets of limy mud; contains fossil teeth	1
5. Shale, dull reddish brown	23
6. Sandstone, like No. 4	2

[35] Allen, V. T., Triassic bentonite of the Painted Desert: Am. Jour. Sci., 5th ser., vol. 19, pp. 283-288, 1930. Camp, C. L., A study of the phytosaurs, with description of new material from western North America: California Univ. Mem., vol. 10, pp. 2-3, 1930.

Chinle formation—Continued.	Feet
7. Shale, dark red to lavender, with few thin beds of gray sandstone at base	51
8. Sandstone, gray to purple; contains mud pellets; desert varnish on weathered surface	5
9. Shale, gray to lavender; upper 5 feet contains nodules of sandy lime	102
Shinarump conglomerate.	
	419

Except for local irregularities the thickness of the Chinle formation is fairly uniform. It is 440 feet in South Sixshooter Peak, in sec. 6, T. 31 S., R. 21 E.; 420 feet near the center of T. 29 S., R. 20 E.; 420 feet on the north side of Lockhart Canyon, in sec. 24, T. 28 S., R. 20 E.; 400 feet at the junction of Cane Creek and Hatch Wash, in sec. 6, T. 28 S., R. 22 E.; 430 feet on the south side of Castle Creek near Pace Bros.' ranch; and 480 feet on the opposite side of Castle Creek. Except at the first three localities mentioned a thin representative of the Shinarump conglomerate is included in the Chinle formation at each locality. A measurement at the Big Bend of the Colorado River above Moab gave 740 feet as the thickness of the Chinle, but it now seems probable that some of the Moenkopi formation was included. Irregular thicknesses of the Chinle formation at the Cane Creek anticline, near the southwest corner of T. 26 S., R. 21 E., and in Moab Valley are conspicuous in view of the regularity of thickness elsewhere. At the crest of the Cane Creek anticline, in sec. 32, T. 26 S., R. 21 E., the Chinle formation is 275 feet thick. There is no conspicuous unconformity at the top of the Chinle, but there is marked angular discordance at the base, so the thinning of the formation over the anticline is probably due to the overlap of Chinle sediments upon the beds that were folded into an anticline at the end of Moenkopi time and incompletely eroded prior to the accumulation of the succeeding sediments. At Moab there is an even more striking irregularity in thickness that is probably attributable to the same cause. On the south side of Moab Valley the Chinle formation is about 450 feet thick, and about 2 miles distant on the opposite side of the valley, at the mouth of Mill Creek Canyon, it is absent. Between Mill Creek Canyon and Moab Bridge across the Colorado River it is nowhere more than a few feet thick.

The bedding of the Chinle formation is irregular, with rapid change in lithology and thickness, particularly in the northern part of the area. In the southern part of the area the formation contains more shale and is somewhat more regularly bedded. Fresh-water fossils collected near Moab show that the Chinle formation is a continental deposit, and the character of the sediments and bedding indicates a fluviatile origin. Some of the finer-grained sediments perhaps accumulated on flood plains or in lakes.

The fresh-water fossils were identified by J. B. Reeside, jr., as Unios of long-ranging types. Fragmentary vertebrate remains are frequently found in the Chinle formation, and small collections of bones and teeth were made. C. W. Gilmore reported that these vertebrate remains are characteristic of the Upper Triassic. A more extensive collection of vertebrate fossils from the Chinle formation has been made by Camp [36] in a large area in northeastern Arizona, northwestern New Mexico, and southeastern Utah, including collections from the cliffs on the south side of Moab Valley due south of the town, in the canyon of the Colorado River above Moab, and in the valley of Indian Creek. Camp reports that the numerous collections of phytosaurian remains indicate the Upper Triassic age of the Chinle formation and that ganoid fish scales and bones collected from the Chinle formation a few feet below the base of the Wingate sandstone on the cliffs due south of Moab are unquestionably of Triassic age. Silicified logs are common in the Chinle formation.

CONTACT OF CHINLE AND WINGATE FORMATIONS

An unconformity has been recognized at many localities at the top of the Chinle formation,[37] and it has been referred to as a widespread unconformity,[38] probably marking a break between rocks of Triassic and Jurassic age. Outcrops in the Moab area show conformity at most places. In distant view the contact is a conspicuous lithologic boundary, but detailed examination usually reveals 30 or 40 feet of bedded sandstone at the base of the cliff that could be included with either the Chinle or the Wingate formation. Differences in lithology between the two formations show that the Chinle could not have been an important contributor of materials during the deposition of the Wingate sandstone if there had been an interval of erosion. Furthermore, the bedded sandstone resembles the Wingate sandstone, and the bedding usually becomes less distinct upward, gradually disappearing in the overlying massive sandstone. The writer, therefore, considers that the bedded sandstone indicates continuous deposition and a gradual change from the conditions under which the Chinle sediments accumulated to those under which the Wingate sediments accumulated. The Wingate sandstone appears to be of eolian origin, and the wind-blown sand accumulating upon the fluviatile Chinle sediments would naturally preserve minor

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[36] Camp, C. L., A study of the phytosaurs, with descriptions of new material from western North America: California Univ. Mem., vol. 10, 1930.

[37] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 48, 1917. Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 11, 1923. Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 70, 1928.

[38] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 94, 1929.

local irregularities, even though deposition were continuous in most of the region. In the field the contact was mapped at the base of the cliff-forming sandstones, and in consequence a part or all of the gradational series of beds has been included in the Wingate sandstone at some places.

The strongest evidence for a notable unconformity between the Chinle formation and the Wingate sandstone in this region is the apparent angular discordance exposed on the cliff west of the Colorado River at Moab. There the interval between a massive ledge in the Chinle formation, locally known as the black ledge, and the base of the Wingate sandstone decreases in about 3 miles from approximately 200 feet to 50 feet. The base of the Wingate is marked by a slightly sinuous contact and contains locally a conglomerate of small chert pebbles. This evidence was previously interpreted to indicate a considerable break between the two formations,[39] but later study by E. T. McKnight has shown that the variation in thickness is due to irregularities of sedimentation in the part of the Chinle formation overlying the black ledge and not to erosion prior to the deposition of the Wingate sandstone.

JURASSIC (?) SYSTEM

GLEN CANYON GROUP

The Glen Canyon group is a name proposed by Gregory and Moore [40] to designate the massive Wingate and Navajo sandstone and the intervening beds formerly called Todilto (?) formation but now named Kayenta formation. These three formations are well exposed in the Moab district and are continuous over a wide area. They are conformable, and though their age is only tentatively considered Jurassic, they are so closely related that any evidence that will fix the age of one of the formations will probably fix the age of the whole group.

WINGATE SANDSTONE

The Wingate sandstone is the most conspicuous formation of all those exposed in the Moab district, as it forms a nearly vertical cliff for the full height of its outcrop. The cliffs of Wingate sandstone extend almost uninterruptedly from the northern to the southern limit of the area, following the courses of the river and its tributaries more or less closely north of Lockhart Canyon but diverging from the river in the southern part of the area, where the strata rise toward Elk Ridge and the rocks above the Permian have been eroded. The Wingate sandstone and the lower part of the overlying Kayenta

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[39] Baker, A. A., and others, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 801, 1927.

[40] Gregory, H. E., and Moore, R. C., The Kaiparowits region: U. S. Geol. Survey Prof. Paper 164, p. 61, 1931.

formation usually form the rim of the canyon walls, above which the strata are stripped back on the broad interstream areas of low relief such as Hatch Point and Hart Point. The thickness of the Wingate sandstone is about 300 feet, ranging from 340 feet in upper Indian Creek to 275 feet under Wilson Mesa.

The cliffs of Wingate sandstone are characterized by vertical joints and blue-black to dark-red color, owing to the coating of desert varnish. (See pls. 5, *B*, and 7, *A*.) Stratification is indistinct or absent in distant view. Normal stratification is not conspicuous, even on fresh surfaces, but the sandstone is cross-bedded in long sweeping tangential beds. On a fresh surface it is light red to buff. It is composed of rounded, iron-coated quartz grains of medium size cemented with calcium carbonate. The cliffs normally recede by the breaking away of large blocks which strew the subjacent slopes, but under certain conditions the sandstone disintegrates and forms rounded surfaces that have the color of the fresh rock. The type of weathering producing rounded surfaces is particularly noticeable on the northeast side of Spanish Valley, and the differentiation of the Wingate from the Navajo sandstone is difficult there because they not only have the same color but are brought together by a fault.

The sediments in the lower part of the Kayenta formation resemble the underlying Wingate sandstone except in bedding and the presence in the Kayenta of a small amount of coarser material. They probably represent the deposition in water of reworked material from the upper part of the Wingate sandstone intermixed with some new material. The contact is a gradational one, arbitrarily drawn at the lower limit of distinctly bedded material. At some localities an irregular line at the top of the massive Wingate sandstone suggests an erosional break, but such irregularities are believed to be inherent in continental sediments, and no significance is attached to them.

The correlation of the Wingate sandstone through a large part of the plateau province presents no difficulties, because of its peculiar topographic expression, appearance, and stratigraphic position. Dutton [41] first applied the name in northwestern New Mexico, and later work has shown the continuity of the formation over a large area.[42] Its correlation with the formations exposed in western Colorado, where the Jurassic formations are thin or absent, presents difficulties. Cross [43] correlated the Wingate sandstone with the upper

[41] Dutton, C. E., Mount Taylor and the Zuñi Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 136–137, 1885.

[42] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 53–55, 1917. Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 12–13, 1923. Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation).

[43] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 650, 1907.

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part of the Dolores formation. Gregory later correlated the Wingate sandstone with the "Lower La Plata sandstone," which overlies the Dolores formation, but subsequent work [44] supports the correlation made by Cross. Cross, however, considered the Dolores formation a unit and inferred that Upper Triassic fossils collected from the lower part of the Dolores formation proved the Triassic age of the Wingate sandstone. The only fossils that have been found in the Wingate sandstone are dinosaur footprints observed by Miser [45] in the lower part of the sandstone along the San Juan River. Regional stratigraphic studies suggest the Jurassic age of the Wingate sandstone, but no definite age assignment can be made from present knowledge.

KAYENTA FORMATION

The Kayenta formation conformably overlies the Wingate sandstone. The lower part of the formation usually crops out at the top of the cliffs of Wingate sandstone, forming a cap of irregularly bedded sediments that contrasts with the sheer wall of Wingate sandstone, in which no bedding appears. (See pls. 5, *B*, and 7, *A*.) Back from the canyon rims the Kayenta formation forms a bench from a few feet to a mile or more in width whose surface is a succession of low discontinuous ledges. Cliffs and rounded nubs of the overlying massive Navajo sandstone rise above this platform. The benches commonly support an abundant growth of small pine trees.

The Kayenta formation is composed largely of sandstone with some thin beds of shale, mudstone, and conglomerate. The sandstones are thin-bedded to massive, fine to coarse grained, crossbedded in part, and from gray-white to buff, red, and lavender. The bedding is very irregular, and even the more massive beds can not be traced far along the outcrop. In color and composition the beds in the lower part of the formation resemble the underlying Wingate sandstone, but the higher beds are lighter colored. A pale lavender color is common in the upper sandstones.

The following section of the Kayenta formation was measured on upper Indian Creek in sec. 20, T. 32 S., R. 22 E. (See pl. 7, *B*.)

Section of Kayenta formation at upper road crossing of Indian Creek

Navajo sandstone.	
Kayenta formation:	Feet
1. Shale red, interbedded with thin beds of red sandstone	23
2. Sandstone, massive, pink, medium grained, quartzose	5
3. Sandstone, massive, white, medium grained, quartzose	30

[44] Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 70, 1928. Baker, A. A., Dane, C. H., and Reeside, J. B., jr., op. cit.

[45] Longwell, C. R., and others, op. cit., p. 13.

	Feet
Kayenta formation—Continued.	
4. Sandstone, thin bedded, medium to fine grained, quartzose	18
5. Conglomerate, blue-gray, with pebbles of sandstone and shale	6
6. Sandstone, evenly bedded, medium to coarse grained, white in lower part, red in upper part	33
7. Conglomerate, steel-gray, pebbles of red shale and red sandstone in quartz-sand matrix	7
8. Sandstone, evenly bedded, medium grained, white on fresh surface; forms conspicuous ledge	21
9. Conglomerate, like No. 7	18
10. Sandstone, medium to fine grained, dull pinkish red, more or less evenly bedded; grades into overlying conglomerate	17
11. Sandstone, evenly bedded, medium grained, buff to red, in part cross-bedded; at top sandstone bed with varvelike banding rests on thin bed of red mudstone, which contains nodules of silicified sandstone	93
Wingate sandstone.	
	271

The bedding of the Kayenta formation serves to distinguish it from the inclosing massive sandstones. (See pl. 7, *B*.) The irregularity of the bedding indicates the fluviatile origin of the formation, and a few Unio shells collected near the top of the formation show that the sediments accumulated in fresh water. The bedding of the Kayenta formation, although distinctly different from that of the Wingate and Navajo sandstones, does not terminate at a sharp contact but both at the top and bottom grades into the more massive bedding of the inclosing sandstones. As described in this report the Kayenta formation includes all the bedded rocks between the two massive sandstones and perhaps includes more beds than are usually assigned to it by other geologists. Also, the upper limit of the pale-lavender sandstones was used as an aid in defining the Kayenta-Navajo contact. The close agreement of several measurements of thickness in the Moab area shows that the boundaries as selected and mapped are fairly constant. The thickness ranges from 230 to 270 feet.

The name Kayenta formation has recently been introduced in the literature [46] to supplant Todilto (?), the name by which this formation has been known for many years. In describing the geology of the Navajo Indian Reservation Gregory applied the name Todilto to a limestone which crops out above the Wingate sandstone at Todilto Park, N. Mex., and farther to the southeast.[47] He suggested as a

[46] Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation).

[47] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 55, 1917.

"working field hypothesis" the correlation of the limestone with the stratified sandstone that appears toward the northwest between the Wingate and Navajo sandstones. Later workers have traced this stratified unit over a large part of the Colorado Plateaus, and the name Todilto (?) formation has been used for several years pending further study to determine its relationship to the Todilto limestone. Recent stratigraphic studies have apparently shown [48] that the Todilto limestone is not equivalent to the stratified unit but is much younger. The new name Kayenta formation has therefore been substituted for Todilto (?) formation, because of the excellent exposures near Kayenta, Ariz.

The age of the Kayenta formation is probably Jurassic, but no fossils that permit a definite age assignment have yet been found in it or the inclosing formations. Three collections of fossils from the Kayenta formation near Cane Creek, below Cane Springs, were described by J. B. Reeside, jr., as internal casts of long-ranging types of Unios resembling *U. dumblei*, *U. dockumensis*, and *U. irioides*. These are the first fossils found in this formation to indicate that the containing beds are fresh-water deposits. Gregory found dinosaur tracks in the Kayenta formation at two localities in the Navajo Reservation in Arizona.[49] Prof. R. S. Lull studied measurements and photographs of these prints and reported that they are not older than the latest Triassic. Dinosaur tracks have been collected from the Kayenta formation in the Green River Desert [50] but have not been studied.

NAVAJO SANDSTONE

The Navajo sandstone is the upper massive sandstone of the Glen Canyon group. It weathers by disintegration, and its exposures are usually rounded surfaces (pl. 7, *B*) which rise above a platform that is floored by the Kayenta formation. In some places the three formations—Wingate, Kayenta, and Navajo—produce a single escarpment, as on the southwest side of Spanish Valley. The sand formed by the disintegration of the Navajo sandstone is piled into dunes by the wind, and this sandstone seems to supply most of the dune sand, as the dunes are most abundant near its outcrop. Several thin beds of limestone of local extent, which range from a few inches to 4 or 5 feet in thickness, are very resistant to erosion and consequently cap small flat-topped buttes or mesas. These mesas are characteristic of the outcrop of the Navajo sandstone in the Moab area.

The sandstone of the Navajo is highly cross-bedded (pl. 8, *A*) and has long been considered by many geologists to be of eolian origin.

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[48] Baker, A. A., Dane, C. H., and Reeside, J. B., jr., op. cit.

[49] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 56, 1917.

[50] Baker, A. A., Geology of the Green River Desert and the east side of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. (in preparation).

The intricate cross-bedding, which is accentuated by the etching effect of weathering, aids in the identification of the sandstone as Navajo, but its identification can not be based alone upon cross-bedding, for other massive sandstones are also more or less cross-bedded. Local lenses of thin normally bedded red sandstone or mudstone are found in places in the Navajo sandstone and are clearly due to sorting and bedding by water. The mass of the sandstone is light gray to buff medium-grained friable quartz sand cemented by calcium carbonate. Its thickness is 360 feet below Wilson Mesa, 345 feet in Cane Creek below Cane Springs, and 430 feet in upper Indian Creek.

No fossils have been found in the Navajo sandstone, but together with the Kayenta formation and Wingate sandstone it is tentatively considered of Jurassic age. The overlying Carmel formation is known by its fossils to be Upper Jurassic.

