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SEDIMENTARY ROCKS OF THE SAN RAFAEL SWELL AND SOME ADJACENT AREAS IN EASTERN UTAH

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INTRODUCTION

Eastern Utah is a part of the Colorado Plateau province, a land of naked rocks, of canyons, buttes, mesas, and cliffs. Exposures of bedrock are almost ideal, and the rocks over large areas lie with only slight inclinations, though a few laccolithic mountain masses and a few abrupt folds vary the general simplicity of the structure. Nevertheless, the paucity of fossiliferous strata and some astonishing lateral changes in the sediments have occasioned misinterpretation of even the most persistent lithologic units, and considerable uncertainty has existed as to correlation between the different sections and as to the appropriate nomenclature. Continuous tracing is of course the most satisfactory means of effecting such correlations, though very closely spaced stratigraphic sections will suffice to give useful and sometimes complete answers to the questions involved. The present paper serves to record stratigraphic data obtained, in part by detailed work and in part by more or less isolated observations, in the portion of the Plateau province which includes the San Rafael Swell and some contiguous districts. The results of earlier investigators are interpreted in the light of these recent data, and an effort is made to present briefly the available information on the stratigraphy of the region treated.

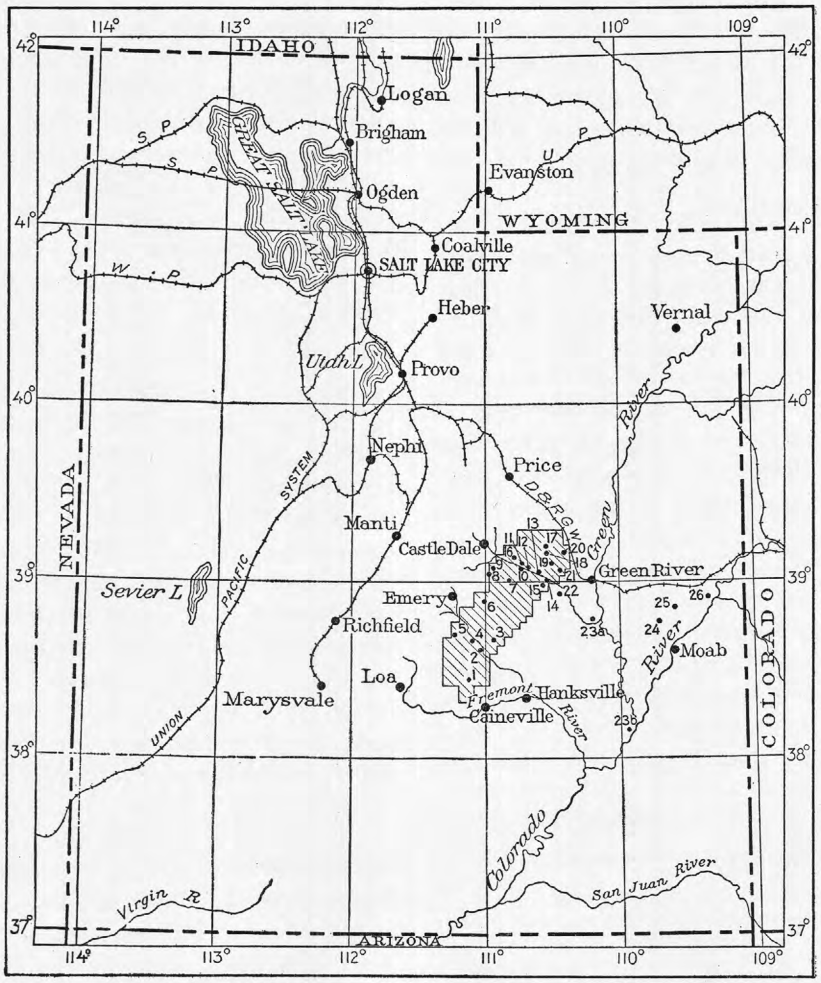

Figure 2.—Index map of Utah, showing location of numbered stratigraphic sections given on pp. 82–110. Shading indicates area of detailed map accompanying a paper on the economic geology of the San Rafael Swell (U. S. Geol. Survey Bull. —, in preparation)

In connection with a study of the oil possibilities of the San Rafael Swell, its entire area except part of the eastern margin was mapped by plane table in detail in 1924 and 1925. This work was begun by E. M. Spieker but shortly afterward was taken over and continued to its completion by Mr. Gilluly. Small areas near Cisco and Crescent were also visited. Mr. Reeside spent several weeks studying the stratigraphy of the Swell in 1924 and visited parts of it again in 1925.

The correlation of the strata of the Colorado Plateau is of great value in deciphering the paleogeographic relations of the region and, because of the recognized influence of paleogeographic conditions on the accumulation of oil and gas, it is of considerable economic importance as well. Accordingly, the areas intervening between Cisco and the San Rafael Swell were studied by the writers jointly for two weeks in 1925 and a week in 1926. As the Green River Desert region had been mapped by Emery [1] in 1917 and much of the country east of Green River by Lupton [2] in

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

[2] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, pp. 115–134, 1914.

1912, and as the exposures are very complete and the topography such as to emphasize the stratigraphic divisions the work was greatly facilitated, and considerable confidence is felt in the correlations here made between the Swell and the mouth of Dolores River. The interpretation of the lateral variations of the different units and the correlations arrived at are shown in Plate 15.

PREVIOUS WORK

Dutton,[3] Gilbert,[4] and Powell,[5] in connection with the early surveys of the plateau province, described adjacent districts and only incidentally mentioned the San Rafael Swell and Green River Desert area. More recent work by Cross,[6] Lupton,[7] Dake,[8] Lee,[9] Emery,[10] Prommel,[11] Moore,[12] and Longwell and others[13] deals directly with its stratigraphic problems. Papers on neighboring areas by many writers have been consulted in making correlations and will be referred to in the appropriate places.

TOPOGRAPHY

The San Rafael Swell is an elongate oval area, surrounded by a rim of inward-facing, almost vertical cliffs. From the top of the cliffs the surface slopes outward in all directions, gently on the west toward Castle Valley and on the north toward the Uinta Basin and more steeply on the south and east toward Fremont River and the Green River Desert. The Green River Desert lies largely on the north and west slopes of a huge but gentle uplift centering near the Blue Mountains. South of the Swell are the Henry Mountains, a group of smoothly rounded masses projecting high above the general surface. West of these mountains lies the Waterpocket Fold, a district remarkably resembling the San Rafael Swell in topography. The north end of this fold is the southern extremity of the area here discussed. To the west the region is bounded by one of the High Plateaus, the Wasatch Plateau, whose top reaches altitudes of 9,000 to 11,000 feet. From the north end of the Wasatch Plateau the much lower escarpment of the Book Cliffs continues eastward to and beyond the Colorado State boundary and the limits of the area described in this paper. South of the Book Cliffs, east of Green River, and north of the La Sal Mountains is a large district showing only minor topographic features rising above the general surface of the plateau.

Over most of the area drainage channels are deeply incised, and to speak of a "general plateau surface" is justified only in dealing with the very largest topographic units. In detail, the country is dissected by an intricate maze of nearly or quite impassable canyons and dotted with buttes and mesas of gigantic dimensions. The local topography is governed in minute detail by the rock structure. Massive sandstones form steep ledges or even-topped benches, and softer shales weather into slopes. Drainage is carried through the thick sandstones by narrow and vertical-walled canyons; through the shales by wider valleys with gentler side slopes. Structural terraces along the watercourses, due to the erosion of soft beds from the nearly flat-lying resistant beds, are a prevailing feature. (See pl. 16.)

SEDIMENTARY ROCKS

GENERAL FEATURES

The rocks exposed in the districts discussed in this paper range in age from Pennsylvanian to Upper Cretaceous. The most widely exposed formations are those of the Triassic and Jurassic systems. Pre-Triassic beds come to the surface in the area locally called Sinbad, within the San Rafael Swell, in the Waterpocket Fold, and in the canyons of Colorado River and its eastern tributaries. A band of Cretaceous beds crops out about the edges of the district—on the south between the Swell and the Henry Mountains; on the west and north in Castle Valley, the Wasatch front, and the Book Cliffs and the adjacent lower plateau.

A few dikes and sills in the southwestern part of the San Rafael Swell are the only igneous rocks in the area, though igneous rocks are prominent in the near-by La Sal, Blue, and Henry Mountains and in the southern High Plateaus. None of the igneous bodies are described in this paper.

Sandstones overwhelmingly predominate in all the formations older than the Mancos shale. The Triassic and Jurassic rocks, the main concern of this paper, are mostly nonfossiliferous and are probably in large part of continental origin.

A generalized section of the rocks exposed in the San Rafael Swell is given in the accompanying table. The correlation with more easterly areas is discussed in detail only for the formations included between the Chinle and Morrison, and is shown diagrammatically in Plate 15.

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[3] Dutton, C. E., Report on the geology of the High Plateaus of Utah, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[4] Gilbert, G. K., Report on the geology of the Henry Mountains, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[5] Powell, J. W., Exploration of the Colorado River of the West, 1875.

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

[7] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, pp. 115–134, 1914; Gypsum along the west flank of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 530, pp. 221–231, 1913; Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, 1916.

[8] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–646, 1919; The pre-Moenkopi unconformity of the Colorado Plateau: Jour. Geology, vol. 28, pp. 61–74, 1920.

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

[10] Emery, W. B., op. cit.

[11] Prommel, H. W. C., Geology and structure of portions of Grand and San Juan Counties, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 4, pp. 384–399, 1923.

[12] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, No. 3, pp. 199–227, 1922.

[13] Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–25, 1923.

General section of rock formations in the San Rafael Swell, Utah

System	Series	Group and formation	Thickness (feet)	Character	Remarks
Quaternary.		Alluvium and terrace gravel.		Sandy clay, sand, and gravel in alluvial fans; terrace gravels 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 above the base 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; such lenses especially numerous toward the base, where they form the Salt Wash sandstone member; subordinate thin lenticular limestones; a rather persistent conglomerate 250 to 350 feet below the top.	McElmo, except basal part, of Cross;[a] McElmo of Emery;[b] Upper McElmo of Lupton[c d] and Dake.[e] At base is Salt Wash sandstone member of Lupton,[c] Emery,[b] and Dake.[e]
		—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.	According to W. T. Lee,[f] probably basal McElmo at type locality; basal part of McElmo of Cross[a] and middle part of McElmo of Lupton;[c d] part of lower McElmo of Dake[e] included in Navajo by Emery.[b]
		Curtis formation.	76–252	Green-gray conglomerate and shale, and gray heavy-bedded sandstone.	Included in Navajo by Emery;[b] Salt Wash of Lupton.[d]
		Unconformity			
		Entrada sandstone.	265–844	Thin-bedded red shale and sandstone at the base; heavy, massive red-brown earthy sandstone above; weathers into rounded forms and steep cliffs.	Upper La Plata sandstone of Cross;[a] included in Navajo sandstone by Emery;[b] "varicolored sandstone and shales" of Longwell and others;[g] included in McElmo of Lupton,[c d] in lower McElmo (Sundance?) of Dake.[e]
		Carmel formation.	170–650	Dense limestone and buff and red sandstone at the base; toward the top dominantly red and green shale with thin sandstones and heavy beds of gypsum.	Base of McElmo of Lupton;[d] included in "marine Jurassic" of Dake[e] and Lee;[h] Todilto (?) formation of Emery;[b] "gypsiferous shales and sandstones" of Longwell and others;[g] middle La Plata of Cross[a] and Paige.[i]
		—Unconformity (?)—			
Jurassic (?).		Glen Canyon group			
		Navajo sandstone.	440–540	Tan to light-gray massive cross-bedded calcareous sandstone, with a few thin local limestones.	Gregory's usage;[j] lower La Plata of Cross;[a] included in Wingate sandstone by Emery.[b]
		Todilto (?) formation.	44–240	Red-brown sandstones, green and red shale, and shale conglomerate, irregularly interfingering and channeled.	Included in Wingate sandstone by Emery.[b]
		Wingate sandstone.	360–400	Buff to tan, pink, and dark-gray massive cross-bedded limy sandstone, with a few thin lenses of limestone. In most places stained red by wash.	Gregory's usage;[j] lower part of Wingate sandstone of Emery;[b] Upper Dolores sandstone of Cross.[a]
		—Unconformity—			
Triassic.	Upper Triassic.	Chinle formation.	141–225	Green and red micaceous sandstone and thin red-brown shales; limestone conglomerate; variegated marl; all lenticular, channeled, and interfingering.	Lower Dolores of Cross.[a]
	Upper (?) Triassic.	Shinarump conglomerate.	70–178	Cross-bedded lenticular conglomerate, sandstone, clay, and shale; interfingering. Much silicified wood. Quartz and chert pebbles predominate 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; red sandstone. Very limy throughout. A massive, persistent light-gray marine limestone and sandstone member 140 to 200 feet above the base and 40 to 150 feet thick—the Sinbad limestone member.	
		—Unconformity—			
Carboniferous.	Permian.	Kaibab limestone.	0–85	Light-gray to cream-colored cherty limestone; some oölite; somewhat sandy in places.	Present only in patches in San Rafael Swell; 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, and the lowest 40 feet largely limestone. Base not exposed.	May include chronologic equivalents of part of typical Kaibab limestone, typical Coconino sandstone, Hermit shale, and part of Supai formation.

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[a] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 641, 1907.
[b] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551–577, 1918.
[c] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 115–133, 1914.
[d] Lupton, C. T., Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, pp. 19–26, 1916.
[e] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–646, 1919.
[f] Lee, W. T., personal communication.
[g] Longwell, C. R., and others, Rock formations of the Colorado Plateau in southern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–23, 1923.
[h] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, 1918.
[i] Paige, Sidney, The La Plata group in the plateau country (unpublished), read before the Am. Assoc. Adv. Sci., December, 1924, Washington, D. C.
[j] Gregory, H. E., The geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, 1917.

PRE-TRIASSIC ROCKS

The exposed rocks older than Triassic are of entirely different facies in the eastern and western parts of the area here described. The western facies was studied in considerable detail in the Waterpocket Fold and at numerous localities in the San Rafael Swell. Observations on the eastern facies in the canyons of Colorado River and its tributaries near and east of Moab were so meager and so cursory that the writers will not attempt in this paper any extended comparison with the rocks of the San Rafael Swell.

