# GEOLOGY AND OIL AND GAS PROSPECTS OF PART OF THE SAN RAFAEL SWELL, UTAH

By James Gilluly

## INTRODUCTION

*Purpose of the report.*—The purpose of this report is to present an account of the general geologic features of part of the San Rafael Swell, Utah, with especial reference to its oil and gas possibilities. Oil-field experience has shown that upfolds or domes in the rocks are generally more favorable to the accumulation of oil and gas than other structural features. The San Rafael Swell is a feature of this type, and the public lands in the region were accordingly withdrawn from entry pending classification as to their oil possibilities. The discovery in 1923 of helium in gas from a well on the Woodside anticline, in sec. 12, T. 19 S., R. 13 E., near the north end of the Swell, aroused considerable additional interest because of the probable value of this gas in national defense.

Numerous factors affect the accumulation of commercially important bodies of oil and gas. The expense of drilling is very great compared with that of geologic study, and although such study can only rarely be completely decisive in advance of drilling, the data thus obtainable are desirable as a basis for classification of the land.

*Location and extent of the area.*—The San Rafael Swell lies in Emery County and northern Wayne County, Utah. The name was doubtless applied in reference to the geologic structure of the region, which is that of a huge swell or dome in the sedimentary rocks. Erosion has carved the Swell into a topography which is very distinctive and striking: geographically, as well as geologically, it is a unit.

The Swell is an elongate oval whose greater axis is about 70 miles long and trends nearly northeast in its southern part but curves to north by east in its northern half. The lesser axis is about 30 miles long.

The area described in this report is of irregular shape and embraces the west flank, the plunging ends, and part of the east flank of the Swell. It covers about 1,483 square miles. (See fig. 10.)

*Earlier work.*—Previous geologic work in this region has dealt with the San Rafael Swell as a whole only casually or in reconnaissance. Dutton [1] discussed the geology in a general way but did no

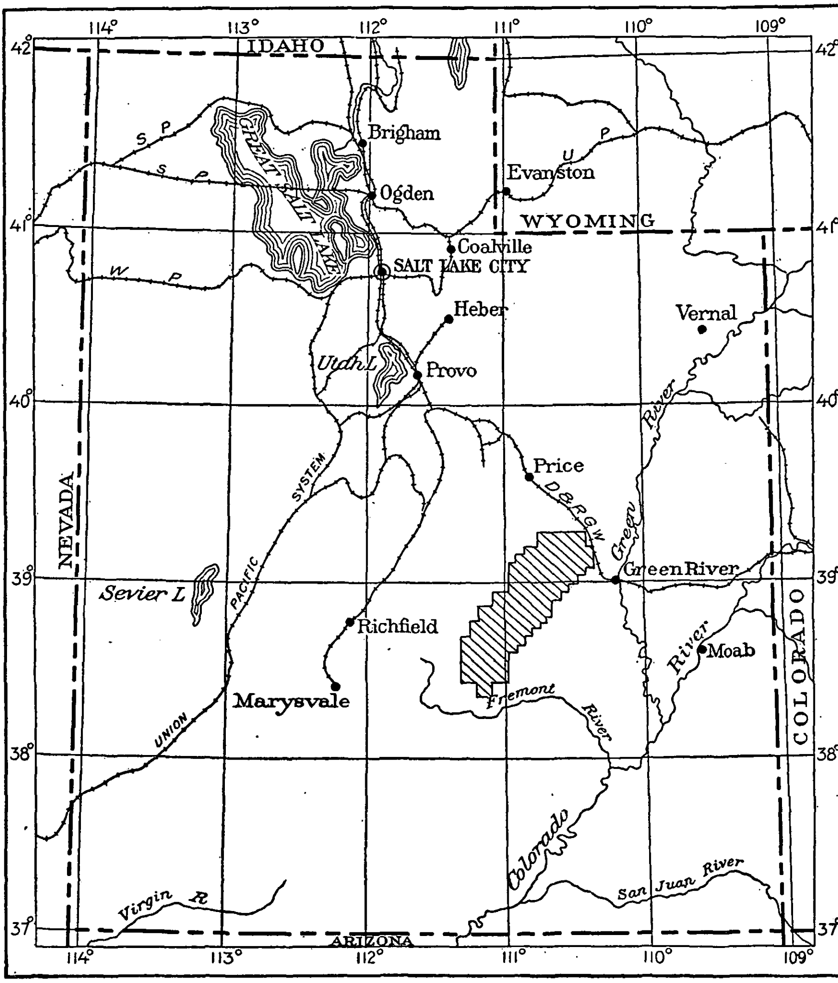



FIGURE 10.—Index map showing location of San Rafael Swell, Utah (shaded area)

work within the region. Lupton [2] and Emery [3] worked in adjoining areas, and Lupton also did some hasty reconnaissance within the area

[1] Dutton, C. E., Geology of the High Plateaus of Utah, pp. 19, 44, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[2] Lupton, C. T., Note on the geology of San Rafael Swell, Utah: Washington Acad. Sci. Jour., vol. 2, pp. 185–188, 1912; Gypsum along the west flank of the San Rafael Swell. Utah: U. S. Geol. Survey Bull. 530, 221–231, 1913; Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 115–133, 1914; Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, 1916.

[3] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551–577, 1918.

covered by this report. Boutwell[4] and Hess[5] examined local points of interest in the San Rafael Swell, but no detailed geologic map of any considerable area within it has been published prior to this survey.

The area is covered by reconnaissance topographic maps of the Price River, San Rafael, and Fish Lake quadrangles of the Geological Survey. These maps are on a scale of 1:250,000 and are of little value in detailed work, though they show well the major features of the country. The General Land Office has recently issued township plats which cover a small part of this area, and these were very useful in the field. The status of land surveys is indicated on Plate 30. No other maps of the San Rafael Swell have been previously published, and accordingly the present survey was nearly independent, being tied only to the land corners of a few widely scattered townships.

*Field work.*—The field work on which this report is based was begun in July, 1924, by a party under the direction of E. M. Spieker. Mr. Spieker withdrew from the field in August, and the writer was placed in charge. Work was continued until late in November, 1924, resumed in May, 1925, and completed in September, 1925. D. J. Fisher, W. H. Newhouse, and C. H. Dane acted as geologic assistants in 1924 and E. T. McKnight and S. S. Nye in 1925.

Mapping was begun in T. 20 S., R. 9 E., and was carried on by means of plane-table triangulation from a measured base line. The triangulation was checked at several points by stadia measurements between primary stations. Altitudes were determined by vertical-angle measurements and tied to datum by two stadia traverses from Geological Survey bench marks a few miles to the west, in Castle Valley. Stadia traverses were made in a number of areas where inaccessible cliffs prevented occupation of points from which the triangulation stations could be seen. A few small tracts on the Reef could not be surveyed accurately by any methods at the disposal of the party, but the geology of these tracts is believed to be fairly well outlined by the dotted formation boundaries on Plate 30, which presents the results of the survey, together with some data obtained from the General Land Office township plats.

*Acknowledgments.*—The writer is indebted to E. M. Spieker for the difficult work of getting the survey under way in an area whose stratigraphy was largely undescribed. The helpful cooperation of J. B. Reeside, jr., who spent several days in the field and who identified most of the fossils, is gratefully acknowledged. Able and con-

---

[4] Boutwell, J. M., Vanadium and uranium in southeastern Utah: U. S. Geol. Survey Bull. 260, pp. 208–209, 1905.

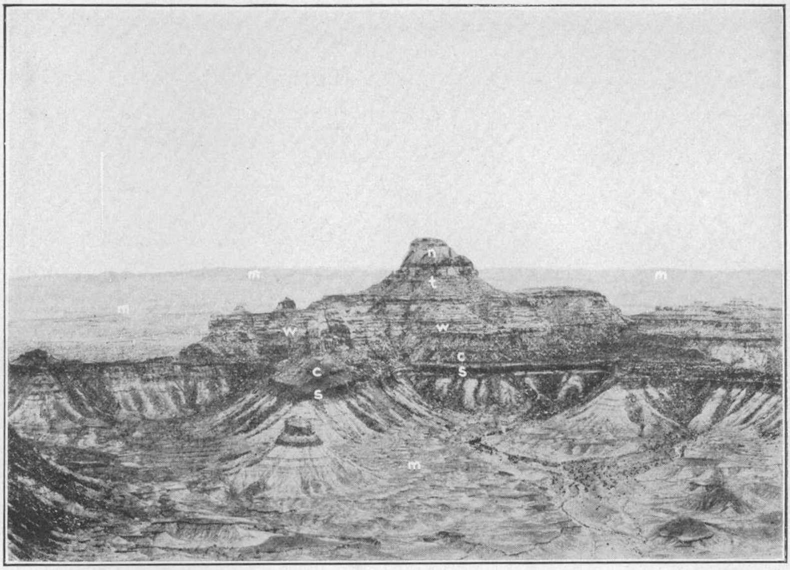
[5] Hess, F. L., Carnotite near Green River, Utah: U. S. Geol. Survey Bull. 530, pp. 161–164, 1913; A sulphur deposit in the San Rafael Canyon, Utah: U. S. Geol. Survey Bull. 530, pp. 347–349, 1913; Uranium-bearing asphaltite sediments of Utah: Eng. and Min. Jour.-Press, vol. 114, No. 7, pp. 272–276, 1922.

scientious geologic assistance was rendered in the field by Carle H. Dane, E. T. McKnight, D. J. Fisher, S. S. Nye, and W. H. Newhouse and in the office by Mr. Dane. Jack Ingram, Sidney Ingram, and R. J. Gordon, camp men, were invaluable because of their familiarity with trails and water holes.

## GEOGRAPHY

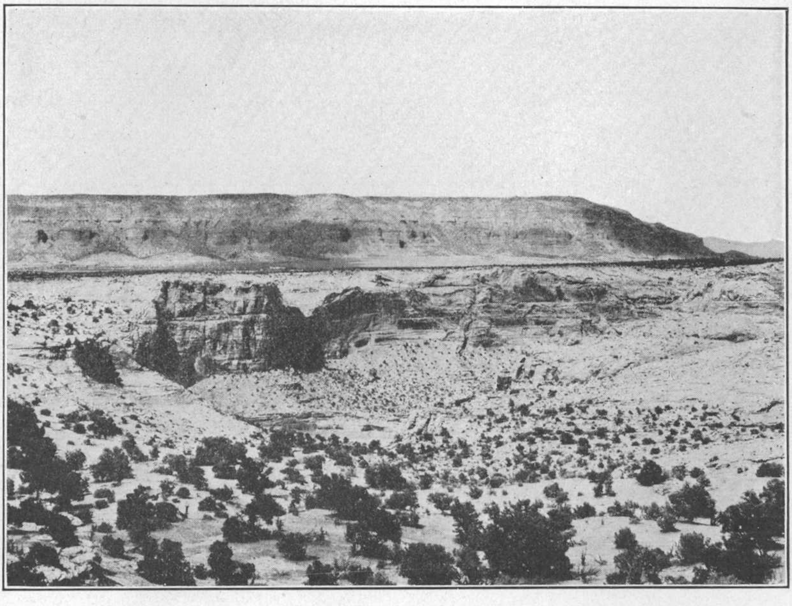
*Surface features.*—The total relief within the district mapped is about 3,700 feet, the altitude ranging from about 4,200 feet in the canyon of San Rafael River at the Mexican Bend to nearly 7,900 feet on Cedar Mountain and some of the higher parts of the Reef.

An open, gently domed area about 10 miles in average width and 40 miles long, occupies the central part of the Swell. This area is locally known as "Sinbad," and that name will be used in the present report. (See pls. 31, *A*, and 33, *A*.) Near San Rafael and Muddy Rivers the region is largely cut into mesas by steep-walled canyons, but in the intermediate country the drainage has not cut so deeply and the valleys are merely round-bottomed depressions in the crest of the dome. Sinbad is ringed about by a high, nearly vertical escarpment of sandstone, known as the Reef, capping less resistant shales and sandstones, a wall which is passable in but few places in its entire periphery. A representative view of the Reef is given in Plate 32, *B*. At some points the Reef rises nearly 2,000 feet above the adjacent part of Sinbad, though a more usual measure is 800 to 1,000 feet, all of which, in places, is in one nearly sheer cliff, although generally the cliff is broken by one, two, or three benches. From the top of these walls the country slopes away from Sinbad on all sides—steeply on the east and south, so that these parts of the Reef are striking hogbacks that plunge directly into the general plateau surface with only very minor accompanying outer ridges. On the west, north, and northeast, however, the thick limestone bed to whose resistance this dominating topographic feature is principally due dips much more gently, so that on these sides a remarkable asymmetric ridge is developed. Outside this part of the Reef the surface descends gradually to lesser but still prominent ridges of younger rocks until, rising outside of the huge depression of Castle Valley, the greatest cliff of all is reached—the huge scarp that forms the east face of the Wasatch Plateau and, swinging to the east and finally to the southeast, forms the edge of the Book Cliffs, which here bound the West Tavaputs and Beckwith Plateaus. Directly north of the San Rafael Swell, however, but one notable cliff intervenes between the Reef and the Book Cliffs—the high, conglomerate-capped face of Cedar Mountain, into which most of the lesser ridges elsewhere present have coalesced. The top of this mountain is about



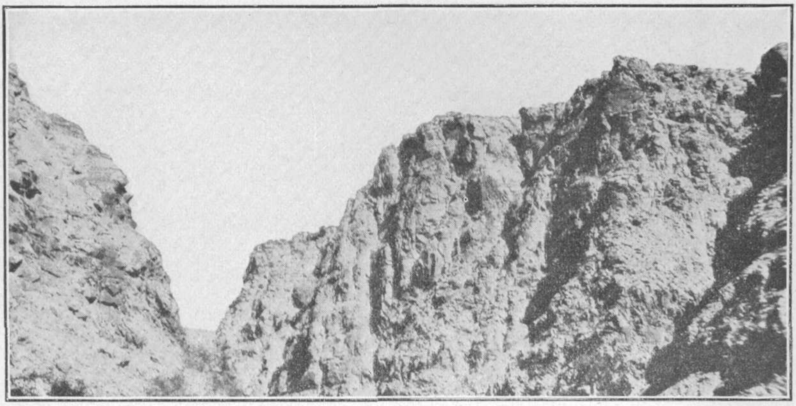

*A.* VIEW LOOKING SOUTH FROM THE REEF AT THE MOUTH OF BUCKHORN WASH, UTAH

Showing Window Blind Butte and, in the distance, Sinbad. m, Moenkopi formation; s, Shinarump conglomerate; c, Chinle formation; w, Wingate sandstone; t, Todilto (?) formation; n, Navajo sandstone



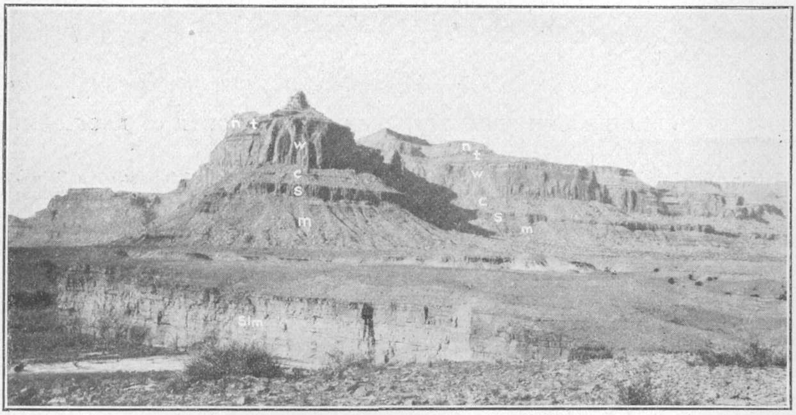
*B.* VIEW LOOKING NORTH FROM "THE WEDGE," NEAR THE MOUTH OF BUCKHORN WASH, UTAH

Showing Buckhorn Wash in the foreground and Cedar Mountain in the distance. Cliff in foreground composed of Navajo sandstone, capped by limestone of basal part of Carmel formation, which forms long dip slope



*A*. BLACK BOX, ON SAN RAFAEL RIVER, UTAH

Cliff composed of Coconino sandstone, 700 feet high

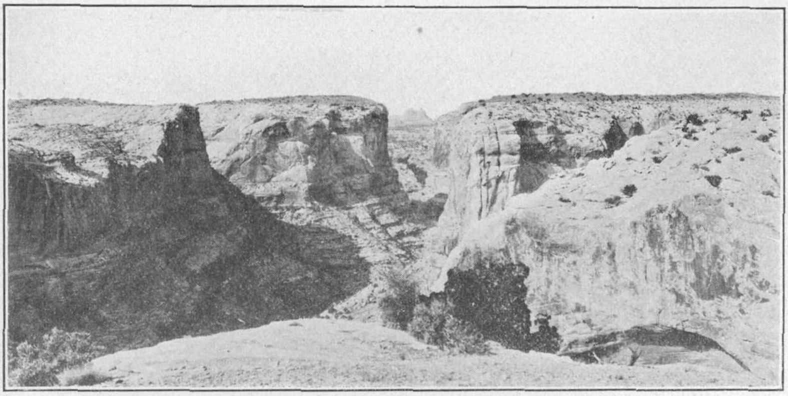



*B*. VIEW LOOKING NORTHWEST FROM POINT NEAR HEAD OF BLACK BOX

The cliff against which the river runs is made by the Sinbad limestone member of the Moenkopi formation. The slope above is made by the upper part of the Moenkopi formation. m, Moenkopi formation; s, Shinarump conglomerate; c, Chinle formation; w, Wingate sandstone; t, Todilto (?) formation; n, Navajo sandstone

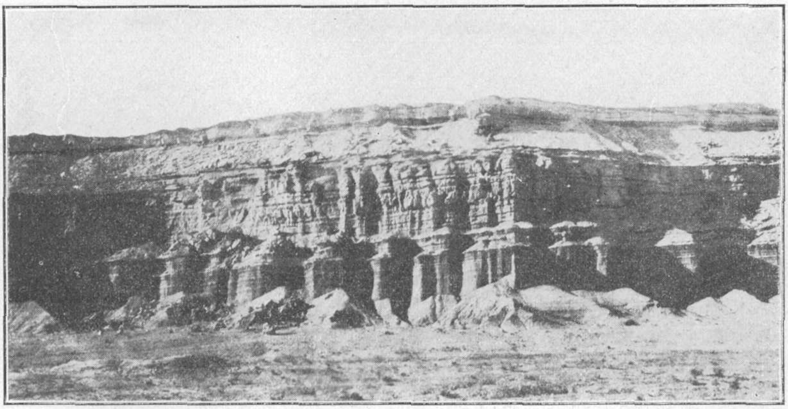
*C*. SPECIMEN OF MOENKOPI SANDSTONE FROM POINT NEAR HEAD OF BLACK BOX

Showing casts of hopper crystals of salt. Natural size



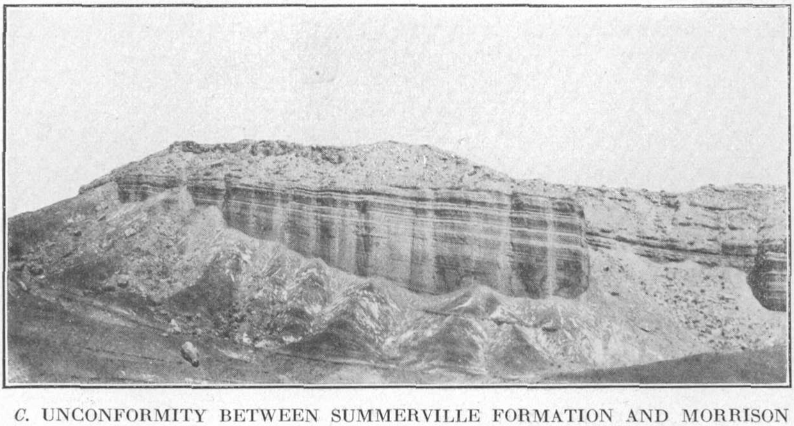
*A.* VIEW LOOKING SOUTH FROM THE REEF, NEAR SALERATUS CREEK, UTAH

Canyon exposes *Todilto (?) formation in the slope at bottom and cliff of* Navajo sandstone, capped by remnants of basal limestone of Carmel formation