The Navajo sandstone is continuous over a large part of the Colorado Plateaus, and though correlation can not be based upon fossil evidence the lithologic character and stratigraphic sequence permit no doubt that the name has been applied to a continuous unit in northeastern Arizona and southeastern Utah. Its correlation with the "La Plata sandstone" of southwestern Colorado, however, has long been uncertain. Cross [51] correlated the sandstone now known as the Navajo sandstone with the "Lower La Plata sandstone." Gregory [52] correlated the Navajo sandstone with the "Upper La Plata sandstone" of Cross. Gilluly and Reeside [53] correlated the Navajo sandstone with the "Lower La Plata" of Coffin [54] and on the authority of Lee [55] stated that it occurred in the type "La Plata" of the San Juan Mountain region. Stratigraphic studies in connection with the detailed mapping in southeastern Utah have shown [56] that the Navajo sandstone thins out before reaching the type locality of the "La Plata sandstone" and that the entire "La Plata sandstone" at the type locality is younger than the Navajo sandstone.

UNCONFORMITY (?) AT THE TOP OF THE NAVAJO SANDSTONE

The red sediments of the Carmel formation, which elsewhere contains marine fossils,[57] were deposited on a slightly irregular floor of Navajo sandstone. This Navajo surface does not have high relief, as there is little variation in thickness of the thin Carmel formation,

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[51] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 644, 1907.

[52] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 52, 1917.

[53] Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and adjacent areas in Utah: U. S. Geol. Survey Prof. Paper 150, p. 73, 1928.

[54] Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geol. Survey Bull. 16, pp. 61–76, 1921.

[55] Lee, W. T., U. S. Interior Dept. Press Mem. 6064, Mar. 30, 1926.

[56] Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation).

[57] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 100, 1929.

but in Dry Valley, near the head of Tank Draw and at a locality 2½ miles farther east, the red Carmel sediments are cut out where they overlap on low swells on the Navajo surface. The relief on the top of the Navajo sandstone may indicate erosion prior to the deposition of the Carmel formation, but it seems equally probable that the red water-laid sediments were deposited upon a surface of slight irregularity that represented the somewhat modified surface of the wind-blown sand. A reddish-brown bed 1 to 2 feet thick composed of sandstone and differing from the overlying mudstones of the Carmel formation is usually present at the contact and possibly represents reworking of unconsolidated Navajo sand involving some planation of irregularities of the surface. The slight relief at the top of the Navajo sandstone does not necessarily indicate erosion and elapse of time prior to the deposition of the Carmel formation.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

SAN RAFAEL GROUP

The name San Rafael group was applied by Gilluly and Reeside [58] to the succession of marine Upper Jurassic formations that crop out in the San Rafael Swell and includes, in ascending order, the Carmel, Entrada, Curtis, and Summerville formations. The Curtis formation is absent in Utah east of the Colorado River, but the other formations of the group are present and are described below.

CARMEL FORMATION

The Carmel formation is represented in the Moab district by red beds, which form a soft zone between the massive Navajo and Entrada sandstones and which usually cause a bench to be formed between these two sandstones. It is composed of soft red thin-bedded sandstone, mudstone, and sandy shale, locally containing some thin cherty limestone and small chert nodules. A distinctive feature of this formation is the wavy or crinkled bedding, which is locally reflected in the base of the Entrada sandstone and makes it difficult to determine an exact boundary between them. The observed thickness of the Carmel formation ranges from 20 to 70 feet, but owing to the difficulty of selecting the boundary in the midst of the crinkled beds, it is possible that some of the Entrada sandstone has been included where the greater thicknesses were observed.

No fossils have been found in the Carmel formation in the Moab district, but it is known to be continuous with the Carmel formation of the San Rafael Swell, where it contains marine invertebrate fossils of

[58] Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 73, 1928.

Upper Jurassic age.[59] At least part of the formation of the San Rafael Swell is therefore of marine origin, and it is probable that the red beds that make up the formation in the Moab area accumulated near the southern limit of the marine invasion. Minor irregularities within the Carmel formation locally suggest an erosional unconformity, but such irregularities are due to the crinkly bedding and do not represent periods of erosion. The writer believes that sedimentation was essentially continuous across the Carmel-Entrada boundary.

The Carmel formation of southeastern Utah was correlated with the "Middle La Plata limestone" of southwestern Colorado by Cross,[60] and this correlation was accepted by several later workers, but the Carmel formation is now known to be older than the "La Plata sandstone" of southwestern Colorado as defined by Cross and to be absent in the San Juan Mountains.[61]

ENTRADA SANDSTONE

The Entrada sandstone, like the Wingate and Navajo formations, is a massive sandstone. The lower part commonly forms a continuation of the gentle slope or bench formed by the Carmel formation, but the greater part of the sandstone crops out in steep cliffs. The Entrada sandstone has been eroded from most of the area but is well exposed along the eastern margin. It forms the steep face of Wilson Mesa and many odd-shaped erosion remnants and isolated mesas in Dry Valley. The upper 2 feet of the Entrada sandstone where it is exposed on Wilson Mesa is locally impregnated with a large amount of iron oxide, and it is the resistance to weathering of this part of the sandstone that has caused the development of the mesa.

The Entrada sandstone is cross-bedded and massive, with no partings of finer-grained sediments. It is composed of medium-sized rounded quartz grains with a weak cement of calcium carbonate. In the northern part of the area it is divisible into two parts (pl. 8, *B*), but toward the south the difference between the two parts is less marked. The upper part is a single massive cross-bedded grayish-white bed 90 to 100 feet thick and separated from the rest of the Entrada sandstone by a definite bedding plane. This part of the formation has been named Moab tongue,[62] the name Moab having been first applied to it by Lee.[63] The main part of the Entrada sandstone is 260 to 300 feet thick exclusive of the Moab tongue. It is banded orange-colored and white through most of the area (pl. 8, *B*), but near

[59] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 100, 1929.

[60] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, 1907.

[61] Baker, A. A., and others, Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation).

[62] Baker, A. A., and others, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, No. 8, pp. 785-808, 1927.

[63] Lee, W. T., unpublished manuscript.

the rim of Castle Valley it becomes dominantly pink. The sandstone is intricately cross-bedded but not on the large scale of the cross-bedding in the Navajo and Wingate sandstones. Normal bedding planes approximately mark the limits of the individual color bands and also separate sets of tangential laminae. Rows of pits ranging in width from a few inches to 10 feet or more follow the bedding planes and are perhaps the most distinctive feature of the outcrop of the lower part of the Entrada sandstone.

The age of the Entrada sandstone can not be determined in the Moab area, but in the San Rafael Swell it lies between strata that contain marine invertebrate fossils of Upper Jurassic age.[64] The Entrada sandstone has commonly been correlated with the "Upper LaPlata sandstone" of the San Juan Mountains in Colorado,[65] but recent stratigraphic studies have shown that it is equivalent to the "Lower La Plata sandstone."[66]

CONTACT OF ENTRADA AND SUMMERVILLE FORMATIONS

The contact between the Entrada sandstone and the overlying Summerville formation appears to be a conformable one in the Moab district. The top of the Entrada sandstone shows no relief; but where a large area of the upper surface is exposed on Wilson Mesa, it is indurated by a high concentration of iron oxide, suggesting that the surface may have been exposed to weathering prior to the deposition of the Summerville formation. This condition was not observed elsewhere in the area. That no considerable time break occurs at this horizon is best attested by the stratigraphic relations that have been observed at other places. In the southern part of the area here described the Moab tongue can not be sharply separated from the rest of the Entrada sandstone. Toward the north and northwest the two parts of the formation are separated by a well-defined bedding plane, and west of the Colorado a thin shale parting appears at this horizon. E. T. McKnight reports that toward the west the Moab tongue decreases in thickness and finally disappears as the underlying shale parting thickens and becomes identical in lithology with the Summerville formation. Such changes in the stratigraphy show that in different parts of the region there was contemporaneous deposition of Entrada sandstone and red beds of the Summerville formation. In the San Rafael Swell a marine formation named the Curtis separates the Entrada sandstone and the Summerville formation.

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64 Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pp. 99-108, 1929.

65 Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 644, 1907. Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 78, 1928. Lee, W. T., and Boyer, W. W., Possibility of finding oil in southeastern Utah and southwestern Colorado: U. S. Dept. Interior Press Mem. 6064, March 30, 1926. Baker, A. A., and others, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists, vol. 11, p. 804, 1927.

66 Baker, A. A., and others, Correlation of the Jurassic formations of portions of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper (in preparation)

McKnight observed that the Curtis formation grades laterally into the Summerville formation near Dellenbaugh Butte, on the Green River. Although the Curtis formation is absent in the Moab district, its absence is not due to unconformity or overlap but is the result of different conditions of sedimentation. Apparently the Entrada, Curtis, and Summerville formations represent, in part at least, contemporaneous marine, littoral, and continental sediments.

SUMMERVILLE FORMATION

The Summerville formation as here identified is a thin formation resting upon the Entrada sandstone and like the Entrada has been eroded from most of the area. It crops out only in the eastern part of the area, principally between Dry Valley and Castle Creek Valley. It has been correlated with the thick and distinct Summerville formation in the San Rafael Swell.

It is composed of red sandy mudstone, fine-grained sandstone, and shale in which large chert nodules are embedded. The chert is peculiar to this formation and serves to distinguish it from all other formations that crop out in the Moab area. It is gray-white to red and occurs in spherical or elongated masses. The spherical masses are usually 3 to 8 feet in diameter, and the elongate masses may be 20 feet or more wide and have a maximum thickness of about 10 feet. These masses are abundant and are practically everywhere present, even in small exposures of the formation. The Summerville formation usually forms a gentle slope at the top of the cliff of Entrada sandstone, and the resistant chert forms hummocks upon the slope. Here and there layers of blue-gray limestone a few inches thick are interbedded with the red beds, but no limestone was observed in association with the chert. The thickness of the formation ranges from 25 to 65 feet.

The relation of the Summerville to the adjacent formations has been discussed in part in connection with the upper contact of the Entrada formation. The top of the Summerville is placed at the base of the first ledge of white sandstone in the Morrison formation, which was deposited on an uneven surface that may represent an erosional unconformity of more than local extent. The red sandstones and mudstones interbedded with the white sandstone ledges of the lower Morrison are similar to the material forming the body of the Summerville formation, and this apparent unconformity may be of no more significance than several other irregular contacts in the irregularly bedded overlying material. Elsewhere in southeastern Utah [67] this contact is marked by a pronounced unconformity, and it is inferred, therefore, that the unconformity at this horizon in the Moab district is more significant than is indicated by local evidence.

[67] Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 81, 1928.

The age of the Summerville formation is Upper Jurassic. This determination is based upon the lateral gradation of part of the Summerville formation into the fossiliferous Curtis formation as reported by McKnight and upon the fact that a tongue of the Entrada sandstone extends into the Summerville formation. Both the Curtis and Entrada formation are known to be of Upper Jurassic age where they crop out in the San Rafael Swell.[68]

CRETACEOUS (?) SYSTEM

LOWER CRETACEOUS (?) SERIES

MORRISON FORMATION

The Morrison formation is exposed near the eastern margin of the area, but except for a capping on a few isolated mesas its outcrop is confined to a small area between Dry Valley and Castle Creek Valley. Together with the thin Summerville formation at the base, it forms the slope between the top of the Entrada sandstone cliff and the base of the ledge-forming Dakota (?) sandstone. The formation is divisible into two parts, which are not sharply divided. The lower part, the Salt Wash sandstone member, consists of irregularly bedded sandstone interbedded with red mudstone and shale, and the upper part consists largely of variegated shale. Lupton [69] first applied the name Salt Wash sandstone to a gray coarse-grained conglomeratic sandstone about 350 feet below the top of the "McElmo" formation in the Green River Desert. The name "McElmo formation" had been applied in so many different ways that Gilluly and Reeside [70] extended the name Morrison formation into this region to include the strata that lie between the Summerville formation and the Dakota (?) sandstone in the San Rafael Swell and abandoned the name "McElmo formation." Lupton's name Salt Wash sandstone was retained for the lower member of the Morrison formation. The total thickness of the Morrison formation is 540 to 565 feet.

The Salt Wash sandstone member consists of white conglomeratic sandstones interbedded with red sandy mudstones and red shale. (See pl. 8, *B*.) The white sandstones are medium to coarse grained, cross-bedded in part, irregularly bedded, and composed of rounded quartz grains cemented with calcium carbonate. The pebbles in the conglomeratic zones are varicolored chert. In places silicified logs are embedded in the massive sandstones. The sandstones are locally impregnated with vanadium minerals and the yellow uranium mineral carnotite. Several small mines and prospect pits have been opened on these beds. The thickness of the Salt Wash sandstone member is about 250 feet, but its upper limits are indefinite and variable.

[68] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pp. 102–108, 1929.

[69] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, p. 127, 1914.

[70] Gilluly, James, and Reeside, J. B., jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 82, 1928.

The upper part of the Morrison formation is largely shale variegated in red and greenish-gray tones. Interbedded with the shale and subordinate in amount are gray silicified sandstone and conglomerate. The conglomerate consists of varicolored chert pebbles embedded in a matrix of silicified white sandstone. The overlying Dakota (?) sandstone also contains pebbles of chert, but the prevalence of varicolored chert pebbles in the Morrison conglomerates is in contrast with the black and gray pebbles in the Dakota (?) sandstone.

The following section measured on the north side of Coyote Creek shows the character of the Morrison sediments:

Section of Morrison formation north of La Sal-Moab road in sec. 3, T. 29 S., R. 23 E., and sec. 34, T. 28 S., R. 23 E.

	Feet
Morrison formation (top uncertain because of faulting):	
1. Shale, variegated, poorly exposed	225
2. Sandstone, soft, white, with conglomeratic zones; pebbles in conglomerate composed largely of black, red, green, yellow, and orange-colored chert with maximum diameter of one-half inch	17
3. Shale, variegated, interbedded with thin ledges of white friable medium-grained sandstone	60
4. Sandstone, coarse grained, white, friable, with some greenish clay nodules	27
5. Shale, variegated, interbedded with white sandstone, some of which is friable and some silicified	11
6. Sandstone, white, friable	10
7. Shale, variegated, interbedded with white friable and red sandstones	33
8. Sandstone, massive, coarse grained, friable, irregularly bedded	13
9. Shale, variegated, with sandstones interbedded in thin beds	7
10. Sandstone, like No. 8	33
11. Sandstone, thin bedded, red and white, interbedded with red shale	11
12. Sandstone, cross-bedded, medium grained, friable	8
13. Shale, red, interbedded with red sandstone; contains thin nodular bed of purplish-red limestone	10
14. Sandstone, white, medium grained, friable except where locally silicified; contains some interbedded red sandstone	12
15. Shale, red, interbedded with red sandstone	22
16. Sandstone, cross-bedded, medium to coarse grained, friable, white, with some conglomeratic streaks	12
17. Mudstone, red	21
18. Conglomerate; matrix consists of medium-grained friable white sandstone with pebbles of varicolored chert one-fourth inch or less in diameter irregularly distributed through it	33
Unconformity.	
Summerville formation.	565

The Morrison formation is separated from the overlying Dakota (?) sandstone by an erosional unconformity which has been recognized over a wide area in southeastern Utah, though no angular discordance was noted in the Moab area. The formation is tentatively classified as Cretaceous (?) by the United States Geological Survey, but a recent reconsideration of the vertebrate fossils that have been collected from the formation at many localities indicates that the formation is of Upper Jurassic age.[71] The Morrison formation is believed to have originated as flood-plain deposits.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

DAKOTA (?) SANDSTONE

The Dakota (?) sandstone is exposed near the eastern margin of the area, between Coyote Wash and Pack Creek, principally in T. 28 S., R. 23 E. It usually crops out as an irregularly bedded ledge at the top of the slope made by the Morrison formation. The ledge forms the rim of a broad platform or bench. (See pl. 9, *A*.) The upper part of the sandstone commonly weathers back from the ledge and is poorly exposed on the nearly flat surface of the bench.

The formation is composed largely of buff to gray-white sandstone and is irregularly conglomeratic, with pebbles of black and gray chert 2 inches or less in diameter. Locally the sandstone has a siliceous cement, but within short distances along the outcrop it changes from a hard quartzite to a soft friable sandstone with calcareous cement. The sandstones range from massive and cross-bedded to thin-bedded and platy. Some gray shale is interbedded with the sandstone, and locally thin lenses of red shale are present. Thin lenses of black carbonaceous shale were observed near the top of the formation at several localities, but no coal was included in it. In some places a thin bed of cherty blue-gray limestone occurs in the formation. The total thickness of the Dakota (?) sandstone is 100 to 180 feet. The variation in thickness is probably due to irregularity of the lower contact. At the upper contact the Dakota (?) sandstone is gradational into the Mancos shale.

Owing to the wide bench developed on the Dakota (?) sandstone and the poor exposures of the upper part of the formation it is difficult to find satisfactory sections for measurement. The following section, measured near the head of Muleshoe Wash, is typical of the formation:

[71] Simpson, G. G., Age of the Morrison formation: Am. Jour. Sci., 5th ser., vol. 12, p. 214, 1926.