COCONINO SANDSTONE

In the western localities the rocks exposed below the Triassic are designated here the Coconino sandstone and the Kaibab limestone. The Coconino is a massive, highly cross-bedded buff to white sandstone, at some places blotched irregularly with red and brown. The thick beds are unbroken by shale. It is dominantly lime-cemented and somewhat friable but nevertheless stands in nearly vertical cliffs whose intricate jointing is characteristic. The grain is uneven but chiefly fine. The basal 40 feet of the thickest exposure in the San Rafael Swell, in the Black Box Canyon of San Rafael River, is chiefly limestone and may belong to an older but conformable formation rather than the Coconino sandstone, though no decisive evidence on this point was obtained. No determinable fossils have been found in the sandstone, and correlation with the type Coconino sandstone, of Permian age, is based upon the apparently conformable stratigraphic position beneath the Kaibab limestone and upon the lithology. In the Circle Cliffs, at Lees Ferry, and in the Grand Canyon district (the type region of the Coconino sandstone and Kaibab limestone) similar lithologic units occur with identical relations—a limestone formation conformably above a sandstone. It is true that it is not possible to trace the formations between the San Rafael Swell, Cataract Canyon, the Circle Cliffs, and Lees Ferry and the Grand Canyon and that there may be question as to the lateral changes in lithology and the chronologic equivalence of the similar units. As noted on the table, the Kaibab limestone in the San Rafael Swell is only the very latest part of the formation as it is represented in the type area, and some part of the Coconino sandstone of the San Rafael Swell may therefore be of the age of the typical Kaibab limestone. Near the junction of Green and Colorado Rivers, United States Geological Survey field parties collected Permian fossils from limestones at the base of beds that grade laterally within a few miles into the Coconino sandstone of Cataract Canyon. Under these fossiliferous beds a red, nearly barren zone several hundred feet thick rests conformably on the top of beds assigned to the Goodridge formation and containing fossils of Pennsylvanian (Hermosa) age. These facts suggest that the lithologic unit designated Coconino sandstone in the San Rafael Swell and Cataract Canyon may contain time equivalents of part of the Supai formation, the Hermit shale, the Coconino sandstone, and the Kaibab limestone of the Grand Canyon region. The name is in use, however, and it seems best for the present, at least, to continue using this name as a convenient designation for the lithologic unit, without implying chronologic identity with the typical Coconino sandstone.

The greatest thickness measured in the San Rafael Swell is 715 feet in the Black Box Canyon of San Rafael River, in the north end of the Swell. The base is not exposed here nor at any other point in the region described by the writers. In Cataract Canyon the sandstone measures nearly 1,000 feet, according to Longwell, Miser, Moore, Bryan, and Paige,[14] who state further that it "has been traced by B. S. Butler, F. L. Hess, H. E. Gregory, C. R. Longwell, and H. D. Miser practically the entire distance from Cataract Canyon to the San Juan oil field by way of White Canyon."

The Coconino thins to the south and west of this region. In the Grand Canyon district it is 250 to 350 feet thick, and Reeside and Bassler [15] and Longwell [16] have shown that still farther to the west it thins yet more and finally is inseparable from the westward equivalent of the underlying Supai formation.

KAIBAB LIMESTONE

Conformably above the Coconino sandstone in the Waterpocket Fold and in parts of the San Rafael Swell lies the Kaibab limestone. Fossils collected by Powell [17] and Newberry [18] near the confluence of the Green and the Colorado were interpreted some years ago by G. H. Girty [19] as probably indicating the presence in that district of a formation equivalent to the "Aubrey" limestone (Kaibab). More recent data confirm this probability, as the highest marine fossils in collections made by Geological Survey parties and examined by Mr. Girty [20] contain the same species as the older collections, though no limestone comparable to the Kaibab limestone of the San Rafael Swell has been found at the top of the section. The Kaibab limestone was not seen in Elaterite Basin by either Emery [21] or the writers, nor is it reported by any of the geologists who have worked along Cataract Canyon, on San Juan River, or in the Henry Mountains. It is present only in thin patches in the San Rafael country, being cut out at many places by the pre-Triassic unconformity.

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[14] Longwell, C. R., and others, op. cit., p. 8.

[15] Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, p. 57, 1922.

[16] Longwell, C. R., The geology of the Muddy Mountains, Nev., with a section to the Grand Wash Cliffs, in western Arizona: Am. Jour. Sci., 5th ser., vol. 1, p. 47, 1921.

[17] Powell, J. W., op. cit., pp. 88–92.

[18] Newberry, J. S., Report of expedition from Santa Fe, N. Mex., to the junction of the Grand and Green Rivers of the Great Colorado of the West, in 1859, p. 98, Washington, 1876.

[19] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 670–674, 1907.

[20] Girty, G. H., oral communication.

[21] Emery, W. B., op. cit.

The maximum thickness of the Kaibab limestone measured in the San Rafael Swell is 85 feet, and it ranges from this thickness down to a thin film. In the Circle Cliffs it is 163 feet thick,[22] at Lees Ferry 250 feet,[23] in the Grand Canyon 400 to 600 feet,[24] and in southwestern Utah and northwestern Arizona 775 to 1,050 feet.[25] Evidently the Kaibab limestone thins to the northeast.

As the Coconino sandstone thickens northeastward, and as the Kaibab limestone lies upon it with an apparently conformable contact, it seems probable that the limestone thins almost wholly by the lateral gradation of the limy (Kaibab) facies into the sandy (Coconino) facies. That this may not be the sole reason for the thinning is indicated by the erosional unconformity below the Moenkopi formation in the San Rafael Swell—an unconformity remarkably well shown in a multitude of canyons on Sinbad and clearly seen as an irregular, rolling surface, in some places rising so as to leave a notable thickness of Kaibab limestone and in others sinking so that the basal chert conglomerate of the Moenkopi formation rests directly on the clean sandstone of the Coconino. There can be no question of the relief on this surface, as the Kaibab remnants are separated by wide areas over which they are absent. It is manifest, therefore, that some of the Kaibab limestone has been removed and that in some part the eastward thinning of the Kaibab is due to pre-Triassic erosion.

Yet it is likely that this erosion in a broad view was not very great, for fossils collected from the Kaibab limestone near the head of Black Box Canyon of San Rafael River were determined by G. H. Girty to belong probably to the widespread *Bellerophon* zone, a relatively thin but persistent zone at the top of the Kaibab in the Grand Canyon district and adjacent regions to the north and west of it. Mr. Girty's report is as follows:

> 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 Canyon of San Rafael River. Kaibab, just below lower Moenkopi:
>
> 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. Head of Black Box Canyon of San Rafael River. Coquina limestone of Kaibab, just below lower Moenkopi shale:
>
> Sponge?
> Batostomella? sp.
> Composita mexicana?
> Nucula levatiformis.
> Leda obesa?
> Schizodus? sp.
> Pleurophorus? sp.
> Anatina? sp.
> Plagioglypta canna.
> Bucanopsis modesta.
> Euphemus subpapillosus.
> Sphaerodoma sp.

The Weber quartzite and overlying Park City formation of the Uinta Mountain region present a lithologic sequence similar to that of the Coconino sandstone and Kaibab limestone of the San Rafael Swell, and the similarity is somewhat strengthened by the presence in the upper (Phosphoria) part of the Park City of a few species that are also present in the Kaibab, such as *Plagioglypta canna*, *Leda obesa*, and *Euphemus subpapillosus*. In both regions the next higher formation is the marine Lower Triassic.

On the other hand, many students of the Uinta region believe that there is an unconformity within or beneath the Park City formation and that the Weber quartzite is proved by the included fossils to be all of Pennsylvanian age. If the Coconino sandstone is of Permian age, as seems probable in spite of the lack of paleontologic evidence, the similarity of the two sections is therefore merely superficial. It is possible that the top of the Weber quartzite as it is defined at some places is Permian [26] and that some part of the Coconino sandstone of the San Rafael Swell is contemporaneous, but it seems more likely that they are of different ages. The unconformity above the Kaibab formation has no recognized counterpart above the Park City formation, and the Park City is possibly somewhat younger than the Kaibab. At any rate a positive correlation between the San Rafael Swell and the Uinta Mountain region is not indicated by the evidence now available.

Concerning the relations between the Coconino and Kaibab formations of this paper and the Tensleep sandstone and the overlying Phosphoria formation of central Wyoming even less may be affirmed, though again the two regions show the similar condition of a sandstone formation followed by a limestone formation, and that in turn by Triassic beds. The Phosphoria likewise has some species in common with the Kaibab of the San Rafael Swell.

PRE-TRIASSIC UNCONFORMITY

The unconformity at the base of the Triassic, mentioned above, is a striking feature in the San Rafael Swell and one of major importance in the geologic

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[22] Longwell, C. R., and others, op. cit., p. 21.

[23] Idem, p. 16.

[24] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, p. 70, 1914.

[25] Reeside, J. B., and Bassler, Harvey, op. cit., pp. 69–76.

[26] Girty, G. H., oral communication.

history of the whole plateau province. Many workers in the Southwest have recognized it, and it has now been traced through much of southern Utah, northern New Mexico, northern Arizona, and eastern Nevada.[27] Yet, although the unconformity is exceedingly widespread, it occurs over large areas close to the same stratigraphic horizon, and if it is true, as has been suggested,[28] that the Coconino and Kaibab grade laterally one into the other, the unconformity is not necessarily of much importance structurally over the plateau province as a whole—that is, it does not indicate a period of orogenic activity.

TRIASSIC SYSTEM

LOWER TRIASSIC SERIES

MOENKOPI FORMATION

Distribution and topographic expression.—The Moenkopi formation lies at the base of the Triassic section over most of the plateau province. It crops out over wide areas in the Waterpocket Fold, the San Rafael Swell, Elaterite Basin, and the canyons of other deeply incised tributaries of Green River.

Over most of this area the Moenkopi formation is exposed in badland topography or in steep slopes beneath the resistant cap of Shinarump conglomerate. Some thick sandstones, however, crop out as ledges, and in the San Rafael Swell the details of the form of the huge Sinbad Dome are beautifully shown in the flexures of a very massive limestone—the Sinbad limestone member—which forms the surface rock over probably four-fifths of Sinbad.

Lithology and thickness.—On the west side of the San Rafael Swell the Moenkopi formation is 735 to 850 feet thick and consists of dominantly red-brown micaceous ripple-marked sandstones, gray lenticular sandstones, and maroon shales, all extremely variable laterally. It includes also, about 200 feet above the base of the formation, a fairly persistent member of thick-bedded light-gray sandy limestone and sandstone, 40 to 150 feet thick, here named the Sinbad limestone member, from its excellent exposures in Sinbad. Near San Rafael River the part of the formation above the Sinbad member has few red strata, and the shales are pyritic and exhibit a dominantly greenish-gray hue in marked contrast with the usual coloring. This gray facies interfingers with the red facies and passes directly into it. Discontinuous gypsum beds occur near the base of the formation in places but are nowhere conspicuous in the Swell. Although the formation appears to be more sandy in the south than in the north, no equivalent of the DeChelly (?) sandstone lentil [29] was recognized.

The Moenkopi is only 585 feet thick at Temple Mountain, on the east flank of the Swell, and 356 feet thick in Elaterite Basin, according to the measurements of Emery.[30] The Sinbad limestone member is represented about 140 feet above the base at Temple Mountain but is not present in Elaterite Basin.

Conditions of deposition.—The irregular lenticular sandstones, the recurrence of mud cracks, clay pellets in sandstones, uniform micaceous beds, and rapid variations, vertically and laterally, all point to continental conditions of deposition for the greater part of the formation. But in the lower part the long, even bedding lines, the good sorting of material, and the association with the unquestionably marine Sinbad limestone member indicate that this portion is of marine origin, at least in the San Rafael Swell.

The green-gray pyritic carbonaceous shales of the local area in the northwestern part of the Swell, though they have not yielded fossils, probably represent delta-pool conditions where much sulphur accumulated. This facies is not confined to the part of the formation below the marine limestone but in this local area, near Window Blind Butte and the mouth of Buckhorn Wash, extends to the very top, and it is probable that here all the Moenkopi is marine. A similar, probably local replacement of normally red strata by gray strata has been noted [31] on Vermilion Creek in Moffat County, Colo., where the Woodside and Thaynes (?) formations contain only gray beds, though not far to the west they are so red as to justify the name Flaming Gorge given to the exposures on Green River by Powell. A second locality of gray beds replacing red in the Woodside and Thaynes (?) formations was noted by Messrs. Spieker and Reeside on the south flank of Blue Mountain in T. 4 N., R. 102 W., Colorado. A second locality in the Moenkopi formation, reported by E. T. McKnight, is adjacent to Green River a few miles above its junction with the Colorado. Probably marine strata occur at many other places in the San Rafael Swell, but fossils are rare, if present at all, and it is believed that most of the Moenkopi of this region is continental.

Local unconformities are present within the formation; one notable example may be seen in the cliff face at Tan Seeps, in Sinbad. None of these appear

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[27] Gilbert, G. K., op. cit., p. 8. Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Ariz.: Am. Jour. Sci., 3d ser., vol. 20, pp. 221–225, 1880. Ward, L. F., Status of the Mesozoic floras of the United States: U. S. Geol. Survey Mon. 48, p. 19, 1905. Robinson, H. H., The San Franciscan volcanic field: U. S. Geol. Survey Prof. Paper 76, p. 24, 1913. Lee, W. T., The Iron County coal field, Utah: U. S. Geol. Survey Bull. 316, pp. 362–364, 1917; General stratigraphic break between Pennsylvanian and Permian in western America [abstract]: Geol. Soc. America Bull., vol. 28, pp. 169–170, 1917. Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 21, 1917. Shimer, H. W., Permo-Triassic of northwestern Arizona: Geol. Soc. America Bull., vol. 30, p. 494, 1919. Dake, C. L., The pre-Moenkopi (pre-Permian?) unconformity of the Colorado Plateau: Jour. Geology, vol. 28, pp. 66–74, 1920. Longwell, C. R., The pre-Triassic unconformity in southern Nevada: Am. Jour. Sci., 5th ser., vol. 10, pp. 93–106, 1925. Longwell, C. R., and others, op. cit., p. 9. Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 60–61.

[28] Longwell, C. R., and others, op. cit., pp. 8–9.

[29] Miser, H. D., Geologic structure of San Juan Canyon and adjacent country, Utah: U. S. Geol. Survey Bull. 751, pp. 122–123, 1925. Gregory, H. E., op. cit., pp. 31–33.

[30] Emery, W. B., op. cit., pp. 558–559.

[31] Sears, J. D., Geology and oil and gas prospects of part of Moffat County, Colo., and southern Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 751, pp. 281, 284, 1925.

to be of any considerable extent, being normal local features in a continental deposit.

Age and correlation.—The correlation of the Moenkopi formation of the San Rafael Swell with the type Moenkopi of the Navajo Reservation is based upon its lithologic character, its stratigraphic position between unmistakable Kaibab limestone and Shinarump conglomerate, and fossil collections made from the Sinbad limestone member. The fossils were submitted to G. H. Girty for determination. He reports as follows:

> The three lots, 5473, 5474, 5475, 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 table below shows the species found.