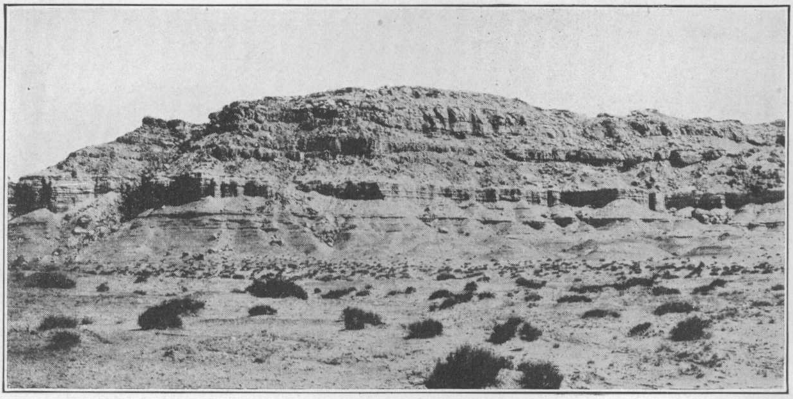
*B.* THE "RED LEDGE," BETWEEN BUCKHORN FLAT AND SAN RAFAEL RIVER, UTAH

Showing earthy facies of Entrada sandstone, which forms the cliff, capped by basal sandstone of Curtis formation, which makes the light band at the crest



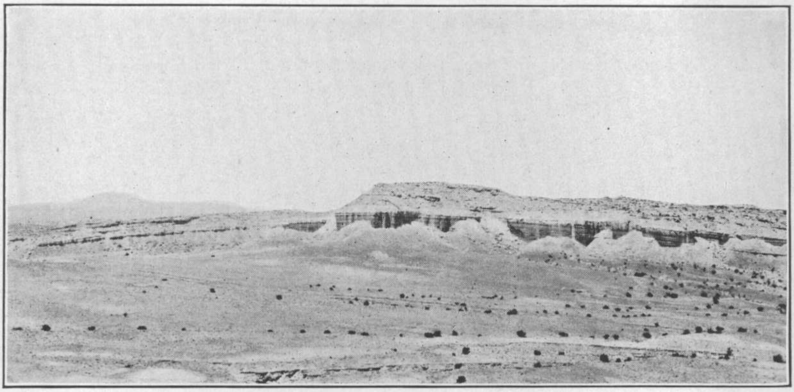
*C.* UNCONFORMITY BETWEEN SUMMERVILLE FORMATION AND MORRISON FORMATION IN COTTONWOOD SPRINGS WASH, UTAH

Evenly banded shale and sandstone of the Summerville formation unconformably overlain by irregular gypsum, sandstone, and clay of the Morrison formation



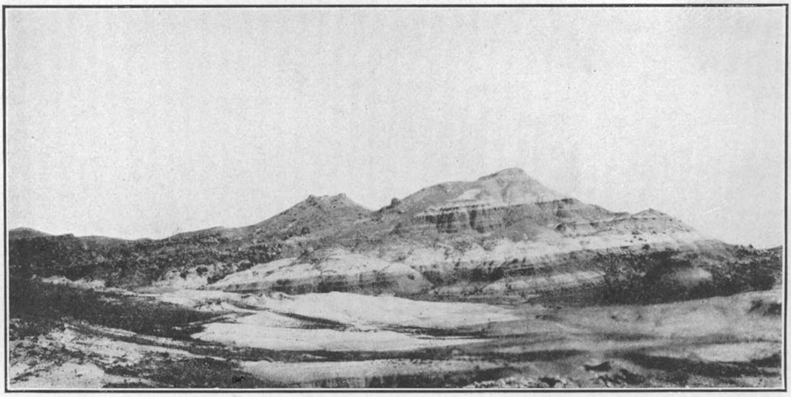
*A.* SALT WASH SANDSTONE MEMBER OF MORRISON FORMATION ON THE WOODSIDE ANTICLINE, UTAH

Unconformably overlying gypsum, shale, and thin sandstone of the Summerville formation. Photograph by E. M. Spieker



*B.* GENERAL VIEW LOOKING NORTH ALONG THE AXIS OF THE WOODSIDE ANTICLINE

Evenly banded cliff composed of Summerville formation, capped by light-colored Salt Wash sandstone member of the Morrison formation



*C.* TYPICAL EXPOSURE OF THE MORRISON FORMATION, NEAR HORN SILVER GULCH, UTAH

1,500 feet above Calf Wash, at its base. The views shown in Plates 31 and 32 are typical of the topography.

Though the topography is thus seen to be orderly in its major features, in detail it is very complex. Toward the east and southeast a mantle of alluvium has masked the lower outer ridges so that the persistent sandstone cliffs so prominent on the other sides are here represented only by sporadic, widely separated buttes and mesas rising from a sandy, rolling plain, the Green River Desert. A number of large mesas and irregular hills on the southwest side of the Swell, in an arrangement at great variance with the orderly topography of the larger part of the region, are due to the resistance of igneous sills and dikes which appear in that locality. Drainage to San Rafael and Muddy Rivers has carved the Reef into a fretted and intricate outline. On the dip slopes of the Reef drainage patterns comparable to those of badlands have been carved, leaving interstream rock masses hundreds of feet high and of striking and fantastic forms. In the soft, valley-making strata and in the alluvium that locally occupies the strike valleys typical badland topography has been developed, with a relief of as much as 200 feet in places.

*Drainage.*—San Rafael and Muddy Rivers are the only perennial streams in the area, and the run-off from the east, south, and west sides of the Swell as well as from most of Sinbad eventually reaches one or the other of them. The principal tributaries of San Rafael River are Huntington, Ferron, and Cottonwood Creeks, by whose junction just northwest of this area the river is formed; Salt Wash, Buckhorn Wash, Red Canyon, and Spring Canyon, which drain part of the Reef; and Mexican Springs and Nuk Woodard Washes, which drain the northern part of Sinbad. The northern part of the eastern portion of the Reef is cut by numerous short canyons which carry the run-off from part of Sinbad and eventually reach San Rafael River east of the area mapped. Similar canyons farther south drain into Muddy River by way of Wild Horse Creek, also east of the area mapped. The other principal tributaries of Muddy River are Ivie Creek, Salt Gulch, Willow Springs Wash, and Starvation Creek, of which only the second and third join the main stream within the limits of this area. The northern and northeastern parts of the Swell, outside the Reef, drain through Cottonwood, Humbug, and Summerville Draws to Price River and through Saleratus (Lost Springs) Creek and Cottonwood Springs Wash to Green River. Of all these streams only the two rivers are perennial throughout, but Cottonwood Springs Wash is perennial through parts of its upper course, and Salt Wash and Willow Springs Wash usually carry some running water at places. The rest have merely scattered water holes or are completely dry except at times of the occasional torrential rains.

The canyons of San Rafael and Muddy Rivers are very striking. The San Rafael flows southeastward across the Swell, without regard to the varying resistance of the rocks it encounters, carving winding canyons as much as 500 feet deep through the outer hogbacks, 1,800 feet deep through the Reef, and 800 feet deep in the Black Box, at the north end of Sinbad. (See pl. 32, *A*.) At the east end of the Black Box it swings sharply northeastward, emerges from its canyon into an open valley, curves with a radius of about a mile through nearly a complete circle, the Mexican Bend, and again trenches a box canyon several hundred feet deep and in places less than 40 feet across at the top. Below the canyon it swings to its regional trend and flows out of the area to join Green River, about 35 miles away.

The course of Muddy River is only slightly more direct than that of San Rafael River, though it has no meanders so striking as the Mexican Bend. It crosses a much narrower portion of the Swell than that along San Rafael River, and its canyons through the Reef are still deeper and less open than those of the San Rafael.

*Climate and vegetation.*—Butler [6] collected data on the climate of Utah to the end of 1918. His figures for Castle Dale, Emery, Giles, and Green River, the nearest points to this area for which observations were recorded, show mean annual temperatures (over periods varying between 12 and 18 years for the several stations) of 45° to 52° F. These records also show annual maxima of 99° to 112° F. and minima of 20° to 35° F. Rainfall records from these places and from Price and Woodside, other near-by towns where the available data cover only five years, show mean annual precipitation ranging from 5.56 inches at Giles to 9.82 inches at Price. It is probable that the climatic conditions in the San Rafael Swell are intermediate to those prevailing at these places. The climate is thus seen to be semiarid, with a wide temperature range. The great summer heat is somewhat compensated by the cool nights, but the high evaporation in summer, by drying the water holes, makes operations in the region difficult. The snowfall is seldom heavy enough to hamper operations of any kind, though winter temperatures are rather rigorous.

The vegetation is typical of the Colorado Plateau, the high land being largely clothed with juniper and some piñon, with a few yellow pines where water is close at hand. Cottonwoods are found in the bottom lands along San Rafael and Muddy Rivers and near water holes along the other streams. Greasewood, sagebrush, and rabbit brush are common along the washes and sparse grass, prickly pear, and lupine are found very widely, though the total pasturage avail-

---

[6] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 60–65, 1920.

able is not great. A few scrub oaks grow on some of the loose sand slopes.

*Culture and travel routes.*—There is not a single permanent settler within the area mapped. Attempts at dry farming have been made at a few places on Buckhorn Flat, Summerville Wash, Fullers Bottom, at the Lockhart cabins, and at Joe Swazey's cabin in Sinbad, but lack of moisture has discouraged the attempts, and all had been abandoned at the time the investigation here described was made.

Cattlemen in the general region of which this is a part have built dams at a few advantageous points for collecting water for their stock. A few corrals and brush fences built to aid in gathering the range animals are about the only other agricultural improvements in the whole area.

The main line of the Denver & Rio Grande Western Railroad crosses the extreme northeast corner of the mapped area. However, the interior of the Swell is much more easily accessible from Castle Valley on the west than directly from the towns on the railroad. Huntington, Castle Dale, Rochester, and Emery, from which roads lead into this area, are served by daily stages down Castle Valley from Price, on the railroad, from which they are, respectively, 22, 30, 58, and 66 miles distant.

A railroad grade that was never used and is now largely destroyed by washouts was built by the Denver & Rio Grande Western Railroad from Greenriver to Huntington by way of Cottonwood Springs Draw, Saleratus Creek, and Buckhorn Flat. It still offers some aid to the automobile or wagon traveler, and the road from Castle Dale and Huntington to Greenriver by way of Buckhorn Flat and Saleratus Creek makes use of some sections. The canyon of Saleratus Creek is very narrow, and the road is consequently badly washed and often impassable.

In 1921 oil companies operating in Sinbad built a road from Buckhorn Flat down Buckhorn Wash to San Rafael River, where a bridge was erected, and thence to the south. This road is practically never used, but it is passable for an automobile and is the best route into Sinbad. The bridge across San Rafael River has been washed away, but this stream can ordinarily be forded in an automobile. The road from Ferron down Horn Silver Gulch and to Sinbad by way of Coal Wash is all but impassable even for wagons. A road into the Swell by way of Black Dragon Canyon, also built during the oil-prospecting period, 1918–1922, is badly washed out but could probably be repaired at comparatively small expense. A road was built some years ago from Rochester to the Horn Silver mine, a copper prospect on the Reef, but it is in very poor shape, as is the road from Emery to Caineville, which was built by oil men about

1920 and which crosses the southwest part of the mapped area. All these roads are but little more than winding trails along which a vehicle can be moved only with difficulty because of washes, loose sand, and rock ledges.

Much of the Reef is inaccessible even on foot, and a horse can be conveniently used only in the interhogback valleys and on the gentler dip slopes. In Sinbad the detours necessitated by the intricate canyons make riding in many places a tedious mode of travel.

*Water and fuel supply.*—Water holes are sparsely scattered over the area, and most of them, except a few in pockets in the sandstone along the top of the Reef and near the south end of Sinbad are unsuited to the use of man, though stock will drink from them. The water of both San Rafael and Muddy Rivers is sometimes so concentrated that even stock will not drink it, but this happens only during the very hottest and driest periods. Throughout the field work except that in the southern part of Sinbad it was necessary for the party to haul from the towns in Castle Valley all the water used for drinking. The water from some of the Cottonwood Springs is potable, and those of a few other localities probably are at times, but none are free from alkali and most are better avoided. Water for drilling would have to be hauled from these water holes or the river, and the expense would depend on the location of the well with reference to them.

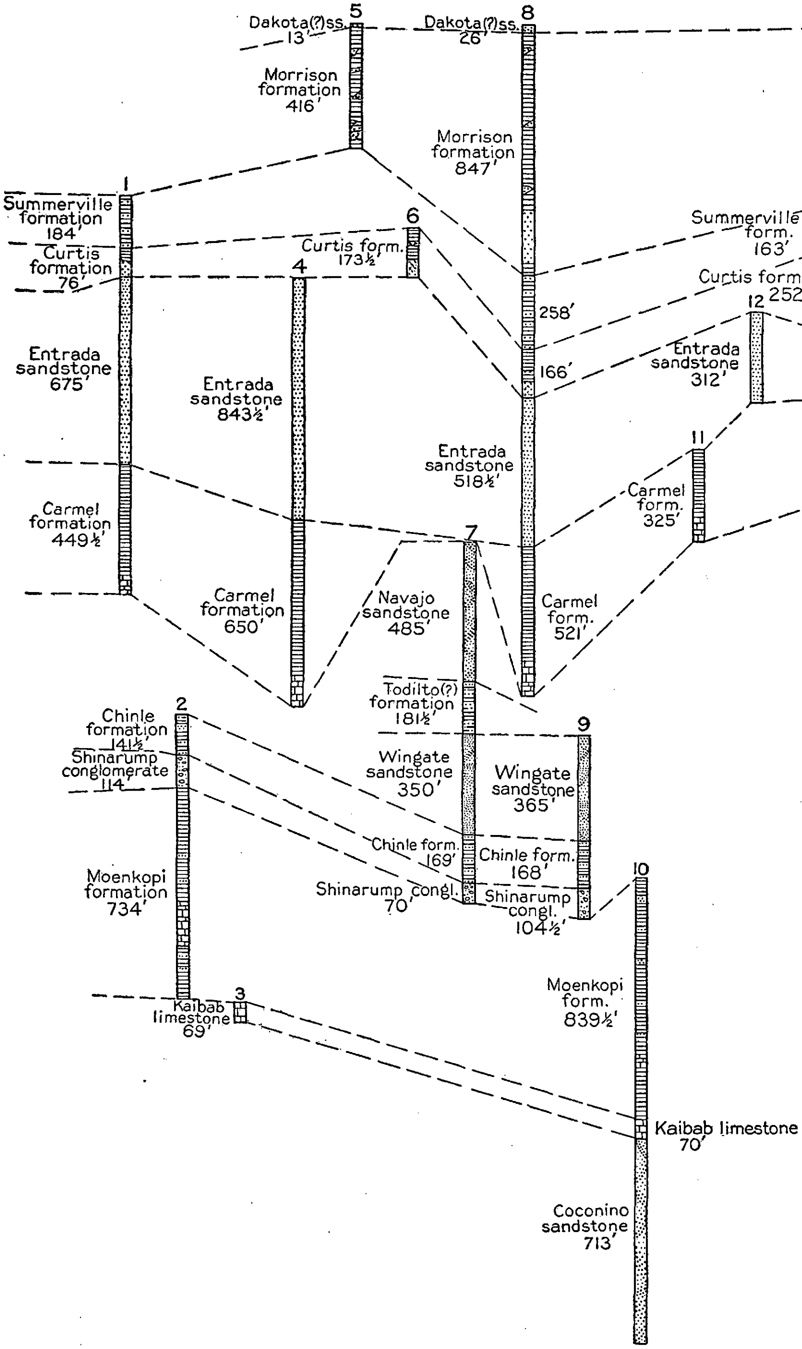
Cedars and piñon offer sufficient fuel for the traveler at nearly every point in the area. For drilling, however, coal would probably have to be hauled. Owing to the proximity of the area to the large mines along the Wasatch Plateau the cost of coal would probably not be excessive.

## STRATIGRAPHY

### GENERAL FEATURES

The beds exposed in the area described in this report range in age from Permian to Recent. The Permian rocks crop out in the canyons dissecting the dome of Sinbad, especially in those on the east side of that tract. Over all of Sinbad except the canyons, however, and throughout nearly all the rest of the area the exposed strata are Mesozoic. A few alluvium-filled valleys are occupied by Recent deposits.

The exposures are nearly complete, and little difficulty is encountered in the identification of the strata from place to place; tracing their lateral variations in both lithology and thickness is thus merely a matter of detailed field work. The lateral variations are very considerable, however, and the correlation of the strata of the Swell with those of other subdivisions of the plateau province is not one




LOCATIONS

1. Starvation Point
2. Cliffs south of Muddy River, southwest part of Sinbad
3. Near "The Tanks," southern Sinbad
4. Muddy River below mouth of Salt Gulch
5. Terrace 2 miles south of Willow Springs Wash
6. Gulch southwest of Drunk Man's Point
7. Saddle Horse Cayon
8. Near Horse Silver Gulch, T. 20 S., R. 8 E.
9. South side of Sawtooth Butte
10. In and near Black Box Canyon
11. South flank of Cedar Mountain, sec. 10, T. 19 S., R. 11 E.
12. Entrada Point, northern flank of the Swell
13. Summerville Point near head of Summerville Wash
14. Curtis Point, sec. 34, T. 19 S., R. 13 E.
15. East flank of Woodside anticline, secs. 17 and 18, T. 19 S., R. 14 E.
16. Cottonwood Springs Wash, sec. 10, T. 20 S., R. 13 E. (unsurveyed)

SECTIONS SHOWING LATERAL VARIATIONS IN THE FORMATIONS EXPOSED IN THE SAN RAFAEL SWELL, UTAH to be made sweepingly. Especially is caution urged by the recognition of a number of unconformities, which are certainly significant in any widespread correlations. Considerable attention was given to the stratigraphy, therefore, because of the economic bearing of these regional relations.