Section of the Dakota (?) sandstone in sec. 15, T. 28 S., R. 23 E., in upper Muleshoe Wash

	Feet
Mancos shale.	
Dakota (?) sandstone:	
Sandstone, quartz, yellow weathering, cross-bedded, with siliceous cement; locally contains black chert pebble conglomerate	33
Poorly exposed but mostly a thin-bedded sandstone	29
Shale, gray	5
Sandstone, gray, thin-bedded, calcareous cement; contains streaks of black chert pebble conglomerate	70
Limestone, gray, cherty	5
Sandstone, gray-white, siliceous cement; contains streaks of black chert pebbles	38
Unconformity.	180
Morrison formation.	

The Dakota (?) sandstone is believed to be in large part of continental origin. No fossils except a few impressions of unidentified leaves were found in it in this area, but typical Dakota plants have been collected from the sandstone in near-by areas,[72] which fix the age of the formation as Upper Cretaceous. The stratigraphic evidence supports this age determination, as the Dakota (?) sandstone grades upward into the Mancos shale, of Upper Cretaceous age, and is separated from the underlying rocks by an erosional unconformity.

MANCOS SHALE

The Mancos shale is incompletely exposed in this area. It crops out above the Dakota (?) sandstone bench in the eastern part of T. 28 S., R. 23 E., and in synclinal areas in T. 27 S., R. 23 E. The Mancos shale is soft and easily eroded, but its remaining outcrops are in large part protected by a cover of younger gravel.

About 800 feet of the Mancos shale is exposed in the area. The greater part of it consists of a homogeneous steel-gray marine shale, but in upper Pack Creek, where the maximum thickness is exposed, it includes a ledge of yellow sandstone composed of medium-grained angular quartz fragments cemented with calcium carbonate. The ledge of sandstone is 160 feet thick and is about 600 feet above the base of the Mancos shale. Its exact stratigraphic position is not accurately known, because steep dips and faulting obscure the relationships near its outcrop. The sandstone is correlated with the Ferron sandstone member of the Mancos shale of the San Rafael Swell region on the basis of a small collection of invertebrate fossils made at the top of the sandstone and determined by J. B. Reeside, jr.

[72] Richardson, G. B., Reconnaissance of the Book Cliffs coal field: U. S. Geol. Survey Bull. 371, p. 14, 1909.

TERTIARY (?) SYSTEM

The ridge between upper Pack Creek and upper Cane Creek, which rises toward the La Sal Mountains, is capped with cemented gravel resting on folded Mancos shale. The gravel is composed of poorly sorted material with a coarse-grained sandy matrix inclosing angular to rounded pebbles of sandstone and igneous rock. The sandstone in the pebbles is of a type common in the Mesozoic sediments that were uptilted during the elevation of the La Sal Mountains. The pebbles of igneous rock are deeply weathered, and although no attempt was made to compare them with the igneous rock of the La Sal Mountains, they doubtless came from these mountains.

The material in the gravel ranges from pebbles a fraction of an inch across to boulders several feet in diameter, but most of the rock fragments and pebbles are less than 6 inches in diameter. The thickness of the gravel ranges from a knife edge to 300 feet. The top of the gravel-covered ridge is 600 to 750 feet above the level of Pack Creek and rises from an altitude of 6,140 feet in sec. 21, T. 27 S., R. 23 E., to 7,150 feet in sec. 25 of the same township. The small size of the area occupied by the gravel suggests that it was either a small alluvial fan or valley fill that was more resistant to erosion after cementation than the soft shale beneath it and was preserved when continued erosion carved valleys into the softer material.

The age of the gravel can not be definitely determined, but it is believed to be Tertiary. The gravel may be of approximately the same age as other gravel deposits in the area that are considered to be of Quaternary age, but differences in lithology and the position of the gravel on a high ridge rising on the flanks of the La Sal Mountains suggest that the gravel between Cane and Pack Creeks is older than the gravel assigned to the Quaternary. The gravel deposits at most of the other localities in the Moab district are thin and uncemented and contain pebbles of fresh igneous rock. None of these criteria are necessarily significant in determining the relative age of the gravel deposits, for conditions under which they accumulated might account for such differences, although the deep weathering and decay of the rounded pebbles of igneous rock suggest longer exposure to weathering after deposition. The deposit between Cane and Pack Creeks forms a slope extending high on the flanks of the La Sal Mountains and apparently represents outwash material that accumulated soon after the uplift of the mountains, probably early in Tertiary time, and at an early stage in the development of the drainage from the mountains.

Deposits of unconsolidated gravel, not shown on the map, cap ridges of Mancos shale south of upper Cane Creek. (See pl. 9, *A*). The gravel-covered ridges rise toward the La Sal Mountains and are clearly portions of outwash plains adjacent to the mountains. The gravel is similar in lithology to the gravel on the ridge between Pack and Cane Creeks and is probably of the same age.

A bed of grayish-pink caliche about 1 foot thick caps one of a group of three outliers of Entrada sandstone at the northwestern limit of the outcrop of that formation on Hatch Point. It lies at the crest of the divide between Hatch Wash and Indian Creek at an altitude of 6,300 feet above sea level, although the point which it caps is not the highest point on the divide. Possibly the caliche was developed locally, but because similar deposits have been observed at widely separated localities in the portion of Utah adjacent to the Moab district, they may perhaps mark the remnants of a widespread surface. In the Green River Desert caliche has been observed by the writer at many places, where it clearly indicates remnants of an old erosion surface, and it has been observed by E. T. McKnight west of Courthouse mail station, northwest of Moab. Below this supposed widespread surface the canyon of the Colorado River near the junction of the Green has been cut nearly 2,500 feet.

QUATERNARY SYSTEM

Unconsolidated gravel and alluvium are common along the larger valleys. The deposits of gravel cap mesas and floor rock-cut terraces and some of the valleys, such as Spanish and Castle Creek Valleys. They are composed of pebbles of igneous rock derived principally from the La Sal and Abajo Mountains. No attempt was made to map the deposits or to differentiate those at the various levels. Only the larger areas of alluvium are shown on the map; small areas occur along the Colorado River, Cane, Indian, and Salt Creeks, and other streams, but are not shown.

Some information on the depth of the alluvium in Moab Valley and at several places along the Colorado River is given by several drill holes. A well in Moab Valley in sec. 12, T. 26 S., R. 21 E., passed through 30 feet of soil and 170 feet of quicksand before reaching bedrock. Another well in sec. 34, T. 25 S., R. 21 E., in Moab Valley near the cliffs west of the river, passed through 56 feet of alluvium. A well near the river south of Moab, in sec. 25, T. 26 S., R. 20 E., passed through 30 feet of surface wash. A well in sec. 31, T. 26 S., R. 21 E., on the bank of the river, passed through 55 feet of sand and gravel. Another well on the bank of the river, in sec. 16, T. 27 S., R. 20 E., passed through 30 feet of surface wash. The well in sec. 12, T. 26 S., R. 21 E., near the middle of Moab Valley, passed through a considerable thickness of alluvium, but the other wells, located near the sides of the valleys and those near the base of steep cliffs, penetrated, as noted above, smaller thicknesses of alluvium.

Four holes were drilled by the United States Reclamation Service in the bed of the Colorado River just below its junction with the

Green River in connection with a study of a proposed dam site at that locality. The holes that were drilled below and within half a mile of the junction went to depths between 90 and 124½ feet without reaching bedrock.[73]

The Colorado River throughout the greater part of its course through the Moab district flows upon an alluvial fill of sand, clay, and gravel. It does not necessarily follow that the Colorado is an aggrading stream and that the fill is increasing in thickness, for the fill may be deposited only temporarily in its present position. The capacity of the stream to carry the load of material available for transportation must be evaluated for a long period of years. Each storm, particularly in the arid parts of the drainage basin, sends torrents down tributary streams that are dry or have only a small flow during most of the year, and great quantities of silt and gravel are dumped into the river. In normal stages of the river it is unable to carry away this material, but between floods from tributary streams the material is gradually distributed and temporarily deposited along the bed of the river. Several times each year floods in the river give it added carrying capacity, and much of this material is moved downstream. Unusually high floods in the river, which occur at wide intervals, may move all the material down to bedrock, and the canyon may then be deepened by the abrasive action of the moving material. As the flood recedes and its carrying capacity decreases the moving débris comes to rest and the smaller volume of water again flows over alluvial material. On the assumption that the entire thickness of alluvial material is moved intermittently and that at such times the canyon is consequently deepened, the river is a degrading stream, although most of the time the water flows over alluvial fill.

That the net result of slow aggradation and periodic degradation of the river bed is a deepening of the canyons is demonstrated by the character of the beds of the tributary streams. If the river had ever been at a much lower level than it is at the present time, most of the larger tributary streams would have cut canyons down to that former level. Subsequent aggradation of the river bed would cause the tributary streams likewise to aggrade their beds. If this were true large areas of deep alluvial fill should be present in the lower stretches of these tributary canyons, but most of these streams have only a thin deposit of alluvial material, and bedrock is common along their courses almost to their junction with the river. It seems apparent that the present level of the lower stretches of the tributary streams represents practically the maximum depth to which their canyons have been cut and that the level of the Colorado River has never been materially lower than it is at the present time.

[73] U. S. Recl. Service Fifteenth Ann. Rept., p. 515, 1916.

IGNEOUS ROCKS

The igneous rocks exposed in the Moab district are restricted to a single mass that crops out in the middle of Castle Creek Valley in sec. 22, T. 25 S., R. 23 E., although the intrusions of igneous rock in the laccoliths of the La Sal and Abajo Mountains are just beyond the east and south borders of the area, respectively. The mass of igneous rock in Castle Creek Valley is a nearly circular pluglike body about 1,500 feet in diameter, which rises several hundred feet above the valley floor. The rock is a gray-white soda trachyte with a fine-grained groundmass, consisting principally of soda-rich plagioclase feldspar of albite-oligoclase composition, with phenocrysts of green hornblende, augite, soda-rich feldspar, and small amounts of apatite, titanite, and magnetite. Some secondary calcite is present.

STRUCTURE

GENERAL FEATURES

The rocks of the Moab district are compressed into numerous folds and are broken by many small normal faults. Several of the folds and faults are approximately parallel and trend about N. 50° W., but some of the folds and many of the faults vary from this dominant trend. Most of the folds are low regular anticlines or domes and shallow synclines, but others, particularly along Spanish Valley, are modified by faulting.

The structural development of the area has been more complicated than the relatively simple structure would seem to indicate. In the southern part of the area the attitude of the strata is related to the plunging north end of the Elk Ridge anticline, a regional fold trending nearly due north. In the northeastern part of the area preexisting structural features were modified by the movements that resulted in the uplift of the La Sal Mountains. At least part of the folding and faulting, particularly in the vicinity of the Colorado River, is related to flowage within the thick series of salt beds that underlie the entire area. The parallelism of the principal structural features, however, suggests that their development was controlled by stresses that were of regional significance. In a broad way the area may be divided on the basis of its structural development into the four provinces described below.

1. A province related to the uplift of the La Sal Mountains, including approximately the eastern tier of townships north of the middle of T. 28 S., R. 23 E., in which the general dip of the rocks is less than 10° away from the mountains, but the rocks dip as much as 70° in a deep, faulted syncline that extends nearly due west from the mountains and joins the Spanish Valley syncline.

2. A province related to the uplift of the Elk Ridge anticline, which includes most of the area south of lower Indian Creek and Hart

Draw, where the principal structure is the gentle monoclinal dip of the plunging north end of the Elk Ridge anticline.

3. A province of nearly flat-lying beds extending southeast from Hatch Point to Dry Valley and in Dry Valley separating the two structural provinces in which the folding and faulting are related to the uplift of the La Sal Mountains and the uplift of the Elk Ridge anticline.

4. A province that includes the folds along the Colorado River and embraces most of the anticlines and domes in the Moab district. They occur along the canyon of the Colorado River and in the adjacent country. Most of the anticlines and domes are small regular folds which cover only a few square miles and have dips in few places more than 10° or 12°. Other folds in this province include the Moab anticline and Spanish Valley syncline, which are complex faulted folds, and the Meander anticline, a sharp, narrow fold that follows more or less closely the canyon of the Colorado River for a distance of several miles. Several small normal faults are present, of which those that form the zone of graben faulting in The Needles and the faults along Moab and Spanish Valleys are most significant.

METHODS OF REPRESENTING STRUCTURE

The geologic structure of the area is shown on the structure contour map (pl. 2), and by three cross sections on Plate 1. The structure contour map shows the attitude of a selected stratum by lines connecting points of equal altitude above sea level. Altitudes of numerous points on the tops of different formations were observed in the field, and altitudes on the stratum selected for contouring were then obtained by subtracting or adding the thicknesses of the formations intervening between the stratum whose altitude was determined in the field and the one selected for contouring. Part of the area described in this report is contoured on the base of the Wingate sandstone and part on the top of the "Shafer limestone" of the Rico formation, and an irregular line on the map (pl. 2), extending north from the southwestern part of T. 31 S., R. 20 E., to the north side of the Cane Creek anticline in the southwestern part of T. 26 S., R. 21 E., marks the division. It seemed desirable to use the "Shafer limestone" as a datum plane in contouring the folds in the vicinity of the Colorado River, because that bed was used as a key horizon in obtaining structural data on these folds. To use the same datum plane throughout the area, however, extending it beneath the thick cover of overlying beds, would have led to inaccuracies in depicting the structure, for there are unconformities and variations in thickness in these overlying beds that can not be evaluated where they are not revealed at the surface. The base of the Wingate sandstone was therefore used as a datum plane in contouring the structure of the greater part of the area. The positions of anticlinal and synclinal axes are shown on the map by lines.

The structure cross sections shown on Plate 1 represent the structure along the lines shown on Plates 1 and 2. The cross sections are constructed with the same vertical and horizontal scale, and there is therefore no distortion due to difference in scale in the structural features as represented. The scale of the structure cross sections is the same as the scale of the maps. Owing to the small scale it is impossible to represent accurately all the minor irregularities, and the folds are actually less regular than shown in the cross sections. Furthermore, the extent and magnitude of unconformities beneath the surface which have been considered in constructing the sections could not be directly observed in the field but were inferred from observations of the local stratigraphy and that of the surrounding region. In addition to depicting the structure, the cross sections also show the surface relief along the line of the section and the effect of different formations in controlling the steepness of surface slopes.

DETAILS OF FOLDS

CASTLE CREEK ANTICLINE

The Castle Creek anticline, near the northern boundary of the area, trends about N. 50° W. and plunges northwest from the La Sal Mountains. Near the mouth of Castle Creek the anticline flattens and does not continue westward to merge with the Salt Valley anticline, which is northwest of the area shown on Plate 2. Only part of the fold is included in the area described in this report. The southwest flank of the anticline dips 3°–10° and extends for nearly 7 miles to the Courthouse syncline. The structural relief between the axis of the Courthouse syncline and the crest of the Castle Creek anticline is over 3,000 feet.

Castle Creek has carved a broad valley at the crest of this anticline, and the valley floor is covered with alluvium. A plug of igneous rock rises above the alluvial floor of the valley in sec. 22, T. 25 S., R. 23 E., and is surrounded by an aureole of the Paradox formation. (See pl. 1.) There is another small outcrop of the Paradox formation at the edge of the alluvium due south of the plug of igneous rock. As the Rico and Hermosa formations do not crop out, the Paradox formation is not in its normal stratigraphic position but has been thrust into the overlying beds. Because of the alluvial fill in the valley it is not possible to determine the extent of the gypsum.

Butler[74] suggested that the anticline may be underlain by a body of igneous rock. This inference was suggested to him by the

[74] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 612, 1920.

close relationship of the anticline to the laccoliths of the La Sal Mountains and the presence of the plug of igneous rock in the valley several miles from the mountains. Gould [75] has suggested that the northwestward-trending anticlines in southeastern Utah and western Colorado either preceded the laccolithic intrusions or were formed by compressive forces contemporaneously with them and influenced the localization and shape of the intrusive bodies that form the end groups of the La Sal Mountains. There is clear evidence that some of the anticlines in the region—namely, the Castle Creek, Cane Creek, and Moab anticlines—had been developed long before the intrusion of the La Sal Mountain laccoliths. They may have been folded more sharply by compressive forces acting contemporaneously with the laccolithic intrusions, but the initial folding preceded the intrusion. Possibly, as Gould suggests, the anticlines exerted some control and influenced the localization of the intrusive bodies. There seems to be no evidence within the Moab district that the Castle Creek anticline is underlain by a large body of igneous rock.

The gypsum of the Paradox formation is high above its normal stratigraphic position in the Castle Creek anticline, but its upward movement was possibly the result of the heat and pressure exerted upon it during the intrusion of the igneous rock. The writer therefore believes that the anticline was formed primarily as the result of regional forces and that the intrusion of the gypsum as well as the igneous rock had no major effect on the deformation of the strata.