Fossils of the Moenkopi formation

	5473	5474	5475
Echinoid spines	----	----	×
Pleuromya? sp	×	×	×
Pleuromya? n. sp	×	×	×
Edmondia? sp., several	----	----	×
Myophoria n. sp	×	----	×
Myacites inconspicuus	×	----	----
Entolium n. sp	×	----	×
Aviculipecten sanrafael n. sp	×	----	×
Aviculipecten sanrafael, several varieties	----	----	×
Aviculipecten occidaneus?	×	----	×
Aviculipecten thaynesianus	×	----	----
Aviculipecten sp. indet	×	----	×
Myalina n. sp., several	×	----	×
Bakewellia? n. sp	----	----	×
Pteria? sp	----	----	×
Astartella forresteri	×	----	×
Pleurophorus n. sp	----	----	×
Pleurophorus sp	----	----	×
Laevidentalium? n. sp	×	----	×
Natica lelia	×	----	×
Natica lelia var	----	----	×
Naticella sp	----	----	×
Holopea sp	----	----	×
Aclisina? sp	×	----	×
Bulimorpha n. sp	×	----	×
Sphaerodoma? n. sp	----	----	×
Zygopleura n. sp	----	----	×
Meekoceras gracilitatis?	----	----	×
Meekoceras? sp	----	----	×
Ostracoda, indeterminate	----	----	×

5473. 200 yards up Red Canyon from its junction with San Rafael River. Sinbad limestone member of Moenkopi formation. Collected by James Gilluly.

5474. Half a mile south of head of Black Box, San Rafael River. Sinbad limestone member of Moenkopi formation. Collected by James Gilluly.

5475. Black Box, San Rafael River. Basal zone of Sinbad limestone member of Moenkopi formation. Collected by James Gilluly.

As Mr. Girty's statement shows, the marine fossils of the Moenkopi formation of the San Rafael Swell permit a very satisfactory correlation with the group that includes the Woodside, Thaynes, and Ankareh formations of the western Uinta Mountain region, now accepted widely as Lower Triassic, though long thought to be Permian. In the eastern Uinta Mountains [32] there is doubt as to the identity of the Ankareh formation, but it seems at least very likely that the Woodside and Thaynes formations are represented even though paleontologic evidence is still lacking. Farther northeast, in Wyoming, the Chugwater formation seems to be the most likely representative of the Lower Triassic, though paleontologic evidence is restricted to pelecypods of doubtful affinities and to the single gastropod *Natica lelia*, all contained in a limestone in the upper part of the formation.

UPPER (?) TRIASSIC SERIES

SHINARUMP CONGLOMERATE

Distribution and topographic expression.—One of the most remarkable formations of the plateau province is the Shinarump conglomerate. It is present over nearly all the region from western New Mexico [33] to southeastern Nevada [34] and northward to the north end of the San Rafael Swell. It is not definitely recognizable in western Colorado nor in the Uinta Mountains, unless it is represented by the siliceous conglomerate at the base of the Ankareh (?) formation which rests unconformably upon the Thaynes (?) formation in the eastern Uinta region,[35] though there is at the present time very little evidence other than the structural relations of the beds. It is possible that the Ankareh (?) is merely an introductory phase of the Nugget sandstone and much later than the Shinarump.

The topographic expression of the Shinarump is strong. It lies between two formations of relatively unresistant material that break down into slopes, between which the Shinarump, though not really an extremely hard formation, has the relief of one. It forms vertical cliffs capping steep Moenkopi slopes, and from its top the weak Chinle formation has at many places been swept for considerable distances, leaving wide conglomerate-capped terraces and mesas characteristic of the formation. Even where the Shinarump is only 30 or 40 feet thick, the wall it offers is in many places unscalable for miles.

Lithology and thickness.—The Shinarump lies unconformably on the Moenkopi, its conglomerates and sandstones resting in the hollows of the uneven Moenkopi surface. Whether this unconformity is angular as well as erosional is not certain. The thinning of the Moenkopi eastward from the south end of the San Rafael Swell may conceivably be due to original thinning of the formation or to angular unconformity.

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[32] Sears, J. D., op. cit., p. 284. Reeside, J. B., jr., Notes on the geology of Green River Valley between Green River, Wyo., and Green River, Utah: U. S. Geol. Survey Prof. Paper 132, pp. 48, 49, 1923.

[33] Gregory, H. E., op. cit., p. 38.

[34] Longwell, C. R., Geology of the Muddy Mountains, Nev., with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., 5th ser., vol. 1, pp. 39-62, 1921.

[35] Sears, J. D., op. cit., p. 284. Reeside, J. B., jr., op. cit., pp. 40, 43, 49

At the southwest end of the Swell, on Muddy Creek, the thickness is 735 feet. At Temple Mountain, on the southeast reef, Emery measured 585 feet and in Elaterite Basin only 356 feet. No system of variations is apparent in northeastern Arizona and northwestern New Mexico with which this progressive eastward thinning of the Moenkopi can be checked. It is certainly presumptive evidence of pre-Shinarump beveling in this region, however.

Throughout the San Rafael Swell and Green River Desert the Shinarump conglomerate is rarely missing where the beds at its horizon are exposed, yet it almost nowhere exceeds 200 feet in thickness and in the greater part of the exposures ranges between 30 and 100 feet.

Its lithologic character is not such as to suggest this remarkable persistence. Everywhere the Shinarump is clearly recognizable as an interfingering series of lenticular gritty sandstones, conglomerates, clean sandstones, variegated mudstones, and even shales—a series cut by hundreds of channel unconformities within itself and composed of lenses which thicken and thin with bewildering rapidity. Despite its local variations, its continuity is essentially unbroken in the western part of the district here discussed. In this area the conglomeratic facies is perhaps less striking than it is farther south, for in many of the exposures the formation is hardly more than a coarse sandstone. The principal pebbles in the conglomerates are white and yellow quartz, black chert, yellow quartzite, and subordinate dense gray limestone, all well rounded and set in a matrix of quartz sand. Silicified and carbonized wood is almost invariably present in this area, as it is through the entire province. Mud balls are numerous. Carnotite and other uranium minerals occur at certain places, notably at Temple Mountain, on the southeast flank of the Swell, where the deposits were mined during the World War.

Conditions of deposition.—The numerous lateral and vertical variations of the Shinarump conglomerate and its apparently conformable position beneath the Chinle formation, which is definitely continental, point to a continental origin for the Shinarump conglomerate also. The evidence is not conclusive, but the improbabilities that arise on a postulate of marine origin seem so great that the evidence cited appears sufficient. A marine transgression extending over 100,000 square miles (the minimum areal extent of the Shinarump conglomerate) would be expected to leave offshore sediments and marine fossils. The only suggestion of such fossils is a collection of pelecypods found by Gregory in the Shinarump at Beautiful Valley, Ariz., one of which was interpreted by T. W. Stanton as "almost certainly marine." [36] This specimen has a carditoid aspect quite unlike that of any nonmarine shells previously recorded from western North America. It is, however, like shells of the genus *Diplodon*, lately described from the nonmarine Triassic Newark group of the eastern United States and has been recently assigned to that genus.[36a] The other specimens are fragmentary and of little value but could be parts of shells of *Unio*, a fresh-water form. This isolated occurrence therefore affords little ground for overthrowing the lithologic evidence in favor of a continental origin, yet a final conclusion must be postponed until further evidence is available.

Age and correlation.—No reports of diagnostic fossils from the Shinarump have been published, but its fossil wood has Upper Triassic affinities,[37] and cycad foliage of Upper Triassic aspect was collected by R. C. Moore [38] near Waterpocket Wash, Garfield County, Utah. The Chinle has furnished Upper Triassic vertebrates and fresh-water invertebrates, and it is probable that the Shinarump is the "basal conglomerate" of the sedimentation which was continued in the Chinle and, like that formation, is of Upper Triassic age.

Correlation with areas outside the plateau province seems impossible at present. The Shinarump probably lenses out to the east beneath the overlap of the Chinle formation, so that the "saurian conglomerate" of the San Juan Mountains, though similarly placed, being the basal member of the Dolores formation of that region, is not the equivalent of the Shinarump.

UPPER TRIASSIC SERIES

CHINLE FORMATION

Distribution and topographic expression.—The Chinle formation is exposed in the San Rafael Swell, in the Waterpocket Fold, in Elaterite Basin and neighboring canyons, and along the Colorado above the junction with Green River. It is undoubtedly equivalent to the lower part of the Dolores formation of the San Juan Mountains, the upper sandstone of that unit probably being the equivalent of the Wingate sandstone of the plateau.

It is typically exposed in steep slopes between the ledge of Shinarump conglomerate and the base of the Wingate sandstone.

Lithology and thickness.—The Chinle formation is apparently conformable upon the Shinarump conglomerate. It is a series of green-gray sandstones, micaceous red-brown sandstones, variegated marls, limestone conglomerates, and maroon shales, all very lenticular and interfingering with one another, though the individual units are considerably more persistent than those in the Shinarump conglomerate. The bedding is rather irregular, and few of the sandstones exceed 5 feet in thickness. Individual beds that can be followed for more than half a mile are exceptional. The sandstones all contain pellets of shale; the shales

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[36] Gregory, H. E., op. cit. (Prof. Paper 93), p. 41.

[36a] Reeside, J. B., jr., Two new unionid pelecypods from the Upper Triassic: Washington Acad. Sci. Jour., vol. 17, pp. 476–478, figs. 1–2, 1927.

[37] Gregory, H. E., op. cit., p. 41.

[38] Berry, E. W., Cycads in the Shinarump conglomerate of southern Utah: Washington Acad. Sci. Jour., vol. 17, pp. 303–307, figs. 1–5, 1927.

have mud-cracked, curled surfaces at many horizons; and these features, combined with the lateral variability of the formation, point to a continental origin. Silicified tree trunks like those in the Shinarump conglomerate are very common.

The Chinle formation ranges in thickness from 141 to 225 feet in the San Rafael Swell and is 300 feet thick in Elaterite Basin, according to Emery.[39] These thicknesses are all notably less than those shown in the country to the south. In the Henry Mountains the formation ("Shinarump, division a," of Gilbert [40]) is 300 feet thick, in the Circle Cliffs 475 feet, and along San Juan River from 830 to 1,182 feet,[41] but in all these localities it is notably more shaly than within the region here discussed. The Chinle formation is continental in origin. Possibly the source of the sediment lay to the north, so that the coarser material was deposited on the nearer part of the basin of deposition while most of the finer was carried farther to the south. It might well be that in a basin of continental deposition a very great thickness of fine detritus might accumulate in the deeper part while a much thinner body of coarser sediment was being deposited on the marginal portions. Especially is this probable in basins where a large fraction of the contributed sediment is in a finely divided state and in those where the area of deposition encroaches gradually upon the original area of denudation. This matter has been elucidated by Lawson [42] for the bolson deposits, but a priori the principle involved appears to the writers as being of very general application. The lithology of the Chinle does not appear to be that of a fanglomerate but rather more characteristic of flood-plain or swamp deposits, but it is suggested that the relations between distribution of thickness and coarseness of sediments of the one may apply with some modifications to the other as well. Later erosion may have stripped off more of the coarser deposits than of the finer, so that the variations in thickness are not necessarily altogether depositional.

There is a marked unconformity at the top of the Chinle in the San Rafael Swell. Cracks in the upper surface are filled to depths of 6 or 8 feet with sands of the overlying Wingate; and fragments of shale and chunks of sandstone of the Chinle are incorporated in the basal beds of the Wingate sandstone. The upper surface of the Chinle formation is slightly rolling when viewed in the large, and its members are cut off at low angles, a truncation which is visible on close inspection.

That this unconformity is not everywhere prominent if, indeed, it is everywhere present, is seen from the references to its uncertainty by Emery,[43] Gregory,[44] and Reeside and Bassler,[45] but the definite evidence seen in the San Rafael Swell is corroborated by observations made elsewhere by Dutton,[46] Gilbert,[47] and Lee.[48]

The unconformity between the Dolores and La Plata in the San Juan Mountains described by Cross [49] is not valid evidence of a break between Chinle and Wingate, as thought by Gregory,[50] because, if Cross's correlation of the upper sandstone of the Dolores with the Wingate sandstone (called Vermilion Cliff by Cross) is correct, that unconformity lies at the top of the Wingate instead of at the base. This matter is further discussed below.

The evidence for the Upper Triassic age of the Chinle has been summarized by Gregory.[51] No new data bearing on this question were obtained by the writers.

JURASSIC (?) SYSTEM

GLEN CANYON GROUP

Throughout the plateau country the most prominent formations present are the group of massive sandstones that rest upon the Chinle formation. To these sandstones the name Glen Canyon group has been given by Gregory and Moore,[52] a name that for some areas replaces the term La Plata "group" and for other areas is applied for the first time as a name for the sandstone assemblage as a whole. The name is derived from the excellent exposures of the rocks in Glen Canyon of Colorado River, Kane County, Utah, and adjacent areas in Arizona. In the Navajo country the group is ordinarily divisible into three units—a thick cross-bedded, dominantly red sandstone at the base, a similar massive sandstone, chiefly tan or white, at the top, and a middle thinner-bedded unit of red shales, lenticular sandstones, and limestones, which is, in most localities, much more limy than the sandstones it separates. The upper and lower divisions were named by the early explorers the White (or Gray) Cliff and Vermilion Cliff groups, respectively, and have been recognized widely by many workers since. The middle thin-bedded division has received less notice until more recently, largely because it is not everywhere developed.

In southwestern Utah the group is not so readily divisible but forms a single unbroken unit, in which

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[39] Emery, W. B., op. cit., p. 563.

[40] Gilbert, G. K., op. cit., p. 6.

[41] Longwell, C. R., and others, op. cit., pls. 1 and 2, pp. 6 et seq.

[42] Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, pp. 23–48, 1915.

[43] Emery, W. B., op. cit., p. 563.

[44] Gregory, H. E., op. cit. (Prof. Paper 93), p. 48.

[45] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 64.

[46] Dutton, C. E., Report on the geology of the High Plateaus of Utah, p. 148, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[47] Gilbert, G. K., op. cit., p. 9.

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

[49] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), p. 7, 1910, and several other folios.

[50] Gregory, H. E., op. cit. (Prof. Paper 93), p. 48.

[51] Idem, pp. 46–47.

[52] Gregory, H. E., and Moore, R. C., manuscript report on geology of southern Utah and northern Arizona.

there is no consistent coloring but which varies capriciously from red to white, though red is more common in the lower part and white in the upper part.[53]

To the east, where the divisions are more marked,[54] Gregory [55] has applied names to distinguish them. For the lower massive division Dutton's name Wingate sandstone was adopted. The name Todilto formation was chosen for the thinner-bedded middle division, and Navajo sandstone for the upper massive division. The name Todilto was originally used for the thin middle division of limestone and sandstone in Todilto Park, N. Mex., and its applicability in more westerly areas to which the division can not be traced continuously is based on the position of the beds to which it is applied, between accepted Wingate and Navajo sandstones.

Lee [56] has suggested that the type Todilto is probably later than the so-called White Cliff of the Henry Mountains, a suggestion to which Emery [57] agreed and which was certainly not excluded by the scanty amount of detailed work which had been done in the intervening areas at that time.