The areal distribution of the formations is shown on Plate 30, and their variations in thickness on Plate 35. Their succession and character are given in the following generalized section:

*Generalized section of rock formations in the San Rafael Swell*

| System | Series | Group | Group and formation | Thickness (feet) | Character |
|---|---|---|---|---|---|
| Quaternary. | | | Alluvium and terrace gravel. | | Sandy clay, sand, and gravel in alluvial fans; terrace gravel on benches along streams. |
| | | | Unconformity | | |
| Cretaceous. | Upper Cretaceous. | | Mancos shale. | 4,000± | Gray marine shale; sandy beds in lower part, rather persistent sandstone members about 200 feet and 600 feet above the base. |
| | | | Dakota (?) sandstone. | 0–55 | Conglomerate; coarse and fine sandstone, in places quartzitic; gray and greenish clay. |
| | | | Unconformity | | |
| Cretaceous (?). | Lower Cretaceous (?). | | Morrison formation. | 415–847 | Clay and shale, variegated, dominantly green-gray, maroon, and mauve; gray sandstone and conglomerate, very lenticular, massive and cross-bedded, especially abundant toward the base, where they form the Salt Wash sandstone member; subordinate thin lenticular limestones; gypsum locally at the base; in the northern part of the area a conglomerate 250 to 350 feet below the top. |
| | | | Unconformity | | |
| Jurassic | Upper Jurassic. | San Rafael group. | Summerville formation. | 125–331 | Thin-bedded chocolate-colored sandstone, earthy red-brown sandstone and shale, some gypsum, and a little limestone in some sections. |
| | | | Curtis formation. | 76–252 | Greenish-gray conglomerate, shale, and gray thick-bedded sandstone. |
| | | | Unconformity | | |
| | | | Entrada sandstone. | 265–844 | Thin-bedded red shale and sandstone at the base; thick, massive red-brown earthy sandstone above, poorly bedded, weathering in rounded forms. |
| | | | Carmel formation. | 170–650 | Dense limestone and buff and red sandstone at the base; dominantly red and green shale, thin sandstones; and thick beds of gypsum toward the top. |
| | | | Unconformity (?) | | |
| Jurassic (?). | | Glen Canyon group | Navajo sandstone. | 440–540 | Tan to light-gray massive cross-bedded limy sandstone, with a few thin limestone lenses. |
| | | | Todilto (?) formation. | 44–240 | Red-brown sandstone, green and red shales, shale conglomerate, irregularly interfingering and channeled. |
| | | | Wingate sandstone. | 360–400 | Buff to tan and dark-gray massive cross-bedded limy sandstone, with a few thin lenses of limestone. Usually stained red by wash. |
| | | | Unconformity. | | |

| | | | | |
|---|---|---|---|---|
| Triassic. | Upper Triassic. | Chinle formation. | 141–225 | Green and red micaceous sandstones and thin red-brown shale; limestone conglomerate; variegated marl; all lenticular, channeled and interfingering. |
| | Upper (?) Triassic. | Shinarump conglomerate. | 70–178 | Cross-bedded lenticular conglomerate, sandstone, clay, and shale, interfingering. Much silicified wood. Quartz and chert pebbles in the conglomeratic portions. |
| | | Unconformity | | |
| | Lower Triassic. | Moenkopi formation. | 735–850 | Green-gray pyritic shale; gypsiferous green and red shale; red micaceous ripple-marked sandstone; gray to buff sandstone; and red sandstone. Very limy throughout, with a thick, persistent gray marine limestone and sandstone member, the Sinbad limestone member 140 to 200 feet above the base. |
| | | Unconformity | | |
| Carboniferous. | Permian. | Kaibab limestone. | 0–85 | Light-gray to cream-colored cherty limestone; some oolite, somewhat sandy in places; equivalent to only uppermost part of typical Kaibab. |
| | | Coconino sandstone. | 715 | White to buff, sugary, friable to hard, massive cross-bedded quartz sandstone of uneven grain. Some grit toward the base; the lowest 40 feet largely limestone. Base not exposed. May include much more than typical Coconino sandstone. |

Because of the economic importance of proper correlation of these strata with those of surrounding regions, and in order to determine the directions in which significant lateral variations occur, numerous detailed sections of the several formations were measured. These are far less important for the purpose of a purely economic report on this particular area, however, and only abridged descriptions are here given. Full discussion of the stratigraphy is given in another report.[7]

## CARBONIFEROUS SYSTEM

### PERMIAN SERIES

#### COCONINO SANDSTONE

The Black Box of San Rafael River has been carved through the northward-plunging end of Sinbad. Its walls are precipitous and practically unscalable. They furnish unbroken exposures of much, perhaps all, of the beds designated in this paper the Coconino sandstone, which is also laid bare in many tributary canyons carved through the lower part of the Moenkopi and the Kaibab throughout Sinbad and to a depth of about 300 feet in the canyon of Muddy River in the south end of the Swell.

The following section was measured in the Black Box on the crest of the northward-plunging anticline which the river crosses just above the Mexican Bend. The major part was measured by plane-table triangulation from a stadia-measured base; the lowest exposures were measured by hand level:

*Section of Coconino sandstone in Black Box*

| | Feet |
|---|---|
| Kaibab limestone. | |
| Unconformity. | |
| Coconino sandstone: | |
| 1. Sandstone, in thick beds, 1 to 15 feet thick, showing large-scale cross-bedding of both tangential and angular types, very uneven grained, gritty and definitely water-laid toward the base, where it contains much feldspar, biotite, and muscovite; finer grained and sugary toward the top, with many subrounded grains having ground-glass surfaces. Lime cemented, closely jointed; weathers like an igneous rock. Colored white to buff in fresh exposures and with a heavy coating of desert varnish on weathered surfaces | 660 |
| 2. Sandstone, buff, gritty, sugary, friable, with rounded grains of quartz and feldspar one-eighth inch or less in diameter in a finer-grained matrix; lime cement | 3 |

[7] 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, pp. 61–110, 1928.

| Coconino sandstone—Continued: | Feet |
|---|---|
| 3. Sandstone, buff, fine grained, highly micaceous, very limy at base, where it includes some thin limestone lenses, less limy above, grading into No. 2 | 22 |
| 4. Limestone, with some sandstone, largely thick bedded, though with some thin beds, varying between sandstone and limestone both along the bedding and across it, with some shaly material in both types. Some quartz and calcite-filled geodes, much flint, and some limonite pseudomorphs after pyrite occur in the limestone portions. Base of exposure is river surface | 26 |
| Total exposed Coconino sandstone | 711 |

No fossils were found in this formation, though a diligent search was made, especially in the limestone at the base. Its correlation with the typical Coconino rests on its lithologic resemblance and its apparently conformable stratigraphic position just beneath the Kaibab limestone. A similar relation between Coconino sandstone and Kaibab limestone exists at Circle Cliffs, at Lees Ferry, and in the Grand Canyon district, though such widespread usage of the names is merely a convenient method of designating the limestone facies as distinguished from the sandstone facies. As indicated in the paper describing in greater detail the stratigraphy of San Rafael Swell,[8] the Coconino sandstone, as the name is applied in this paper, may contain time equivalents of part of the Kaibab limestone, the Coconino sandstone, the Hermit shale, and part of the Supai formation of the Grand Canyon region.

### KAIBAB LIMESTONE

The relations of the Kaibab limestone to the Coconino sandstone are not clear. At no point observed does the irregularity of the contact surface indicate any notable erosion. Cherty sandstone and thin shale at the base of the Kaibab in one or two localities appear to be conglomeratic, but the subangular cherts whose presence gives this impression may have been secondarily formed in place. The exposures of the actual boundary are rarely perfect enough for certainty, but there appears to be gradation in most places. The characteristic joint sets of the Coconino sandstone are not present in the overlying limestone. This is suggestive of difference in age, though the possibility of recementation of the limestone after jointing makes the existence of any unconformity quite uncertain.

There is no such uncertainty with regard to the upper contact of the Kaibab. This shows marked erosion, a local relief of about

[8] Gilluly, James, and Reeside, J. B., jr., op. cit.

15 feet being seen in an area of about 5 acres near the Lockhart cabins. In the hollows of this surface a gritty white clay forms the basal member of the overlying Moenkopi, and in many other localities, especially toward the south end of Sinbad, the Moenkopi has rather persistent conglomerate beds at this horizon. The unconformity thus clearly visible locally makes itself evident regionally by the disappearance and reappearance of the Kaibab limestone between the Coconino sandstone and the Moenkopi formation. This is clearly seen in traveling up Nuk Woodard Wash from the San Rafael, the Kaibab being cut out by this unconformity about 2 miles south of the river and reappearing in a lens about half a mile long and 20 feet thick a mile or so farther upstream. The same phenomenon is clearly seen in many washes near The Tanks and Tan Seep.

The Kaibab is dominantly a limestone, light gray to cream-colored, somewhat sandy in places; the rounded and subrounded sand grains are quartz, showing secondary enlargement and considerable range in size. The formation is notably fossiliferous and in some localities contains a coquina bed. Chert geodes lined with quartz and large calcite crystals are numerous and characteristic. Pyrite and mica are notable in the sandy lower part, which grades downward into a thin basal member of sandstone and shale. Cavities filled with secondary asphalt are not uncommon. The limestone grades imperceptibly into limy sandstone both along and across the bedding, but the dominant facies is clearly the limestone. No dolomite was found by field tests. The maximum measured thickness is 85 feet, measured about half a mile south of the Lockhart cabins, but this figure may be exceeded in places. The unit ranges from this maximum down to a knife-edge in thickness, and over much of the area it is not present.

Fossils collected about a quarter of a mile below the Lockhart cabins, at the head of the Black Box, were studied by G. H. Girty, who reports as follows:

I refer these two lots without hesitation to the Permian. The fauna of lot 5472 has obvious Paleozoic affinities and shows relationships to the fauna of the Manzano group and that of the Phosphoria formation. The fauna of lot 5476 is in many respects peculiar, for it consists largely of mollusks with a notable rarity though not complete absence of brachiopods. Some of the pelecypods of this fauna (which are represented in greater variety and perfection in other collections) are peculiar, and they apparently represent genera new to the Carboniferous. Nevertheless the Paleozoic age of the fauna seems well assured through the presence of such types as *Composita* and *Euphemus*. This is apparently the horizon which has sometimes been called the "*Bellerophon* limestone" and has been regarded as marking the top of the Paleozoic.

5472. Head of Black Box of San Rafael River. Kaibab, just below Moenkopi formation.

Pustula aff. P. montpelierensis.
Pustula nevadensis?
Composita sp.
Edmondia aff. E. gibbosa.
Parallelodon sp.
Schizodus sp.
Aviculipecten sp.
Lima? sp.
Myalina aff. M. perattenuata.
Griffithides sp.

5476. Coquina limestone just below lower shale of Moenkopi formation. Head of Black Box section. Kaibab.

Sponge?
Batostomella? sp.
Composita mexicana?
Nucula levatiformis.
Leda obesa?
Schizodus? sp.
Pleurophorus? sp.
Anatina? sp.
Plagioglypta canna.
Bucanopsis modesta.
Euphemus subpapillosus.
Sphaerodoma sp.

## TRIASSIC SYSTEM

### LOWER TRIASSIC SERIES

#### MOENKOPI FORMATION

Above the Kaibab limestone is a thick series of dominantly red-brown sandstone and mudstone, shale, and fine conglomerate with a thick, persistent marine limestone and sandstone from 140 to 200 feet above the base. These beds are correlated with the Moenkopi formation of the Navajo country and the Waterpocket Fold on the basis of lithology, fossil content, and stratigraphic position.

The Moenkopi of the San Rafael Swell is divided by the persistent limestone just mentioned into three members. The limestone, ranging from about 40 to 150 feet in thickness and containing scattered sandstone lenses, is a very resistant bed. It forms the cap of many of the buttes and mesas of Sinbad, the gentle swell of which follows the surface of the limestone. For this reason it has been named[9] the Sinbad limestone member of the Moenkopi formation.

The following section of the Moenkopi is representative of the formation as it is characteristically developed on the northeast side of the Swell. It is a composite section, the strata above the Sinbad limestone member being measured at the mouth of Red Canyon, and that member and the lower division being measured northward from San Rafael River at the Lockhart cabins, at the head of the Black Box. Except for the Sinbad limestone member, which is 150 feet thick on Muddy River, this section is representative of the formation throughout the eastern and southern parts of the Swell.

[9] Gilluly, James, and Reeside, J. B., jr., op. cit., p. 65.

*Section of Moenkopi formation above the Sinbad limestone member, measured at the mouth of Red Canyon*

| | Feet |
|---|---|
| Shinarump conglomerate: Conglomerate and coarse sand; forms a vertical ledge. | |
| No noticeable angular or erosional unconformity at this locality. | |
| Moenkopi formation: | |
| 1. Clayey sand and sandy clay, 80 to 90 per cent sand, soft; forms slope | 20 |
| 2. Sandstone, very fine grained, mottled gray and red, the red being perhaps due to wash. Massive at both top and bottom, flaggy in the middle, with a shale parting | 24 |
| 3. Shale, micaceous, very well laminated, ripple marked and mud cracked, dark red-brown | 2 |
| 4. Sandy mudstone and sandstone, chocolate-brown mudstone, with a few thin bands of green-gray sandy shale and red and green micaceous sandstone | 11 |
| 5. Sandstone, flaggy, micaceous, red-brown | 5 |
| 6. Mudstone and sandstone, like bed 4 | 6 |
| 7. Sandstone, massive, limy, ledge forming, red-brown | 4 |
| 8. Mudstone and sandstone, like bed 4 | 16 |
| 9. Sandstone, like bed 5 | 4 |
| 10. Mudstone and sandstone, like bed 4 | 79 |
| 11. Sandstone, like bed 7 | 10 |
| 12. Mudstone and sandstone, like bed 4 | 25 |
| 13. Sandstone, like bed 7 | 4 |
| 14. Mudstone and sandstone, like bed 4 | 15 |
| 15. Sandstone, like bed 7 | 3 |
| 16. Sandstone and mudstone, like bed 4 | 9 |
| 17. Sandstone, like bed 7 | 5 |
| 18. Mudstone and sandstone, like bed 4 | 61 |
| 19. Sandstone, dark gray, weathering light gray, micaceous, concretionary, with a few thin shale partings | 42½ |
| 20. Shale, chocolate-brown to brick-red, micaceous, gypsiferous, with a few thin lentils of limy sandstone | 126 |
| 21. Sandstone, red-brown, ripple bedded, limy, quartzose, micaceous, with heavy iron stain; forms a strong ledge | 9 |
| 22. Sandstone, thin bedded, lime cemented, ripple marked, buff at the bottom, brick-red above, with a wavy boundary between the color types | 37 |
| 23. Shale, green-gray, micaceous, gypsiferous, interlaminated with thin sand lentils making up about 10 per cent of the member | 21 |
| 24. Sandstone, fine grained, gray, shaly, gypsiferous, limy, ripple marked, alternating with subordinate green-gray well-laminated shale | 27 |

| Moenkopi formation—Continued. | | Feet |
|---|---|---|
| 25. Sandstone, massive, fine grained, lime cemented, brown-gray on fresh fracture, weathering dark brown. It is cross-bedded on a small scale and weathers to a semiplaty débris; forms a strong ledge | | 9 |
| 26. Sandstone, like bed 22 | | 36 |
| Sinbad limestone member: | | |
| 27. Limestone and subordinate sandstone, with a fauna of pelecypods and cephalopods. The sandstone facies is micaceous and not well bedded, blending into the limestone without sharp boundaries either along or across the bedding. The limestone is gray on fresh exposure and weathers light gray to buff, with a hackly surface. It is marked by stylolites and dendrites and contains oolite-like grains of asphalt throughout the bed | 19 | |
| 28. Sandstone, gray, fine grained, massive, cross-bedded, divided by a shaly parting in the middle; weathers brown | 15 | |
| 29. Limestone, massive, dense, in part crystalline, dirty purplish gray, weathering light gray, strongly petroliferous; brachiopod and molluscan fossils are abundant; breaks in irregular angular fragments | 11½ | |
| Total Sinbad limestone member | | 45½ |
| 30. Shale, buff to yellow, limy and sandy, with interbedded layers of edgewise conglomerate. It is seamed and veined with gypsum and shows small-scale intraformational contortion. Forms a slope | | 7 |
| 31. Shales and subordinate sandstone, in thin alternating beds, including some gypsum. The shale, which makes up three-fourths of the member, is gray, slightly sandy, and gypsiferous. The sandstone is dark gray, thin bedded, and minutely cross-laminated and weathers into platy medium-gray fragments. The member as a whole is a slope former, exposed below the strong ledges of the Sinbad limestone member | | 146 |
| 32. Sandstone, buff-brown, limy, thin bedded, fine grained, ripple bedded, seamed with gypsum, forms a ledge | | 2½ |
| 33. Sandstone, yellowish-stained gypsum, and shale, the sandstone friable, of the type of bed 6, about as thick as the shale and gypsum combined | | 24½ |
| 34. Sandstone, thin bedded, light gray, fine grained, friable, limy, composed dominantly of white quartz with scattered specks of limonite; weathers to platy fragments | | 1½ |

| | Feet |
|---|---|
| Moenkopi formation—Continued. | |
| 35. Shale, sandy, blue-gray, well laminated, gritty, micaceous, limy, interbedded with yellowish gypsum that makes up about two-thirds of the bed | 2 |
| Total thickness of Moenkopi formation | 839½ |

Unconformity.
Kaibab limestone.

The Moenkopi at the north end of the Swell is extremely variable along the strike, both in color and in lithology. Around Window Blind Butte it is dominantly light greenish gray above the Sinbad limestone member, but at the mouth of Red Canyon the corresponding strata are almost wholly reddish brown. At the Lockhart cabins the shale and sandstone beneath the Sinbad limestone member are chiefly yellow to gray, but to the west the lower half of these beds becomes dark red while the upper half maintains its yellow hue. Similar variations occur capriciously in the cliffs near Mexican Bend, but they are not so marked. Comparison of the section given above with others where the greenish-gray facies is present seems to show a correlation between the color and the lithology. Where the beds are red and brown they are principally micaceous ripple-bedded sandstone, but where they are greenish gray they are chiefly pyritic sandy shale and shaly sandstone.

It appears probable that all these beds were laid down in very shallow water. There is a possibility that the color and lithologic variations noted are attributable to deposition in a delta. The reddish-brown sandstones and shales may represent terrestrial deposits oxidized during their deposition; the green sandy shales and pyritic shales are probably deposits of more or less stagnant, muddy delta pools in which the rivers forming the red beds dropped their generally slightly finer débris under conditions where oxidation was inhibited and, indeed, strong reducing agents were present. The gypsum seams are perhaps best interpreted as deposits of concentrated lagoons or of playa basins on flood plains.

An arid climate during a part of Moenkopi time is further indicated by casts of hopper crystals of salt in the red sandstones. (See pl. 32, *C*.)

Three lots of fossils collected from the Sinbad limestone member near the Lockhart cabins were examined by G. H. Girty, who reports as follows:

These three lots display the same fauna, the one which in the Grand Canyon section was at first called Permian; in the Wasatch section, "Permo-Carboniferous"; and in the Idaho section, Lower Triassic. An abrupt and impressive faunal change marks the transition from Permian to Triassic in all these sections, and the higher fauna is now generally recognized as of Mesozoic age, The following lists show the species that have been identified in the collections:

Pleuromya? sp.
Pleuromya? n. sp.
Myophoria n. sp.
Myacites inconspicuus?
Aviculipecten occidaneus?
Aviculipecten thaynesianus.
Aviculipecten sanrafael, n. sp.
Aviculipecten sanrafael, several var.
Aviculipecten indet., several sp.
Entolium n. sp.
Edmondia? sp.
Edmondia? sp.
Myalina n. sp.
Myalina n. sp.
Astartella forresteri.
Laevidentalium? n. sp.
Natica lelia.
Natica lelia var.
Aclisina? sp.
Aclisina? n. sp.
Bulimorpha n. sp.
Bakewellia? n. sp.
Pteria? sp.
Pleurophorus n. sp.
Pleurophorus sp.
Naticella sp.
Holopea? n. sp.
Sphaerodoma? n. sp.
Zygopleura n. sp.
Meekoceras gracilitatis?
Meekoceras? sp.
Ostracoda, indet.

## UPPER (?) TRIASSIC SERIES

### SHINARUMP CONGLOMERATE

The Shinarump conglomerate forms a persistent ledge, capping steep slopes of the upper part of the Moenkopi formation in a wall that is scalable at but few places in the entire periphery of Sinbad. Although extremely variable in detail, its wide distribution is evidence of its unity as a formation over many thousands of square miles of the plateau province.

The Shinarump is 114 feet thick just south of Muddy River, in Sinbad, 70 feet near the head of Saddle Horse Canyon, 105 feet at Sawtooth Butte, 178 feet at the mouth of Buckhorn Wash, and 112 feet in Red Canyon. These variations seem quite unsystematic and give no clue to regional lensing. The formation is irregularly bedded and shows rapid lateral variations; and intraformational unconformities are the rule rather than the exception. Marl, lumpy shale, and clay are present in nearly every section, but the dominant and characteristic rock is hard limy or quartzitic sandstone in which lenses of conglomerate, strings of gravel, and large angular fragments of silicified and carbonized wood are plentiful. The sandstone is invariably cross-bedded, usually at rather steep angles, but no regional trend to the cross-bedding was observed. The formation rests on a scoured surface of the Moenkopi, and some of its variation in thickness is due to this channeling. The actual irregularity of the lower surface is not more marked than that of numerous intraformational unconformities of the Shinarump, but the strong contrast in type of sediments with the Moenkopi formation, the close association with the overlying Chinle formation, of known Upper

Triassic age, and the wide distribution of the conglomerate all point to the existence of a significant time break between it and the Moenkopi, although no angular discordance was observed at this horizon.