COURTHOUSE SYNCLINE

The axis of the Courthouse syncline crosses the Colorado River in sec. 24, T. 25 S., R. 21 E., and extends S. 50° E. about 5 miles along the drainage of Nigger Bill Creek. The syncline becomes more shallow toward the southeast and ends in sec. 10, T. 26 S., R. 22 E. The part of the syncline included in the Moab area is the southeast end of a fold that extends for many miles west of the Colorado River. It is a symmetrical syncline, with dips of about 6° on both flanks. The northeast flank rises to the Castle Creek anticline, but the southwest flank terminates against the fault zone on the northeast side of Moab Valley after a structural rise of about 600 feet. The oldest rocks exposed in the Courthouse syncline east of the Colorado River are near the top of the Kayenta formation. As shown in cross section A–A′ (pl. 1), the southwest flank of the syncline is inferred to dip more steeply at depth than at the surface, because of the presence of unconformities that truncate formations toward the crest of the Moab anticline.

[75] Gould, L. M., The rôle of orogenic stresses in laccolithic intrusions: Am. Jour. Sci., 5th ser., vol. 12, pp. 119–129, 1926.

MOAB AND SPANISH VALLEYS

GENERAL FEATURES

The broad valley, including Moab and Spanish Valleys, which extends southeastward from the west side of the Colorado River at Moab, is a structural valley, but the geologic structure is not simple, nor is the structure the same throughout the length of the valley. Similar structural conditions continue eastward from the southeast end of Spanish Valley to the limit of the mapped area in the southeastern part of T. 27 S., R. 23 E., making the total length of the part of this structural feature lying east of the river more than 18 miles within the area mapped. West of the Colorado River McKnight [76] has mapped a zone of faulting and folding which extends 35 miles or more to and beyond the Green River. The folding is insignificant, however, compared with the faulting along this zone. For 10 or 12 miles west of the Colorado River there is a single large fault which is continuous with the zone of faulting and steep dips on the southwest side of Moab Valley. About 5 miles west of the river this fault has a displacement of about 2,600 feet, but the displacement decreases southeastward, and the fault passes into a monoclinal fold which dips as high as 40°. The monoclinal fold is broken by numerous small normal faults. It continues to the southeast as a faulted monoclinal fold but decreases in height and finally passes into an area of complicated faulting in the southwestern part of T. 27 S., R. 23 E.

In the vicinity of Moab the valley is a faulted anticline which extends about 5 miles southeast of the river. The anticline flattens near the center of T. 26 S., R. 22 E., and the gentle dip of the southwest flank of the Castle Creek anticline extends without interruption to Spanish Valley, where the dip changes and the strata rise steeply on the monocline that follows the southwest side of the valley, forming an asymmetric syncline. Toward the southeast this syncline is continuous with the graben of upper Pack Creek Valley, which consists of a relatively flat-bottomed steep-sided syncline bounded by several small normal faults that drop the central block below a monocline dipping gently toward the southwest. The Moab-Spanish Valley structure may therefore be divided for convenience into three segments—the Moab anticline near the Colorado River, the normal syncline near the central part of the valley, and the faulted syncline or graben near the eastern margin of the area. The three subdivisions will be described as the Moab anticline, the Spanish Valley syncline, and the Pack Creek synclinal graben.

[76] McKnight, E. T., report in preparation.

MOAB ANTICLINE

The Moab anticline is elliptical in shape and extends along Moab Valley from the area west of the river to the northwestern part of T. 26 S., R. 22 E. The northeast flank of the anticline has a maximum dip of 9° toward the Courthouse syncline, and the southwest flank has a maximum dip of 16° toward the Kings Bottom syncline, but both flanks are faulted near the margin of the valley, and local steep dips are present in and near the fault zones. On each side of the valley large masses of gypsum crop out, and in wells drilled in the valley a great thickness of salt and shale has been encountered. The center of the valley is believed, therefore, to be underlain by the Paradox formation, and the gypsum appears to be the residuum from the removal of the soluble salt. The sandstones of the Glen Canyon group form the rim rock on both sides of the valley. The Wingate sandstone apparently closes around the southeast end of the uplift in sec. 17, T. 26 S., R. 22 E., where there is a relatively sharp rise in the valley floor. East of the Colorado River the Chinle formation is about 400 feet thick on the southwest side of the valley and is thin or absent on the northeast side. The Rico and Cutler formations are both absent, but purplish-gray brecciated nonfossiliferous limestones correlated with the Hermosa formation crop out in a narrow zone near the edge of the alluvium on both sides of the valley. The gypsum masses are in part overlain by these limestones dipping steeply away from the valley. As shown below, this anticline has been the site of folding during several different periods, and doubtless the anticline is folded more sharply at depth than is apparent in surface rocks. The attitude of the surface rocks and the interpretation of the subsurface relations are shown in cross section A–A′, Plate 1.

The marginal fault zones consist principally of normal faults with a maximum displacement of about 300 feet. Although the characteristics of the faulting on both sides of the valley are similar, the two zones of faulting were probably developed at different times and from different causes. The faults on the southwest side of the valley are the continuation of the zone of faulting which is expressed by a single fault with a displacement of about 2,600 feet a few miles west of the Colorado River. The displacement along this fault decreases toward the southeast, and it merges into a steep monocline. Northeast of the fault zone steep dips toward the valley in secs. 7, 17, and 18, T. 26 S., R. 22 E., mark this monocline. The dips in the opposite direction nearer the edge of the alluvium are believed to be a secondary feature related to the salt flowage. The contemporaneous monoclinal folding and the normal faulting occurred late in the Cretaceous period or early in the Tertiary and resulted from regional stresses. The deformation followed the line of previous folding approximately but appears to have been a short distance southwest of the axis.

The faulting on the northeast side of the valley is probably of relatively recent date and resulted from the uplift of the overlying sediments accompanying the flowage of the salt and the later settling of the strata as the salt was eroded. Within this fault zone the strata are crumpled and there are several sharp anticlines of local extent. Both flanks of a narrow anticline in secs. 5, 6, 7, and 8, T. 26 S., R. 22 E., are cut by normal faults of opposite displacement, as shown in the cross section in Plate 1. A well was drilled on this anticline in sec. 8 to a depth of 1,525 feet. The lower 400 feet of the well was drilled in salt.

The Moab anticline has been interpreted by Harrison [77] and by Prommel and Crum [78] as a salt dome in which the salt has been forced through a great thickness of overlying rocks and eventually reached the surface. Undoubtedly the thick salt beds underlying the area have flowed under pressure, but the salt does not appear to have been intruded into the overlying beds to form a typical salt dome, as suggested by these writers. On the contrary, the existing structure seems to have resulted from the thinning of the cover over the salt beds by erosion, and the weight of the overlying rocks in adjoining areas caused the salt to flow and to lift and rupture the thin cover. Subsequent solution and erosion removed the salt, and, if the process is still active, erosion and solution keep pace with the movement of the salt and it is not projected far above the surface. The major structural features of the valley are the result of regional folding and not of the vertical force exerted by plastic salt moving under pressure.

The writers mentioned above state that the masses of gypsum exposed in Moab Valley are far above their normal stratigraphic position and have reached their present position by intrusion into the overlying beds. It appears to the writer that the gypsiferous masses, although they have been disturbed by flowage, are not far removed from the normal position of the top of the Paradox formation and that their apparently abnormal position is fully explained by stratigraphic evidence. The initial stage in the folding of the Moab anticline occurred at the end of the Permian epoch, after normal deposition of the Paradox, Hermosa, Rico, and Cutler formations. The folded strata were eroded, and the Cutler, Rico, and part of the Hermosa formations were removed from the crest of the anticline. After the deposition of the Moenkopi formation upon the beveled edges of the older formations further folding occurred at the end of Moenkopi time. The Moenkopi formation was removed by erosion at the crest of the anticline, and the underlying Hermosa formation

[77] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 118, 125, 1927.

[78] Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulation: Idem, p. 381; Structural history of parts of southeastern Utah from interpretation of geologic sections: Idem, p. 817.

was further eroded. The elevated surface due to the post-Moenkopi folding was eroded only in part before the deposition of the Upper Triassic Chinle formation, which overlaps the older beds. The Chinle formation is absent at the mouth of Mill Creek Canyon, but across the valley 2 miles distant it is about 450 feet thick. At the end of Chinle time the salt beds of the Paradox formation in the Moab anticline were covered by only a few hundred feet of the Hermosa formation. Post-Chinle formations were deposited across the anticline and folded during later periods, but erosion removed them from the crest of the anticline and cut still deeper into the Hermosa formation. The load of overlying sediments upon the salt series on the flanks of the anticline was much greater at this stage of its development than during any previous stage, and the thickness of the limestone beds over the salt series was less. As erosion proceeded a critical point between the force exerted by the plastic salt under pressure and the strength of the cover was reached at a relatively recent time, and further weakening of the cover resulted in its rupture. The extruded material from the Paradox formation was removed by solution and erosion except for the gypsum residue remaining on both sides of the valley. Slight faulting and local folding disturbed the regularity of the anticlinal folding as a result of the pressure exerted by the salt. Some normal faulting doubtless resulted from adjustments following the solution and removal of the salt. This interpretation of the development of the Moab anticline fits all the facts observed in the field, requires little extrapolation of the observed facts, and is therefore believed to be more nearly the true explanation than the theory hitherto advanced that the anticline is a normal salt dome.

SPANISH VALLEY SYNCLINE

The next segment of the structural valley southeast of the Moab anticline is the Spanish Valley syncline, which is that portion of the structural valley between the northwestern part of T. 26 S., R. 22 E., and the northwestern part of T. 27 S., R. 23 E. The syncline is asymmetrical, with a long gently dipping northeast limb rising to the Castle Creek anticline and a short steeply dipping southwest limb rising to the zone of normal faults that marks the limit of the northeast limb of the Kings Bottom syncline. These normal faults have displacements of about 300 feet, with the dropped side toward the valley. Steeply dipping rocks—the Chinle, Wingate, and Kayenta formations—dip below the alluvium on the southwest limb, and the Navajo sandstone dips below the alluvium on the northeast limb. The center of the valley is filled with alluvium to an unknown depth.

PACK CREEK SYNCLINAL GRABEN

The third segment of the structural valley is a faulted syncline or synclinal graben which extends in an arc, convex southward, from the northwestern part of T. 27 S., R. 23 E., to the east boundary of the same township. A large part of the surface over this segment is covered with valley fill and gravel, which partly conceal the structure. It is a steep-sided flat-bottomed syncline bounded on both sides by normal faults, with the downthrown side toward the axis of the syncline. The Mancos shale is infolded in the syncline, and the lower 800 feet of the formation has been preserved from erosion. The faults that bound the syncline on the northeast range in displacement from 60 to 150 feet. Northeast of these faults the rocks rise with a low dip toward the mountains, but southwest of the faults the dip steepens to 20°–30° and locally is as high as 70°. Similarly on the southwest side of the syncline the regional dip is low and away from the mountains, and northeast of the faults the rocks dip 20°–70°. The faults on this side of the syncline have a maximum displacement of about 300 feet. Southwest of the syncline, in the southwest quarter of T. 27 S., R. 23 E., the rocks are sharply folded and are broken by numerous faults. Besides the faults that parallel the trend of the syncline there is another system of normal faults that trends about S. 45° W.

The structure and trend of the Pack Creek graben suggest that it is closely related to the uplift of the La Sal Mountains, which are just east of the area mapped. Beyond the limits of the area the synclinal graben trends directly toward the mountains, but its mountainward extension was not examined. If the graben is related to the uplift of the mountains or to the intrusion of igneous rocks, the curved trend might then be explained by the accommodation of deformation due to forces originating in the mountains to preexisting lines of weakness that trend about N. 50° W. The structural depression of the graben forms only a slight interruption of the regular dip of the strata away from the mountains. Perhaps tension created in the surrounding rocks by the uplift of the mountains or readjustments after the intrusion of igneous rocks caused the rocks of the graben to settle or sag.

KINGS BOTTOM SYNCLINE

The Kings Bottom syncline is a broad fold between the Moab anticline on the northeast and the Cane Creek anticline on the southwest. (See cross section A–A′, pl. 1.) It trends about N. 35° W. and extends about 7 miles southeast of the Colorado River near Kings Bottom to the northwestern part of T. 27 S., R. 22 E. The syncline is broad and flat where it crosses the river and gradually becomes shallower toward the southeast. The surface dips on the northeast limb are as high as 16°, and the highest dips recorded on the southwest limb are about 11°. The Navajo sandstone crops out in the bottom of the syncline.

CANE CREEK ANTICLINE

The Cane Creek anticline, which follows in part the valley of Cane Creek, trends about S. 50° E. and extends about 6 miles southeast of the Colorado River. (See cross section A–A′, pl. 1.) Both sides of the anticline dip 10°–12°, but the northeast slope is much longer than the southwest slope. The oldest rocks exposed are the upper 300 feet of the Hermosa (Pennsylvanian) formation. The closure on the Cane Creek anticline is about 650 feet at the saddle between the Cane Creek anticline and the Shafer dome. The small faults on the Cane Creek anticline are insignificant and probably have not influenced the accumulation of petroleum.

The possibilities of obtaining petroleum from this anticline appeared to be excellent, but three wells have been drilled without success. Two test wells were drilled—one in the SW. ¼ sec. 31, T. 26 S., R. 21 E., to a depth of 5,000 feet, and the other in sec. 5, T. 27 S., R. 21 E., to a depth of 3,520 feet. The well in sec. 31, T. 26 S., R. 21 E., obtained showings of oil and gas at depths of 2,025, 3,645, and 4,950 feet, all in the Paradox formation, and showings of gas in the Hermosa formation at a depth of 1,408 feet and in the Paradox formation at a depth of 4,976 feet. The showings of oil and gas at a depth of 2,025 feet indicated the presence of oil and gas in large quantities, but inability to shut the water off effectively prevented a thorough test. After testing deeper strata without obtaining oil, an unsuccessful attempt was made to exhaust the water at the upper horizon (2,025 feet). A third well, intended to test the flank of the salt body as a favorable place for the accumulation of oil, was drilled west of the river in the NE. ¼ sec. 25, T. 26 S., R. 20 E., but was abandoned at a depth of 4,107 feet. The future possibilities of finding oil in this anticline are considered on pages 83–84.

SHAFER DOME

The Shafer dome is in the west-central part of T. 27 S., R. 20 E. A bend in the Colorado River crosses the crest of the dome, but most of the dome lies west of the river. The trend of the elongated dome is N. 65° E. Its southeast flank dips 3°–6°. The closure between it and the Cane Creek anticline is about 400 feet, and the structural relief between it and the saddle separating it from the Lockhart anticline, to the south, is more than 500 feet. The crest of the dome is about 250 feet lower than the crest of the Cane Creek anticline and about 250 feet above the crest of the Lockhart anticline. The upper 150 feet of the Hermosa formation comprises the oldest rocks exposed at the crest of the Shafer dome.

The Shafer dome, like the Cane Creek anticline, is a closed fold that would seem to afford some of the most favorable conditions for the accumulation of petroleum. In 1926 a test well was drilled on the crest of the dome to a depth of 5,863 feet and encountered a sequence of rocks similar to that encountered in the deepest well on the Cane Creek anticline. No commercial production of oil was obtained.

HATCH POINT AREA OF IRREGULAR LOW FOLDING

A belt of low irregular folds about 7 miles wide extends S. 40° E. from the Shafer dome about 27 miles and continues beyond the limits of the area mapped. Most of this belt of folding underlies the part of the district named Hatch Point, but part of it extends farther to the southeast under Dry Valley. The southeast half of the belt is a broad, shallow, irregular-shaped synclinal basin elongated parallel to the trend of the belt. The closure of the basin is about 200 feet, with the lowest point near the southwest corner of sec. 35, T. 29 S., R. 22 E.

In a general way this belt of slightly folded rocks divides areas of more intensely folded and faulted rocks. To the southwest lie the folds and faults that appear to be related to the uplift of the Elk Ridge anticline and the formation of the Abajo Mountains; to the northeast lie folds and fault zones in part related to the formation of the La Sal Mountains.

LOCKHART ANTICLINE

The Lockhart anticline, which trends about N. 65° W., roughly follows the lower part of Lockhart Canyon near the center of T. 28 S., R. 20 E. The saddle that separates it from the Shafer dome is about 500 feet below the crest of the Shafer dome and about 300 feet below the crest of the Lockhart anticline. The closure of the anticline is about 100 feet, as it is separated from the Rustler dome by a low saddle. An area of about 6 square miles is included within the lowest closing contour. The oldest rocks exposed are 400 feet below the top of the Rico formation.

A well on the crest of the anticline at the mouth of Lockhart Canyon was drilled to a depth of only about 500 feet. As the Lockhart anticline is part of a related group of anticlines, and as there is no reason to expect different subsurface conditions, a deep well on the Lockhart anticline would probably encounter the same rocks as those in the wells on the Cane Creek anticline and Shafer dome.