WINGATE SANDSTONE

Distribution.—The Wingate sandstone is widely distributed. It is present in the San Rafael Swell, southeastward into western Colorado, and wherever beds at its horizon are exposed over all of northwestern New Mexico, northeastern Arizona, and southern Utah. It has been traced by Gregory and Moore [58] into the single massive sandstone at Zion Canyon, which includes equivalents of both Wingate and Navajo sandstones, and it is with little doubt represented in the Jurassic sandstone in southern Nevada described by Longwell.[59] (See pl. 17, *A*, *B*.)

Thickness.—In the Navajo country the Wingate sandstone ranges from 30 to 450 feet in thickness.[60] In the Circle Cliffs it averages 300 feet.[61] In the Henry Mountains it is the lower part of the 500 feet of the so-called Vermilion Cliff group measured by Gilbert.[62] In the San Rafael Swell the measurements range between 360 and 400 feet. According to Emery [63] the massive member at the base of his Wingate sandstone in Elaterite Basin is 375 feet thick.

The Orange Cliffs of the upper Colorado Valley are made by this massive sandstone, capped by a hard ledge at the base of the thin-bedded Todilto (?) formation. The sandstone becomes thinner in this direction, being 210 feet thick near Courthouse mail station on the road between Moab and Thompsons, 250 to 275 feet in Salt Valley, and 250 feet near the mouth of Dolores River. Sections and photographs by Coffin [64] show its continuation, with comparable thickness, up Dolores River to the south and in Sinbad and Paradox Valley. Mr. Reeside, in company with C. E. Dobbin, visited Sinbad and Paradox Valley in 1926 and agrees with this interpretation.

Lithology.—Throughout the western part of the San Rafael Swell the Wingate sandstone is very massive, with few or no partings of shaly material between the beds. Most of the strata are highly cross-bedded on a very large scale and in a most irregular manner, though not a few are characterized by slabby fractures and even bedding. The grain is uniformly fine, no silt occurs except in a few lenticular beds, and almost no mineral but quartz is present except for the few thin lenses of limestone. These limestones are largely silicified, and none observed exceed 2 feet in thickness. The cement of the sandstone is nearly everywhere lime, commonly not very firm.

Toward the east the beds appear to become less massive. A 340-foot cliff of Wingate at the mouth of Buckhorn Wash is divisible into only four beds, and in Salt Valley the average bed is only about 12 feet thick. The shale partings are very thin in Salt Valley, but only a few miles to the east, at the mouth of Dolores River, the average bed, except the one massive unit that forms the uppermost 40 feet, is only 3 to 8 feet thick, and the layers are nearly everywhere separated by shale partings not more than an inch thick. This thin bedding is not prominent, however, in the western Colorado localities discussed by Coffin.

The color of the Wingate cliff is nearly everywhere red. At many places this is not at all an original hue but is due to wash from the maroon shale lenses in the overlying Todilto (?) formation. Where the dip is steep and the shales have been swept back some distance from the lip of the cliff, the sandstone may be buff or gray. However, in many places the color is an original pink, somewhat darkened on weathering. On the whole this formation is reddish as compared with the overlying Navajo—a distinction which long ago gave rise to the name Vermilion Cliffs and whose validity is somewhat emphasized by the local name Orange Cliffs applied to the ledges of this formation from the mouth of Green River eastward.

Conditions of deposition.—The origin of the Wingate sandstone has long been a subject of interest in the geology of the plateau. The conditions that permitted the deposition over such tremendous areas of

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[53] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 63.

[54] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 82, 1920. Dake, C. L., op. cit., p. 638.

[55] Gregory, H. E., op. cit., pp. 50–59.

[56] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, pp. 13, 14, 1918

[57] Emery, W. B., op. cit., pp. 568–570.

[58] Gregory, H. E., and Moore, R. C., op. cit.

[59] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 46, 1921.

[60] Gregory, H. E., op. cit. (Prof. Paper 93), p. 54.

[61] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, p. 217, 1922.

[62] Gilbert, G. K., op. cit., pp. 6–7.

[63] Emery, W. B., op. cit., p. 565.

[64] Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geol. Survey Bull. 16, pp. 48–55, 1921.

such thick masses of uniform fine sand, including in the western exposures so few thin beds, are indeed difficult to picture. The remarkable large-scale tangential cross-bedding and the absence of fossils, except a few dinosaur tracks, fit well the character of a desert dune deposit. The considerable amount of indisputably water-laid material and the limestone pans are explicable, if such an origin is assumed, as due to wash during storms and to deposition in playas in periods of high ground-water level. The thinner bedding toward the east seems to require deposition in water, and the shale partings there confirm this inference. Whether these waters were marine, brackish, or fresh, however, no evidence known to the writers appears to disclose.

Age and correlation.—Opinion as to the age of the Wingate sandstone has fluctuated from a general assignment to the Triassic to about the same agreement on the Jurassic. The information upon which to decide this question has been eagerly sought for more than 40 years, and hardly any more pertinent data are available to-day than at the time of the early explorers. Cross [65] assigned the Wingate (his so-called Vermilion Cliff sandstone) to the Triassic, on the basis of the Triassic fossils in the Dolores and the correlation of his Vermilion Cliff with the upper sandstone portion of that formation. Recent work has emphasized the significance of the unconformity between the Chinle and the Wingate to which Gilbert [66] called attention long ago, and, if the correlation of Cross is correct, this unconformity occurs between the fossiliferous beds of the Dolores and the base of the sandstone member. Accordingly the fossils can not be considered as proving the Triassic age of the so-called Vermilion Cliff—the present Wingate sandstone. Gregory's assignment of the Wingate to the Jurassic, on the other hand, was due to his interpretation of it as the lower part of the La Plata sandstone of the San Juan Mountain region.[67] As this correlation is almost certainly incorrect, the inference of Jurassic age derived from the assignment of the La Plata to the Jurassic period fails. The question is discussed at length on pages 72-73, after the description of the Navajo sandstone, for both formations are closely involved, and the data available are similar for both.

The correlation of the Wingate sandstone of this district with that of surrounding regions is based largely on (1) its distinctive lithology and position between the equally distinctive Chinle formation and the overlying thin-bedded Todilto (?); (2) the tracing of the Wingate from the Navajo country to the Waterpocket fold by Gregory and Moore, to the north end of the Fold by Moore, and thence throughout the San Rafael Swell by the present writers. The correlation of the Wingate sandstone, thus verified as a continuous unit from northern Arizona to San Rafael River, with the lower massive member of Emery's Wingate in Elaterite Basin is based on its lithologic character and its position above the Chinle. Variable thickness of the member without any unconformity at the top is mentioned by Emery as an argument against the classification of it as a formation, but this argument loses much weight in view of the possible irregularities because of the unconformity at the base and fails completely in the face of the actual tracing of the outcrop over so wide an area. Although mapping of the unit was not carried up the Colorado from the mouth of Green River, the clear-cut features of the lithology permit no doubt of the identity of the sandstone of the Orange Cliffs at Elaterite Basin with that at Moab. From Moab it was traced without any break as far as the mouth of Dolores River. The work of Coffin extends its continuity from a locality a few miles southeast of this point as far as Paradox Valley. In view of the correlation offered by Cross [68] between Colorado River and the type section of the Dolores formation in the San Juan Mountain country, it seems that the Wingate is to be definitely correlated with the upper sandstone member of the Dolores formation and not with the lower part of the La Plata, as has been long assumed in spite of Cross's early work.

TODILTO (?) FORMATION

Distribution and topographic expression.—The name Todilto was applied by Gregory [69] to a limestone resting on the Wingate sandstone in Todilto Park, N. Mex. In the region northwest of the type locality and separated from it by areas in which younger beds only are exposed, Gregory applied Todilto to a unit which contained thin-bedded sandstone, shale, and minor beds of limestone and which he believed to occupy a place in the sequence of formations identical with that of the typical Todilto limestone. No work has been done in later years to substantiate this correlation, and there is at the present time some doubt that it is correct. In this paper the name Todilto is therefore applied with a query to the unit of sandstone and shale in the northern exposures. The Todilto (?) formation, as thus defined, is widely distributed, though it has not been recognized in the Vermilion Cliffs near Lees Ferry nor in southwestern Utah. It has been traced from the San Juan River region to Rainbow Bridge through Cataract Canyon and to the Henry Mountains by Miser, Paige, and Longwell [70] and northward along the Waterpocket Fold by Moore.[71] The formation is well developed in the San Rafael

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[65] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 636, 1907.

[66] Gilbert, G. K., op. cit., p. 9. Dutton, C. E., op. cit., p. 148. Emery, W. B., op. cit., p. 563. Gregory, H. E., op. cit. (Prof. Paper 93), p. 48. Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 64

[67] Gregory, H. E., op. cit., p. 51.

[68] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 472-473, 1905.

[69] Gregory, H. E., op. cit. (Prof. Paper 93), pp. 55-56.

[70] Longwell, C. R., and others, op. cit., p. 12.

[71] Moore, R. C., op. cit., p. 218.

Swell (see pl. 17, *C*), in the Green River Desert, and up Colorado River from the mouth of Green River. It was recognized between Moab and Monticello and in Salt Valley and was traced to the east by the writers as far as the mouth of Dolores River. It is unquestionably present well southeast of this point, as is seen from the descriptions and photographs by Coffin.[72]

Throughout this area the Wingate sandstone typically stands in a nearly vertical wall, the top of which is a resistant, very limy sandstone. This is the lowest member of the thinner-bedded, somewhat shaly sandstones and occasional limestones of the Todilto (?) formation. In most localities only the lower member is very resistant, so that it caps the Wingate cliffs; the upper parts are softer and weather down quickly, leaving benches beneath the overlying cliffs of the Navajo sandstone.

Thickness and lithology.—In the Navajo country the Todilto (?) formation is as much as 200 feet in thickness.[73] Moore measured 125 to 215 feet of Todilto (?) in the Circle Cliffs,[74] Longwell assigns a thickness of 249 feet to it near Trachyte Creek,[75] and in the San Rafael Swell it ranges in thickness from 44 to 240 feet and averages probably about 120 feet. Toward the east it averages about the same, being 150 feet thick (measured by Emery) in Elaterite Basin, 120 feet near Courthouse mail station on the Moab-Thompsons road, 75 to 100 feet in Salt Valley, and about 200 feet near the mouth of Dolores River.

The Todilto (?) formation differs but little in composition from the Navajo and the Wingate. It is thinner bedded, however, is exceedingly variable, and carries many lenses of clean well-laminated shale, usually red. Limestones occur locally, though they are hardly more numerous in the Todilto (?) than in the Navajo and Wingate. Shale pellets and angular chunks of shale are very common in the sandstone beds.

The contact of the Todilto (?) formation with the Wingate sandstone in most of the western localities is abrupt rather than transitional, but the impression was gained, as the beds were traced toward the east, that the Todilto lithology is increasingly difficult to differentiate sharply from that of the Wingate sandstone, and in the upper Dolores Valley the two were not differentiated by Coffin [76] but were both included in the upper sandstone of the Dolores formation.

The upper boundary of the Todilto (?) is also difficult to determine in some localities. Usually there is a rather definite change from the more or less parallel bedding of the Todilto (?) to the irregular cross-bedding of the Navajo sandstone, but the Navajo in its variations locally approaches in bedding that of the Todilto (?), and at many places it would be difficult to select any except an arbitrary boundary through a distance of 50 feet, or even more. It is the opinion of the writers that deposition was essentially continuous from the base of the Wingate to the top of the Navajo, with only such breaks as inevitably accompany continental deposition and only such erosion as would be expected in local variations of streams.

Conditions of deposition.—From the irregular, lenticular form of the beds, the interfingering shale, sandstone, and shale conglomerate, the presence of mud cracks, and numerous unquestionable scoured and filled channels, the origin of the Todilto (?) formation is ascribed with considerable confidence to deposition by rapidly shifting currents. Whether these currents were in rivers or tidal channels is somewhat uncertain. The only fossils found in the formation in Arizona have been dinosaur tracks and in the San Rafael Swell a small indeterminate pelecypod in sec. 16, T. 20 S., R. 13 E., west of Cottonwood Springs. The tracks probably favor a continental origin for the formation; the pelecypod may be marine or nonmarine. Near Moab, Utah, A. A. Baker [77] has recently collected several species of *Unio* that indicate with certainty deposition of the formation in fresh water in that area. The question is therefore unsettled, though a continental origin seems much more probable.

Age and correlation.—The dinosaur tracks found by Gregory in Arizona were determined by Lull [78] to be not older than uppermost Triassic. The shells found by Mr. Baker near Moab belong to long-ranging types that might be found at many horizons from Upper Triassic upward. No other data are available for this formation as distinct from the associated Wingate and Navajo sandstones, and the age of the group is discussed after the description of the Navajo.

Emery [79] noted this zone in the Green River Desert, but as he believed that its variable distance above the base of the Wingate (as shown by his Elaterite Basin and Temple Mountain sections) precluded the possibility of its representing the Todilto of the Navajo country, he included it in the Wingate. The evidence of the unconformity beneath the Wingate has been strengthened by numerous observations since that time, and the irregularities in thickness seem thereby sufficiently explained.

That the thin-bedded zone—the Todilto (?) formation—resting upon the Wingate is at a somewhat variable distance above the base is indeed the fact. Yet if the mass of lenticular sandstones and shales constituting the Todilto (?) is considered a fluviatile deposit between two series of dune sands, such variation is to be expected and offers no bar to the con-

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[72] Coffin, R. C., op. cit., pp. 48–50.

[73] Gregory, H. E., op. cit. (Prof. Paper 93), pp. 55–56.

[74] Moore, R. C., op. cit., p. 205.

[75] Longwell, C. R., and others, op. cit., pl. 2.

[76] Coffin, R. C., op. cit., pp. 48, 50.

[77] Oral communication.

[78] Gregory, H. E., op. cit. (Prof. Paper 93), p. 56.

[79] Emery, W. B., op. cit., pp. 565–567.

ception of the unit as a formation. The point that seems most important is the continuity of a zone of deposits by shifting currents, perhaps tidal but probably fluviatile, between two deposits, which, whatever their origin, were surely laid down under fairly similar conditions that were widely different from those of the intermediate zone. The question whether this intermediate series is everywhere of exactly the same age seems not a crucial one in view of the wide areas over which it is unbroken, and if its beds are homotaxial rather than synchronous in deposition, it seems still to merit recognition as a distinct formation, with an important place in the geologic history of the plateau country.

Toward the southeast the Todilto (?) is clearly recognizable in western Colorado, where it is included by Coffin[80] in the Dolores. The thin-bedded sandstones just above his massive Dolores sandstone are almost certainly equivalent, at least in the lower part, to the Todilto (?) formation of southeastern Utah, though they may also include a small part of the Navajo at the top.