The appended section of the Shinarump conglomerate indicates its general character where it has been observed throughout the San Rafael Swell:

*Section of Shinarump conglomerate south of Muddy River, 2 miles southeast of mouth of Muddy River Canyon through the Reef*

| | Feet |
|---|---|
| Chinle formation: Shale, olive-green, sandy, flaky | 1½ |
| Shinarump conglomerate: | |
| 1. Conglomerate, extremely variable, cross-bedded, with pebbles largely of quartzite, white quartz, and white, black, gray, and cream-colored chert, as much as three-fourths inch in diameter, in a coarse sandstone matrix with much mudstone (probably transported as mud balls) in some places. Along the exposure the conglomerate is everywhere a cliff former, at some places all in one bed, at others in many 2 to 5 foot beds separated by mudstone lenses. Carbonaceous fragments are very numerous | 58 |
| 2. Mudstone, green, sandy | 7 |
| 3. Mudstone, shaly, mottled purple and green, showing slickensides on a small scale in nearly every plane, forming a ledge | 10 |
| 4. Mudstone, very limy, mottled purple, green, and yellow with some angular yellow quartz fragments one-fourth inch or less in diameter | 23 |
| 5. Shale, variegated, green, brown, ocher, purple; color changes being irrespective of bedding. Forming a smooth slope | 16 |
| Total Shinarump conglomerate | 114 |
| Unconformity, sharp lithologic change, no notable angular discordance. | |
| Moenkopi formation: Shale and sandstone, maroon and red-brown at top | 291 |

No fossils other than silicified logs were found in the Shinarump conglomerate in this area. Some fossils have been reported from more southerly areas, but they were not sufficiently diagnostic to do more than suggest an Upper Triassic age for the conglomerate. However, the apparently gradational upper contact makes it seem probable that the Shinarump may be considered the basal conglomerate of the overlying Chinle formation, whose Upper Triassic age is shown by both vertebrate and invertebrate remains. The clear unconformity between the conglomerate and the Lower Triassic Moenkopi formation also accords with this view, and although an Upper Triassic age for the Shinarump can not be considered proved, it seems most likely.

### UPPER TRIASSIC SERIES

#### CHINLE FORMATION

Succeeding the Shinarump conglomerate with apparent conformity is the series of fine-grained red sandstone, shale, variegated marl, clay, and limestone conglomerate of the Chinle formation. The members of this formation are lenticular, being extremely variable and discontinuous along the strike, and, by their mud cracks, ripple marks, worm borings, and intraformational conglomerates, give further evidence of fluviatile deposition. Their generally well-oxidized condition accords with the hypothesis of a continental origin of the formation, though this feature is not considered strong evidence.

In the San Rafael Swell the Chinle formation is notably thinner than it is in its type area or in general in the southern plateau country. It is also dominantly sandstone in this region, whereas to the south it is dominantly shale. The correlation is unquestionable, however, being based on practically continuous tracing through the intervening areas as well as on the position of the Chinle between the unmistakable Shinarump conglomerate and the equally characteristic Wingate sandstone. The work of Longwell, Miser, Moore, Bryan, and Paige,[10] Emery,[11] Dake,[12] and others has shown the gradual thinning of the Chinle formation northward from the type locality as well as its increasingly sandy character in this direction.

The Chinle formation is exposed in rather steep slopes surmounted by the vertical wall of the Wingate sandstone. Its thickness is fairly constant, being 168 feet at the mouth of Buckhorn Wash, 163 feet in Cane Wash, 168 feet in Red Canyon, 169 feet in Saddle Horse Canyon, 225 feet at Sawtooth Butte, and 141 feet on Muddy River just below the canyon through the western part of the Reef. The Buckhorn Wash section is considered thoroughly representative and is given in detail below.

*Section of the Chinle formation at the mouth of Buckhorn Wash*

Wingate sandstone: Sandstone, tinged with green at the base for 2 feet, above which it is buff, stained red on the surface with wash, cross-bedded, massive, showing only eight or ten true bedding surfaces in over 350 feet of strata. The lower few feet is shaly and lenticular, in some places occupying scoured channels in the lower beds, but there is no evidence of any angular unconformity between the two formations.

---

[10] 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.

[11] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551–577, 1918.

[12] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–646, 1919.

| Chinle formation: | Ft. | in. |
|---|---|---|
| 1. Shale, limy, green and purple, showing scour and fill |  | 4 |
| 2. Sandstone, greenish gray, ripple marked, very micaceous, with a few shaly lenticular partings, very limy. Shale flakes numerous | 8 | 6 |
| 3. Shale, greenish gray to chocolate-brown, mottled, well laminated, displaying mud cracks |  | 2 |
| 4. Sandstone, greenish gray, ripple marked |  | 2 |
| 5. Shale, like bed 3, much squeezed | 2 |  |
| 6. Sandstone, green-gray to brick-red, mud cracked, ripple marked, with some shale pellets along bedding planes and some thin shale partings | 4 | 6 |
| 7. Shale, maroon, with a few lenses as much as 2 inches thick of ripple-marked, thin-bedded greenish-gray sandstone | 3 |  |
| 8. Sandstone, tan, fine grained, with some shale partings and numerous shale flakes, micaceous, limy, thin bedded, cross-bedded, forming a strong ledge | 12 |  |
| 9. Shale and red-brown sandstone alternating; shale micaceous; sandstone thin bedded and ripple bedded | 1 | 6 |
| 10. Sandstone, greenish gray, very limy, with calcite seams along the fractured surfaces; ripple bedded, rill marked, and contains many small shale pellets; upper surface mud cracked | 1 |  |
| 11. Shale and sandstone, alternating; sandstone micaceous, ripple marked, and cross-bedded; shale blocky, poorly laminated, and red-brown except where leached to greenish gray along some of the joints | 2 | 6 |
| 12. Sandstone, green-gray, hard, limy, ripple and rill marked, seamed with calcite along joint surfaces, and containing animal borings one-eighth to one-sixteenth of an inch in diameter | 1 |  |
| 13. Shales and sandstones, like bed 11 | 3 | 6 |
| 14. Sandstone, reddish gray at base, greenish gray at top, very fine grained, ripple bedded, very limy; contains shale pellets one-quarter of an inch or less in size and forms a small ledge | 2 |  |
| 15. Sandstone, shaly, greenish gray, lensing out in 8 feet | 1 | 6 |
| 16. Sandstone, reddish gray, from massive to laminated, ripple marked, mud cracked, micaceous, forming a ledge | 3 |  |
| 17. Mudstone, very sandy, chocolate-brown, micaceous | 4 | 6 |
| 18. Shale conglomerate, containing angular fragments of shale as large as 2 by 4 by 6 inches. Very micaceous along certain bedding surfaces. Passes upward into ripple-marked, rill-marked greenish-gray sandstone with several lenses of shale conglomerate. In some places weathers |  |  |

| Chinle formation—Continued. | Ft. | in. |
|---|---|---|
| into rounded forms, in others into thin plates due to the rippling. Forms a ledge | 12 | |
| 19. Shale, maroon, micaceous, lenticular, passes out laterally, upper surface scoured | 1 | 6 |
| 20. Sandstone, red-brown, micaceous, shaly, cross-bedded, ripple marked, mud cracked, lenticular, with some interbedded shale; contains animal trails and borings as much as three-sixteenths inch in diameter | 1 | |
| 21. Shale, maroon, micaceous, well laminated | 11 | |
| 22. Sandstone, greenish, mottled light red in places, contains fragments of green shale scattered throughout; mud cracked, rill marked, thin bedded in lower part, massive above, where it weathers into rounded forms; forms ledge | 16 | 6 |
| 23. Shale, green-gray, purple, maroon, well laminated, mud cracked, with some very thin lenses of dark reddish-gray, fine-grained ripple-bedded sandstone, forming about 20 per cent of the bed | 4 | |
| 24. Sandstone, greenish gray, very limy, micaceous, ripple marked, massive. The lower contact is irregular owing to reworking of bed 25. Forms ledge | 1 | |
| 25. Limestone conglomerate, mottled purple and ash-gray, with some drab. Limestone pebbles, light gray and purple, 2 inches in maximum length; matrix is limy sandstone; whole bed forms cliff; weathers into nodular forms, much fractured and jointed | 6 | |
| 26. Marl, red-brown, soft, slightly sandy, becoming sandier upward, with some sand lenses; weathers into a slope | 5 | |
| 27. Limestone, nodular, shaly, passing upward into red-brown, slightly sandy marl, fractured and colored green along the cracks. Checked and cracked into parallelopipeds. Forms a ledge | 4 | |
| 28. Shale, brick-red, with subordinate brown sandstone lenses as much as 2 inches thick, passing upward into blocky, very limy, massive fine-grained red shaly sandstone, mottled with green along the numerous joints. Above the lower 10 feet marl predominates, containing, in the upper few feet, nodules of dense purple crystalline limestone from the size of a pea to that of a walnut. Forms a slope | 21 | |
| 29. Sandstone, drab, weathering light greenish gray, cross-bedded both angularly and tangentially. Forms a ledge | 2 | |
| 30. Shale, maroon, micaceous, interbedded with very thin bedded, ripple-bedded reddish-brown sandstone. The member is about 70 per cent sandstone. Forms a slope | 5 | |

| Chinle formation—Continued. | Ft. | in. |
|---|---|---|
| 31. Sandstone, red-brown, thinly laminated, ripple marked, cross-bedded, very fine grained; weathers into small curved plates about a quarter of an inch thick, blotched with green due to leaching. Forms a ledge | 3 | 6 |
| 32. Shale, brick-red, weathering chocolate-brown | 7 | 6 |
| 33. Sandstone, drab, weathering light greenish-gray, medium grained; carries muscovite, biotite, and magnetite, chiefly rounded quartz, very limy, ripple marked, in one massive blocky bed, forming a ledge | 1 | 9 |
| 34. Shale, maroon, micaceous, with many glistening surfaces, perhaps indicating desiccation | 14 | |
| Total Chinle formation | 167 | 11 |

Very uneven surface with a relief of 15 to 20 feet within 100 yards.

Shinarump conglomerate: Coarse to fine grained, limy cross-bedded ledge-forming sandstone with sporadic quartz pebbles becoming less numerous upward.

## JURASSIC (?) SYSTEM

### GLEN CANYON GROUP

#### WINGATE SANDSTONE

The massive Wingate sandstone rises in a vertical wall above the Chinle slopes to form the lower part of the main "rim rock" of Sinbad.

In Red Canyon the sandstone is 365 feet thick; at the mouth of Buckhorn Wash, 380 feet; in Cane Wash, 369 feet; in Saddle Horse Canyon, 375 feet; and on Muddy River, 450 feet. The distinctive features of this thick sandstone are its massiveness, its marked vertical jointing, and its large-scale tangential cross-bedding, disposed at all angles and in all directions, with only a few true bedding surfaces. In some localities it has interbedded shale and even shale conglomerate in the lower few feet, but from about 20 feet above the base to its top there is little material that is certainly water-laid. Thin cherty limestone lenses are present in some sections, but are everywhere subordinate. The uniform fine grain and the peculiar cross bedding render an eolian origin the most probable one for most of the Wingate in the San Rafael Swell.

Unweathered specimens of the sandstone range in color from white to pink, tan, and dark brown, but the weathered cliffs are nearly everywhere red-brown and in some places even black, owing to desert varnish and to wash from the red shaly beds of the overlying Todilto (?) formation. The name Vermilion Cliff applied to this unit by the early explorers was probably suggested by this stain.

The following section is believed to be typical of the unit:

*Section of Wingate sandstone measured in Cane Wash*

| | Ft. | in. |
|---|---|---|
| Todilto (?) formation: Buff sandstone, with beds 5 to 10 feet thick, alternating with thinner-bedded zones of interbedded buff sandstone and green shale. The buff sandstones carry fragments of the green shale. The thicker sandstones are cross-bedded tangentially, at steep angles. In some places the bedding is much contorted, as if by slumping due to water scour. Some shale conglomerates, with chunks as much as 8 inches long arranged at all angles to the bedding, also thin lenses of green shale as much as 12 feet long, formed in place, prove this series to be water-laid. Grades into underlying sandstone | 30+ | |
| Wingate sandstone: | | |
| 1. Sandstone, tangentially cross-bedded, very dark brown, nearly black, owing to petroleum impregnation | 21 | |
| 2. Green shale, well laminated, persistent for some distance | | 2 |
| 3. Sandstone and shale conglomerate. Some of the angular shale chunks, which are arranged at all angles to the bedding, reach sizes of 1 foot by 5 inches by one-half inch, but the average size is about one-fourth inch. Passes by gradation into bed 4 | 5 | 6 |
| 4. Green shale and sandstone, thin bedded, containing much muscovite, chlorite, and gypsum, very well laminated. A lens | 2 | |
| 5. Sandstone, buff, with a few black layers carrying grains of asphalt | 71 | |
| 6. Sandstone, dominantly buff, but with considerable black, the cross-bedding surfaces being the boundaries between the types. Tangential cross-bedding on a large scale | 15 | |
| 7. Sandstone, mostly black but with some buff, containing small black iron concretions at the top. Tangential cross-bedding | 39 | |
| 8. Sandstone, lenses of tangentially bedded and horizontally bedded buff and black. Ripple surfaces and contorted bedding common. The cross-bedding is indicated by the scattered, slightly larger grains of quartz on surfaces of finer material | 4 | 6 |
| 9. Sandstone, white, with lenses of black material, sharply cut off on horizontal surfaces by tangential cross-bedding in various directions | 1 | |
| 10. Sandstone, black, with subordinate buff, tangential cross-bedding | 4 | |
| 11. Sandstone, buff, with a few black bands, not noticeably cross-bedded | 12 | 6 |

| Wingate sandstone—Continued. | Ft. | in. |
|---|---|---|
| 12. Sandstone, black and buff, tangentially cross-bedded; forms a strong ledge | 6 | 6 |
| 13. Sandstone, buff, with very subordinate black bands, the upper half all buff, tangentially cross-bedded | 20 | |
| 14. Sandstone, black, interbedded with buff, laterally persistent, but of irregular thickness, tangentially cross-bedded | 13 | |
| 15. Sandstone, buff, massive, with only two true bedding planes, one 20 feet and the other 83 feet above the base, strongly cross-bedded tangentially | 95 | |
| 16. Sandstone, light red, separable from bed 17 only by the color difference, tangentially cross-bedded at high angles. Lenses out in 300 feet | 10 | 6 |
| 17. Sandstone, buff, tangentially cross-bedded at high angles. The only true bedding surfaces in the otherwise massive member are 3, 10, and 23 feet above the base | 44 | |
| Beds 15, 16, and 17, are all deeply pitted with solution cavities, which range from very small ones to hollows 3 feet in diameter. These pits apparently start along bedding surfaces, but are not controlled by them in their subsequent development. | | |
| Total Wingate sandstone | 364 | 8 |

Unconformity not marked except by slight channeling.

Chinle formation: Shale, green, and well-bedded lenticular sandstone.

As no fossils have ever been found in this Wingate sandstone, other criteria must be used in determining its age. A widespread unconformity [13] separates the Wingate sandstone from the Chinle formation, which is definitely of Upper Triassic age. Many writers have assumed that this unconformity marks the end of Triassic time. However, Cross believed that in the San Juan Mountain area the lowest unconformity in the Mesozoic section occurs at the top of the Dolores formation, the upper part of which he correlated with the so-called Vermilion Cliff sandstone (Wingate sandstone of present nomenclature) by way of Dolores and Colorado Rivers [14] and on the basis of his work in the San Juan area Cross drew the Triassic-

[13] Dutton, C. E., Report on the geology of the High Plateaus in Utah, p. 148, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880. Gilbert, G. K., Report on the geology of the Henry Mountains, p. 9, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877. Lee, W. T., oral communication. Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, p. 563, 1918. Gregory, H. E., The geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 48, 1917. Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, p. 64, 1922.

[14] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 656, 1907.

Jurassic boundary at the top of his Dolores formation, which would throw the Wingate sandstone into the Triassic period. In the light of present knowledge no unquestionable age assignment can be made, though the probabilities seem to incline slightly toward the Jurassic.

### TODILTO (?) FORMATION

The rocks here designated Todilto (?) formation rest upon the massive Wingate sandstone, into which they grade without notable break. The sandstones of which the Todilto (?) is largely composed differ lithologically from those of the Wingate only in their thinner bedding and the inclusion of shale pellets. In short, it is only the evidently water-laid character of this formation that justifies its separation from the two massive, largely eolian sandstones between which it lies. In places the thinner-bedded Todilto (?) formation crops out only as a band across the face of a cliff which exposes Navajo and Wingate in a vertical wall; but in most localities it forms a bench above the Wingate from which the Navajo has been cut back for some distance. The lower sandstones of the Todilto (?) are more firmly cemented than the upper, so that they form persistent and in many places overhanging ledges capping the sheer Wingate cliffs.

The thickness of the Todilto (?) formation is inconstant. In Buckhorn Wash it is 110 feet; in Saddle Horse Canyon, 180 feet; in a tributary of Cottonwood Springs, 155 feet, with the base not exposed; and at Black Dragon Canyon, just east of the area mapped, 240 feet. It averages perhaps 150 feet in the San Rafael Swell.

The major features of the lithology of the formation seem to point to a fluviatile origin. The great variations in thickness from place to place would accord with this inference. However, it may be in part of marine origin. Some very small pelecypod casts collected from the upper sandstones in Cottonwood Springs Draw were submitted to J. B. Reeside, jr., for determination. He reports as follows:

> Lot 12836. This lot contains a number of casts of a single species of pelecypod. It is small, without sculpture, and might be compared with several genera, some of which indicate a marine, some a nonmarine habitat. The recent collection of several species of *Unio* near Moab, Utah, by A. A. Baker shows that the Todilto (?) formation there is nonmarine in origin and suggests that it is also nonmarine in the San Rafael Swell, though the small pelecypods in the present lot are insufficient to settle the question.