RUSTLER DOME

The Rustler dome, named from Rustler Canyon, is a small dome lying east of the Colorado River in Tps. 28 and 29 S., R. 20 E. To it the names of No. 4 dome and Indian Creek dome have been applied by geologists of oil companies, but these two names are not used by the writer, because No. 4 carries no geographic significance and because Indian Creek, which follows the crest of a large anticline farther south, does not cross the Rustler dome.

The Rustler dome is 3 miles long by 2 miles wide and attains its highest altitude in sec. 5, T. 29 S., R. 20 E. It is a low fold, and a closure of about 50 feet separates it from the Lockhart anticline on the north and the Gibson dome on the south, both of which are larger folds. The top of the Rico formation crops out near the crest of the dome.

GIBSON DOME

The Gibson dome is at the south end of the group of folds which includes the Gibson dome, Rustler dome, Lockhart anticline, Shafer Dome, and Cane Creek anticline and which are linked together by saddles so that they form a curved area occupied by high structural features extending from the northwestern part of T. 30 S., R. 21 E., to the north line of T. 27 S., R. 21 E. The Gibson dome is an elongate dome that trends about N. 65° W. and extends about 7 miles along lower Indian Creek in Tps. 29, 29½, and 30 S., R. 20 E., and T. 30 S., R. 21 E. The northwest end of the fold swings nearly due north and is separated from the Rustler dome by a slight saddle. The maximum dip on the north flank of the dome is 4°, but the dip does not exceed 2° on the south flank. (See cross section B–B′, pl. 1.) This fold is a small one at the northern limit of the plunging north end of the large fold named the Elk Ridge anticline, which is south of the area mapped. The closure of the dome is about 200 feet where a low saddle separates it from the north end of the anticline. The oldest rocks exposed consist of the upper 200 feet of the Rico formation.

Four wells have been drilled on the crest of the Gibson dome, but only the Empire Gas & Fuel Co.'s well, near the west line of sec. 6, T. 30 S., R. 21 E., was drilled deep enough to test the Paradox formation. This well was abandoned at a depth of 4,183 feet. Showings of oil and gas were obtained. Although this well was not drilled at the extreme high point of the dome, it was close to the axis of the fold and not more than 50 feet below the top, well within the closed part, so that it apparently constitutes a good test of the fold.

LOCKHART SYNCLINE

The Lockhart syncline, which centers in sec. 1, T. 29 S., R. 20 E., in the upper part of Lockhart Canyon, is a small, roughly circular structural basin. The closed part of the basin is approximately 2½ miles in diameter and more than 700 feet deep. Beyond the lip of the basin on the north and east the beds lie nearly flat, but on the west and south they rise from the basin to the Lockhart, Rustler, and Gibson domes. (See cross section B–B′, pl. 1.) There is a difference of about 1,400 feet in the altitude of the same beds in 2½ miles between the syncline and the east end of the Lockhart anticline. A normal fault with a downthrow of about 200 feet toward the syncline separates it from the Lockhart anticline. This nearly circular depression is a peculiar type of structure whose origin is probably related to the flowage of salt during the uplift of the anticlines. The effect of salt flowage on the formation of the folds in the area is considered on pages 74–76.

MONOCLINE IN SOUTHERN PART OF DISTRICT

South of the area mapped the Elk Ridge anticline extends south to the Utah-Arizona line, occupying a broad area between the Abajo Mountains and the Colorado River. The plunging north end of the anticline enters the southwestern part of the Moab district, where the strata dip 1°–3° N. or NE. There are minor irregularities on the monoclinal slope; such as a small depression in T. 31 S., R. 21 and 22 E., but the northeast dip continues until it is terminated by the Gibson dome and the shallow syncline underlying Dry Valley. The structural rise along the monocline is more than 2,500 feet from the syncline in Dry Valley to the southwest limit of the area mapped.

BIG INDIAN-LISBON VALLEY FAULTED ANTICLINE

The crest of the faulted anticline that outlines Big Indian and Lisbon Valleys lies outside the area mapped, but near the eastern margin of the area, in Tps. 29, 29½, and 30 S., Rs. 23 and 24 E., the beds rise steeply toward the northeast on the flank of the Big Indian-Lisbon uplift. Near the crest of the anticline Dakota sandstone is faulted against Hermosa limestone. The fault extends into the area mapped in Tps. 28 and 29 S., R. 23 E., but its displacement decreases toward the northwest, and its maximum displacement within the district is 300 feet. The displacement decreases to zero near the center of T. 28 S., R. 23 E.

MEANDER ANTICLINE

An almost continuous arch, to which Harrison [79] has applied the name Meander anticline, begins near the mouth of Indian Creek and extends down the Colorado River Canyon to the southern limit of the area mapped. The rocks in the lower walls of the Colorado Canyon dip 10°–40° away from the river, but the higher rim rocks are tilted either slightly or not at all. In a general way the tilting is less near the north end and more pronounced near the junction of the Colorado and Green Rivers. The lower part of Red Lake Canyon is followed by an arch similar to that along the Colorado River. Because of the local nature of this folding, no attempt is made to show it in detail on the structure contour map forming Plate 2.

Near the junction of the Green and Colorado Rivers more than half the thickness of the Hermosa formation has been penetrated by the downward cutting of the river, and the formation has been penetrated to a less degree progressively upstream. At the mouth

[79] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 125, 1927.

of Red Lake Canyon, where a mass of gypsum is exposed, the Hermosa may have been cut through by the river, but the gypsum probably ruptured the overlying rocks and has been elevated slightly above the normal position of the top of the Paradox formation. As the river cut deeper into the Hermosa formation, the cover of sedimentary rocks overlying the salt in the Paradox formation was finally weakened to such a degree that the pressure exerted upon the plastic salt by the weight of the sediments in the areas adjoining the canyons exceeded the strength of the cover and caused it to arch. The Paradox formation has been exposed at no place along the Meander anticline within the area mapped except at the mouth of Red Lake Canyon.

Harrison considered that the weight of the sediments in the areas adjoining the canyons was adequate to cause the development of the Meander anticline, but his diagrams show that he considered the salt to be intruded into the Hermosa formation. The theory advanced by Prommel and Crum assumes the presence of salt domes which controlled the position of the river, as contrasted with the theory advanced by Harrison and the writer that the arching of the beds is of recent date and the result of a weakness of the cover over the salt beds developed by the downcutting of the river.

FAULTS

GENERAL FEATURES

Some of the many faults in the Moab district are closely related to well-defined anticlines or synclines, and others have no apparent relation to such folds or to each other. All are normal faults with the exception of two small thrust faults that cross Mill Creek Canyon on the northeast side of the Moab anticline and a few thrust faults with displacements of a few feet in the southwestern part of the district. The dip of most of the normal fault planes is nearly vertical, but some dip as low as 55°. All the faults except one have displacements of 300 feet or less, and many of them have displacements of less than 100 feet. A fault in secs. 17 and 18, T. 27 S., R. 23 E., on the southwest side of Spanish Valley, has a displacement of about 500 feet.

The Shay graben, in the southeast corner of the area, is a clean-cut graben made by two approximately parallel normal faults. The Needles fault zone, southeast of the junction of the Colorado and Green Rivers, is a combination of many small grabens. The graben faults at both of these localities strike nearly at right angles to the strike of the strata which they cut. They have, therefore, a radial arrangement on the plunging north end of the Elk Ridge anticline, which suggests a relation in origin, but the radial arrangement may be accidental. The Shay graben is near the Abajo Mountains and was probably formed as the mountains were uplifted. The Needles fault zone is many miles from the Abajo Mountains, but, as it is adjacent to areas along the Colorado River where the rocks are obviously disturbed by uplift due to flowage in underlying salt beds, it was probably developed as a result of such flowage.

SHAY GRABEN

The Shay graben trends N. 65° E. across T. 32 S., R. 22 E. It has been mapped for 6 miles across the valley of Indian Creek and Shay Mesa, from which it is named. The fault on the north side of the graben ends near the west line of the township, but the south fault continues to the southwest beyond the limit of the area. Most of the course of the south fault across the area and farther to the southwest is clearly marked by faceted spurs. The faults limiting the graben have displacements of about 300 feet, and the fault planes converge downward with hades of about 5°. Where the graben crosses Indian Creek Canyon the rim of Wingate sandstone is broken, and the less precipitous slopes formed by the dropped Navajo and Kayenta formations form a break in the canyon wall through which the road into Indian Creek Valley has been built.

The cause and age of the faulting in the Shay graben can not be definitely determined. As mentioned above, the graben is oriented radially with respect to the plunging north end of the Elk Ridge anticline. In later paragraphs it will be shown that the uplift of the Elk Ridge anticline probably occurred at the end of the Cretaceous period and that the Abajo Mountains were elevated at a later time, probably early in the Tertiary. The graben cuts the flank of Shay Mountain, one of the laccolithic mountains that compose the Abajo Mountain group,[80] and could hardly have persisted in its present simple form if it had antedated the mountain uplift. It is possible that the faulting occurred subsequent to the mountain uplift, but the most reasonable inference is that the faulting was contemporaneous with and due to the intrusion of the laccoliths and the elevations of the mountains.

NEEDLES FAULT ZONE

At the southwest corner of the area near the junction of the Green and Colorado Rivers, a remarkable array of turrets and spires named The Needles is the result of weathering of blocks of the massive Cedar Mesa sandstone member of the Cutler formation. These blocks are outlined by parallel joints and faults that form narrow discontinuous grabens. The grabens are not simple structural features with two normal faults limiting them, but wherever there are rock exposures in the dropped block the rock is seen to be broken by numerous faults parallel to the limiting faults, so that the expression "ribbon faulting"

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[80] Thorpe, M. R., Structural features of the Abajo Mountains, Utah: Am. Jour. Sci., 4th ser., vol. 48, pp. 379-389, 1919.

aptly describes the conditions. The top of the dropped block is invariably soil-covered except near the end of the grabens. The photographs in Plates 9, *B*, and 10, *A*, *B*, illustrate the faulting and the flat alluvial surface of the dropped block. A cross section of the fault zone shown on cross section C–C′ (pl. 1) is generalized and does not show the details of faulting within the blocks. The trails through The Needles follow the grassy flats in the grabens, which furnish an easy route through what otherwise would be a difficult part of the area to traverse.

The grabens trend N. 20° E. and are half a mile to more than 3½ miles long. The average width between the limiting faults is about 500 feet, but the graben of Red Lake Canyon has a width of nearly 2,000 feet at its south end. Because of the soil covering on the dropped blocks it is impossible to determine the exact amount of displacement along the faults, but the height of the canyon wall is believed to be an approximate measure of the displacement, which would usually be less than 300 feet. The faulted area extends an unknown distance beyond the southwestern margin of the area mapped.

The faulting occurred late in geologic time, but no precise age can be assigned to it. Numerous stream channels can be traced across the area transverse to the grabens. They are marked by hanging valleys and obviously antedated the faulting. Along Cyclone Canyon no drainage has been established, and the canyon floor consists of a series of basins with divides 10 to 50 feet high between them. In other places a preexisting stream course was interrupted by the graben, and the present drainage line turns at right angles and follows the graben. The walls of most of the graben canyons are vertical and are fault faces in which there has been slight erosion.

The movement in the Needles fault zone took place after the surface of the Moab district had acquired approximately its present form. It therefore occurred at a relatively recent date and long after the last period of regional deformation. Flowage of the salt and gypsum of the Paradox formation from beneath the area of graben faulting into the Meander anticline, which also is believed to have formed at a relatively recent date, seems to offer an adequate explanation of the faulting. As the salt and gypsum flowed toward the anticline from beneath the massive limestone and sandstone cover, these massive beds were broken by approximately parallel fracture planes, and the blocks bounded by such planes settled unevenly.

EFFECT OF MOVEMENTS IN THE SALT ON GEOLOGIC STRUCTURE

The writer's conclusions concerning the part played by movements in the salt in the development of the geologic structure and the relation of the salt to the inclosing strata have been discussed on preceding pages, but the following brief summary of these conclusions is here presented.

The presence of salt beneath the surface in the vicinity of Moab was not suspected until wells were drilled for oil. The first well to enter the salt was drilled in Salt Valley in 1918–19, and each well drilled in the district since then has entered the salt if drilled to sufficient depth. As practically all the showings of oil and gas obtained in wells have been found in the salt-bearing Paradox formation, knowledge of the relation of the salt to the inclosing strata has a direct bearing on future prospecting for oil.

The writer considers that many of the anticlines in the Moab district are incipient salt domes but that they are not typical salt domes similar to those found in the United States near the Gulf coast [81] and in northwestern Europe.[82] There can be no question that there has been plastic flow of the salt series. In the gypsum masses exposed at the surface bedding planes are contorted and included shale beds are crumpled and broken. Cores of salt taken from a well in Paradox Valley, Colo., show flowage of the salt.[83] Although the salt has undoubtedly been thickened beneath the anticlines of the Moab district, there is no evidence, except in Castle Creek Valley, that a "neck" or "plug" of salt has been forced into overlying beds. Dane reports that at several places in Utah north and northeast of the Moab district and in western Colorado plugs of the plastic salt and gypsum of the Paradox formation have been intruded many hundreds of feet into the overlying sediments.[84] At Moab and in the canyon of the Colorado River at the mouth of Lower Red Lake Canyon the salt has been forced through the overlying sediments, but, as explained in the description of the Moab anticline (p. 66) and the Meander anticline (p. 72), the thickness of the cover over the salt had been reduced by erosion to not more than a few hundred feet, and the salt and gypsum did not move far from their normal stratigraphic position to reach the surface. There is no evidence that the salt has been forced into the overlying beds on the anticlines, such as the Shafer dome and the Cane Creek anticline, where these overlying beds are not broken at the surface. Except for the anomalous brown shale encountered in the well drilled by the Big Six-Western Allied Oil Co. in sec. 12, T. 26 S., R. 21 E., in Moab Valley, none of the wells have shown the presence of any beds intervening between the Hermosa formation and the salt series, and all the wells that have been drilled through the Hermosa formation have shown it to be of nearly uniform thickness.

Most of the folds in the Moab district were formed during periods of regional folding, but some features of the folds are directly due to

[81] DeGolyer, E. L., and others, Geology of salt dome oil fields, Am. Assoc. Petroleum Geologists, 1926.

[82] Van der Gracht, W. A. J. N.. van Waterschoot, The saline domes of northwestern Europe: Southwestern Assoc. Petroleum Geologists Bull., vol. 1, pp. 85–92, 1917.

[83] Prommel, H. W. C., and Crum, H. E., Structural history of parts of southeastern Utah from interpretation of geologic sections: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 819–820, 1927.

[84] Dane, C. H., Geology of the Salt Valley anticline and the northwest flank of the Uncompahgre Plateau, Grand County, Utah: U. S. Geol. Survey Bull. (in preparation).

movement within the salt series. As there was a uniform blanket of sediments over the salt beds at the end of the Permian, at the time of the first folding, the impulse causing the folding had to come from some other source than differential pressure on the salt beds. After an anticline had started to form, regional pressure exerted on the plastic salt would tend to cause it to flow and accumulate under the areas which offered relief from the pressure—namely, the upward-bowing anticlines; consequently the anticlines would have greater growth than pressure on nonplastic rocks would have caused. The Lockhart syncline lies within a semicircle of arched strata that includes the Lockhart anticline and the Rustler and Gibson domes. The presence of this anomalous structural basin so closely associated with the group of anticlines favors the interpretation that it originated from internal adjustments to regional pressure by flowage within the salt beds, rather than that it is a normal type of structure developed by folding independent of the presence of salt. The Lockhart syncline appears to represent a sink-hole type of structure, the result of settling over salt beds as the salt moved into the anticlines. The Meander anticline and the associated grabens in The Needles, according to the writer's interpretation, are due to flowage in the salt, as described on pages 72 and 74. The Moab anticline was formed during periods of regional folding, but movement in the salt probably accounts for local folding and faulting on the flanks of the anticline. The Castle Creek anticline is a regional fold locally modified by the intrusion of the salt plug.

The conclusions above set forth concerning the relation of the salt to the folds and the relation of movement in the salt to the formation of the folds are somewhat at variance with the conclusions of Harrison [85] and Prommel and Crum.[86] Harrison concluded that intruded salt plugs of the Moab Valley type were exposed by erosion during Shinarump time and only recently have been reexposed by the removal of the post-Shinarump sediments. He also concluded that domes of the Cane Creek anticline type and the Meander anticline are of comparatively recent origin and the result of bulging over salt beds which are under pressure of the adjacent highlands. Prommel and Crum concluded that salt plugs were intruded into the overlying formations contemporaneously with late Pennsylvanian and Permian folding and that the Meander anticline is of similar origin and independent of the present topography.

[85] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 111-113, 1927.

[86] Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulation: Idem, pp. 373-393.