NAVAJO SANDSTONE

Distribution and topographic expression.—The Navajo sandstone is one of the most widespread formations of the plateau country. It was named from its prominent development in the Navajo Reservation but has been traced to the west and north and has been recognized as making up the White Cliffs of southern Utah. It is present in the walls of Glen Canyon, the Echo Cliffs, the Waterpocket Fold, and the Henry Mountains. The Navajo forms a cliff completely encircling the San Rafael Swell (see pl. 18) and is exposed in many canyons through the Green River Desert and up Colorado River to the eastern border of Utah. In Colorado it is identifiable as the "Lower La Plata" of Coffin,[81] and farther south it occurs in the type La Plata of the San Juan Mountain region.[82]

Through most of this area the Navajo forms a very characteristic topography, marked by huge domes and rounded masses where the overlying rocks are soft or have been removed and by sheer cliffs many scores of feet high where they are resistant. These cliffs and domes are among the most prominent features of the country and give much of the picturesque grandeur for which plateau scenery is so famous.

Lithology and thickness.—The lower contact of the Navajo sandstone is in most places definite, though locally gradational, as water-laid material is common in the sandstone and in places occurs at the base; that is, conditions characteristic of Todilto (?) deposition persisted longer in some places than in others.

Cross-bedding on a large scale is typical; a bed 100 feet or more thick may show no true bedding but only long lines of tracery descending at angles as high as 30° with the true bedding and curving at the base into parallelism with it. Some angular cross-bedding is also present, as well as a subordinate amount of even, parallel lamination, but the dominant and striking feature of the sandstone, here as elsewhere, is the large-scale tangential bedding.

The individual laminae differ but very slightly in grain, the bedding being apparently brought out by a scattering of slightly coarser grains over the surface of normal laminae. Nearly all the grains are quartz, though some agate and a little feldspar are present. Toward the top of the formation in the San Rafael Swell there is in many places an interrupted zone of lenticular limestones, though isolated limestone lenses occur at many other horizons also. The limestone zone is typically expressed in the topography as a wide bench, above which the "beehive" domes of the upper Navajo rise and below which the cliffs fall vertically to the upper bench of the Todilto (?) formation. One zone of sporadic pebbles 2 or 3 inches in diameter was found on the wedge between Buckhorn Wash and San Rafael River, but it is apparently almost unique. The pebbles are quartz, highly polished and faceted—perfect examples of "dreikanter."

In the southwesterly exposures the Navajo is described as white; in the Navajo Reservation it is red. In the San Rafael Swell it is dominantly gray to tan but in places red. Toward the east the principal color is gray, though in places the formation is white. The cement is calcite, locally stained with iron oxide.

Conditions of deposition.—The Navajo has been considered a typical eolian deposit by many writers since the first suggestion of this origin by Gregory. Indeed, it seems difficult to conceive of any other mode of deposition for this tremendous mass of sand. The cross-bedding, cutting itself off at all angles apparently without system; the texture, a scattering of larger grains over wide surfaces of smaller; the well-rounded grains; and the absence of silt are all reconciled with this theory, though none of these features can be said to constitute proof in itself. The presence of the dreikanter mentioned above also accords with this view. The limestone lenses unquestionably bespeak the existence of some basins, probably ephemeral, in which water stood, and there is evidence in the even stratification of many beds that many clastic members of the sandstone were also deposited from water. This would, of course, be expected in any desert dune country, for the torrential rains of such a region would surely leave traces of their reworking of some dune sand and its deposition in interdune depressions.

Age and correlation.—No fossils have ever been reported from the Navajo sandstone. Its age can accordingly not be definitely determined but must be judged by its general stratigraphic relations. Whatever the age of the Navajo, it is closely bound up with

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[80] Coffin, R. C., op. cit., p. 50.

[81] Idem, pp. 61–76.

[82] Lee, W. T., U. S. Interior Dept. Mem. for the Press, Mar. 30, 1926.

the Wingate and Todilto. Tracing over wide regions in the plateau by Moore,[83] Gregory,[84] Miser,[84] Lee,[84] and the writers, although disclosing local unconformities within the Todilto (?) formation and at its base, has led to complete agreement that the three sandstones are a unit of deposition and that these unconformities are all attributable to such minor fluctuations in the streams depositing the Todilto (?) formation as would be expected in any fluviatile deposit. Emery so minimized the importance of the Todilto (?) formation that he recognized no break between the base of the Wingate and the top of the Navajo but referred the entire thickness to the Wingate sandstone.[85] Toward the east no pre-La Plata (post-Todilto) unconformity was recognized by Coffin north of Paradox Valley, though to the south of that locality evidence of at least local erosion was found.[86] Cross[87] found an unquestionable unconformity between his Dolores and La Plata formations in the San Juan Mountains, but the evidence cited by him seems not to exclude completely the explanation that the La Plata overlaps the Dolores formation, for it thins remarkably in the direction of the mountains, as does also the Dolores, perhaps owing to nondeposition. This hypothesis is not advanced very confidently, however, for the San Juan Mountain area has been an active orogenic center at several periods, so that unconformities present there may well be absent in the comparatively inactive regions to the west. It is certain, at any rate, that in southwestern Utah there is no unconformity in the thick mass of sandstone—well shown, for example, at Zion Canyon—into which both Wingate (Vermilion Cliff and "upper Dolores massive sandstones" of Cross) and Navajo (White Cliff and lower La Plata of Cross) have been traced.[88]

Above the Navajo sandstone lies the fossiliferous marine Upper Jurassic zone of Utah. With the fossils of the Chinle formation also taken into account, the age of the entire Glen Canyon group is fixed as later than some part of the Upper Triassic and earlier than some part of the Upper Jurassic. The question where to draw the Jurassic-Triassic boundary thus presents a dilemma. If the boundary is placed at the base of the Wingate sandstone it is necessary to assume continuous deposition between the two periods in the San Juan Mountain region, for there is no evidence of a stratigraphic break beneath the massive sandstone of the Dolores formation present in that region and believed to be equivalent to the Wingate. If the prominent unconformity at the base of the La Plata sandstone of the San Juan Mountains is selected as a boundary the conditions are reversed; the unconformity of the plateau province is in the midst of the Upper Triassic, and sedimentation was continuous across the Triassic-Jurassic boundary in such areas as the Zion Canyon region and essentially continuous in the San Rafael Swell. On the whole it seems that there is no present basis for any categoric location of this boundary. The Glen Canyon group may be Jurassic or Triassic; the probabilities slightly favor the Jurassic age of most of it, as indicated here by assignment to the Jurassic with a question.

Of the regions north of those mentioned here only the Uinta Mountain region and central Wyoming seem to offer a correlative of the Glen Canyon group. In the Uinta Mountain region the Nugget sandstone is similar in lithology and in position beneath the marine Upper Jurassic Twin Creek limestone, though there is no evidence available to show what part of the Glen Canyon group the Nugget may represent. In central Wyoming a much thinner sandstone, usually included in the Sundance formation as a basal member, suggests in many features that it may be equivalent to the Nugget sandstone and to some part of the Glen Canyon group.

JURASSIC SYSTEM

SAN RAFAEL GROUP

Above the Navajo sandstone is the long-recognized marine Upper Jurassic succession, here named the San Rafael group, from its splendid exposures in the San Rafael Swell. It is divisible into four formations, described below as the Carmel, Entrada, Curtis, and Summerville formations, in ascending order.

CARMEL FORMATION[89]

Distribution and topographic expression.—The Carmel formation is the lowest formation of the group. It has been traced from southwestern Utah, where it was first observed by Gilbert, with few interruptions around the south end of the High Plateaus, along the Waterpocket Fold,[90] in the Henry Mountains,[91] along Glen Canyon,[92] and throughout the San Rafael Swell. In the eastern part of the Green River Desert no fossils have been found in the Carmel formation, nor have any been reported from it in the neighborhood of Bluff, though the formation is recognizable there. Traced to the east it is represented by thin-bedded sandstones and shales which are correlated[93] with the middle limy member of the La Plata sandstone of the San Juan Mountains. It is recognizable on the west side of the High Plateaus near Salina (where it is saliferous), Manti, and Thistle, and it is, in part at least, represented farther north in the Uinta and Wasatch Mountains by the Twin Creek limestone.

The lower part of the formation is in most places very limy and resistant, capping vertical cliffs of the Navajo (pl. 18, *A*) and extending in wide esplanades beneath the slopes of the weak shales in the upper

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[83] Moore, R. C., op. cit., pp. 216-217.

[84] Oral communication.

[85] Emery, W. B., op. cit., p. 565.

[86] Coffin, R. C., op. cit., pp. 71-72.

[87] Cross, Whitman, and Hole, A. D., U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), 1910. See also Cross, Whitman, folios 57, 60, 130, 153.

[88] Gregory, H. E., and Moore, R. C., op. cit. Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 64.

[89] This formation is named from Mount Carmel, Utah, where Gilbert first recorded it, by H. E. Gregory and R. C. Moore (op. cit.).

[90] Gregory, H. E., and Moore, R. C., oral communications. Dake, C. L., op. cit., p. 637.

[91] Gilbert, G. K., op. cit., p. 6.

[92] Paige, Sidney, oral communication.

[93] Lee, W. T., U. S. Interior Dept. Mem. for the Press, March 30, 1926.

part. Where little limestone is present, however, the formation is swept from the upper surface of the Navajo, which is left as a terrace.

Lithology and thickness.—Measurements of thickness of the Carmel formation range in the San Rafael Swell from a maximum of 650 feet near the junction of Last Chance and Starvation Creeks, on the west flank, to 170 feet at Black Dragon Canyon and 95 feet (described as Todilto (?) by Emery) near Temple Mountain, on the east flank. At the mouth of San Rafael River it is 95 feet; near Courthouse mail station, 47 feet; in the Salt Valley anticline, 60 feet. It is represented by only a thin shaly zone at the mouth of Dolores River, but at Bluff it is 50 feet thick.[94]

The lower contact of the Carmel is an apparently smooth or only slightly rolling surface. The basal beds are nearly everywhere very limy buff to greenish-yellow sandstones, evidently composed of reworked sand from the Navajo sandstone. Its parallel, even bedding cuts off the steep cross-bedding of the Navajo over wide surfaces, but whether an unconformity is represented is impossible to determine, because of the irregular bedding of the Navajo. Above the buff sandy basal beds there is in many places a few feet of light-gray limy shale, and then a series of gray fossiliferous sandy limestones which reach thicknesses approaching 100 feet in places along the west side of the Swell. Elsewhere they are much thinner, and for considerable distances east of the Swell the limestone facies is not present, though the middle calcareous member of the La Plata sandstone of western Colorado is very probably at this horizon. The fossils are confined to the limy phase in the Swell, but none have been reported from the limestones of the La Plata of Colorado.

Where the formation is thickest the basal limestones pass upward into a series of gray, orange-red, and greenish shales, with much gypsum in highly contorted beds and massive strata as much as 40 feet thick. Anhydrite occurs in some of the limestones, and some salt is present in the formation along Muddy River and in the western part of the Swell. The well-known salt deposit near Salina is almost surely in equivalent beds.

The thinner facies of the Carmel formation in and east of the Green River Desert is a series of thin shaly brown and gray sandstones and red sandy shales, with a few gypsum lenses and a little limestone. Along the Waterpocket Fold the series is very gypsiferous, and this facies is more persistent than the limy one.

In the eastern localities the boundary with the conformably overlying Entrada sandstone is difficult to draw. There is a highly contorted zone of red-brown earthy sandstone with minor amounts of interbedded red shale which is to be placed either at the top of the Carmel formation or at the base of the Entrada sandstone. The contortions (shown in pls. 18, *C*, and 19, *A*) are surely depositional features, possibly due to subaqueous erosion and flow. The bedding both above and below the contorted zone is even and horizontal, proving the absence of angular unconformity. In the opinion of the writers most of this zone is better included in the Entrada sandstone, as it is dominantly and stone, and it is so included in the accompanying sections and charts. Some observers, however, would perhaps be inclined to draw the boundary between the Carmel and Entrada formations at the top of the zone. Either assignment appears permissible, in the opinion of the writers, as the two formations appear to be conformable and to represent continuous deposition. The division into two units is quite arbitrary, is made purely for the purpose of emphasizing the lithologic differences, and is not believed to have important significance in the geologic history of the region.

Conditions of deposition.—The marine origin of the limestone facies of the Carmel formation is clearly proved by the inclusion of abundant marine fossils. Very shaly limestones closely associated with the fossiliferous sandy limestones contain nodules of anhydrite, and at least one on the west flank of the Swell is traceable directly into a shaly anhydrite zone. Much of the gypsum, though by no means all, in the upper, noncalcareous part of the formation is cavernous and contorted on a scale which must imply volume changes of considerable amount, a feature that would seem to point to derivation of at least some of the gypsum from anhydrite. The association with salt mentioned above, though not conclusive, also points to deposition in lagoons by evaporation of marine waters. The interbedded shales are very even, and there are few abrupt variations in lithology, so that no support is given by the lithology to a hypothesis of deposition in an interior basin. The hypothesis of marine origin is further favored by the apparently conformable contact with the overlying Entrada formation, whose deposition in marine waters, although not yet established by the finding of fossils, seems probable from the character of its stratification and lithology. No dogmatic statement appears warranted, but the hypothesis of a marine origin of the entire Carmel formation in the San Rafael Swell area seems to be the most workable. The thinner, more variable shales and sandstones of the more easterly regions of the Green River Desert, Moab, and Salt Valley may represent deposits in the fluctuating margin of such a salt lagoon, and the disappearance of the formation at the mouth of Dolores River and the recurrence of thin-bedded limy material in the middle of the La Plata sandstone of Colorado would accord with erosion and continental deposition in those districts. All this is speculative in the extreme, but such data as are at present available seem to agree with it fairly well.

Age and correlation.—The age of the Carmel formation has long been recognized on the basis of many fossil collections as Upper Jurassic. In the course of the work covered by this report fossils were collected from the limestones of the lower part of the formation in many parts of the area. These fossils are listed in the accompanying table, together with others collected some years ago by Robert Forrester and not yet noted in the literature.