The following section is considered typical of the Todilto (?) formation as developed in the San Rafael Swell:

*Section of Todilto (?) formation measured in Saddle Horse Canyon*

| | Ft. | in. |
|---|---|---|
| Navajo sandstone: Sandstone, buff to yellow-gray, massive, cross-bedded on a very large scale; forms vertical cliff. | | |
| Transitional contact. | | |
| Todilto (?) formation: | | |
| 1. Shale, green, very sandy | 1 | |
| 2. Sandstone, white to greenish gray, much cross-bedded, containing a few shale pellets, shale lenses, and small limonite concretions | 4 | 3 |
| 3. Shale, green, passing by gradation into bed 2 | 3 | 6 |
| 4. Sandstone, greenish gray, hard, in one bed, ripple marked throughout, cross-bedded on a very minute scale; contains flakes of shale | | 8 |
| 5. Shale, maroon, clayey | | 6 |
| 6. Sandstone, like bed 4 | | 6 |
| 7. Shale, green at base, passing up into maroon, flaky | | 8 |
| 8. Sandstone, buff, tangentially cross-bedded; weathers into benches and slopes | 12 | 6 |
| 9. Sandstone, white and tan, containing green shale pellets. The sandstone is coarse grained, ripple marked, and ripple bedded throughout | 2 | 2 |
| 10. Sandstone, pink, very micaceous, thin bedded, top surface channeled, with a relief of more than 1 foot | 8 | |
| 11. Sandstone, white, ripple marked throughout, cross-bedded at angles up to 28° (largely angular, but some tangential); carries many comminuted fragments of green shale; very micaceous | 2 | |
| 12. Shale, green; a parting | | 2 |
| 13. Sandstone, pink, in beds averaging 6 to 8 inches thick with a thin very limy bed at the top | 5 | |
| 14. Sandstone, in alternating laminae of pale red and white carrying small fragments of green shale. The sandstone is fine grained and cross-bedded. The top 6 inches is micaceous shale conglomerate | 6 | |
| 15. Shale, maroon, slightly sandy | 1 | |
| 16. Sandstone, light red, with a few maroon shale partings; carries pellets and flakes of green shale | 2 | |
| 17. Shale, maroon, like bed 15 | | 6 |
| 18. Sandstone, of the channel type, torrentially cross-bedded; contains flakes of green shale as large as 2 inches by three-eighths of an inch. Extremely variable along the strike. Very resistant, forming a ledge | 2 | 6 |
| 19. Sandstone, gray, coarse grained, tangentially cross-bedded; carries large flakes of muscovite and scattered shale pellets throughout, especially at the base. At 40 feet above the base the gray sandstone is replaced (by channeling) by red micaceous, very thin bedded sandstones. Above this the member passes upward through violently | | |

| | Ft. | in. |
|---|---|---|
| Todilto (?) formation—Continued. | | |
| cross-bedded material carrying flakes of green shale into well and evenly bedded, dominantly light brick-red sandstone with alternating white bands one-quarter of an inch to 10 inches thick. This sandstone is rather friable and contains green mineral fragments, quartz, magnetite, sporadic mica, and some chlorite with very little silt. At 50 feet above the base the member is entirely of the thin laminated type. The lamination is poorer above about 70 feet from the base, and ferruginous and limy concretions occur | 87 | 6 |
| 20. Sandstone, brick-red, bleached green along joints, very micaceous, very fine grained, extremely thin bedded and well bedded, ripple marked on a small scale. A lens | 9 | |
| 21. Sandstone, white, friable, containing green shale pellets from 3 inches by half an inch to microscopic size. These leave a pitted surface on weathering. The member is cross-bedded at large angles, thick bedded in general appearance, thinner bedded at bottom. At the base the sandstone is interlaminated with shale, and lenses of sandstone are inclosed by shale, deposited in channels as much as 5 feet deep cut in bed 22. The member has a pink cast due to wash from the upper Todilto but is actually gray. Angular cross-bedding as steep as 17°, with some tangential cross-bedding, occurs. A layer of green shale 15 feet above the base pinches out along the strike in 20 feet. Shale conglomerate with chunks of shale as much as 6 inches long appears at this horizon. Green shale flakes occur sporadically throughout the member which forms a strong persistent ledge crowning the Wingate cliff for miles | 31 | |
| 22. Shale, green, flaky, persistent, from 2 feet to 2 inches thick; grades into upper part of Wingate seemingly by transition | 1 | |
| Total thickness of Todilto (?) formation | 181 | 5 |
| Wingate sandstone. | | |

The correlation of this thin-bedded sandstone zone with the Todilto formation is based upon tracing by Gregory [15] and Moore [16] along the Waterpocket Fold to the Navajo Mountain area and by Gregory [17] thence eastward in the Navajo Reservation. This correla-

[15] Gregory, H. E., oral communication.

[16] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, p. 218, 1922.

[17] Gregory, H. E., The geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pl. 2, 1917.

tion is contrary to the interpretation of Emery,[18] who believed that the calcareous zone here called Carmel formation was at the horizon of the Todilto, a belief shared by Lee [19] in 1918.

### NAVAJO SANDSTONE

The great Mesozoic sandstone of the San Rafael Swell is the Navajo. It is a clean sandstone whose color ranges from white to tan and buff. It is massive, with widely spaced true bedding surfaces, but is everywhere tangentially cross-bedded on a gigantic scale. The cross-bedding laminae truncate one another at all angles in a very striking way. There are a few thin limestones, chiefly in the upper half of the formation, but all are lenticular, none of those observed exceeding half a mile in length and 5 feet in thickness. They are quantitatively unimportant, but they decidedly affect the topographic expression of the sandstone, for the zone through which they occur tends to form benches below which the sandstone is exposed in vertical cliffs and above which it rises in rounded domes and "beehives"—features governed by the position of this hard zone between the softer sandstones below and above it.

The Navajo has often been considered an example of eolian deposition. The discovery in it of excellent "dreikanter" by J. B. Reeside, jr., near Buckhorn Wash, in this area, seems to strengthen this theory of origin.

No detailed sections of the Navajo were measured, because of its inaccessible cliffs and the lack of distinctive stratigraphic horizons where it is exposed on gentler slopes. Determinations with alidade and stadia-measured bases and by triangulation incident to mapping give the following results:

*Thickness of Navajo sandstone*

| | Feet |
|---|---|
| Salt Wash, 1 mile below Saddle Horse Gulch | 485 |
| South side of Buckhorn Wash, on The Wedge | 460 |
| Junction of Calf Wash and Buckhorn Wash | 565 |
| Head of Red Canyon | 540 |
| Canyon at head of Cottonwood Springs Draw | 440 |
| West cliff of the Reef north of Muddy River | 650 |

As the Navajo passes by transition into the underlying Todilto(?) formation, the lower boundary is somewhat arbitrarily chosen, and the variations in measured thickness may be partly due to this cause, though later erosion by the transgressing Upper Jurassic sea may account for them.

[18] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, p. 567, 1918.

[19] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, p. 14, 1918.

Unequivocal evidence for unconformity at the top is difficult to find, owing to the lack of true bedding planes in the Navajo. The reworked sandstone which in many places forms the base of the Carmel formation is sharply succeeded by dense limestone. The sandstone bed, or the limestone, where the sandstone is not present, cuts sharply across all the cross-bedding laminae of the Navajo and presents a lithologic contrast that gives ample evidence of a distinct break. If the submergence of the hypothetical desert of Navajo time was accompanied by tilting, the transgressing sea may have effected considerable erosion in the soft sands, and there may be an angular unconformity. In view of the variations in thickness of the underlying Todilto (?) it is impossible to decide from present evidence how important the break really is, for variations in thickness may be due as well to inequalities of the base as to unequal erosion at the top.

## JURASSIC SYSTEM

### UPPER JURASSIC SERIES

### SAN RAFAEL GROUP

#### CARMEL FORMATION

The sandstones and limestones forming the basal part of the Carmel formation sharply succeed the thick mass of Navajo sandstone. In some places a thin zone of reworked Navajo sandstone as much as 8 feet thick occurs at the base of the Carmel, but in other places the transition is abrupt from the cross-bedded massive Navajo sandstone to the well-bedded dense crystalline limestone of the Carmel formation.

At the base the Carmel is everywhere limy and somewhat sandy. Dense and oolitic fossiliferous limestones are characteristic of the lower 100 feet and are so resistant as to form the crest and clean-swept dip slopes of the Reef, as much as 5 miles wide. Laterally these limestone beds vary, becoming sandier and even limy sandstones in many places, but their limy and fossiliferous character is very striking in this area of thick sandstones, so that they form notable stratigraphic key beds.

The lower Carmel is the horizon of the "fossiliferous sectile limestone" of Gilbert,[20] the "marine Jurassic" of Lupton [21] (who classed it as "McElmo" in his measured section, though calling attention to

---

[20] Gilbert, G. K., Geology of the Henry Mountains, p. 6, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[21] Lupton, C. T., Geology and coal resources of Castle Valley, Utah: U. S. Geol. Survey Bull. 628, p. 24, 1916.

its probable greater age) and Dake,[22] and the Todilto (?) formation of Emery.[23]

The name Carmel formation has been applied to the formation by Gregory and Moore,[24] from Mount Carmel, in southwestern Kane County, Utah, where it was long ago observed and described by Gilbert. It has been traced by them to the north end of the Waterpocket Fold, within 10 miles of the area covered by the present report.

Fossils collected from the lower part of the Carmel formation at several points in the area have been determined by J. B. Reeside, jr., as follows:

Ostrea engelmanni Meek?
Ostrea strigilecula White.
Trigonia n. sp. aff. T. americana Meek.
Trigonia quadrangularis Meek.
Trigonia montanaensis Meek.
Camptonectes stygius White.
Camptonectes extenuatus Meek and Hayden.
Camptonectes bellistriatus Meek and Hayden.
Plicatula n. sp.
Modiola subimbricata Meek.
Pholadomya kingi Meek.
Tancredia sp.
Dosinia sp.?
Tellina sp.?
Corbula? sp.
Dentalium? subquadratum Meek.
Cardioceras cf. C. distans Whitfield.

These are regarded as Upper Jurassic, of an age approximately equivalent to that of the Sundance formation of Wyoming.

The Carmel becomes shalier and more gypsiferous upward, and in the upper part heavy gypsum beds occur as described by Lupton.[25] The upper two-thirds of the formation is much softer and more easily eroded than the lower part. Its outcrop is accordingly a valley whose width depends largely on the dip of the beds but whose surface is everywhere dissected into typical badlands. The uppermost beds are more sandy and resistant and grade into the overlying Entrada sandstone.

The thickness of the formation varies greatly. It is 509 feet on Salt Wash in sec. 28, T. 20 S., R. 9 E., 325 feet on the south flank of Cedar Mountain, 200 feet on the east side of Cedar Mountain, 221 feet in Cottonwood Wash, 650 feet on Muddy River just below the mouth of Salt Gulch, and 450 feet near the junction of Last Chance

---

[22] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–640, 1919.

[23] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 568–570, 1918.

[24] Gregory, H. E., and Moore, R. C., Stratigraphy of southern Utah (in preparation).

[25] Lupton, C. T., Gypsum along the west flank of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 530, pp. 221–231, 1913.

and Starvation Creeks. The section measured on the south flank of Cedar Mountain is selected as typical:

*Section of Carmel formation on south side of Cedar Mountain near head of westward-flowing branch of Buckhorn Wash, in sec. 10, T. 19 S., R. 11 E.*

| | Ft. | in. |
|---|---|---|
| Entrada sandstone: Sandstone, maroon, fine grained, gypsiferous, forming a cliff. | | |
| Carmel formation: | | |
| 1. Gypsum, green, bedded, with much selenite veining; forms ledge | 4 | |
| 2. Sand, red and green, and green shale, both highly gypsiferous and interbedded with white and green gypsum beds as much as 1½ feet thick | 26 | 10 |
| 3. Gypsum, massive | 5 | |
| 4. Shale, green, some clean, some sandy, interbedded with soft red and gray sandstone and containing beds of gypsum as much as 2 feet thick | 81 | 4 |
| 5. Gypsum, massive, clean white alabaster | 5 | 3 |
| 6. Sand, maroon, soft, shaly, alternating with shale and gray sandstone, with thin gypsum beds and much secondary selenite veining | 7 | |
| 7. Gypsum, greenish white | 3 | |
| 8. Sands, green, gray, and red, highly gypsiferous, soft | 3 | 6 |
| 9. Gypsum, white, soft, pure; forms a flat bench | 5 | |
| 10. Gypsum, interbedded in lower 6 feet with thin lenses of gray crystalline limestone from one-fourth inch to 30 feet long and from paper-thin to 2 inches thick. The gypsum is very clean and hard; the upper 10 feet forms a persistent ledge | 16 | 9 |
| 11. Clay, gray-green and chocolate-red, highly gypsiferous, in places sandy, interbedded with gray micaceous shale, biotite-bearing sandstone, and clean gray quartz sands. Secondary gypsum seams as much as 1 inch thick occur | 17 | 10 |
| 12. Gypsum, alabaster, green, forming a ledge, in which bedding is apparent on distant view but not prominent in detail | 6 | 3 |
| 13. Sandstone, green-gray, fine grained, ripple marked, cross-bedded, practically massive in the upper 8 feet, forming a ledge | 20 | 9 |
| 14. Limestone, thin bedded to blocky, very hard, mostly dense, but oolitic and fossiliferous in places, with a drab shale bed toward the top. Forms a persistent ledge | 8 | 6 |
| 15. Shale, hard, limy and sandy, drab, weathering cream-gray, thin bedded, slabby, ripple marked, and interbedded with shaly, cross-bedded sandstone, which is gray, platy, and fossiliferous, and with a resistant basal member varying from limestone to oolitic sandstone and forming a strong ledge | 47 | 6 |

| Carmel formation—Continued. | Ft. | in. |
|---|---|---|
| 16. Limestone, shaly, sandy, and even conglomeratic, containing small chert pebbles. Dense and hard except at the top. Carries numerous *Camptonectes*, *Trigonia*, and *Ostrea* | 24 | 8 |
| 17. Sandstone, green-gray to buff, very limy, thin bedded, ripple marked, tangentially cross-bedded, interbedded with slightly sandy greenish-gray shale, which is not well laminated and contains lenses of sandstone | 29 | 6 |
| 18. Variable member, ripple marked throughout, composed of interfingering sandstone and shale lenses, all showing cross-bedding. The fine-grained chloritic sandstones are buff, weathering light brown, and are very limy; the clean flaky shales are greenish gray with some thin maroon bands | 2 | 8 |
| 19. Limestone, sandy, varying to sandstone in places along the strike, vuggy, very fossiliferous, approaching a coquina in some places, a red oolite in others. Some thin maroon and green shales are interbedded | 5 | 6 |
| 20. Alternating thin-bedded sandstone and shale | 1 | |
| 21. Sandstone, yellow, weathering brown, hard, ledge forming, thin bedded, very limy, showing facets of calcite on fractured surface | | 10 |
| 22. Shale, greenish, limy, and muscovite bearing, interbedded with sandstone which is yellow, weathering brown, fine grained, shaly, and friable | 2 | 2 |
| Total Carmel formation | 324 | 10 |

Unconformity, a rolling surface, broadly irregular.

Navajo sandstone: Sandstone, buff, massive, cross-bedded, exposed to a depth of 30 feet in the gully.

### ENTRADA SANDSTONE

Rising above the badland valleys of the Carmel formation are the steep cliffs of the Entrada sandstone. These cliffs, which are impassable at many points, are composed of massive sandstone and subordinate shale resting conformably upon the gypsiferous shale and sandstone of the Carmel and grading down into them.

The formation was named[26] from its conspicuous outcrop on Entrada Point, in the northern part of the San Rafael Swell. Its heavy bedding and red color give it some resemblance to the Navajo of southeastern Utah and northwestern New Mexico, a similarity much more pronounced in areas farther east. But the prominence of true bedding at intervals of 1 to 15 or 20 feet and the absence

[26] Gilluly, James, and Reeside, J. B., jr., op. cit., p. 76.

of sweeping, large-scale cross-bedding, together with the presence of considerable shale, are differences which appear very significant. This sandstone was classed as "McElmo" by Lupton,[27] but the presence unconformably above it of sandstone that bears marine Jurassic fossils precludes this reference. It was called Navajo by Emery.[28]

Longwell, Miser, Moore, Bryan, and Paige [29] have identified these rocks over considerable areas in southern Utah, referring to them as "varicolored sandstones and shales," and found that they do not correspond to the Navajo sandstone as mapped by Gregory in the western part of the Navajo country but lie above it. This correlation was also suggested by Dake [30] and has been confirmed by Gregory [31] in field work done since the publication of his reports on the Navajo country. Pending the determination of the relation of the type Todilto to the formation mapped as Todilto in the Navajo Mountain area only temporary field names were given to the unit by any of these men. As it is well exposed in the San Rafael Swell and is here overlain by fossiliferous rocks, which do not occur elsewhere, the type locality is chosen in this area.

The Entrada sandstone is variable in thickness, being 405 feet thick at Black Dragon Wash, just east of the Swell; 312 feet at the type locality, Entrada Point; 265 feet in Cottonwood Springs Draw; 534 feet near Horn Silver Gulch; 844 feet on Muddy River opposite the mouth of Salt Gulch; and 675 feet on Starvation Creek 2 miles west of the mouth of Last Chance Creek.

Its general type remains the same, however, throughout the area. It is shaly and thick bedded, and most of the true bedding planes are traceable for long distances. It weathers into rounded, horizontally grooved cliffs that give the impression of a pile of books whose backs are turned toward the observer. (See pl. 33, *B*.) Many beds are micaceous, and considerable true shale is interbedded. This shale and much fine silt in the sandstone members make a sharp contrast to the clean, nonmicaceous Navajo and together with the notable differences in bedding seem conclusive evidence of wide differences between the conditions of deposition of the Entrada and the Navajo.

The following section taken on Entrada Point between Summerville Wash and Saleratus Creek is presented as the type section of the Entrada sandstone.

---

[27] Lupton, C. T., Geology and coal resources of Castle Valley, Utah: U. S. Geol. Survey Bull. 628, pp. 23–26, 1916.

[28] Emery, W. B., op. cit., pp. 570–572.

[29] Longwell, C. R., and others, op. cit., p. 14.

[30] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, p. 640, 1919.

[31] Gregory, H. E., oral communication.

*Section of Entrada sandstone measured on Entrada Point*

| | Feet |
|---|---|
| Curtis formation: Conglomerate, composed of chert pebbles in a green-gray sandstone matrix. | |
| Erosional unconformity, rolling surface of low relief. | |
| Entrada sandstone: | |
| 1. Sandstone, reddish chocolate-colored, becoming gray toward the top, thinly laminated, cemented by lime | 5 |
| 2. Sandstone, chocolate-red, medium grained, massive, weathers into rounded forms | 8 |
| 3. Sandstone, chocolate-brown, mostly thinly laminated, massive in places | 3½ |
| 4. Sandstone, chocolate-brown, medium to fine grained, massive, weathering into rounded forms | 13 |
| 5. Sandstone, light red, coarse, gritty | 2 |
| 6. Shale, red, weathering gray, sandy, thin bedded | 1½ |
| 7. Sandstone, chocolate-red, fine grained, massive, cross-bedded | 2 |
| 8. Shale, green-gray, well laminated, alternating in thin layers with red, gray-green, and gray sandstones and becoming sandier toward the top | 2½ |
| 9. Sandstone, chocolate-red, fine grained, massive, forming a bench. In the upper 4 feet there are many angular and subrounded fragments of fine-grained green-gray sandstone ranging in size from half an inch to 15 by 2 inches, disposed at all angles to the bedding | 29 |
| 10. Sandstone and shale; sandstone micaceous, mottled red and green; shale sandy, chocolate red | 5½ |
| 11. Sandstone, chocolate-red, massive, fine grained, cross-bedded, in thin laminae | 4 |
| 12. Sandstone, fine grained, and variegated shales | 2 |
| 13. Sandstone, chocolate-red, massive, weathering into rounded forms, cemented by lime | 14 |
| 14. Sandstone, chocolate-red, thin bedded, medium to fine grained | 15 |
| 15. Sandstone, chocolate-red, very fine grained, variable along strike, massive, forming cliffs in some places, terraces in others, cemented with lime | 22 |
| 16. Sandstone, chocolate-red, bleached green in places, thin bedded, fine grained, upper surface channeled | 11 |
| 17. Sandstone, gray, cross-bedded tangentially, medium grained with coarser granules near base, almost surely water-laid, forming a ledge | 30 |
| 18. Sandstone, light gray, fine grained | 2 |
| 19. Sandstone, red, fine grained, massive, forming a cliff | 18 |
| 20. Sandstone, chocolate-brown, thin bedded, medium to fine grained | 7 |
| 21. Sandstone, chocolate-red, bedded in layers 2 to 8 inches thick | 5 |
| 22. Shale, chocolate-red, well laminated | 1 |

| Entrada sandstone—Continued. | Feet |
|---|---|
| 23. Sandstone, gray, red in places, medium-grained, massive, concretionary toward the top | 3 |
| 24. Shale, micaceous, and thin-bedded sandstone, chocolate-brown to red, with greenish streaks through it | 3 |
| 25. Sandstone, light gray to pink, medium grained, massive, with discontinuous shaly partings cemented with lime | 5 |
| 26. Sandstone, dark brown, thinly laminated, weathering like shale | 2 |
| 27. Sandstone, chocolate-brown, cross-bedded, massive, fine-grained; both upper and lower surfaces are irregular | 5 |
| 28. Sandstone, chocolate-brown, with a few gray bands, coarse grained at base, medium grained above, friable | 30 |
| 29. Sandstone, gray and yellow, in thick beds showing contorted cross bedding. Composed largely of white quartz, dark and light mica stained with manganese, cemented by lime, friable, and with a shale parting at 7½ feet above the base | 11 |
| 30. Sandstone, reddish brown, medium grained, massive, weathering into rounded forms, cross-bedded toward the top, upper surface rolling, with a relief of 1 foot | 22 |
| 31. Sandstone, gray, mottled, thin bedded, shaly | 7 |
| 32. Sandstone, reddish brown, medium grained | 1 |
| 33. Sandstone, greenish gray, shaly, fine grained, containing many red grains, probably agates | 20 |
| Total thickness of Entrada sandstone | 312 |
| Carmel formation: Gypsum | 6 |

### CURTIS FORMATION

The upper surface of the Entrada sandstone is eroded and scoured to varying depths. The unconformity is certainly angular in some localities, notably about 2 miles southeast of Curtis Point, on Cottonwood Springs Wash, and at Horn Silver Gulch, and possibly the great variation in thickness of the Entrada is due to regional angular unconformity. The time interval represented by this unconformity was not great, however, for the fauna of the overlying Curtis formation is practically identical with that of the Carmel, nearly 1,000 feet stratigraphically below.