PERIODS OF DEFORMATION

The relative simplicity of the geologic structure of the Moab area does not suggest the numerous periods of deformation or the various causes of deformation, but some of the structural history is revealed by the stratigraphic record, and part of it may be inferred from physiographic evidence and the regional geology. The successive periods of deformation have been discussed at different places in the report but will be summarized under this heading to give a connected story of the structural history.

The earliest recorded folding occurred after the deposition of the Cutler formation at about the end of Permian time, as is indicated by an angular discordance between the Cutler (Permian) and the overlying Moenkopi (Lower Triassic) formations at Moab and at Castle Creek and by a decrease in thickness of the Cutler formation over the Cane Creek anticline. All of the Cutler and Rico formations and part of the Hermosa formation were removed by erosion from the crest of the Moab anticline before the deposition of the Moenkopi formation. The Castle Creek, Moab, and Cane Creek anticlines were folded first at the end of the Permian. In the rest of the area the Moenkopi formation appears to lie conformably upon the Cutler formation.

Another period of folding followed Moenkopi time and the axes of the resulting folds appear to be the same or practically the same as those of the preceding period of folding. The Moenkopi formation is thin at the crest of the Cane Creek anticline, and a pronounced angular unconformity between the Moenkopi formation and the overlying Chinle formation is exposed in the canyon walls of lower Cane Creek. (See pl. 6, *A*.) The Moenkopi formation is absent over the Moab anticline. Except for the local variation in thickness of the Moenkopi formation over the Moab and Cane Creek anticlines, this formation shows a regional trend in its change in thickness. The absence of the Moenkopi formation over the Moab anticline is clearly due to erosion following its deposition and folding, and not to overlap upon a preexisting knob or ridge of older sediments, for the basal part of the Moenkopi formation extends farthest up on the flank of the anticline.[87] Erosion not only stripped the Moenkopi formation from the crest of the Moab anticline but cut into the underlying Hermosa formation.

The post-Moenkopi erosion surface upon which the Shinarump conglomerate and the Chinle formation were deposited was apparently a surface of considerable local relief. The Shinarump conglomerate is thin and of irregular occurrence over most of the area, but the

[87] Baker, A. A., and others, Notes on the stratigraphy of the Moab region: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 793, 1927.

Chinle formation maintains a fairly uniform thickness except across the anticlines. The Chinle formation has scarcely more than half its normal thickness at the crest of the Cane Creek anticline, but the greatest variation occurs at Moab. It is absent in Moab Valley near the mouth of Mill Creek Canyon, where the Wingate sandstone rests directly upon the Hermosa formation, but about 2 miles distant, on the other side of the valley, it is about 450 feet thick. As no angular discordance or marked unconformity was noted between the Chinle formation and the overlying Wingate sandstone, the variations in thickness are believed to be due to nondeposition and overlap.

Subsequent to the deposition of the Chinle formation there was a long period of almost continuous deposition, during which no extensive folding is known to have occurred. This period of quiescence was interrupted by widespread folding at the end of the Cretaceous period, apparently related to and accompanying the folding and elevation of the Rocky Mountains. Most of the structural features are believed to have acquired their present form during this period of movement. The date of the structural disturbance can not be determined from local structural data except that the Mancos formation is involved, and the deformation is therefore of post-Mancos age. The Waterpocket Fold was formed near the end of the Cretaceous period, for it involves late Cretaceous strata and is overlain by essentially flat-lying Wasatch rocks.[88] Because of structural analogies with the Waterpocket Fold, Gilluly [89] considers the folding of the San Rafael Swell to be of the same age. The Elk Ridge anticline is a regional fold with characteristics similar to both the Waterpocket Fold and the San Rafael Swell, and its origin may reasonably be inferred to be contemporaneous. Most of the deformation followed the lines of weakness created by the earlier folding and resulted in further development of the older folds. In the vicinity of Moab, in addition to further folding of the Moab anticline, the large fault west of the Colorado River and the steep monocline east of the river, forming the southeasterly continuation of the displacement, originated during the post-Cretaceous folding. The anticlines near the Colorado River below the Cane Creek anticline, except the Meander anticline, probably also originated during this period of folding.

The formation of the laccolithic mountains that are conspicuous features of the Colorado Plateaus and are so similar in form, structure, formations involved, and origin that their contemporaneity seems assured was the next notable event in the structural history of the area. In addition to the two laccolithic mountains—the La Sal

[88] Dutton, C. E., Report on the geology of the High Plateaus of Utah: pp. 280–281, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880. Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 12–13, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[89] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pp. 126–127, 1929.

Mountains,[90] near the eastern margin of the area, and the Abajo Mountains,[91] near the southern margin—whose formation resulted in structural disturbance within the area mapped, the group of laccolithic mountains also includes the Henry Mountains [92] and Navajo Mountain.[93] The time of formation of these mountains has been considered to be early Tertiary, without conclusive evidence. The writer is in accord with this assignment but is unable to offer substantiating evidence beyond the inconclusive observation that the strata on the west slope of the Abajo Mountains dip into the mountains in conformity with the dip of the east flank of the Elk Ridge anticline, which suggests that the mountains were elevated on the flank of a preexisting arch. As the writer believes that the Elk Ridge anticline was elevated at the end of the Cretaceous period, a Tertiary age for the uplift of the laccolithic mountains is suggested. A tentative assignment of the laccolithic intrusions to early Tertiary time is as definite an assignment as can be made on the evidence now available. The structural disturbances associated with the uplift of the laccolithic mountains are confined to a small area in the immediate vicinity of the mountains,[94] and most of the structural features of the Moab area are therefore believed to be independent of such disturbances. The uplift of the La Sal Mountains, however, has caused a steepening of the dip at the northeast corner of the Moab area and is probably responsible for the formation of the Pack Creek synclinal graben in T. 27 S., R. 23 E. This faulted syncline is now continuous with the Spanish Valley syncline, whose date of origin is placed at the end of the Cretaceous, but, as described on pages 66–67, the continuity of these similar structural features is apparently accidental and due to the intersection of two folds formed at different times. The Shay graben, in T. 32 S., R. 22 E., seems to be the only structural feature within the area that resulted from the uplift of the Abajo Mountains.

There is no evidence of folding or faulting of the strata subsequent to the uplift of the mountain masses until the surface features of the area had assumed nearly their present form—in other words, until a comparatively recent date. The features developed during this stage of the structural history are due to movements in the thick body of salt underlying the entire area. Arching of the strata along the Meander anticline and rupture of the cover at Moab and the mouth of Red Lake Canyon resulted from this process. The graben faulting

[90] Gould, L. M., The rôle of orogenic stresses in laccolithic intrusion: Am. Jour. Sci., 5th ser., vol. 12, pp. 119–127, 1926.

[91] Thorpe, M. R., Structural features of the Abajo Mountains, Utah: Am. Jour. Sci., 4th ser., vol. 48, pp. 379–389, 1919.

[92] Gilbert, G. K., Geology of the Henry Mountains, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[93] Baker, A. A., Geology of Monument Valley-Navajo Mountain region, Utah: U. S. Geol. Survey (report in preparation). Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 128, 1917.

[94] Gilbert, G. K., op. cit., p. 53. Baker, A. A., op. cit.

near the junction of the Green and Colorado Rivers is attributed by the writer to subsidence in the area from which the salt moved. This process of salt flowage must be active at the present time, and the deformation should become more pronounced as erosion cuts more deeply into the beds overlying the salt.

OIL AND GAS

HISTORY OF DRILLING

During the last 40 years many wells have been drilled in southeastern Utah in the hope of finding oil, and in spite of the early failures sporadic drilling has continued until the present time. The first wells were drilled in the Green River Desert south of the town of Greenriver, about 40 miles northwest of the Moab district, where a well was drilled in 1891 and three more in 1899 and 1900. From 1910 to 1914 there was a renewal of activity in that area, during which several more wells were drilled. A few test wells have been drilled there since 1914. Most of these wells, which are 1,400 to 1,800 feet in depth, were drilled in order to test sands in the Morrison formation, which are impregnated with oil at their outcrop in that area. None of these wells found more than a trace of oil, although some gas was found in one or two of the wells.[95]

After the early drilling in the Green River Desert a test well was started near Goodridge, on the San Juan River in southern Utah, about 100 miles south of Moab. Oil seeps are found there in the Hermosa and Rico formations, and in order to test these horizons the first well was started in the fall of 1907, and oil was encountered on March 4, 1908, at a depth of 225 feet. This well, the first drilled in the San Juan oil field, was a gusher and threw oil 70 feet above the floor of the derrick. From 1908 to 1911 many wells were drilled near the discovery well, but not all of them were completed. Small production was obtained from several wells in the field, and it continued to produce for many years. All the oil produced was used locally, partly as fuel in later drilling and partly as refined products from a local refinery. Since 1911 a few wells have been drilled but at present there are no producing wells in the field.[96]

The Jones well, in sec. 13, T. 22 S., R. 22 E., a few miles southwest of Cisco, was drilled to a depth of 1,800 feet in 1899–1900 and was the first well drilled in or near the Moab district. A well was drilled on the Salt Valley anticline in sec. 5, T. 23 S., R. 20 E., in 1918–19 to a depth of 825 feet and obtained a showing of oil and gas. Drilling started in the vicinity of Crescent, a few miles west of Thompsons,

[95] For a more detailed account of drilling activity on the Green River Desert prior to 1914, see Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 117–121, 1914.

[96] More detailed accounts of drilling in the San Juan field are given in the following reports: Gregory, H. E., The San Juan oil field, San Juan County, Utah: U. S. Geol. Survey Bull. 431, pp. 11–25, 1911. Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 98–103, 1912. Miser, H. D., Geologic structure of San Juan Canyon and adjacent country, Utah: U. S. Geol. Survey Bull. 751, pp. 141–142, 1925.

in 1920, and several wells have been drilled there since that time. Showings of oil and gas were encountered in the well of the Crescent Eagle Oil Co. in sec. 4, T. 22 S., R. 19 E., about 6 miles southwest of Thompsons. In 1920 the Western Allied-Big Six Oil Co. drilled to a depth of 2,450 feet in sec. 12, T. 26 S., R. 21. E., in Moab Valley, and obtained showings of oil and gas that encouraged further drilling. Later in 1920 the same company started another well in sec. 34, T. 25 S., R. 21 E., in Moab Valley west of the Colorado River and encountered several showings of oil and gas. Drilling was suspended after reaching a depth of 2,870 feet, but after oil had been found in other wells in the region this well was cleaned out and drilling was resumed in the fall of 1926. After drilling to a depth of 5,345 feet the well was abandoned early in 1928. Drilling was started near Cisco in 1921, and up to the present time eight wells have been drilled which have produced gas and have obtained showing of oil from a sandstone near the horizon of the Dakota (?) sandstone.

A test well known as the Frank Shafer No. 1, on the Cane Creek anticline in sec. 31, T. 26 S., R. 21 E., was started in the winter of 1924–25 by the Utah Southern Oil Co. and the Utah Oil Refining Co. The Midwest Exploration Co. later took over the drilling of this well under an agreement with these companies. In December, 1925, a green paraffin-base oil with a gravity of 36° Baume was found at a depth of 2,028 feet. The oil and gas that gushed from the well caught fire and burned the rig. The blaze was soon extinguished and the well brought under control, but it was not possible to shut off water from a higher horizon, so drilling was continued. Oil and gas were encountered at a depth of 3,628 feet in August, 1926, and the oil was reported to have risen 800 feet in the well. A gas pocket was reported at a depth of 4,980 feet. Drilling was suspended in December 1926, at a depth of 5,000 feet, but in the fall of 1927 an unsuccessful attempt was made to recover oil from the beds at 2,028 and 3,628 feet. Encouraged by the first occurrence of oil in the No. 1 well on the Cane Creek anticline, the operators made preparations to drill several more wells, and in March, 1926, a test well known as the J. H. Shafer No. 1 was started by the same group of companies on the Shafer anticline, 8 miles down the river from the No. 1 well. This well obtained showings of oil but did not encounter the oil-bearing bed found at 2,028 feet in the No. 1 well and was abandoned at a depth of 5,863 feet, the greatest depth reached in any of the wells. A third well—the Prommel No. 1—drilled by the Midwest Exploration Co. under contract with the Snowden-McSweeney Co., was started later in the fall of 1926 in sec. 5, T. 27 S., R. 21 E., and abandoned at a depth of 3,520 feet. So far as known no showings of oil or gas were found in this well. Early in 1926 two wells were started near Moab, one by the Utah Oil Development Co., in sec. 8, T. 26 S., R. 22 E., and another, in April, by the Empire Petroleum Co., in the NW. ¼ sec. 20, T. 25 S., R. 21 E. Some showing of oil was obtained in the well of the Utah Oil Development Co., but drilling was suspended at a depth of 1,525 feet. The Empire Petroleum Co. drilled a shallow well and then skidded the rig to a second location, where another shallow well was drilled. This company then started the erection of a standard rig to drill a deep test at the same location, but the rig was not completed.

Since the field work in the Moab district was completed the Utah Southern Oil Co. has drilled additional wells designed to test the flanks of the anticlines. In January, 1928, the John L. Shafer No. 1A was drilled on the north flank of the Cane Creek anticline a short distance west of the Colorado River, in sec. 25, T. 26 S., R. 20 E. The well was reported to have obtained a show of gas at 2,055 feet. It was abandoned in June, 1929, at a depth of 4,107 feet. Northwest of the area considered in this report the King No. 1 well was started in June, 1928, in sec. 13, T. 23 S., R. 20 E., on the east side of the Salt Valley anticline, and abandoned at a depth of 3,829 feet. So far as known to the writer no showings of oil or gas were obtained.

In the southern part of the district five wells were started in 1926. Four were on the Gibson dome, in the valley of Indian Creek, and one on the Colorado River at the mouth of Lockhart Canyon. The well of the Empire Gas & Fuel Co. in sec. 6, T. 30 S., R. 21 E., which was spudded August 19, 1926, and drilled to a depth of 4,163 feet obtained small showings of oil and gas. It was abandoned in July, 1927. In sec. 1, T. 30 S., R. 20 E., the Utah Petroleum Corporation spudded a well September 1, 1926. After reaching a depth of 1,643 feet drilling was suspended in April, 1927. In sec. 3, T. 29½ S., R. 20 E., the Deseret Petroleum Co. spudded a well June 25, 1926, and drilled it 514 feet. Another shallow well, reported to be 300 feet deep, was drilled by the Western States Development Co. in sec. 34, T. 29 S., R. 20 E. This well was spudded July 30, 1926. The well spudded August 5, 1926, on the Lockhart dome, in sec. 16, T. 28 S., R. 20 E., by the Utah Southern Oil Co., was drilled to a depth of 527 feet.

Several wells have been drilled in southeastern Utah adjacent to the area described in this report. In sec. 16, T. 30 S., R. 25 E., about 6 miles east of the area here described, the Union Oil Co. of California began to drill March 26, 1927, and continued to a depth of 5,010 feet. Showings of oil and several small gas pockets were found. The Elk Ridge well of the Midwest Exploration Co., in sec. 30, T. 34 S., R. 19 E., in Dark Canyon, 18 miles south of the Moab district, was spudded September 14, 1926, and drilled to a depth of 4,422 feet, but was abandoned when the well reached igneous rock. No oil or gas was found. On September 16, 1926, the Utah Southern

Oil Co. spudded a well in sec. 28, T. 40 S., R. 18 E., about 5 miles north of the San Juan field described above. The well was drilled to a depth of about 3,650 feet and ended in igneous rock. Only slight showings of gas were obtained. West of the junction of the Green and Colorado Rivers the Texas Co. drilled a well 2,200 feet deep in sec. 34, T. 29 S., R. 16 E., in 1923–24. This well started in higher formations and did not reach the horizon where drilling of the wells east of the river began.

POSSIBILITY OF OIL AND GAS PRODUCTION

The "Goodridge formation," which includes the Hermosa and Rico formations, contains small quantities of oil near Goodridge and Mexican Hat, on the San Juan River in southern Utah,[97] and the Hermosa formation contains natural gas seeps on the Green River near its junction with the Colorado River.[98] Few of the wells drilled in the Moab district obtained even a showing of oil in the Hermosa formation, but most of them obtained small quantities of oil or gas at various horizons within the salt series of the Paradox formation. In the writer's opinion the black shales and perhaps the limestones interbedded with the salt are the source of the oil and gas, which have accumulated in small amounts in favorable places. The black shales and limestones constitute a small percentage of the salt series, and individual beds are thin and apparently discontinuous, as records of adjacent wells show no similarity in sequence of beds penetrated. This discontinuity is probably due to the flowage of the associated salt but may be due in part to irregularity of deposition.

Early drilling showed the presence of a thick series of salt beds beneath the area, and theories assuming the intrusion of salt plugs into overlying beds were advanced to explain the origin and type of folds present in the area. As the upturned strata surrounding salt plugs have been prolific producers of oil from salt domes in various parts of the world,[99] some of the more recent drilling in the Moab district has been planned to test the strata surrounding the supposed salt plugs. The wells drilled on the flanks of the anticlines have disclosed conditions similar to those encountered at the crests of the folds, but an insufficient number of wells have been drilled to test the flanks thoroughly. The writer considers that the salt has not been intruded into overlying beds except in the Castle Creek anticline and that the anticlines are not salt domes within the ordinary meaning of the term.