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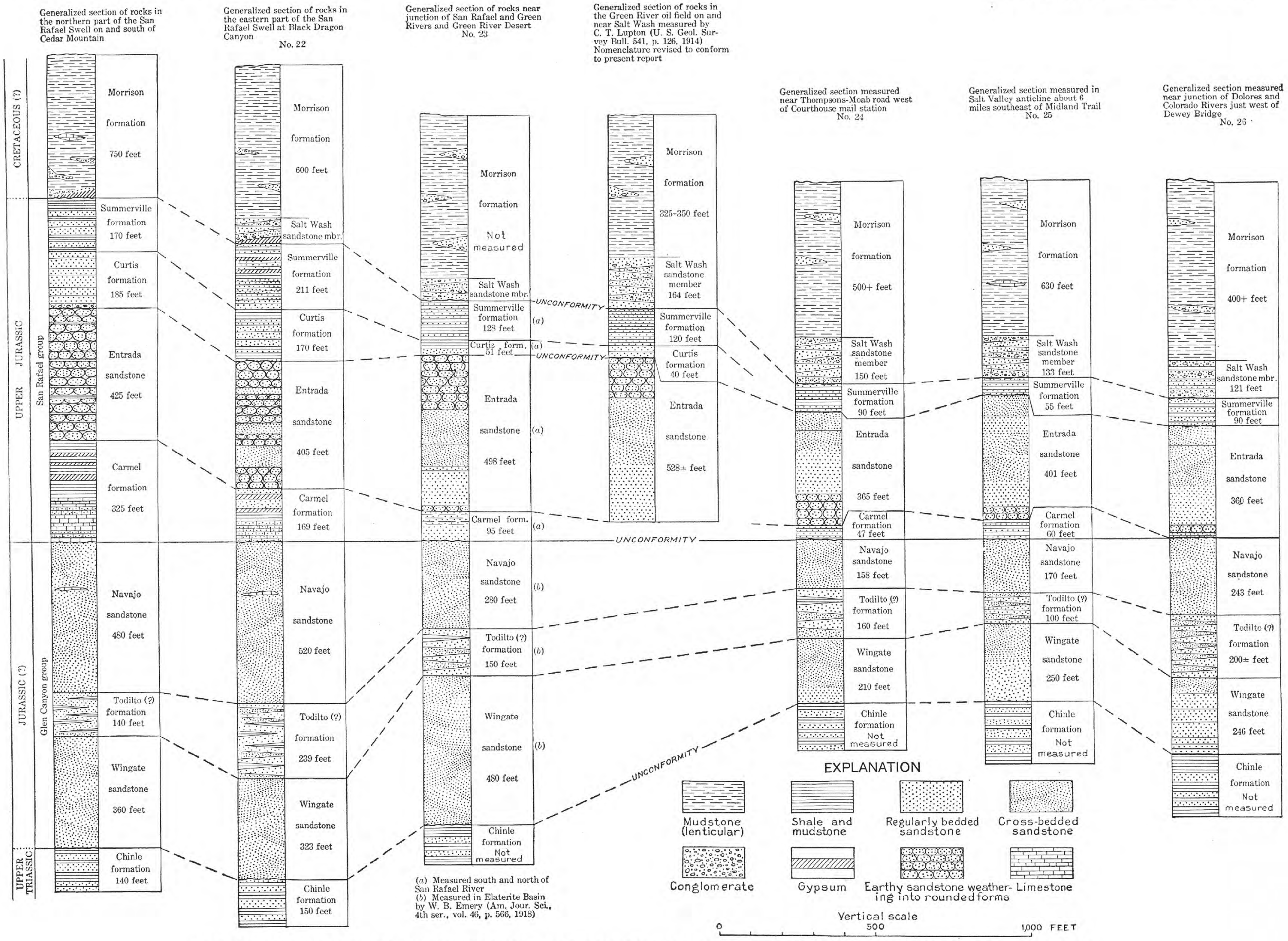
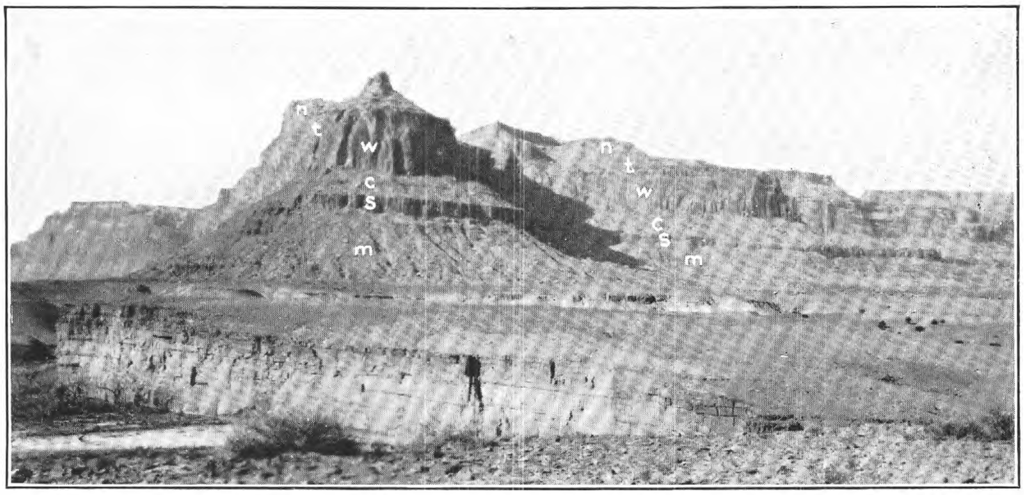
[94] Longwell, C. R., and others, op. cit., pl. 1.



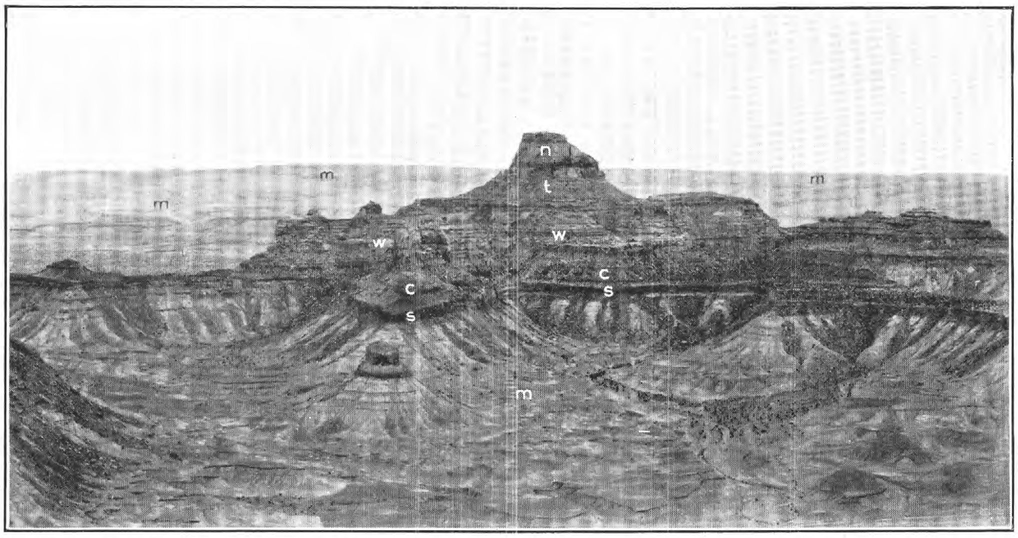
(a) Measured south and north of San Rafael River
(b) Measured in Elaterite Basin by W. B. Emery (Am. Jour. Sci., 4th ser., vol. 46, p. 566, 1918)

GENERALIZED COLUMNAR SECTIONS OF THE JURASSIC AND JURASSIC (?) ROCKS OF SOUTHEASTERN UTAH



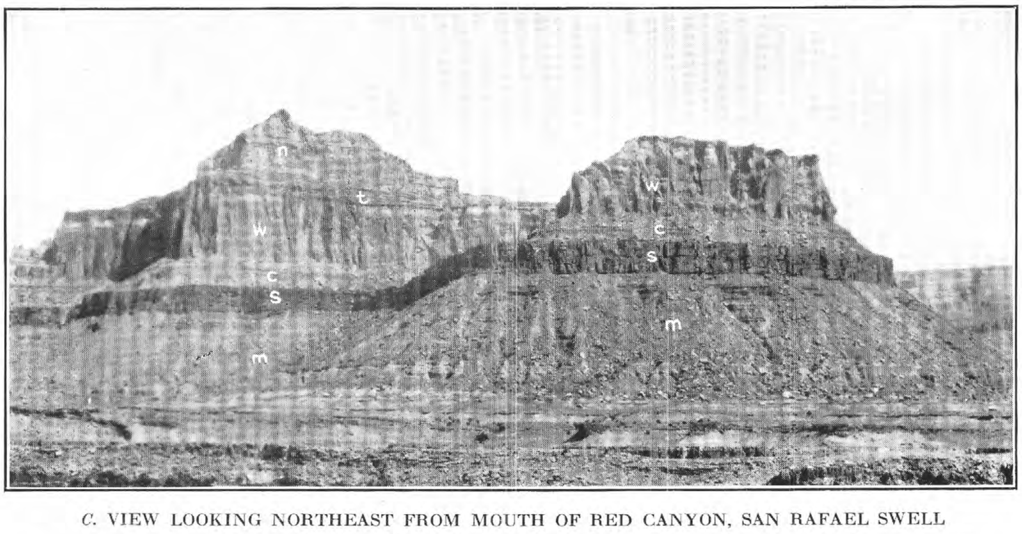
A. VIEW LOOKING NORTHWEST FROM POINT NEAR HEAD OF BLACK BOX OF SAN RAFAEL RIVER, SAN RAFAEL SWELL, UTAH

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, Upper part of the Moenkopi; s, Shinarump conglomerate; c, Chinle formation; w, Wingate sandstone; t, Todilto (?) formation; n, Navajo sandstone



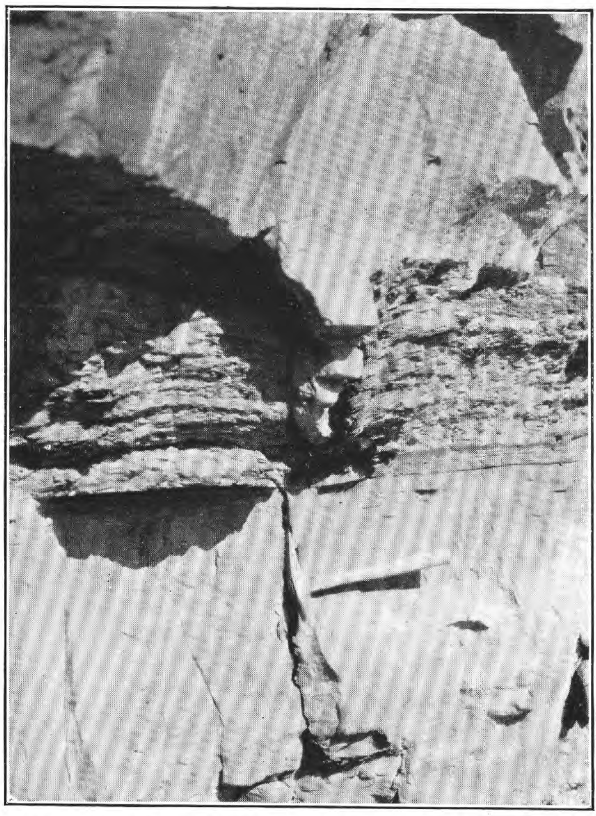
B. VIEW LOOKING SOUTH FROM THE REEF AT MOUTH OF BUCKHORN WASH, SAN RAFAEL SWELL

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

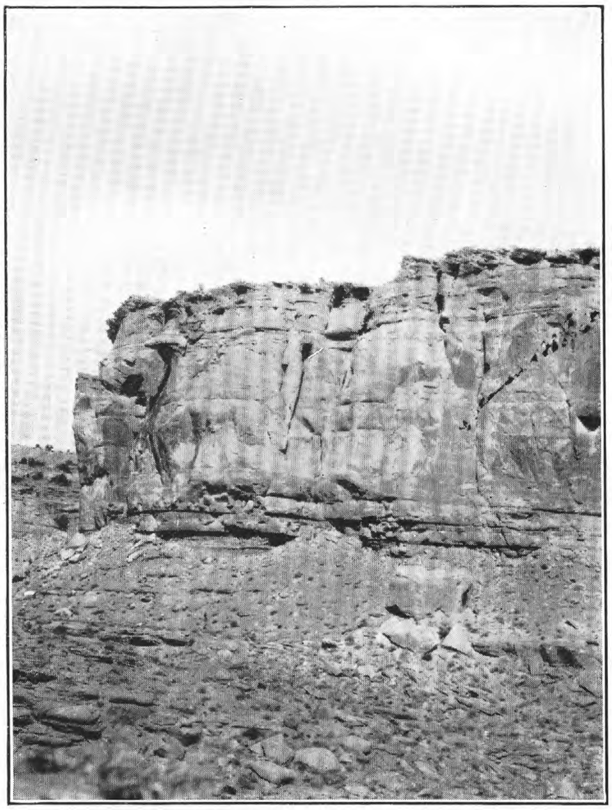


C. VIEW LOOKING NORTHEAST FROM MOUTH OF RED CANYON, SAN RAFAEL SWELL

m, Moenkopi formation; s, Shinarump conglomerate; c, Chinle formation; w, Wingate sandstone; t, Todilto (?) formation; n, Navajo sandstone

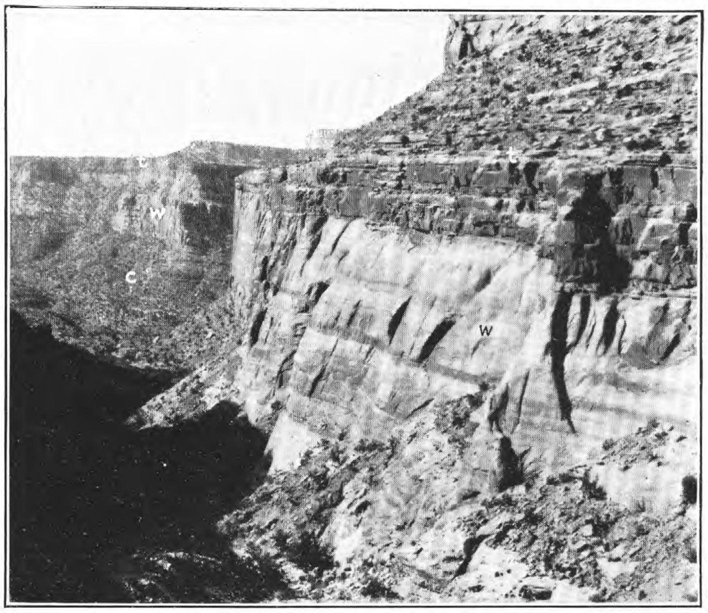


A. UNCONFORMITY, CHANNEL IN CHINLE SHALE FILLED BY SANDSTONE OF THE WINGATE SANDSTONE



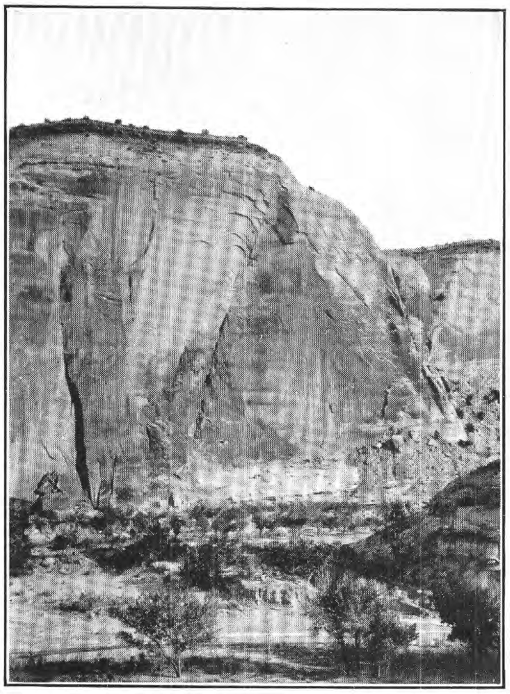
B. WINGATE SANDSTONE, RESTING ON CHINLE FORMATION NEAR COURTHOUSE MAIL STATION ON THOMPSONS-MOAB ROAD, UTAH