The lower few feet of the Curtis formation is of variable lithology. Interlensing shale, conglomerate, and sandstone replace one another laterally in rapid succession and occupy the valleys scoured in the upper surface of the Entrada sandstone. *Pentacrinus*, *Ostrea*, *Camptonectes*, *Tancredia*, and other Upper Jurassic forms are present. Usually within 40 feet of the base a series of greenish-gray glauconitic sandstones commences. This part of the formation is prominent in the cliffs and the dip slopes behind the outcrops of the Entrada formation. It is thick bedded, is notably cross-bedded, and weathers into discoid and log-shaped rounded masses of a slightly brownish hue. The upper part of the formation is locally somewhat shaly, but generally it is a fine-grained sandstone similar to that below. It grades upward through alternations of red-brown sandstone and maroon shale into the overlying Summerville formation.

The Curtis formation is of variable thickness, having its maximum development in the northern San Rafael Swell and thinning toward the east and south so that it disappears a few miles east of Green River and a few miles south of Sand Creek in the Waterpocket Fold. At the type locality, Curtis Point, on Cottonwood Springs Wash, it is 193 feet thick; 5 miles southeast of this point, 165 feet; and at the mouth of Black Dragon Canyon, perhaps 12 miles farther southeast (outside the mapped area), 170 feet. At Summerville Point it is 252 feet thick; near the junction of the roads from Huntington and Castle Dale to Green River on Buckhorn Flat, 182 feet; near Horn Silver Gulch, 166 feet; just west of Drunk Man's Point, 173 feet; and about 3 miles southwest of the junction of Last Chance and Starvation Creeks, only 76 feet. Estimates of the thickness at Sand Creek in the Waterpocket Fold were about 30 feet and near Hanksville about 20 feet.

Lupton [32] correlated the conglomerate and sandstone of the Curtis formation of the present report with his Salt Wash sandstone member of the McElmo formation in the vicinity of Green River, Utah.[33] However, from sections measured by the writer in Green River Desert at intervals from Black Dragon Canyon to a point within 5 or 6 miles of the type locality of the Salt Wash member, where there was no difficulty in recognizing the strata described by Lupton, there is equally little question that his Salt Wash sandstone member lies above the Curtis formation (which is not there conglomeratic) and forms the basal part of the Morrison formation of the present report. It is clear that the marine sands of the Curtis formation can not be a part of the continental "McElmo" formation and must be excluded from it on both lithologic and faunal grounds.

Emery did not differentiate this formation in his work in the Green River Desert but included it in his Navajo sandstone.[34] It is recognizable in his description, however:

---

[32] Lupton, C. T., Geology and coal resources of Castle Valley, Utah: U. S. Geol. Survey Bull. 628, pp. 23, 25, 1916.

[33] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 124, 126–127, 1914.

[34] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, p. 571, 1918.

The thin-bedded upper part of the Navajo contrasts strongly with the massive lower part just described. The beds are sandstone and sandy shale and are for the most part brick-red in color, but near the middle of the series is a conspicuous zone of light-colored beds which, though of similar lithology to the associated beds, differ in that they are light greenish in color. With them are associated irregular bunches of quartz which weather into small rounded red balls or lozenges resembling in appearance red rubber bath sponges.

The Navajo sandstone of Emery includes the strata referred in this paper to the Entrada, Curtis, and Summerville formations. The quartz masses mentioned by Emery are present in the Curtis formation but are especially numerous in the overlying red beds of the Summerville formation.

The following section is offered as the type section of the Curtis formation:

*Section of Curtis formation measured on Curtis Point, on Cottonwood Springs Wash*

| | Ft. | in. |
|---|---|---|
| Summerville formation: Mudstone and sandstone, green-gray and red-brown, alternating in thin beds, very limy, covered with silica lumps and masses of secondary quartz. | | |
| Transition zone at base 17 feet thick. | | |
| Curtis formation: | | |
| 1. Sandstone, green-gray, weathering brown, very limy, fine grained, thin bedded, platy, cross-bedded in 6-inch layers between thicker layers of slightly coarser, less limy sandstone that weathers buff | 21 | |
| 2. Sandstone, green-gray, fine grained, friable, containing clay pellets at many horizons, and numerous loglike iron-stained concretions; forms steep ledgy slope | 84 | 6 |
| 3. Sandstone, green-gray, containing many black and green grains, fine grained, thin bedded, lenticular, interfingered with lenses of green gritty sandstone (weathering buff) which carries many red grains as well as the green and black. The member is cross-bedded throughout; individual beds range from 4 inches to 2 feet in thickness. Forms a vertical cliff, capped by projecting ledge | 10 | 6 |
| 4. Grit, green-gray, with sporadic pebbles; cross-bedding dips north but is not as general as in lower beds. The member lenses out within 100 yards. A 2-inch shale parting occurs in the middle | 2 | 2 |
| 5. Shale, green-gray, flaky | 5 | |
| 6. Conglomerate, green-gray, containing mostly brown, gray, and white chert and jasper pebbles averaging between one-eighth and one-fourth inch in size but reaching one-half inch. Very limy; cross-bedding dips at angles as great as 22° S., directly opposite to the dip in bed 4 | 3 | |

| Curtis formation—Continued. | Ft. | in. |
|---|---|---|
| 7. Shale, dark gray | 15 | 6 |
| 8. Conglomerate, like bed 4; contains echinoid spines | 1 | |
| 9. Shale, green-gray, flaky | 2 | 6 |
| 10. Conglomerate, like bed 4; thickens downward by scour and is 12 feet thick within 100 yards to the north | 4 | 6 |
| 11. Shale parting, dark gray | | 6 |
| 12. Grit, grains nearly all smaller than wheat grains | | 6 |
| 13. Shale, slightly sandy, dark gray, fissile | 7 | 6 |
| 14. Sandstone, gray, weathering buff, limy, with a few thin shale lenses | 4 | 6 |
| 15. Shale, sandy, dark gray, containing many thin lenses of well-bedded ripple-marked fine-grained limy sandstone which make up about 20 to 30 per cent of the member. The shale is carbonaceous toward the top | 7 | |
| 16. Sandstone, clayey, mouse-colored with some red tinges, fine grained, limy, alternating with sandy shale of the same color. The sandstone is especially prevalent at bottom and top. Gypsiferous in upper part, with a 3-foot massive bed of gypsum at the top | 23 | |
| 17. Shale, gray and green-gray, with a little red along some beds, well laminated | | 8 |
| Total Curtis formation | 193 | 4 |

Erosional unconformity.

Entrada sandstone: Sandstone, red, thin bedded, very fine grained.

Fossils collected from the Curtis formation at several localities along Saleratus Creek by E. M. Spieker and J. B. Reeside, jr., were identified by Mr. Reeside as follows:

Cidaris sp.
Pentacrinus asteriscus Meek and Hayden.
Ostrea strigilecula White.
Camptonectes stygius White.
Eumicrotus curta Hall.
Tancredia inornata Whitfield.

All are regarded as Upper Jurassic, of approximately equivalent age to that of the Sundance formation of Wyoming.

The green tinge of the Curtis formation is due to a green mineral which was examined by M. I. Goldman and determined to be glauconite.

#### SUMMERVILLE FORMATION

The Summerville formation rests on the Curtis with a transitional contact. It consists of a series of thin-bedded red-brown sandstones, maroon mudstone, and chocolate-brown shale. Gypsum beds are common in the upper part of the formation, and the whole is much seamed with secondary veinlets of gypsum. In the northern part of the area the bedding is very even and continuous, but farther down the west flank of the Swell it is irregular, and the beds are lenticular and show much channeling and numerous intraformational unconformities. The latter facies is also the prevailing one in areas to the east of the Swell and is found in the Salt Valley anticline, at the mouth of Dolores River, and, according to the descriptions by Coffin,[35] it possibly forms the lower part of his McElmo formation of southwestern Colorado. It is present in the Waterpocket Fold, where it was recognized but not differentiated from the main body (Entrada sandstone) of the "Upper Jurassic sandstone" by Moore.[36] It forms the upper part of the lithologic member referred to by Longwell, Miser, Moore, Bryan, and Paige [37] as "varicolored sandstones and shales." Emery [38] included the rocks of this formation, with the underlying Curtis and Entrada of the present report, in his Navajo formation. Lupton [39] included this zone in the "McElmo" of his Castle Valley report, it being represented by the "gypsum," "shale," and "sandstones" between the top of his Salt Wash sandstone member (Curtis formation of the present report) and the first conglomerate above, a section including 335 feet of beds. In the area near Green River examined by Lupton [40] it corresponds to the 120 feet of sandstones just beneath his Salt Wash sandstone member.

At the type locality on Summerville Point, near the head of Summerville Wash in the northern part of the San Rafael Swell, the formation is 163 feet thick; on the east flank of the Woodside anticline, in sec. 18, T. 19 S., R. 14 E., 128 feet; on Curtis Point, in sec. 34, T. 19 S., R. 13 E., 125 feet; 3 miles farther down Cottonwood Springs Wash, 241 feet; and near Black Dragon Canyon, east of the mapped area, 210 feet. On the west flank of the Swell the Summerville formation ranges in thickness from 258 feet near Horn Silver Gulch to 331 feet near Drunk Man's Point and 184 feet near the junction of Starvation and Last Chance Creeks.

The following section is offered as the type for the Summerville formation:

---

[35] Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geol. Survey Bull. 16, pp. 77–97, 1921.

[36] Moore, R. C., oral communication.

[37] Longwell, C. R., and others, op. cit., p. 14.

[38] Emery, W. B., op. cit., p. 571.

[39] Lupton, C. T., The geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, p. 25, 1916.

[40] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, p. 126, 1914.

*Section of Summerville formation on Summerville Point, near head of Summerville Wash*

| | Feet |
|---|---|
| Morrison formation: Clay, chocolate-colored, containing many lumps of gypsum 4 inches or less in diameter and passing through a zone 6 inches thick into a gray shaly sand with some carbonaceous material | 4 |
| Unconformity, not very well marked. | |
| Summerville formation: | |
| 1. Sandstone, chocolate-colored, thin bedded | 2 |
| 2. Clay, with several thin sandstones | 4½ |
| 3. Sandstone, thin bedded, cross-bedded, ripple marked, micaceous | 2 |
| 4. Clay, sandy, chocolate-colored | 2 |
| 5. Sandstone, gray, fine grained, minutely cross-bedded by current rippling | 3 |
| 6. Clay, sandy, and sandstone. The clay is chocolate-colored and interbedded with gypsum and with thin well-laminated brown sandstones (not over 2 inches thick), also with thin (not over 1 inch) gray sandstones. Clay greatly predominates, becoming more sandy toward the top. The sandstone ledges give a banded "pipe organ" appearance when the cliff is viewed from a distance | 103 |
| 7. Gypsum, chocolate-colored, mottled with green, weathering in a gnarled, lumpy manner | ¼ |
| 8. Clays, chocolate-colored, interbedded with talclike gray silt, with thin chocolate-colored limy sandstone (in beds which are nowhere over 2 inches thick and are usually much thinner) and with mottled, largely chocolate-colored clays | 32 |
| 9. Sandstone, chocolate-colored, very fine grained, very limy, with conchoidal fracture | 1 |
| 10. Clay, reddish, interbedded with thin limy green-gray sandstones, from a fraction of an inch to 8 inches in thickness, most being very thin | 14 |
| Total Summerville formation | 163¾ |
| Transitional boundary. | |
| Curtis formation: | |
| Limestone, gray, weathering brown, sandy, containing many geodes lined with chalcedony, rock crystal, and calcite | ¾ |
| Sandstone, gray-green | 197 |

No fossils have yet been found in the Summerville formation, and its age must be determined wholly on the basis of its relations to the formations between which it lies. However, as it passes by gradation downward into the fossiliferous Curtis formation, which is definitely Upper Jurassic, and as it also lies unconformably beneath the Morrison formation, whose Lower Cretaceous age is doubtful and which may also be Jurassic, it seems safe to refer it to the Jurassic period without question.

## CRETACEOUS (?) SYSTEM

### LOWER CRETACEOUS (?) SERIES

#### MORRISON FORMATION

There is an unconformity, both angular and erosional, at the top of the Summerville formation. The angular divergence of the beds was at no point in this area observed to exceed the amount shown on the cliffs east of Cottonwood Springs Wash, 2 miles southeast of Curtis Point, where it is 4°. (See pl. 33, *C*.) In most sections it is not noticeable. It might be considered purely local and unimportant were it not for the erosional unconformity everywhere noted at this horizon and the angular discordance of approximately 8° observed at this horizon southeast of this area on the road between Hanksville and the Granite ranch along the northeast foothills of Mount Ellen.

Above this unconformity lie the clay, sandstone, and conglomerate of the Morrison formation. The basal portion of this formation, on the east flank of the Swell, is a series of conglomeratic sandstone lenses of the channel type, interbedded with far subordinate amounts of clay and some gypsum and limestone. On the west flank the sandstones are much less prominent, in many places a single 5-foot bed being the sole representative of the series which reaches 200 feet in thickness on the east flank. From the descriptions given by Lupton [41] this series is very probably his Salt Wash sandstone member, whose inconspicuous appearance on the west flank of the Swell probably led to his correlating the Curtis formation of this report with the type Salt Wash sandstone member of his Green River area.[42] (See pl. 34, *A*.)

The Morrison above the Salt Wash sandstone member is a series of variegated clays, dominantly blue-green, interbedded with subordinate lenticular conglomeratic sandstones and thin cherty limestones. (See pl. 34, *C*.) About 200 feet below the top is a persistent chert-pebble conglomerate, between 3 feet and about 40 feet thick, continuous over the whole north end of the Swell and forming very resistant hogbacks, of which Cedar Mountain and the ridge west of the Denver & Rio Grande Western Railroad between Desert siding and Woodside are typical. This conglomerate disappears to the south and is not present south of Muddy River. Lee [43] observed a similar conglomerate in more easterly areas near Cisco and Thompson and regarded it as the lower conglomerate bed of

[41] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, pp. 126, 127, 1912.

[42] Lupton, C. T., Geology and coal resources of Castle Valley, Utah: U. S. Geol. Survey Bull. 628, pp. 21–25, 1916.

[43] Lee, W. T., oral communication.

the Dakota (?) sandstone. Its lenticular character seems to throw doubt on this interpretation, however, and as the lithology of the beds above it is nearly identical with that of the beds below, the whole series above the Salt Wash sandstone member, up to the base of the first sandstone below the Mancos shale, is in this report considered Morrison.

Above this conglomerate the formation again consists dominantly of clay with subordinate sandstone lenses, though the sandstones are perhaps more numerous than they are in the portion between the Salt Wash sandstone member and the conglomerate.

The two following sections illustrate the differences in the development of the Morrison on the two flanks of the Swell:

*Section of Morrison formation measured on Horn Silver Gulch, on west flank of San Rafael Swell, in secs. 35 and 36, T. 20 S., R. 8 E.*

| | Ft. | in. |
|---|---|---|
| Dakota (?) sandstone: Grit, gray, limy, cross-bedded, with iron concretions as much as 1 foot in diameter. Contains small rounded to subangular pebbles of black and white chert, white and rose quartz, and clay in a slightly gritty matrix. Forms a persistent ledge, above which the Mancos shale begins | 26 | |
| Unconformity. | | |
| Morrison formation: | | |
| 1. Shale, light gray, blue-gray, and greenish gray, variegated | 96 | |
| 2. Sandstone, slightly gritty, light gray, somewhat friable. Subrounded rose quartz, white quartz, and biotite make up the rock; cemented with lime. A lens about 200 yards long | 3 | 6 |
| 3. Shale, very poorly laminated, light gray, gypsiferous | 42 | |
| 4. Conglomerate, lens; disappears within half a mile in one direction and 300 feet in the other; nearly all gravel, very little sandstone | 4 | |
| 5. Shale, clay, and thin nodular limestones. The clay and shale are dominantly light gray, banded with purple and mauve, and carry numerous 4-inch nodular bands of dense blue-gray limestone. Forms a slope strewn with limestone and silicified limestone nodules derived from these beds | 93 | |
| 6. Conglomerate with sand lenses, which make up about a third of the member. Consists largely of well-rounded pebbles of flint with some jasper and brown chert averaging three-eighths of an inch in diameter but ranging from the size of sand to 2½ inches. Varies in thickness, in places being 20 feet thick, and one-half clay. The conglomerate persists for a long distance | 6 | |
| 7. Shale and clay, with some thin limestones as in bed 5; variegated, indigo-gray, light gray, and maroon | 66 | |

| Morrison formation—Continued. | Ft. | in. |
|---|---|---|
| 8. Limestone, green-gray, dense, much silicified. The bed is a lens disappearing within 100 yards along the strike | 3 | 6 |
| 9. Clay, variegated, interbedded with purple, maroon, white, and gray marl; brick-red shale; and sandstones which are in a few thin lenses 6 inches to 1 foot thick and rarely over 200 feet long. The clays are gray, purple, red, and brown, variegated along and across the bedding. In the corresponding zone 100 yards away there are several thick sandstones which lens out before reaching this section | 134 | 6 |
| 10. Sandstone, slightly gritty, cross-bedded and very lenticular, being less than 150 feet long | 1 | 6 |
| 11. Marl, white | 7 | 6 |
| 12. Clay, purple, limy, varying to limestone, slightly clayey | 9 | |
| 13. Shale and clay, purple, micaceous, gypsiferous | 2 | |
| 14. Clay, white, brick-red, and purple, containing a few thin limestones and passing upward into dead-white marl with a few shaly maroon limestones | 31 | 6 |
| 15. Sandstone, grayish red, fine grained, hummocky, lenticular, containing lumps of marl and clay | 1 | 6 |
| 16. Clays, red | 9 | |
| 17. Clay, gray, with a bench of purple limestone at 15 feet from the base, also a few thin sandstone lenses | 22 | |
| 18. Marl, purple, with limestone lumps | 1 | |
| 19. Clay, gray-green, with thin lenticular sandstones and an 8-inch limestone | 21 | |
| 20. Channel sandstone, conglomeratic, cross-bedded, cemented with silica; carries silicified bones at the top. Capping a winding ridge, the sandstone lens, nowhere over 100 yards wide, can be traced for miles. It is clearly a fossil stream channel, trending northeast | 9 | 6 |
| 21. Clay, light green-gray, with a persistent 6-inch limestone ledge at 7 feet above the base | 48 | |
| 22. Limestone, shaly, gray, weathering brown | 1 | 6 |
| 23. Clay, gray | 51 | |
| 24. Sandstone, conglomeratic, like bed 20, variable along its trend and lenticular across it, trending northeast; thins out and disappears in about one-eighth mile along its course in one direction, though continuing in the other for a long distance | 13 | 6 |
| 25. Clay, gray but with some purple variation and interbedded with some marl, lumpy and weathering brownish purple | 34 | |
| 26. Channel sandstone, like bed 20, but lensing out in both directions along its trend | 13 | 9 |

| Morrison formation—Continued. | Ft. | in. |
|---|---|---|
| 27. Clays, gray, like bed 25, with a 3-inch sandstone at 16 feet above the base | 23 | 6 |
| 28. Channel sandstone, very lenticular | 2 | |
| 29. Clay, light green-gray, pinkish gray, purple-gray, and tan, with very subordinate shaly limestone and brown marl | 6 | |
| 30. Channel sandstone, with grit pockets, lenticular, although the beds at this horizon are sandy for long distances | 14 | |
| 31. Sandstone, white, friable, lenticular | 1 | 6 |
| 32. Clays, blue-gray, becoming sandier upward and passing into bed 31 | 3 | |
| 33. Sandstone, like bed 31 | 1 | 3 |
| 34. Clay, gray, with some shaly limestone and sandstone lenses 4 inches thick and 30 feet long | 16 | 6 |
| 35. Sandstone, cross-bedded, conglomeratic, containing pebbles (largely flint and gray chert) as much as a quarter of an inch in size | 4 | |
| 36. Clay, like bed 29 | 21 | |
| 37. Limestone, a lens, nodular, sandy, with small chert pebbles through it | | 6 |
| 38. Clay, gypsiferous, gray | 4 | |
| 39. Gypsum, alabaster, with thin seams of green clay, contorted, perhaps by hydration of the gypsum. Jasper crusts of irregular shape as much as 2 inches thick. Some have hollow centers filled with crystalline quartz. Lower 10 feet forms a ledge, the upper part a slope. There is less clay above than below | 24 | |
| Total thickness of Morrison formation | 847 | |

Unconformity in which the gypsum cuts down across the bedding of the red shales and sandstones of the Summerville formation as much as 3 feet in 30 feet of outcrop. The unconformity is angular and erosional.