[97] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 93–94, 1912. Miser, H. D., Geologic structure of San Juan Canyon and adjacent country, Utah: U. S. Geol. Survey Bull. 751, pp. 140–141, 1925.

[98] Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulations: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 387, 1927.

[99] DeGolyer, E., and others, Geology of salt-dome oil fields, Am. Assoc. Petroleum Geologists, 1926.

Although commercial production of oil and gas has not been obtained in the Moab district, promising showings were encountered from time to time. The crests of most of the domes and anticlines and the flanks of some of them have been penetrated by wells. The failure to obtain commercial production from the considerable number of wells thus drilled does not offer particular encouragement for success in further drilling, but because oil and gas are known to be present in the Paradox formation, there remains the possibility that some well in the Moab district will encounter a larger accumulation of oil or gas in that formation than has yet been found.

URANIUM AND VANADIUM

Uranium and vanadium minerals locally impregnate the sandstones in the lower part of the Salt Wash member of the Morrison formation. The outcrops of these sandstones have been prospected, and numerous short drifts have been driven, particularly in Tps. 27 and 28 S., R. 23 E. This area is part of a larger area encircling the La Sal Mountains, where efforts have been made to locate bodies of ore rich enough to be mined profitably.

The ore-bearing minerals consist of the uranium mineral carnotite associated with several vanadium minerals, among which are hewettite and roscoelite. The minerals appear to be irregularly disseminated through the sandstones, and the ore deposits are reported by Hess [1] to be of relatively low grade. The ores have been mined primarily for uranium, and the vanadium has been produced as a by-product, but recent foreign production of both uranium and vanadium has made it unprofitable to work these deposits. The market price of radium in 1930 was about $65,000 a gram, and Hess expresses the opinion that under present conditions and technique radium can not be extracted from these ores and marketed at much less than $100,000 a gram.

SALT, GYPSUM, AND POTASH

The salt and gypsum of the Paradox formation constitute a potential resource; but because of the abundance of these materials in districts better situated with respect to markets, it is doubtful that the deposits in the Moab district will be exploited for salt or gypsum for many years.

The salt beds contain various minerals, among which potassium-bearing minerals have been noted in cuttings from some wells in southeastern Utah. A sample of potassium-bearing salts from the Crescent Eagle well, near Thompsons, Utah, a few miles north of this area, contained 49.05 per cent of potassium oxide.[2] Lang tentatively

[1] Hess, F. L., U. S. Bur. Mines Mineral Resources, 1926, pt. 1, p. 269, 1929.

[2] Lang, W. B., Potash investigations in 1924: U. S. Geol. Survey Bull. 785, pp. 38–39, 1926.

assigned the potassium-bearing salt beds to the "McElmo" formation, but the writer believes that this age assignment is in error and that these beds should be included in the Paradox formation. Some potassium was also reported in the salt penetrated between depths of 2,412 and 2,508 feet in the Frank Shafer No. 1 well, in sec. 31, T. 26 S., R. 21 E. Some of the oil companies had careful examinations made of cuttings from their wells but did not find potassium minerals. The practical absence of potassium from the well cuttings can not be construed as indicating that potassium is not present in the salt, for all the wells within the area were drilled with churn drills, and the very soluble salts of potassium probably would not survive the agitation of the water by the drill and be detected as solid matter in the sludge. So far as the writer is aware, no tests were made for potassium in the water bailed from the wells. The General Petroleum Co. drilled a well in Paradox Valley, in western Colorado, with a rotary rig and took cores of most of the salt beds that were penetrated, but the writer does not know of any potassium minerals having been observed in this well.

It is unfortunate that more systematic efforts were not made to detect potassium salts in the wells that have already been drilled. The results of the drilling show only that the salt-bed series is thick and extends over a large area. The potassium salts known to be present locally have not been demonstrated to be of widespread occurrence or present in sufficient quantity to be of commercial value.

RECORDS OF WELLS

The records of seven deep wells drilled in the area are given on the following pages. The well drilled in Lisbon Valley by the Union Oil Co. of California is 6 miles east of the area mapped, but its record is included to show that subsurface conditions east of the area are similar to those near the Colorado River. The records of the shallow wells are not shown. The lithologic descriptions are those given by the drillers, and the writer has interpreted the formation boundaries.

Record of J. H. Shafer No. 1 well in sec. 16, T. 27 S., R. 20 E.

	Thickness (feet)	Depth (feet)
Hermosa formation:		
Blue limestone	25	25
Red sandstone; water-bearing	38	63
Limestone	10	73
Sandstone; water-bearing	8	81
Red shale	19	100
Hard brown limestone	10	110
Blue shale and hard shell	21	131
Gray limestone	14	145
Shale	63	208
Gray limestone	74	282
Shale	3	285
Gray limestone	65	350
Hermosa formation—Continued.		
Black slate	15	365
Black limestone	10	375
Gray limestone	39	414
Black shaly limestone	11	425
Gray sandy limestone	15	440
Muddy gray sandstone	25	465
Hard gray sandy limestone	20	485
Dark sandstone	10	495
Sandy brown shale	30	525
Gray limestone	45	570
Brown shale	20	590
Brown limestone	6	596

Record of J. H. Shafer No. 1 well in sec. 16, T. 27 S., R. 20 E.—Continued

	Thickness (feet)	Depth (feet)
Hermosa formation—Continued.		
Gray shale	3	599
Brown limestone	6	605
Interbedded shale and limestone	21	626
Gray limestone	29	655
Blue shale and gray limestone	25	680
Sandstone	5	685
Gray limestone	11	696
Gray shale	5	701
Gray limestone	17	718
Sandstone; water-bearing	6	724
Gray limestone	29	753
Blue shale	11	764
Sandstone; salt water and show of oil	18	782
Gray limestone and gray shale	323	1,105
Black limestone	70	1,175
Black shale	5	1,180
Interbedded gray limestone and gray shale	150	1,330
Black limestone	32	1,362
Gray limestone	138	1,500
Limy shale	25	1,525
Black limestone and black shale	40	1,565
Gray limestone	45	1,610
Paradox formation:		
Limestone and salt	10	1,620
Salt	13	1,633
Shell	2	1,635
Salt	100	1,735
Limestone	10	1,745
Brown sandstone	10	1,755
Black slate	15	1,770
Black shale	18	1,788
Black limestone	8	1,796
Salt	4	1,800
Limestone and salt	23	1,823
Salt	76	1,899
Gray limestone	39	1,938
Black shale	102	2,040

	Thickness (feet)	Depth (feet)
Paradox formation—Continued.		
Salt	10	2,050
Limestone	25	2,075
Gray shale	19	2,094
Limestone	6	2,100
Sandstone, shale, and salt	25	2,125
Salt	130	2,255
Limestone	15	2,270
Gray shale	95	2,365
Salt	18	2,383
Gray shale	107	2,490
Salt	100	2,590
Shale and gypsum	10	2,600
Salt	190	2,790
Shale and gypsum	35	2,825
Salt	165	2,990
Limestone	50	3,040
Salt	200	3,240
Sandy shale	30	3,270
Black shale	35	3,305
Salt	43	3,348
Gray shale and gypsum	62	3,410
Salt	130	3,540
Gray shale	55	3,595
Salt	65	3,660
Gray shale	36	3,696
Salt	264	3,960
Black shale	5	3,965
Salt	360	4,325
Gray shale and gypsum	55	4,380
Salt	476	4,856
Brown shale	41	4,897
Gray shale and gypsum	118	5,015
Salt	265	5,280
Black shale	40	5,320
Gray sandy shale	70	5,390
Salt	125	5,515
Black shale and gypsum	55	5,570
Gray sandy shale	20	5,590
Black limestone	25	5,615
Gray sandy shale	65	5,680
Limestone	10	5,690
Molas formation(?):		
Variegated shale, fresh water	173	5,863

Record of Frank Shafer No. 1 well in sec. 31, T. 26 S., R. 21 E.

	Thickness (feet)	Depth (feet)
Alluvium:		
Sand and gravel	55	55
Hermosa formation:		
Gray shale	8	63
Hard gray limestone	7	70
Gray sandstone, water bearing	12	82
Gray shale	3	85
Gray sandstone	10	95
Gray shale	30	125
Brown limestone	5	130
Brown sandy shale	10	140
Brown sandstone	10	150
Brown shale	12	162
Hard brown limestone	38	200
Gray limestone	17	217
Brown sandstone	2	219
Brown shale	18	237
Gray shale	3	240
Gray limestone	92	332
Gray limy shale	4	336
Gray limestone	16	352
Gray limy shale	4	356
Gray limestone	9	365
Gray shale	3	368

	Thickness (feet)	Depth (feet)
Hermosa formation—Continued.		
Gray limestone	5	373
Gray sandy shale	17	390
Brown sandy limestone	30	420
Gray sandy limestone	30	450
Gray shale	2	452
Hard gray limestone	15	467
Brown sandy limestone	7	474
Gray shale	21	495
Hard gray limestone	105	600
Blue limestone	100	700
Brown limestone	100	800
Gray to black limestone	87	887
Gray limy shale	4	891
Hard gray limestone	4	895
Black limestone	7	902
Gray limestone	7	909
Blue shale	2	911
White limestone	8	919
Gray limestone	3	922
Gray and black limestone	23	945
Gray shale	15	960
Gray limestone	15	975
Brown limestone	50	1,025
Blue shale	2	1,027

Record of Frank Shafer No. 1 well in sec. 31, T. 26 S., R. 21 E.—Continued

	Thickness (feet)	Depth (feet)
Hermosa formation—Continued.		
Gray limestone	31	1,058
Black limy shale	40	1,098
Black limestone	19	1,117
Gray limestone	170	1,287
Brown shale	22	1,309
Brown shale, sticky with tar	2	1,311
Black limestone	7	1,318
Blue shale	3	1,321
Dark-gray limestone	5	1,326
Gray shale	19	1,345
Gray shale, sticky	9	1,354
Light-gray shale	6	1,360
Blue shale	12	1,372
Gray limestone	8	1,380
Gray shale	17	1,397
Gray limestone	11	1,408
Gray to brown limestone; gas	17	1,425
Brown shale	26	1,451
Hard shell	1	1,452
Black shale	13	1,465
Gray shale	10	1,475
Paradox formation:		
Gray limestone with some gypsum	21	1,496
Gray shale, sticky	2	1,498
Gray limestone with some salt	5	1,503
Salt	42	1,545
Salt, limestone, and shale	18	1,563
Gray limestone	2	1,565
Brown shale	67	1,632
Gray limestone	23	1,655
Salt	178	1,833
Limestone	2	1,835
Gray shale	30	1,865
Salt; showing of oil	125	1,990
Gray sandy limestone	20	2,010
Gray sandy shale with salt	15	2,025
Dark sandy limestone; gas and oil	33	2,058
Black shale	5	2,063
Limestone	3	2,066
Salt	79	2,145
Limestone	2	2,147
Salt	41	2,188
Limestone	1	2,189
Salt and gypsum	4	2,193
Limestone	1	2,194
Salt with thin shale beds	59	2,253
Limestone	2	2,255
Salt with thin shale beds	8	2,263
Limestone	2	2,265
Salt and gypsum	28	2,293
Black shale	3	2,296
Salt and gypsum	46	2,342
Limestone	3	2,345
Salt	30	2,375
Black shale	3	2,378
Salt	31	2,409
Black shale	3	2,412
Salt showing some potash	96	2,508
Limestone	3	2,511
Salt with some gypsum	71	2,582
Black shale	2	2,584
Gray shale	20	2,604
Salt	122	2,726
Limestone	1	2,727
Gray shale	2	2,729
Salt with thin beds of shale	21	2,750
Limestone	3	2,753
Paradox formation—Continued.		
Salt	62	2,815
Limestone	1	2,816
Gray shale and limestone	36	2,852
Limestone	5	2,857
Salt	113	2,970
Limestone	2	2,972
Salt	35	3,007
Limestone	1	3,008
Black shale	19	3,027
Gray shale with some sandstone	10	3,037
Salt	221	3,258
Black shale	87	3,345
Salt	38	3,383
Limestone	2	3,385
Gray sandy shale	6	3,391
Salt	31	3,422
Black shale	92	3,514
Salt	108	3,622
Black shale	6	3,628
Sandy limestone and shale	5	3,633
Black shale; show of oil	17	3,650
Black shale with gypsum	20	3,670
Gray sandy shale	3	3,673
Salt	6	3,679
Black sandy shale	9	3,688
Salt	165	3,853
Fine-grained sandstone and shale	6	3,859
Sandstone, shale, and gypsum	6	3,865
Black shale	22	3,887
Black shale, salt, and gypsum	5	3,892
Salt	163	4,055
Black shale	11	4,066
Limestone	1	4,067
Shale and gypsum	58	4,125
Salt	71	4,196
Limestone	2	4,198
Salt	30	4,228
Limestone	2	4,230
Salt	42	4,272
Sandy shale and gypsum	28	4,300
Limestone	1	4,301
Shale	34	4,335
Salt	10	4,345
Black shale	15	4,360
Salt	15	4,375
Black shale	21	4,396
Salt	54	4,450
Shale	15	4,465
Gray sandy shale and salt	43	4,508
Salt	12	4,520
Gray sandy shale	10	4,530
Salt and gypsum	9	4,539
Salt	13	4,552
Limestone and shale	13	4,565
Shale	23	4,588
Salt	102	4,690
Gray shale	10	4,700
Salt and shale	35	4,735
Salt	30	4,765
Gray shale	15	4,780
Salt	70	4,850
Black sandy shale	66	4,916
Salt	16	4,932
Salt and shale	16	4,948
Limestone	1	4,949
Salt and gypsum; gas	27	4,976
Salt	24	5,000

Record of J. L. Shafer No. 1 A well in sec. 25, T. 26 S., R. 20 E.

	Thickness (feet)	Depth (feet)
Alluvium:		
Surface wash	30	30
Rico and Hermosa formations:		
Red sandstone	8	38
Limestone	4	42
Blue limestone	6	48
Brown sandstone	3	51
Gray limestone	3	54
Red clay	11	65
Red sandstone	5	70
Broken limestone	40	110
Gray limestone; sulphur water	5	115
Hard gray limestone	10	125
Blue limestone	10	135
Gray limestone	50	185
Blue limestone	10	195
Gray limestone	30	225
Blue shale	5	230
White limestone	89	319
Brown shale and clay	11	330
Gray limestone	10	340
Brown limestone	5	345
Gray limestone	115	460
Interbedded gray limestone and shale	24	484
Gray limestone	35	519
Black limestone	6	525
Gray limestone	25	550
Blue sandy limestone	4	554
Blue limestone	11	565
Gray limestone	23	588
Shale	3	591
Black limestone	4	595
Gray limestone and shale	4	599
Gray limestone	5	604
Blue clay	4	608
Gray limestone	6	614
Coarse gray sandstone	6	620
White sandy limestone	31	651
Red limestone	9	660
Red clay	2	662
Red limestone	11	673
Brown limestone	11	684
Red clay	1	685
Brown limestone	42	727
Gray limestone	38	765
Blue limestone	3	768
Gray limestone	25	793
Brown clay	1	794
Brown limestone	15	809
White limestone	8	817
Brown limestone	5	822
White limestone	33	855
Blue limestone	12	867
Gray limestone	7	874
Blue limestone	6	880
Gray limestone	18	898
Gray sandstone	7	905
Gray limestone	34	939
Brown coarse-grained sandstone; water	11	950
Brown sandy limestone	10	960
Gray limestone	116	1,076
Blue limestone	26	1,102
Black limestone	17	1,119
Gray limestone	174	1,293
Black limestone	12	1,305
Gray limestone	11	1,316
Brown shale	6	1,322
Gray limestone	56	1,378
Blue limestone	9	1,387
Gray limestone	59	1,446
Blue limestone	22	1,468
Gray limestone	3	1,471
Blue limestone	5	1,476
Black limestone	2	1,478
Gray limestone	63	1,541
Blue limestone	4	1,545
Gray limestone	5	1,550
Blue limestone	5	1,555
Gray limestone	40	1,595
Black limestone	16	1,611
Gray limestone	29	1,640
Blue shaly limestone	5	1,645
Blue limestone	5	1,650
Rico and Hermosa formations—Continued.		
Gray limestone	28	1,678
Brown limestone	23	1,701
Dark-gray limestone	3	1,704
Brown shale	6	1,710
Brown limestone	10	1,720
Gray limestone	78	1,798
Black limestone with a little shale	46	1,844
Gray limestone	7	1,851
Gray limy shale	6	1,857
Gray sandy limestone	2	1,859
White limestone	23	1,882
Brown limestone and shale	11	1,893
Gray limestone	92	1,985
Brown limestone	43	2,028
Gray limestone	20	2,048
Paradox formation:		
Blue shale	20	2,068
Brown shale	8	2,076
Black shale and anhydrite	6	2,082
Black shale	4	2,086
Gray limestone	37	2,123
Gray shale	2	2,125
Gray limestone	9	2,134
White sandstone	2	2,136
Salt with thin beds of shale and limestone	234	2,370
Sandy limestone; water	36	2,406
Black shale	25	2,431
Sandy limestone	9	2,440
Anhydrite	3	2,443
Sandy limestone	32	2,475
Blue clay	2	2,477
Limestone	2	2,479
Salt	15	2,494
Shale	2	2,496
Salt	5	2,501
Black shale	30	2,531
Salt with thin beds of black shale	39	2,570
Gray limestone	42	2,612
Soft black shale	8	2,620
Limestone	1	2,621
Black shale	26	2,647
Gray sandy limestone	25	2,672
Salt	34	2,706
Gray shale	11	2,717
Salt	34	2,751
Gray shale	4	2,755
Salt	38	2,793
Limestone	2	2,795
Salt	48	2,843
Gray sandy limestone	17	2,860
Anhydrite	8	2,868
Black shale	17	2,885
Salt	143	3,028
Anhydrite	7	3,035
Anhydrite and limestone	5	3,040
Gray and black shale	6	3,046
Shale and anhydrite	6	3,052
Gray limestone	8	3,060
Shale, limestone, and gypsum	4	3,064
Gray shale	30	3,094
Gray shale and sandy limestone	1	3,095
Gray sandy shale	4	3,099
Gray shale and gypsum	3	3,102
Anhydrite	3	3,105
Salt and gray shale	1	3,106
Salt	4	3,110
Salt and anhydrite	10	3,120
Salt and black shale	55	3,175
Salt	257	3,432
Anhydrite, gray shale, and gypsum	11	3,443
Limestone	2	3,445
Gray shale	9	3,454
Salt and black shale	6	3,460
Salt	120	3,580
Black shale	10	3,590
Salt streaked with black shale	25	3,615
Salt	73	3,688
Black shale	52	3,740
Salt and shale streaks	10	3,750
Salt	357	4,107

Record of well drilled by Embar-Big Six Oil Cos. in sec. 34, T. 25 S., R. 21 E.