Cliff 210 feet high



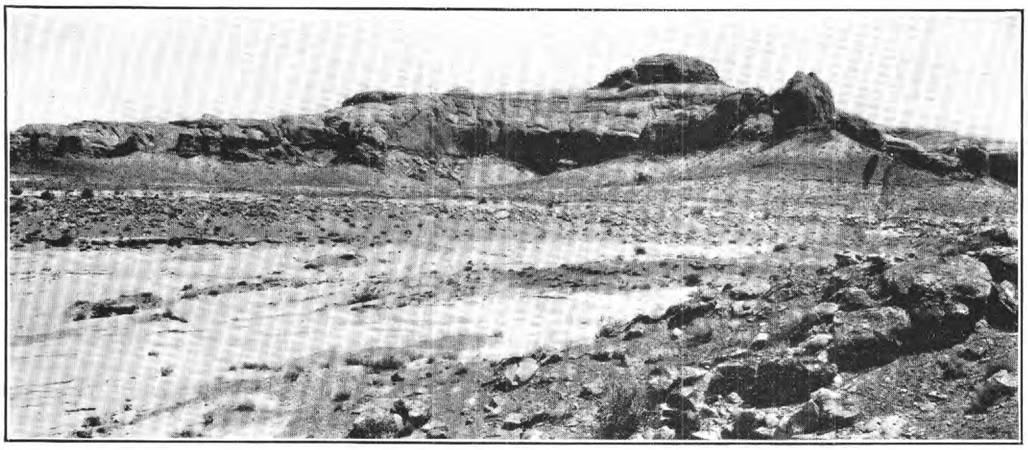
C. TYPICAL OUTCROP OF TODILTO (?) FORMATION NEAR HEAD OF SPRING CANYON, NORTHERN PART OF SAN RAFAEL SWELL, UTAH

c, Chinle formation; w, Wingate sandstone; t, Todilto (?) formation



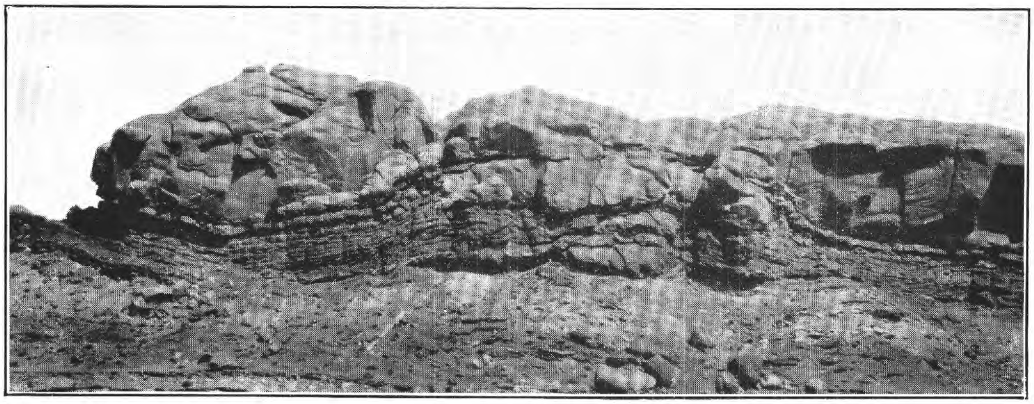
A. CLIFF OF NAVAJO SANDSTONE, CAPPED BY BASAL LIMESTONE BEDS OF CARMEL FORMATION ON SALT WASH, NORTHWESTERN PART OF SAN RAFAEL SWELL, UTAH

Top of Todilto (?) formation barely visible near right just above creek. Thickness of Navajo, 485 feet



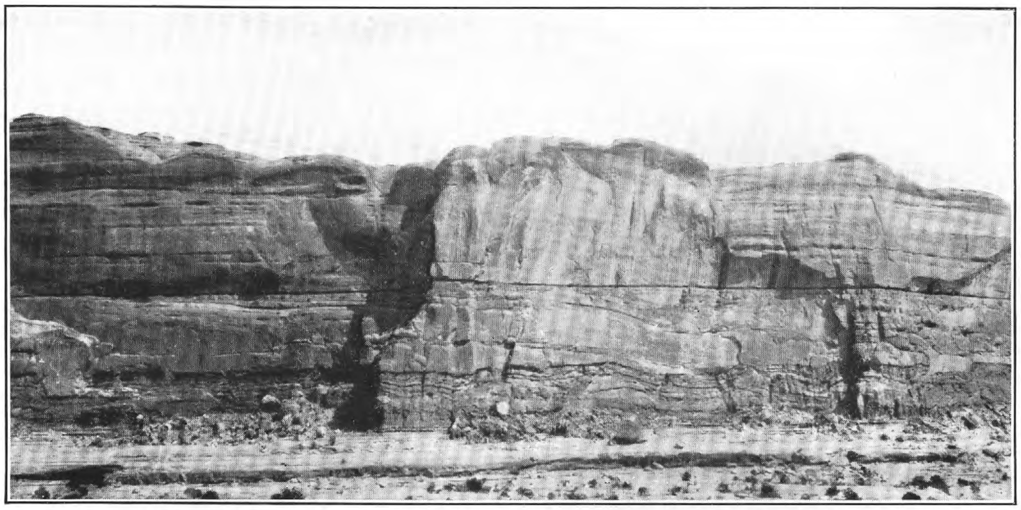
B. VIEW TAKEN 2 MILES SOUTH OF SAN RAFAEL-GREEN RIVER JUNCTION, UTAH

Navajo sandstone forms white patch in left foreground; slope is made by soft shale and sandstone of the Carmel formation. The rounded cliff exposes the lower 325 feet of the Entrada sandstone



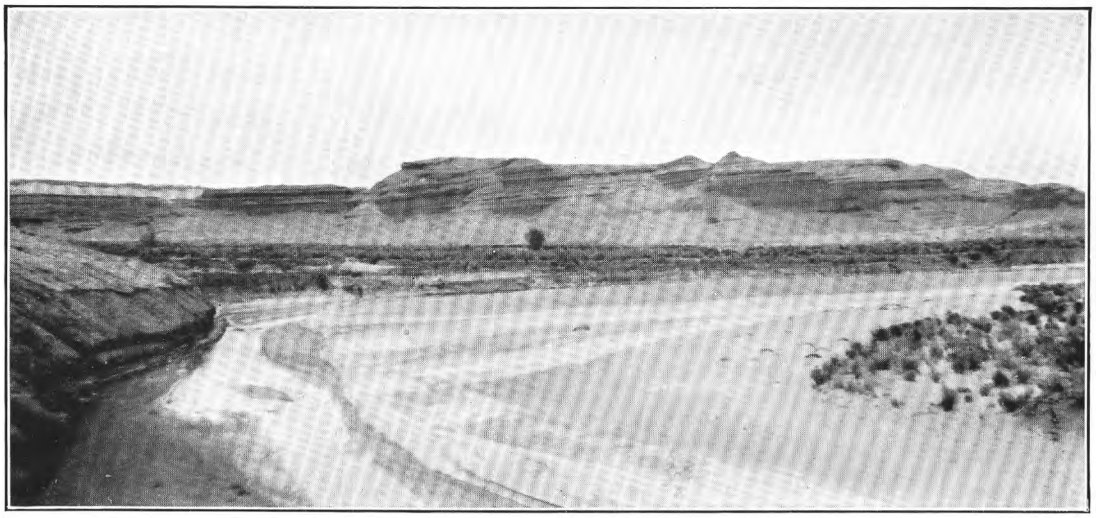
C. NEARER VIEW OF CLIFF SHOWN IN *B*

Shows contorted bedding at base of Entrada sandstone above slope made by Carmel formation



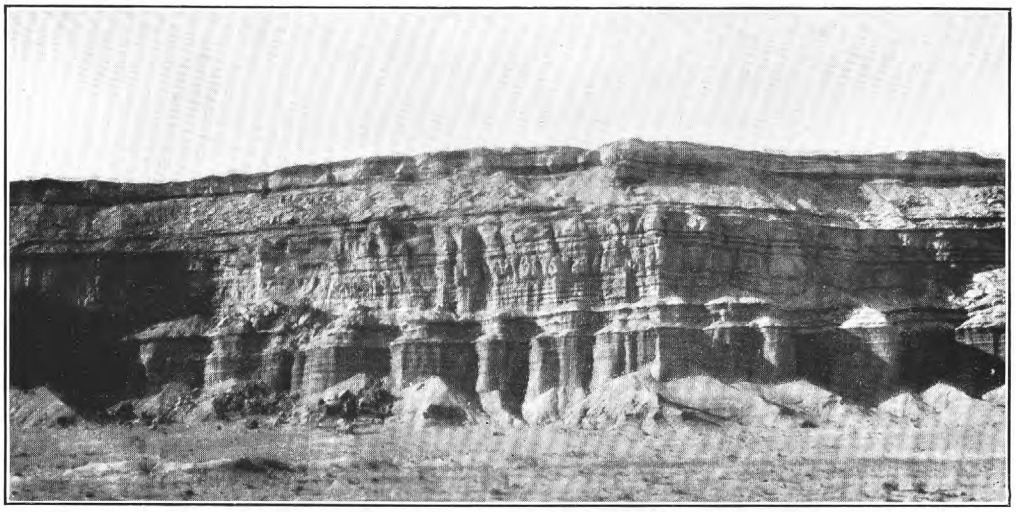
A. VIEW NEAR COURTHOUSE MAIL STATION, THOMPSONS-MOAB ROAD, UTAH

Bench in foreground made by Navajo sandstone; thin shaly zone (not prominent) at foot of cliff composed of Carmel formation; the cliff, which shows remarkable contorted bedding at the base, is made of Entrada sandstone, of which about 320 feet is here shown



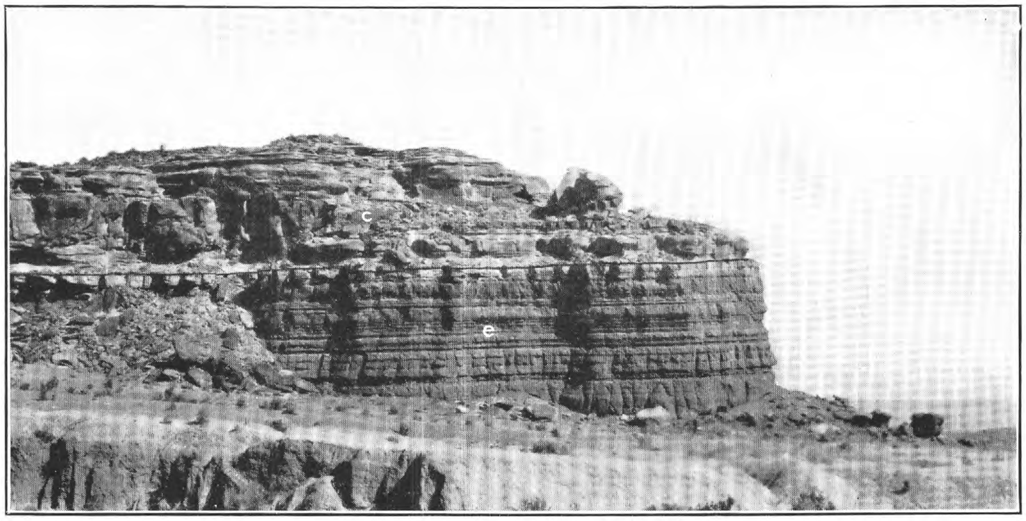
B. VIEW ON MUDDY RIVER AT THE MOUTH OF SALT GULCH, WEST FLANK OF SAN RAFAEL SWELL, UTAH

Cliff in distance is made of Entrada sandstone, here represented by its soft, earthy facies



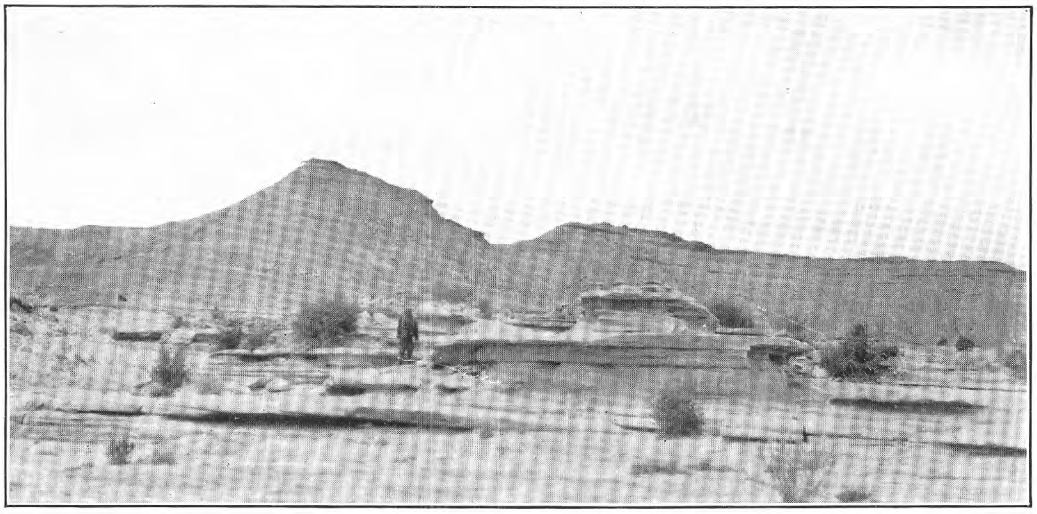
C. THE RED LEDGE, BETWEEN BUCKHORN FLAT AND SAN RAFAEL RIVER, WEST FLANK OF SAN RAFAEL SWELL