Summerville formation: Sandstone and micaceous shale, alternating in thin beds, seamed with secondary gypsum.

*Section of Morrison formation east of Woodside anticline, on east flank of the San Rafael Swell, in secs. 17 and 18, T. 19 S., R. 14 E.*

| | Feet |
|---|---|
| Dakota (?) sandstone: Grit, ill exposed, at base of Mancos shale | 2 |
| Unconformity. | |
| Morrison formation: | |
| 1. Clay, variegated, yellow, cream-colored, chocolate-colored, bluish gray, greenish gray, brick-red, etc. Contains discontinuous bands of gritty medium-gray limestone, which weathers dark brown. The limestones contain sporadic grains one-sixteenth to one-eighth of an inch in diameter of jasper and black chert and smaller grains of translucent quartz. Seams of secondary calcite are common | 25 |

| Morrison formation—Continued. | Feet |
|---|---|
| 2. Sandstone with conglomerate at base, which carries pebbles of clay, chert, limestone, and jasper as much as 3 inches in size, light gray, fine grained, cemented with lime, cross-bedded, and much stained with desert varnish | 11 |
| 3. Shale, marly, medium gray with greenish cast | 20 |
| 4. Limestone, dense, medium gray with greenish tinge and some lilac-red spots. There is much iron stain along joints. The bed is badly shattered. The upper 4 feet is a dirty-purplish shaly limestone | 6 |
| 5. Clay, variegated, like bed 1; limy bands have considerable secondary calcite | 33½ |
| 6. Sandstone, light gray, fine grained, limy cement, cross-bedded, conglomeratic at base, carrying pebbles of limestone, chert, and jasper, much desert varnish | 5 |
| 7. Clay, variegated, like bed 1 | 28¼ |
| 8. Sandstone, light gray, much cross-bedded, with several bands of fine conglomerate (mainly black and gray chert pebbles) cemented with silica. Much desert varnish | 18 |
| 9. Clay, variegated, like bed 1. Gritty limestone bands in places give way to limy grit and limestone conglomerate carrying chert pebbles 1 inch or less in diameter. The member weathers into steep slopes covered with jagged pebbles | 64 |
| 10. Sandstone, lenticular, like bed 8 | 3 |
| 11. Clay, like bed 9 | 18½ |
| 12. Limestone, medium gray, lenticular but a larger lens than the average, as it is traceable for over half a mile. In places makes a slight bench | 4½ |
| 13. Clay, like bed 9 | 52 |
| 14. Grit and conglomerate, cemented firmly with silica, locally fracturing across the pebbles, though in places it is limy, with secondary calcite along fractures. Much stained with desert varnish | 9 |
| 15. Clay, like bed 1, except that limestone lenses are confined to the upper parts | 25½ |
| 16. Sandstone, light gray, limy, very fine grained, massive, firmly cemented, breaking into angular joint blocks about 1 foot on a side, and with blotches of limonite stain on the outcrop | 5 |
| 17. Conglomerate, composed largely of chert pebbles, cemented with silica, and containing pebbles of sandstone as large as 4 by 2 inches. Layers of cross-bedded sandstone and grit as much as 4 feet thick are included. Stream bedded throughout. This is the conglomerate that caps Cedar Mountain and forms the prominent hogback west of the Denver & Rio Grande Western Railroad south of Woodside | 19 |
| 18. Shale, limy, greenish gray | 3 |

| Morrison formation—Continued. | Feet |
|---|---|
| 19. Clay, purplish (bluish gray at a distance), rather flaky toward the top, approaching a shale in fissility; breaks into angular fragments | 4½ |
| 20. Conglomerate, mottled purple and gray, containing limestone pebbles 1¼ inches or less in size | ½ |
| 21. Clay, drab to green-gray, weathering into steep slopes | 45 |
| 22. Sandstone, light gray, with some limonite stain, tangentially cross-bedded, very friable | 3 |
| 23. Clay, faint greenish yellow-gray | 8½ |
| 24. Sandstone, light gray, weathering drab to brown, thin bedded, cross-bedded | 2½ |
| 25. Clay, drab or faint greenish yellow-gray, soft, structureless | 16 |
| 26. Sandstone, medium gray, cross-bedded, with fine conglomerate at the base. The bed contains small lenses of quartzite in the midst of generally friable, lime-cemented material. Many grains are coated with limonite | 5½ |
| 27. Clay, light greenish gray | 19 |
| 28. Sandstone, light gray, cross-bedded, with bedding angles as great as 32° with the true bedding. No consistent trend to the cross-bedding is apparent | 12 |
| 29. Clay, variegated, dominantly light greenish gray with tinges of red | 9 |
| 30. Limestone, dark green, dense, cherty | 1 |
| 31. Clay, like bed 29 | 21 |
| 32. Sandstone, dark green, calcareous, friable, very lenticular | 1 |
| 33. Shale, variegated, somewhat fissile | 3 |
| 34. Sandstone, lenticular, dark green | ½ |
| 35. Clay, like bed 29 | 3½ |
| 36. Limestone, light greenish gray, dense, siliceous | 1½ |
| 37. Clay, like bed 29 | 19 |
| 38. Limestone, very dense, green-gray; weathers into nodular forms | 1 |
| 39. Clay, like bed 29 | 6 |
| 40. Clay and sandstone, alternating. The clay, which predominates, is of the type of bed 29. The sandstone is cross-bedded, limy, greenish gray, and weathers brown | 14 |
| Salt Wash sandstone member: | |
| 41. Sandstone and clay, about 85 per cent sandstone, light gray, fine grained; forms a strong bench nearly half a mile wide. Clay partings and seams as much as 1 foot thick occur, especially near the base. In the main the sandstone is massive, yielding rounded forms on weathering, and forms ledges as much as 12 feet thick. Cross-bedding is common. Certain layers in the cross-bedded mem- | |

Morrison formation—Continued.

| Salt Wash sandstone member—Continued. | Feet | |
|---|---|---|
| bers are fine grits or even finely conglomeratic; this is especially noticeable toward the top | 74 | |
| 42. Clay, light to medium gray with a slight greenish cast, in part variegated. Polished pebbles ("gastroliths") are strewn on this slope | 11 | |
| 43. Sandstone, light gray, friable on weathering, lenticular | 2½ | |
| 44. Clay, like bed 42 | 6 | |
| 45. Clay and sandstone, about one-third sandstone like bed 43 in ledges 6 inches to 2 feet or more thick, which weather light brown and are very hard, probably being cemented with silica. A 1-foot ledge 11 feet above the base is a quartzitic grit. The sandstone at the top of this member makes a bench which is here 50 feet wide. The clay making up two-thirds of this member, is like that in bed 42 | 27 | |
| 46. Clay, light medium gray, with a greenish cast, but in part variegated, with a dirty purplish tinge, probably limy | 7 | |
| 47. Clay and limestone, about two-thirds clay, one-third limestone. Limestone is medium gray, weathering dark gray, in some places brown, dense, in ledges as much as 1 foot thick. No fossils noted here, but fragmentary gastropods occur elsewhere at this horizon. The clay is like that of bed 46 | 18½ | |
| 48. Gypsiferous clay, mainly green-gray with many seams of fibrous white secondary gypsum. Near top a few thin sandstone layers occur | 11 | |
| 49. Gypsiferous sandstone, grading upward into bed 48, greenish gray, friable, with much secondary fibrous gypsum. This is apparently a resistant stratum, as it caps a rather extensive bench | 15 | |
| 50. Gypsum, massive and fibrous, dirty, with clay and sand. The gypsum is cherry-red, pink, and white, forming a strong ledge | 5½ | |
| Total Salt Wash sandstone member | | 177½ |
| Total thickness of Morrison formation | | 724¾ |

No unconformity can be detected here, though elsewhere a low angular unconformity and some erosion are shown at this horizon.

Summerville formation.

The rocks here correlated with the Morrison formation have in this region been hitherto referred to the "McElmo" formation. They are, however, lithologically identical with the well-known Morrison of the Dinosaur National Monument, on the south flank of the Uinta Mountains, about 100 miles north by east of this area. Dinosaur bones collected by E. T. McKnight on Last Chance Creek on the west flank of the San Rafael Swell, were identified by C. W. Gilmore, who reports as follows:

> The fossil bones apparently belong to one individual and are identified as pertaining to the well-known genus *Diplodocus*, which belongs to that group of dinosaurs known as the sauropods, which contains the largest ones known. The genus is not known outside of the Morrison formation, so the presumption is that these bones come from equivalent beds.

There has been so wide diversity in the usage of the term "McElmo" in different parts of the plateau province that it has seemed advisable to use the term Morrison for these beds rather than to attempt to restrict the usage of McElmo. There seems ample lithologic and fossil evidence for the extension of the term Morrison formation into this locality.

## CRETACEOUS SYSTEM

### UPPER CRETACEOUS SERIES

#### DAKOTA (?) SANDSTONE

The Dakota(?) sandstone is not present everywhere in this area between the Morrison formation and the Mancos shale. In some places a few lenses of conglomeratic sandstone resting in depressions of the Morrison surface and overlain by Mancos shale are probably representative of this sandstone, though they may be merely channel sands of the Morrison. However, long, continuous exposures at this horizon generally reveal persistent conglomerates and sandstones, many of them quartzitic, in places containing plant fragments and *Halymenites*, and ranging in thickness from a feather edge up to about 50 feet. Fossil plants collected by Richardson[44] near Woodside show this to be the equivalent of the Dakota sandstone. The stratigraphic position and lithology also correspond to those of beds widely accepted as Dakota. But because of the likelihood of differences in age at so great distances from the typical Dakota locality, and because of the differences of opinion as to how much should be included under the name, the correlation is here questioned and the formation is designated Dakota(?) sandstone. Topographically the formation finds its expression in low hogback ridges, not very prominent even where it is best developed. In the south end of the Swell the Mancos

---

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

shale rests directly on Morrison clays and there is no Dakota(?) sandstone present for several miles of outcrop.

The following section is regarded as a fairly typical one for this area:

*Section of Dakota (?) sandstone measured in Cottonwood Wash in sec. 1, T. 18 S., R. 13 E.*

| | Feet |
|---|---|
| Mancos shale: Shale, sandy, gray, gypsiferous. | |
| Dakota(?) sandstone: | |
| 1. Quartzite, dark green, very hard, fine grained, with sporadic coarse grains | 1½ |
| 2. Shale, gray, very sandy, with gypsiferous concretions | 7 |
| 3. Sandstone, gray-green, weathering dark green, conglomeratic, containing sporadic pebbles as much as half an inch in diameter, cemented with silica into a rather fine grained quartzite at the top | 4 |
| 4. Sandstone, gray-green, weathering brown, massive, cemented with lime | 10 |
| 5. Conglomerate, gray, weathering brown, slightly green toward the top. The pebbles are chiefly chert in lower part, of an average size of half an inch and a maximum of about three-quarters of an inch in a matrix of coarse-grained angular to subangular sand, largely cemented with lime though locally siliceous. The middle of the member is free from pebbles, but the top 2 feet consists of about 50 per cent pebbles (quartzite and chert) as much as 3 inches in diameter | 13 |
| Total thickness of Dakota (?) sandstone | 35½ |
| Unconformity. | |
| Morrison formation: Clay, sandy, gray, concretionary toward the top. | |

### MANCOS SHALE

The Mancos shale rests conformably on the Dakota (?) sandstone or, in its absence, unconformably on the Morrison formation. Only the lower few hundred feet of the Mancos is exposed within the area mapped during this survey. Its outcrop west, north, and northeast of the San Rafael Swell is carved deeply, forming Castle Valley, which may be taken as the limit of the Swell in these directions.

The Mancos is a gray shale, sandy in its lower 100 feet and, on the east side of the Woodside anticline, with a shaly sandstone equivalent to the Ferron sandstone member about 150 to 250 feet above the base. As only a few score feet of the Mancos lies within the area mapped and as its character in several adjacent areas is described in other publications,[45] no detailed section is given here.

[45] Richardson, G. B., op. cit., pp. 14–16. Clark, F. R., The Farnham anticline, Carbon County, Utah: U. S. Geol. Survey Bull. 711, pp. 1–2, 1919. Lupton, C. T., Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, pp. 30–33, 1916; Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, pp. 128–129, 1914. Spieker, E. M., and Reeside, J. B., jr., Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. America Bull., vol. 36, pp. 436–440, 1925.

## QUATERNARY SYSTEM

Terrace gravel and alluvium occur at many places in this area, principally along the larger streams. They are nowhere of great thickness or extent and are accordingly omitted from the geologic map and need not be described in detail.

## IGNEOUS ROCKS

A number of sills and dikes occur in the southwestern part of the area. All the sills are southwest of Muddy River. These rocks are comparatively resistant to erosion and form prominent topographic features, of which Heep Mountain and Starvation Point are examples. The sills occur at several horizons in the sedimentary column, mostly in the upper part of the Carmel formation and in the Entrada sandstone, though some are found as high as the Morrison formation. They vary in thickness from a knife-edge to about 80 feet. The dikes are narrow, averaging 10 or 15 feet in width, and have a marked tendency to trend slightly west of north.

The dikes and sills are composed of rocks which, both in the hand specimen and under the microscope, appear to be of identical types. Careful inspection of many contacts between dikes and sills showed that in each locality the sill is cut by the dike and the dike has a chilled border against the sill. Nevertheless, their close association in the field and their similarity in composition leaves little doubt that both are of essentially contemporaneous origin.

The dikes, with two exceptions, are of uniform composition; the sills, on the other hand, are nearly all composite—that is, inside the chilled selvage of each individual mass is a mantle, from a few inches to a score of feet thick, of very dark rock, within which, and intruding it with an irregular contact which may be either sharp or blended, is a much lighter colored rock. The mafic rock is predominant over the light-colored type in the sills, and although nearly all stages of gradation between these two rock types are seen, in general the boundary separating them is fairly distinct. The thick sills show some slight tendency to gravity stratification, with a concentration of the heavy facies toward the base, but this is not very marked, and tongues and apophyses of the feldspathic type occur almost at the bottom of some of the sills. Two dikes show small amounts of salic material, and it may be that they represent feeders for the sills, but neither dike was traceable into a sill.

The mafic rock of both dikes and sills is locally porphyritic and shows in hand specimens phenocrysts of olivine, biotite, and feldspar in a dense greenish-black groundmass in which biotite flakes are numerous. The microscope shows this darker type to consist of biotite, augite, olivine, brown hornblende, labradorite ($Ab_{38}An_{62}$), analcite, magnetite, apatite, thomsonite, and some serpentine and chlorite. The rock is an analcite-biotite diabase.

The lighter-colored facies is equigranular and, in the hand specimen, shows numerous acicular crystals of hornblende, which are commonly one-fourth inch long but which near the contact of the two facies reach lengths of 2 inches. Biotite is extremely variable in quantity, some specimens having nearly or quite as much biotite as hornblende, whereas others are practically without any biotite. Feldspar makes up the bulk of the rock. In thin sections the light-colored rock is seen to be free from the olivine that is prominent in the diabase and to contain predominant orthoclase, labradorite ($Ab_{45}An_{55}$), analcite, biotite, hornblende, augite, thomsonite, apatite, and magnetite.

The amphibole is soda bearing and this, together with the high content of analcite (25 per cent) makes the rock referable to the alkaline syenites. A rock that is very similar except for the presence of titaniferous femic minerals and the subordinate amount of orthoclase has been named teschenite by Tyrrell.[46]

The relations of the syenite to the diabase are discussed in detail elsewhere.[47]

Nothing is known of the date of the intrusion of these rocks beyond the fact that they are of post-Morrison age. From analogy with the igneous rocks of the Henry Mountains and the High Plateaus they are probably Tertiary.

## STRUCTURE

### GENERAL FEATURES

As the name suggests, the dominant structure of the San Rafael Swell is that of a dome. It is a huge elongate kidney-shaped fold, of striking prominence for over 70 miles and traceable as a more gentle feature for many miles farther to the north. It is difficult to set sharp limits to the structure of the Swell, for the northward dips at the north end continue for many miles, nearly to the center of the Uinta Basin, and the westward dips of the west flank continue well into the Wasatch Plateau. On the south and east sides, however, the limits are much more definite, as a series of sharp folds intervene between the Swell and the Waterpocket Fold, to the southwest, and on the east and southeast the gentle eastward rise of the Green River Desert begins within a short distance of the Reef.

[46] Tyrrell, G. W., The picrite-teschenite sill of Lugar, Ayrshire: Geol. Soc. London Quart. Jour., vol. 72, pp. 64–131, 1916.

[47] Gilluly, James, Analcite diabase and related alkaline syenite from Utah: Am. Jour. Sci., 5th ser., vol. 14, pp. 199–211, 1927.

The asymmetry of the Swell is very marked, the west flank (which includes most of the area here mapped) having dips that average about 3° to 6° and only exceptionally reach 10°, whereas the east and southeast flanks dip at angles as great as 70° and almost everywhere in excess of 30°. There is probably considerable faulting along the eastern part of the Reef, several miles outside the area examined.

Superimposed upon the principal dome of the Swell are a number of irregular structural features. Minor folds that plunge nearly in accordance with the dominant dips of the dome are the rule, though the several small subsidiary folds near the crest of the uplift are irregularly disposed and include some closed depressions and domes. None of these are large, and it seems probable that they are rather superficial features, perhaps connected in origin with minor adjustments during the principal folding of the Swell.

The larger minor folds are the Woodside anticline, in the northeastern part of the area, and the Starvation Creek anticline, in the southwestern part, with the associated synclines.

Faulting of small extent has occurred at many places in the area. The influence of the faulting on the altitude of any stratum at a given point is ordinarily altogether insignificant in comparison to that of the folding.