[The strata penetrated by this well have undoubtedly been faulted, and it is not possible to make a satisfactory interpretation of the well record]

	Thickness (feet)	Depth (feet)
Alluvium	56	56
Hermosa and Paradox formations:		
Blue limestone; show of oil and gas at 104 feet	171	227
Brown limestone	20	247
Hard blue limestone	27	274
Red shale	11	285
Brown shale	27	312
Hard gray limestone	6	318
Hard blue limestone	55	373
Black shale; show of oil and gas	6	379
Blue shale and limestone	26	405
Salt	3	408
Blue shaly limestone	12	420
Shale	2	422
Black limestone	19	441
Brown limestone	10	451
Blue limestone	11	462
Red shale	2	464
Gray and brown limestone	48	512
Black shaly limestone	13	525
Gray limestone	21	546
Black shaly limestone	4	550
Black limestone	15	565
Chocolate-brown shale	1	566
Red shale	14	580
Blue shale; sulphur water	30	610
Hard sandy limestone	20	630
Sandy shale	10	640
Black limy shale	54	694
Sandy shale; show of oil and gas	41	735
Gray limestone	30	765
Black limestone	15	780
Gray limestone	120	900
Variegated shale	26	926
Limestone	3	929
Blue shale	3	932
Blue limestone	34	966
Gray shale	17	983
Salmon shale	25	1,008
Blue limestone	3	1,011
Blue shale	6	1,017
Black limestone; show of oil and gas	35	1,052
Blue shale	60	1,112
Red shale	34	1,146
Brown limestone	3	1,149
Sandstone; show of oil	2	1,151
Hard black limestone	12	1,163
Blue clay; show of gas and salt water	49	1,212
Grayish-brown limestone	11	1,223
Brown shale	14	1,237
Blue sandy limestone	8	1,245
Blue shale; show of gas	45	1,290
Brown shale	20	1,310
Gray shale, sulphur water	30	1,340
Brown shale	173	1,513
Gypsum	27	1,540
Brown shale	30	1,570
Black shale	10	1,580
Brown shale	10	1,590
Black shale	320	1,910
Hermosa and Paradox formations—Continued.		
Black shale and salt	50	1,960
Gray shale	36	1,996
Sandy brown shale; show of oil and gas	19	2,015
Chocolate-brown shale	45	2,060
Brown sandy shale; show of gas	105	2,165
Black shale; show of oil; water	30	2,195
Salt	40	2,235
Black shale	48	2,283
Fine-grained sandstone; show of gas	2	2,285
Salt	25	2,310
Gray shale	40	2,350
Black shale; show of oil and gas	68	2,418
Gray shale	27	2,445
Salt with thin beds of black shale	300	2,745
Gray shale	10	2,755
Gray sandstone	55	2,810
Black shale; show of oil and gas	60	2,870
Blue shale	54	2,924
Dark-gray shale	136	3,060
Brown shale	65	3,125
Light-gray sandstone and gypsum	57	3,182
Gray sandstone	18	3,200
Light-brown shaly limestone	12	3,212
Light-brown sandy shale	6	3,218
Light-gray shale	7	3,225
Gray and blue shale	39	3,264
Gray shale	37	3,301
Blue shale	46	3,347
Gray shale	14	3,361
Gray sandy shale	37	3,398
Black shale	110	3,508
Black shale and gypsum	17	3,525
Gray shale	325	3,850
Black shaly and sandy limestone; show of oil and gas	35	3,885
Gray sandy shale	68	3,953
Gray sandy shale with salt beds	32	3,985
Dark shale	40	4,025
Hard sandy limestone	15	4,040
Gray sandy shale	45	4,085
Sandy limestone; show of oil	10	4,095
Gray and black sandy limestone	25	4,120
Black shale	20	4,140
Brown shale	30	4,170
Conglomerate	190	4,360
Gray limestone	15	4,375
Hard sandy limestone; show of gas	35	4,410
Sandy shale with thin limestone beds	565	4,975
Sandy shale with thin limestone beds and thick beds of hard sandstone; show of oil and gas	370	5,345

Record of Prommel No. 1 well, in sec. 5, T. 27 S., R. 21 E.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Rico formation:			Hermosa formation—Continued.		
Red sandstone	210	210	Gray limestone	50	1,610
White limestone	10	220	Blue shale	10	1,620
Red sandstone	30	250	Gray limestone	35	1,655
Hermosa formation:			Black shale	57	1,712
Gray limestone	10	260	Black limestone	18	1,730
Interbedded limestone and shale	20	280	White limestone, water bearing	56	1,786
Gray limestone	10	290	Gray limestone	14	1,800
Green shale	15	305	Black shale	4	1,804
Limestone	45	350	Gray limestone	56	1,860
Brown sandstone; sulphur water	15	365	White limestone	6	1,866
Blue and gray limestone	85	450	Gray limestone	49	1,915
Sandstone, water bearing	4	454	Black shale	35	1,950
Gray limestone	46	500	Gray limestone	8	1,958
Black limestone	15	515	Black shale	12	1,970
Gray limestone	165	680	Gray limestone	42	2,012
Red clay	10	690	White limestone	13	2,025
Gray limestone	11	701	Gray limestone	20	2,045
Red shale	9	710	Paradox formation:		
Gray limestone	45	755	Black and gray shale and black and gray limestone	95	2,140
Blue shale	7	762	Salt	57	2,197
Gray limestone	18	780	Brown and black shale with thin beds of limestone	143	2,340
Blue shale	20	800	Salt	105	2,445
Gray limestone	31	831	White shale	35	2,480
Blue shale	9	840	Salt	115	2,595
Gray limestone	30	870	Black shale	5	2,600
Blue shale	10	880	Salt	10	2,610
Gray limestone	30	910	Limestone, salt, and gypsum	5	2,615
Blue shale	10	920	Brown limestone	5	2,620
Gray limestone	23	943	Black shale	29	2,649
Blue shale	7	950	Shale, limestone, and gypsum	60	2,709
Gray limestone	57	1,007	Salt	297	3,006
Blue shale	8	1,015	Gray limestone	6	3,012
Gray limestone	294	1,309	Gray shale	20	3,032
Shale	17	1,326	Salt	193	3,225
Gray limestone	144	1,470	Shale and gypsum	60	3,285
Black limestone	23	1,493	Salt	137	3,422
Gray limestone	26	1,519	Gray limestone	16	3,438
Gray shale	23	1,542	Shale	22	3,460
Gray limestone	8	1,550	Salt	60	3,520
Sandy limestone, water bearing	10	1,560			

Record of well drilled by Empire Gas & Fuel Co. in sec. 6, T. 30 S., R. 21 E.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Alluvium:			Rico formation—Continued.		
Sandy loam	15	15	Red shale	72	477
Cutler formation:			Gray limestone	17	494
Red sandstone	47	62	Red sandstone	14	508
Rico formation:			Red shale	6	514
Blue limestone	28	90	Hermosa formation:		
Red sandstone	10	100	Sandy limestone	4	518
Sandy limestone	6	106	Gray limestone	10	528
Limestone	3	109	White sandstone	10	538
Sandy shale	6	115	Limestone	5	543
Sandstone; water bearing	3	118	White sandstone	3	546
Limestone	4	122	Shale	4	550
Brown sandstone	6	128	Limestone	17	567
Limestone	2	130	Shale	9	576
Red sandstone	20	150	Limestone	4	580
White sandstone	14	164	Light-colored shale	15	595
Red shale	71	235	Sandy shale	5	600
White sandstone	17	252	Blue shale	26	626
Red shale	4	256	Red shale	5	631
Sandy limestone	10	266	Blue limestone	6	637
Red shale	78	344	Blue slate	5	642
Sandy shale	11	355	Gray limestone	8	650
Red shale	40	395	Sandy limestone	20	670
Red sandy limestone	10	405	Gray shale	47	717

Record of well drilled by Empire Gas & Fuel Co. in sec. 6, T. 30 S., R. 21 E.—Continued

	Thickness (feet)	Depth (feet)
Hermosa formation—Continued.		
Red sandstone	5	722
Gypsum, sandstone, and shale	10	732
Sandy limestone	25	757
Hard limestone	43	800
White sandstone	15	815
Hard limestone	15	830
White sandstone	4	834
Hard limestone	19	853
Gray sandstone	24	877
Blue sandy limestone	16	893
Hard limestone	30	923
Hard white sandstone	10	933
Hard limestone	31	964
Gray shale	9	973
Limestone	31	1,004
Sandstone	5	1,009
Limestone	39	1,048
Blue slate	6	1,054
Sandstone	8	1,062
Sandy limestone	10	1,072
Gray limestone	10	1,082
Blue slate	8	1,090
Red rock	23	1,113
Limestone	4	1,117
Sandy limestone	8	1,125
Blue slate	4	1,129
Limestone	10	1,139
Red rock	3	1,142
Limestone	12	1,154
Shale	4	1,158
Limestone	26	1,184
Red rock	5	1,189
Sandstone	7	1,196
Limestone	52	1,248
Blue slate	11	1,259
Limestone	8	1,267
Slate	3	1,270
Limestone	5	1,275
Sandstone	8	1,283
Limestone	5	1,288
Slate	2	1,290
Limestone	115	1,405
Sandstone	5	1,410
Limestone	12	1,422
Slate	8	1,430
Sandstone	5	1,435
Limestone	29	1,464
Sandstone	10	1,474
Blue limestone	8	1,482
Gray shale	12	1,494
Sandy limestone	23	1,517
Sandstone	4	1,521
Gray shale	9	1,530
Gray limestone	78	1,608
Gray shale	4	1,612
Hard blue limestone	24	1,636
Slate	5	1,641
Hard blue limestone	14	1,655
Gray shale and gypsum	5	1,660
Hard blue limestone	40	1,700
Sandstone	5	1,705
Limestone	22	1,727
Slate	3	1,730
Limestone	2	1,732
Slate	7	1,739
Limestone	8	1,747
Slate	6	1,753
Sandy limestone	4	1,757
Gray shale	8	1,765
Limestone	17	1,782
Blue-gray shale	9	1,791
Black shale	19	1,810
Hermosa formation—Continued.		
Limestone	2	1,812
Gray shale	4	1,816
Limestone	40	1,856
Blue shale	4	1,860
Limestone	2	1,862
Slate	13	1,875
Hard limestone	47	1,922
Shale	8	1,930
Slate	7	1,937
Shale	37	1,974
Limestone	33	2,007
Paradox formation:		
Salt	18	2,025
Limestone	17	2,042
Slate	33	2,075
Limestone	15	2,090
Shale	10	2,100
Sandstone	8	2,108
Salt	26	2,134
Salt and shale	16	2,150
Gray shale	5	2,155
Black shale	42	2,197
Limestone	20	2,217
Salt	33	2,250
Gray sandy shale	30	2,280
Salt	70	2,350
Gray shale	28	2,378
Brown shale	7	2,385
Gray shale	10	2,395
Shale and gypsum	18	2,413
Gray limestone	34	2,447
Salt	228	2,675
Limestone	35	2,710
Salt	58	2,768
Shale	4	2,772
Limestone	10	2,782
Salt	111	2,893
Black shale	2	2,895
Salt	165	3,060
Limestone	24	3,084
Shale	9	3,093
Limestone	14	3,107
Salt	63	3,170
Limestone	3	3,173
Salt	83	3,256
Blue slate	32	3,288
Limestone	63	3,351
Sandy shale	15	3,366
Limestone	9	3,375
Sandy limestone	11	3,386
Salt	10	3,396
Limestone	9	3,405
Salt	115	3,520
Limestone	8	3,528
Black shale	25	3,553
Black slate	27	3,580
Gray limestone	7	3,587
Gray sandy shale	16	3,603
Limestone	24	3,627
Salt	13	3,640
Limestone	10	3,650
Gray sandy limestone; show of gas	11	3,661
Limestone and salt	30	3,691
Salt	40	3,731
Black shale	4	3,735
Limestone, gypsum, and salt	39	3,774
Salt	109	3,883
Gray sandy limestone	30	3,913
Sandy limestone and salt	60	3,973
Salt	80	4,053
Gray limestone	64	4,117
Salt	46	4,163

Record of well drilled by Big Six-Western Allied Oil Co. in sec. 12, T. 26 S., R. 21 E.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Alluvium:			Paradox formation—Continued.		
Soil	30	30	Sandstone; water bearing	1	931
Quicksand	170	200	Salt	197	1,128
Paradox formation:			Sandstone; show of oil	10	1,138
Blue and black shale	730	930	Salt; oil at 1,380–1,420 feet	512	1,650

Record of well drilled by Union Oil Co. of California in Lisbon Valley, in sec. 16, T. 30 S., R. 25 E.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Alluvium	17	17	Paradox formation—Continued.		
Rico formation:			Gray limestone	25	2,145
Red shale	138	155	Gray salt	345	2,490
Hermosa formation:			Black shale	5	2,495
Gray sandy limestone	75	230	Dark limestone	5	2,500
Pink sandy shale	10	240	Dark limy shale	50	2,550
Gray sandy limestone	30	270	Gray salt	15	2,565
Gray limestone	265	535	Gray sandstone; show of oil	1	2,566
Dark shale	45	580	Salt	104	2,670
Gray limy shale	75	655	Gray limy shale	20	2,690
Gray limestone	110	765	Sandy limestone	3	2,693
Dark shale	65	830	Salt; pocket of gas at 2,693 feet	287	2,980
Gray limy shale	30	860	Dark limy shale	32	3,012
Gray limestone	95	955	Salt	5	3,017
Dark shale	65	1,020	Dark sandy shale	20	3,037
Gray limy shale	15	1,035	Salt with limestone beds	213	3,250
Gray limestone	50	1,085	Dark limy shale; pocket of gas at 3,250 feet	10	3,260
Dark limy shale	100	1,185	Gray limestone	30	3,290
Gray limestone	10	1,195	Salt	170	3,460
Gray limy shale	15	1,210	Salt with limestone beds; pocket of gas at 3,510 feet	680	4,140
Dark shale	75	1,285	Gray sandy shale	40	4,180
Gray limy shale	25	1,310	Black limy shale; pocket of gas at 4,180 feet	60	4,240
Gray limestone	60	1,370	Gray salt	80	4,320
Gray limy shale	50	1,420	Dark limy shale; pocket of gas at 4,340–4,345 feet	90	4,410
Black shale	110	1,530	Gray salt	205	4,615
Gray limy shale	90	1,620	Sandstone	10	4,625
Paradox formation:			Dark limy shale	55	4,680
Gray salt	145	1,765	Gray salt	50	4,730
Gray shale	10	1,775	Dark limy shale	30	4,760
Black shale	25	1,800	Gray salt	160	4,920
Gray salt	145	1,945	Gray sandy limestone	40	4,960
Dark shale	25	1,970	Gray salt	50	5,010
Gray shale	10	1,980			
Gray salt	105	2,085			
Gray limestone	20	2,105			
Gray salt	15	2,120			

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