### METHODS OF REPRESENTING STRUCTURE

The local attitude of beds is indicated on the accompanying map (pl. 30) by the strike and dip symbol, which consists of a bar showing the strike (or direction of a level line on its surface) and an arrow and figure showing the direction and amount of dip (or inclination of its surface with the horizontal) of a bed at that point. Lines showing the positions of anticlinal and synclinal axes supplement these symbols and bring out regional relations much more fully. However, the use of contours, where possible, is the most satisfactory for structural representation. Contours are lines connecting points of equal altitude on a selected stratum or "key" bed. The difference in altitude between the consecutive contours is constant (on the accompanying map 100 feet), so that where the dip is steep the contours are close together, and where the dip is gentle they are spaced more widely. The key horizon represented by the contours on Plate 30 is the base of the Shinarump conglomerate. The altitudes are determined by direct readings in the field and by calculation from altitudes of other strata whose thickness is known from measurements (as discussed under "Stratigraphy").

The structure of the base of the Shinarump conglomerate, which is indicated on the map, does not necessarily reflect accurately the structure of the pre-Coconino beds, because there are two exceedingly widespread unconformities between these horizons. Neither of these unconformities has been shown to be notably angular, yet it is probable that the angular unconformity in Moab Valley north of Moab [48] represents one of these erosion surfaces, and there may be considerable variance in the location and extent of pre-Coconino and post-Shinarump structural features.

## SUBSIDIARY FOLDS

*Woodside anticline.*—The Woodside anticline is a steep asymmetric fold of crescentic shape. Its crest lies near the line between secs. 12 and 13, T. 19 S., R. 13 E. From this point its axis curves gently east of north and east of south, plunging in both directions, so that the total length of the area within the closing contours is less than 7 miles, though the closure amounts to fully 800 feet. On the west side of the anticline dips of 10° to 16° are common, but on the east side dips of 3° to 9° are more characteristic for 2 miles or so from the axis. On the west a sharp syncline intervenes between this fold and the north extension of the Swell, its axis being only a mile west of the Woodside anticlinal axis. To the southeast this syncline plunges steeply, and at the edge of the mapped area there is only slight evidence of its presence, the dips to the south and north of it are practically concordant, and the irregularities of the major Swell structure are nearly smoothed out. This syncline also plunges steeply to the northeast, its axis passing out of the mapped area at about the middle of the east line of T. 18 S., R. 13 E. The Woodside anticline is thus a high, narrow fold superposed on the east flank of the northward-plunging end of the San Rafael Swell.

The Curtis formation is exposed at the crest of the Woodside anticline, surrounded by Summerville and Morrison beds.

*Starvation Creek anticline.*—West of the plunging south end of the San Rafael Swell lies an asymmetrical anticline very similar to that near Woodside. The steep side, having dips of 10° to 18°, faces the Swell in an arc whose general trend is north-northwest. The southwest flank of this dome has much gentler dips—3° to 5°—toward a syncline which separates this feature from the huge anticline of the Waterpocket Fold, just to the southwest. The Starvation Creek anticline has a structural closure of about 700 feet and plunges both northwestward and southward into structural saddles. The southern continuation of this anticline passes into another fold, the north end of which projects into the area surveyed. The beds exposed in the syncline between the Starvation Creek anticline and the main mass of the Swell belong to the Carmel formation, and it is the group of resistant limestones in the lower part of that formation that,

[48]According to J. B. Reeside, jr. (oral communication), there is a 4° angular unconformity at this place between the Moenkopi formation and rocks of Cutler age.

capping the topographic dome of the anticline, reflect so exactly the structure of the underlying rocks.

The saddle between the Starvation Creek anticline and the next southerly anticline is occupied by beds of the Entrada, Curtis, Summerville, and Morrison formations.

*Minor folds.*—An anticlinal nose extending from the main body of the Swell northeastward to Cottonwood Springs Draw in the southwestern part of T. 19 S., R. 13 E., is the principal secondary structural feature in the northern part of the area. This nose, whose prominence is due to rather steep westerly dips into a parallel plunging syncline about 1½ miles away, plunges at about the same angle as the main Swell. It merely marks an offset in the regional strike; as a structural feature favorable for oil accumulation it is probably negligible.

The northward extension of the main Swell structure through the middle of Tps. 18 and 19 S., R. 12 E., forms a terrace-like nose of low dips. It may be that there is a small closed area or dome near the township line between secs. 33 and 34, T. 18 S., R. 12 E., and secs. 3 and 4, T. 19 S., R. 12 E. (unsurveyed), but the local contortions of the gypsiferous zone of the Carmel formation near that place render details somewhat obscure. At any rate, it is certain that no very considerable closure occurs there.

Farther south, in the middle of Sinbad, there is a group of domes, basins, plunging anticlines, and synclines near and forming the crest of the Swell. They are so irregular in grouping and trend that it is difficult to outline them accurately, and they are probably not strongly reflected in the structure of the deeply buried formations. The trend of the main axis of the Swell is difficult to follow because of these minor irregularities, one of which, a short distance outside the area mapped, was the site of a well drilled by the Carter Oil Co. in 1921.

## FAULTS

A zone of faulting extends in a northerly direction through the east halves of Tps. 19 and 18 S., R. 12 E., and across the line into T. 18 S., R. 13 E. The faults seem to be of two types—a nearly north-south line of en échelon faults which trend slightly west of north on the west and a short group of intersecting faults on the east. The intersecting faults constitute two sets, one trending about N. 50°–70° W. and the other about N. 70°–85° E. This group may have resulted from torsional stresses; the north-south faults seem more probably the result of slight vertical readjustments. Neither group has much effect on the structure, as the fault displacements are nowhere great, 60 feet being the maximum throw observed.

A third group of faults occurs near the axis of the plunging syncline in the southeastern part of T. 19 S., R. 13 E., and the northwestern part of T. 20 S., R. 14 E. There is a small graben in secs. 35 and 36 of the former township, an intermediate block being downthrown about 50 to 60 feet with reference to the adjacent ones. The main fault, though perhaps discontinuous at the hinge, seems to be of the scissors type. In its southeast half it is downthrown as much as 60 feet on the northeast, but the displacement gradually dies out northwestward and is succeeded by a southwest downthrow of as much as 50 feet. This faulting was probably contemporaneous with the folding of the Woodside anticline. It was perhaps connected with readjustments of such massive members as the Wingate and Navajo sandstones in the flexing of the syncline, whose asymmetry appears to accord with such an interpretation.

A zone of faults trends northwestward across the north end of Sinbad just southeast of Window Blind Butte. A few east-west faults intersect the dominant northwesterly ones. The faults of this zone have greater throws (as much as 100 feet in one) than those above described. It is possible that they have caused the abrupt extinction of the syncline to the northeast of them, permitting the differential folding to be smoothed out along this fracture zone. Another possibility is that the northeasterly resultant of the folding forces of the Swell which found expression in the plunging anticlinal nose northeast of this zone may have caused a northeasterly slipping in the lower rocks and the production of this fault zone as a result of the tension so developed. These possible explanations do not seem quite so likely to be true, however, as a third—that the faults are due to nearly vertical readjustments later than the principal folding—for the parallel graben and horst formed by them do not seem easily explainable by the other hypotheses but are quite to be expected under this one.

The irregular group of faults in the south end of Sinbad and extending westward up Muddy River and Willow Springs Draw largely trend across the strike of the Swell. These faults are the largest in the area, one having a displacement of 340 feet, and tend dominantly to displace the beds in the same direction as the pitch of the axis of the Swell. Perhaps they were formed at the time of the folding. To the northeast there are a number of shorter faults which seem without systematic arrangement, though perhaps they, too, have a tendency to cut the axis of the Swell transversely. They have considerable displacement but are exceedingly variable in direction and amount of throw. The hypothesis that they are due to the fracturing of the heavy Coconino sandstone during the folding of the Swell or in later adjustments seems, as with the group near the Window Blind Butte, to be the most acceptable explanation of their origin. This hypothesis also seems applicable to the fault on the west flank of the Reef between Eagle Canyon and the head of

Kimball Draw. At the south end this fault gives way to a sharp flexure which is traceable as a pitching syncline for several miles to the west.

A number of lesser faults are widely distributed through the area, but their small displacements are insignificant when compared with those due to folding.

### DATE OF DEFORMATION

All the bedrock formations within the area of the Swell are involved in the folding. The principal folding is accordingly of post-Mancos age, but no closer dating is possible from local purely structural data. However, the marked similarity of the San Rafael Swell to the Waterpocket Fold with respect to the strata involved and the general northerly trend, together with the marked asymmetry of both uplifts in the same sense, furnish strong presumptive evidence of their contemporaneity. If they are contemporaneous, then the major folding of the San Rafael Swell was post-Cretaceous, for the Waterpocket Fold involves late Cretaceous strata and is overlain by essentially flat-lying Wasatch rocks.[49]

Dutton was uncertain in his statements as to the date of the folding of the San Rafael Swell, wavering between an assignment to Cretaceous-Eocene time [50] and to post-Eocene time.[51] Davis [52] has suggested that this second interpretation was perhaps based upon the concentric outline of the Tertiary outcrops west and north of the Swell and upon the lack of adjustment to structure of San Rafael and Muddy (Curtis) Rivers. These streams were cited by Dutton [53] as typical antecedent streams. Davis [54] has adduced reasons to question the antecedence postulated. His reasons, which to the writer appear compelling, are as follows: (1) If Muddy (Curtis) River and San Rafael River are antecedent and have maintained their courses since Eocene time, far closer adjustment to structure than exists would seem almost inevitable. (2) The streams are both small and weak, and hence incompetent to maintain their courses against very great obstacles. (3) The streams head against the dip of the Eocene beds, a relation very favorable to headward extension, so that they should be longer, and hence more powerful, now than

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

[50] Op. cit., pp. 44, 45.

[51] Idem, pp. 19, 20.

[52] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard College Mus. Comp. Zoology Bull., vol. 5, No. 4, p. 140, 1904.

[53] Dutton, C. E., The physical geology of the Grand Canyon district: U. S. Geol. Survey Second Ann. Rept., p. 63, 1882.

[54] Davis, W. M., op. cit., pp. 154, 155.

at an earlier period. Yet they are of very moderate size even now. All these drainage features are readily reconciled with an origin of the major streams by superposition on Eocene rocks, as suggested by Davis, or by inheritance from a late Tertiary peneplain. This last possibility was not considered by Davis, and, indeed, no late Tertiary erosion surfaces have yet been recognized in the immediate vicinity of the Swell. Peneplains of probable Miocene and Pliocene age are, however, known in the Uinta Mountains and probably were once widespread in the region.[55] The inconsequent drainage of the Swell may have been established on one of these surfaces and be now an inheritance from such a cycle.

This possibility seems to throw doubt on or even invalidate any criteria so far advanced for determining the date of the deformation of the Swell from its physiography, and it seems necessary to fall back upon the structural analogies with the Waterpocket Fold as the best clue obtainable. As already stated, there can be no doubt of the post-Cretaceous and pre-Wasatch age of that fold, and it seems likely that the Swell, as a structural feature, also dates from that time.

Nevertheless, the northerly dip of the Tertiary rocks on top of the Book Cliffs, north of the Swell, and their westerly dip on the Wasatch Plateau, west of the Swell, seem to point to a renewal of uplift in post-Eocene time. In the Wasatch Plateau the dips of the Eocene formations are in places very steep, and their regional dip is probably about 6° or 8° W. This attitude, however, is probably due to the displacements along the numerous faults of that plateau and can not in itself be considered evidence of important regional post-Wasatch uplift of the Swell.

The northward dips of the Tertiary rocks of the Uinta Basin, north of the Swell, doubtless reflect differential vertical movements of post-Eocene time. They do not necessarily indicate, however, rejuvenation of the San Rafael Swell folding, especially in view of their persistence far to the east of the Swell. Probably the unit of deformation there involved is the basin of deposition whose axis is now followed by Strawberry and Duchesne Rivers, and the synclinal structure of the Uinta Basin may be referable to isostatic adjustments to the loading of the region in Eocene and possibly later time[55] by sediments derived chiefly from the Uinta Mountains but probably also in some part from the San Rafael Swell and the uplift previously mentioned which has its center near the Blue Mountains. That the erosion of these features was accompanied or followed by isostatic uplift seems very probable, but the physiographic evidence cited above seems to indicate that such uplift was rather slight.

[55] Bradley, W. H., personal communication.

## ECONOMIC GEOLOGY

Interest in the economic geology of the area centers around four possible products—gypsum, vanadium and uranium minerals, oil, and gas.

The gypsum resources of the district are, beyond question, very large. Beds nearly 30 feet in thickness occur, and 6-foot beds are common in the lower part of the Carmel formation. The beds at the top of the Summerville, though reaching thicknesses as great as 8 feet in places, are altogether insignificant in comparison because they are far more lenticular and irregular as well as less pure. The gypsum resources are described by Lupton.[57] The distance of the area from market is undoubtedly the sole factor prohibiting exploitation of these reserves at the present time.

Vanadium-uranium ores have been mined at several localities along the east flank of the Swell, as described by Boutwell[58] and Hess,[59] but although stains of carnotite are plentiful in the area mapped, no accumulations were seen that seem to warrant exploration under present conditions.

The principal economic interest in the area centers in the oil and gas possibilities. It has been found that upfolds in the strata are commonly more favorable for accumulation of oil and gas pools than downfolds or areas in which the beds are essentially uniform in inclination. This is not an invariable rule, but for purposes of exploration in the Rocky Mountain region it is believed to be the best guiding principle.

The San Rafael Swell, being a prominent domal upwarp, naturally was considered a favorable area for prospecting. The presence of considerable detrital asphalt in the Sinbad limestone member of the Moenkopi formation, together with the occurrence of oil in the Pennsylvanian rocks of the San Juan oil field and in the Cane Creek dome, near Moab, also point to this district as worthy of thorough testing. The sedimentary asphalt of the Shinarump conglomerate and some higher horizons is also evidence of the existence of petroliferous rocks of pre-Shinarump age in the general region.

Three deep test wells, as well as a number of shallow wells, have been driven in the area of the Swell. The Carter Oil Co.'s test was made near the crest of the Swell, in sec. 34, T. 23 S., R. 11 E., but was on the steeper flank, about 4 miles southeast of the area mapped. Drilling was begun in July, 1921, and the hole was carried to a depth of 3,035 feet. No oil or gas having been found, drilling was stopped in February, 1922. The well begins near the top of the Coconino

---

[57] Lupton, C. T., Gypsum along the west flank of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 530, pp. 221–231, 1913.

[58] Boutwell, J. M., op. cit.

[59] Hess, F. L., op. cit.

sandstone and penetrates a series of thick red and white sandstones and limestones for its entire depth. The log gives the driller's interpretation of the section passed through.

*Record of Carter Oil Co.'s well in sec. 34, T. 23 S., R. 11 E., Emery County*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Sandy lime | 105 | 105 | Sand | 40 | 2,185 |
| Lime | 95 | 200 | Lime | 15 | 2,200 |
| Sandy lime | 60 | 260 | Hard lime | 10 | 2,210 |
| Lime | 5 | 265 | Lime | 10 | 2,220 |
| Sandy lime | 35 | 300 | White lime | 30 | 2,250 |
| Sand | 30 | 330 | Red lime | 15 | 2,265 |
| Sandy lime | 550 | 880 | White lime | 35 | 2,300 |
| Lime | 5 | 885 | Hard lime | 160 | 2,460 |
| Red lime | 100 | 985 | White lime | 90 | 2,550 |
| Lime | 700 | 1,685 | Shale and red rock | 10 | 2,560 |
| White lime | 20 | 1,705 | Shale | 3 | 2,563 |
| Red sand | 5 | 1,710 | Lime | 22 | 2,585 |
| White sand | 55 | 1,765 | Blue lime | 60 | 2,645 |
| Lime | 15 | 1,780 | Lime | 40 | 2,685 |
| Red sand | 50 | 1,830 | Sand | 170 | 2,855 |
| Red lime | 25 | 1,855 | Sandy lime | 13 | 2,868 |
| Gray sandy lime | 5 | 1,860 | Red lime | 12 | 2,880 |
| Lime | 220 | 2,080 | Pink lime | 10 | 2,890 |
| Sandy lime | 15 | 2,095 | Lime | 10 | 2,900 |
| Sand | 10 | 2,105 | Sand; top of water at 2,943 feet | 55 | 2,955 |
| Lime | 15 | 2,120 | Sandy lime | 45 | 3,000 |
| Sand | 15 | 2,135 | Lime; hole plugged and abandoned at 3,035 feet | 35 | 3,035 |
| Lime | 10 | 2,145 | | | |

The numerous heavy limestone beds shown in the log, which are in marked contrast to the uniformly clean sandstone exposed to a depth of about 700 feet in the Black Box and to depths of about 300 feet in Muddy River Canyon, evoke comparison with the Goodridge formation of the San Juan field. It seems likely that the driller's interpretation of the beds as limestones, at least in the upper few hundred feet, is in error, but it is probable that the lower 2,000 feet penetrate Pennsylvanian beds.

Another deep test was made on the subsidiary Woodside anticline, by the Utah Oil Refining Co., in sec. 12, T. 19 S., R. 13 E. It commenced at the top of the Curtis formation and was 3,270 feet deep when closed in. It is believed to have penetrated the Kaibab and the upper beds of the Coconino. Gas was struck in a sandstone at 3,120 to 3,165 feet, probably in the upper beds of the Coconino sandstone. Tests showed the gas to be noncombustible, chiefly carbon dioxide, containing helium in notable quantities. Accordingly the entire area included within the closing contour of the anticline and a protective strip without it was set aside as Helium Reserve No. 1, by Executive Order of March 21, 1924. The boundaries of the reserve were modified on January 28, 1926, to the limits shown on Plate 30. No further development has taken place, the reserve being established for national emergency.

The Woodside well was located in one of the best places for testing the beds between the Summerville formation and the Coconino sandstone; but the Carter well was located on the steep flank of the Swell, probably at least 3 miles east of the axis, and its negative results can hardly be considered conclusive evidence of the barrenness of the beds penetrated by it. It appears that the beds lower than the upper part of the Coconino have not yet been adequately tested in the San Rafael Swell.

In 1921 the Leonard Petroleum Co. drilled a well in sec. 8, T. 21 S., R. 9 E., on Salt Wash, to a depth of 2,780 feet, probably reaching the Coconino sandstone. The well was located on a monocline with no evidence of closure and is not a conclusive test of the strata through which it passed. The same is true of the numerous shallow wells drilled along the west flank of the Swell. Records of the depths attained by these wells are not available, and it is not known what strata they penetrated. Because of their location with respect to the structural features of the district, however, they can not be considered of particular significance.

The other wells drilled near this area have started too high in the strata to reach the Pennsylvanian at reasonable depths. These include the Caineville well, which probably started in the Entrada sandstone; the Ferron and Huntington wells, which began in the lower part of the Mancos shale; and the Flat Tops well, in the Green River Desert, which probably began in the Entrada or Summerville. The Flat Tops well is probably not on an anticline, an additional reason for questioning its value as a test.

The Circle Cliffs well of the Ohio Oil Co. was suitably located to test the lower strata and failed to yield favorable results. Nevertheless, the oil produced at Cane Creek, near Moab, is derived from Pennsylvanian beds which, although not known with certainty to be present beneath the San Rafael Swell nor to be petroliferous if they are there, have sufficient economic interest to warrant adequate testing of their possibilities. In the opinion of the writer the Swell should be adequately tested by wells drilled on the crest or the gently dipping west flank to depths sufficient to penetrate such Pennsylvanian rocks as may underlie it.

Localities which seem from surface structural data most favorable for such testing are, first, the anticlinal crests about 1 mile east of Tan Seep; second, the flat area about 1 mile south of the junction of the road from the Carter oil camp to San Rafael River and that from Joe Swazey's cabin, in Road Hollow; third, about 4 miles south and 2 miles east from the butte known as "The Wickiup," all in Sinbad.