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

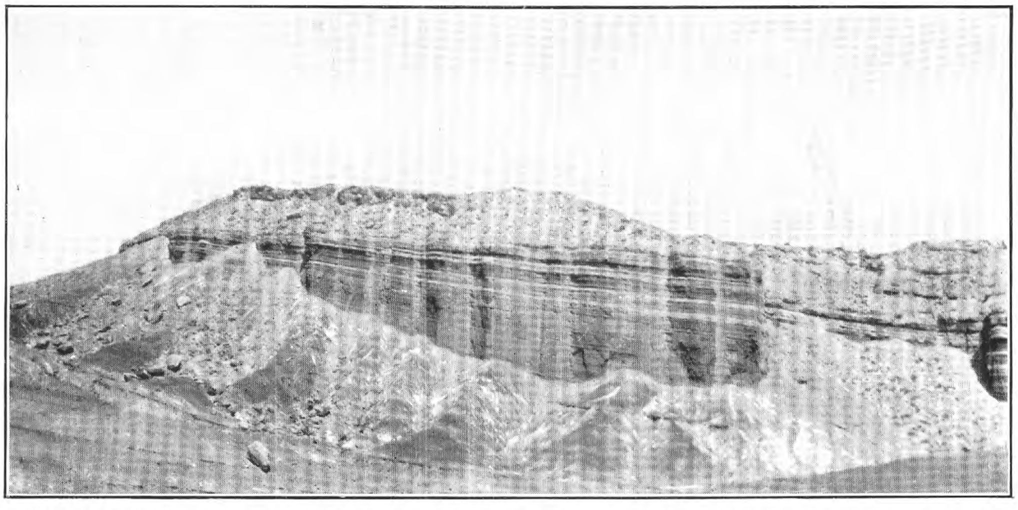


A. CLIFF AT MOUTH OF HORN SILVER GULCH, WEST FLANK OF SAN RAFAEL SWELL, UTAH

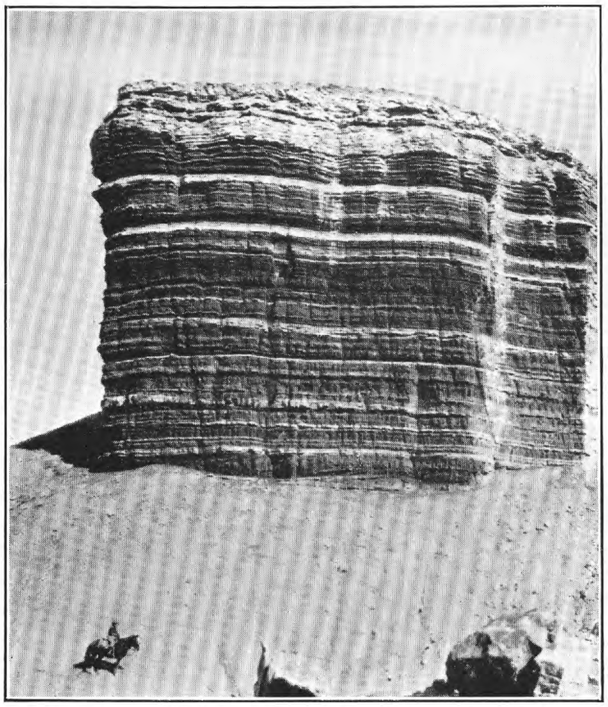
e, Earthy facies of Entrada sandstone, showing characteristic spheroidal weathering; c, concretionary sandstones at the base of the Curtis formation



B. ROUNDED CONCRETIONARY MASSES IN SANDSTONE OF CURTIS FORMATION IN FOREGROUND, SLOPE OF SUMMERVILLE FORMATION ABOVE, NEAR DRUNK MAN'S POINT, WESTERN PART OF SAN RAFAEL SWELL

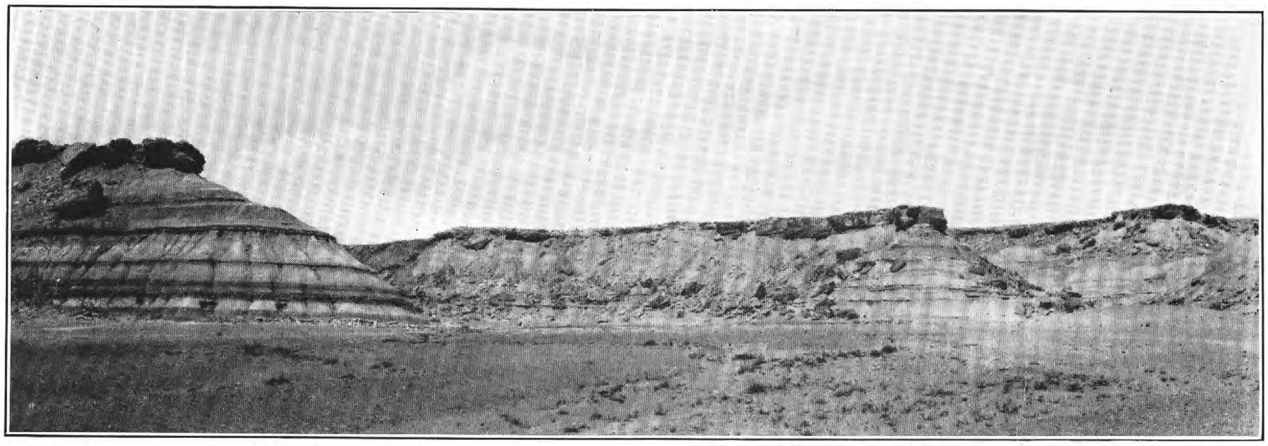


C. UNCONFORMITY BETWEEN EVENLY BANDED SHALES AND SANDSTONES OF THE SUMMERVILLE FORMATION AND THE IRREGULAR GYPSUM, SANDSTONES, AND CLAYS OF THE OVERLYING MORRISON FORMATION, COTTONWOOD SPRINGS WASH, NORTHEASTERN PART OF SAN RAFAEL SWELL

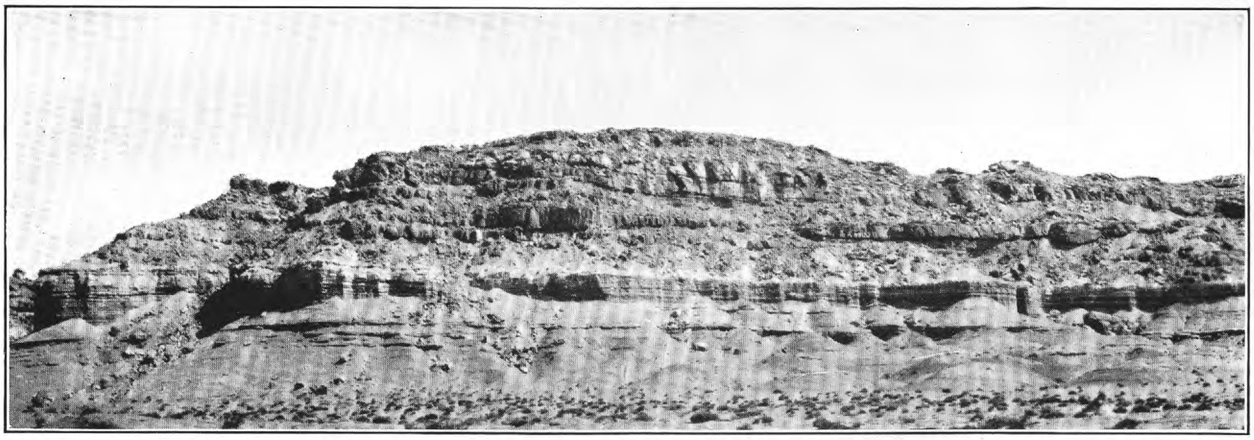


A. BUTTE OF SUMMERVILLE FORMATION NEAR CREST OF WOODSIDE ANTICLINE, NORTHEASTERN PART OF SAN RAFAEL SWELL, UTAH

Capped by white gypsum of the base of the Morrison formation. The white bands in the face of the cliff are sandstones of the Summerville



B. VARIEGATED CLAY AND SANDSTONE OF MORRISON FORMATION, BUCKHORN FLAT, WESTERN PART OF SAN RAFAEL SWELL, UTAH



C. SALT WASH SANDSTONE MEMBER OF MORRISON FORMATION UNCONFORMABLY OVERLYING GYPSUM, SHALES, AND THIN SANDSTONES OF SUMMERVILLE FORMATION, WOODSIDE ANTICLINE, NORTHEASTERN PART OF SAN RAFAEL SWELL

Photograph by E. M. Spieker

Fossils of the Carmel formation

	Lot 1	Lot 2	6280	6281	6282	6284	12555	12556	12557	12558	12560	12570	12581	12582	12835	12839	12840	12841	12842
Serpula sp. undet				×															
Pentacrinus asteriscus Meek and Hayden		×																	
Pinna kingi Meek	×			×															
Gervilia sp. (n. sp.?)	×																		
Ostrea engelmanni? Meek								×											
Ostrea strigilecula White	×	×	×	×	×		×	×	×		×	×				×	×	×	×
Ostrea sp. undet						×													
Trigonia quadrangularis Meek				×	×			×				×	×		×	×	×		
Trigonia montanaensis Meek							×	×	×		×			×					×
Trigonia n. sp. aff. T. americana Meek							×												
Trigonia sp. undet				×	×	×				×									
Camptonectes pertenuistriatus Hall and Whitfield	×			×	×														
Camptonectes stygius White			×	×		×	×			×				×			×	×	×
Camptonectes extenuatus Meek and Hayden							×	×				×	×		×				
Camptonectes bellistriatus? Meek and Hayden												×							
Camptonectes sp. undet		×							×		×								
Plicatula n. sp							×												
Lima (Plagiostoma) occidentalis Hall and Whitfield	×																		
Lima sp. undet	×																		
Modiola subimbricata Meek	×																×		
Modiola sp. (n. sp.?)	×																		
Pleuromya subcompressa (Meek)	×																		
Pleuromya newtoni? (Whitfield)															×				
Pleuromya kingi (Meek)	×																		
Pleuromya sp. undet				×															
Pholadomya kingi Meek										×									
Pholadomya sp. undet				×		×							×						
Cyprina? sp. undet		×		×		×													
Astarte? sp. undet	×				×														
Tancredia inornata (Whitfield)					×								×						
Dosinia sp. undet												×	×		×	×	?		
Corbula? sp							×												
Dentalium? subquadratum Meek							×		×		×								
Neritina? phaseolaris White			×	×															
Lyosoma powelli White														×					
Cardioceras cf. C. distans Whitfield							×												

Lot 1, unnumbered. Ten miles below Castledale, Utah, on San Rafael River. Collected by Robert Forrester.

Lot 2, unnumbered. Eight miles west of Cliff Siding, Emery County, Utah; 175 feet above base. Collected by Robert Forrester.

6280. Big Holes, Emery County, Utah; in lower 30 feet. Collected by Robert Forrester.

6281. Coal Wash, Emery County, Utah; in lower 30 feet. Collected by Robert Forrester.

6282. Devils Canyon, Emery County, Utah; in lower 30 feet. Collected by Robert Forrester.

6284. North of Salt Wash, Emery County, Utah; in lower 30 feet. Collected by Robert Forrester.

12555. The Wedge, 2 miles south of Fullers Bottom, Emery County, Utah; 6 to 12 feet above base. Collected by W. H. Newhouse.

12556. The Wedge, between Buckhorn Wash and San Rafael River, Emery County, Utah; 10 feet above base. Collected by D. J. Fisher.

12557. San Rafael River below Fullers Bottom; 18 feet above base. Collected by W. H. Newhouse.

12558. San Rafael River, below Fullers Bottom; 15 feet above base. Collected by W. H. Newhouse.

12560. San Rafael River, below Fullers Bottom; 17 feet above base. Collected by W. H. Newhouse.

12570. Two miles west of Lost Spring, on Saleratus Wash, Emery County, Utah; in an oolite 100 feet above base. Collected by John B. Reeside, jr.

12581. One and one-half miles west of Lost Spring, on Saleratus Wash, Emery County, Utah; in lower part. Collected by E. M. Spieker.

12582. Buckhorn Flat, Emery County, Utah; about 100 feet above base. Collected by E. M. Spieker.

12835. Cottonwood Springs Wash, sec. 10, T. 20 S., R. 13 E., Emery County, Utah; 68 feet above base. Collected by James Gilluly.

12839. Cottonwood Springs Wash, sec. 35, T. 19 S., R. 13 E., Emery County, Utah; 40 feet above base. Collected by James Gilluly.

12840. Cottonwood Springs Wash, sec. 33, T. 19 S., R. 13 E., Emery County, Utah; at base. Collected by James Gilluly.

12841. Salt Wash Canyon, sec. 25, T. 20 S., R. 9 E., Emery County, Utah; 16 feet above base. Collected by James Gilluly.

12842. Salt Wash Canyon, sec. 25, T. 20 S., R. 9 E., Emery County, Utah; 21 feet above base.

There is no doubt that this fauna is Upper Jurassic and that all the species also occur in the Sundance formation of Wyoming. Similar collections, with a few other species, have been reported by Howell and Gilbert,[95] Dake,[96] Emery,[97] and Lupton [98] from various parts of Utah, though some of them may include also fossils from beds as late as the Curtis formation, described on pages 78–79.

The correlation of the marine Jurassic of Utah has long been a matter of controversy. Cross [99] pointed out the fact that there are three great sandstone units in the neighborhood of the La Sal Mountains, the lowest forming part of the Dolores formation and equivalent to the Wingate sandstone, which he called Vermilion Cliff, and the upper two forming the La Plata sandstone and equivalent, in his opinion, to the White Cliff sandstone of Powell, now known as Navajo. As the marine Jurassic lies above the Navajo it is thereby assigned to a place later than the La Plata sandstone as thus interpreted. Other writers found, over most of the Colorado Plateau, only the two sandstone units of Powell, with which Cross had correlated his three sandstones, and assumed a correlation of these two units with the two divisions of the La Plata of Cross. This assignment again placed the marine Jurassic above the La Plata sandstone and correlated the thin-bedded zone between the two sandstones with the middle La Plata of Cross; that is, the Wingate, Todilto, and Navajo formations were thought to be equivalent to the La Plata sandstone and to form the La Plata "group."[1] The later work of Coffin [2] and Lee [3] and the tracing from the San Rafael Swell to Moab by the writers has shown that the lower sandstone (Wingate) is part of the Dolores formation, as Cross said; that the upper sandstone (Navajo) is the middle sandstone of Cross, the lower La Plata only; and that the marine Jurassic includes, by a marked lateral change in lithology, the thin-bedded middle zone and upper sandstone of Cross, the middle and upper La Plata. Emery [4] was nearly correct in his interpretation of the relations eastward from the Green River Desert, in which he called the present Carmel formation middle La Plata and the present Entrada sandstone upper La Plata, though wrong, as pointed out by Dake [5] and as shown above, in classifying the present Carmel formation as the equivalent of Gregory's Todilto and in lumping the Navajo, Todilto (?), and Wingate formations as a unit under the name Wingate sandstone. In the following table the correlations based on the tracing and measurements of the present report are compared with those of the writers cited above.

ENTRADA SANDSTONE

Distribution and topographic expression.—Immediately succeeding the shales and gypsum of the Carmel formation, with apparent conformity, is a thick series of earthy sandstones and subordinate shales, here named the Entrada formation, from their strong development on Entrada Point, in the northern part of the San Rafael Swell.

The Entrada sandstone is present around the Swell, in the Waterpocket Fold, northeast of the Kaiparowits Plateau, in the Henry Mountains, and along San Juan River, as well as in the Green River Desert and farther east in western Colorado. It constitutes a lower part of the "Flaming Gorge group" of Gilbert,[6] is the lower part of the "Upper Jurassic sandstone" of Moore,[7] and is part of the "varicolored sandstones and shales" discussed by Longwell, Miser, Moore, Bryan, and Paige.[8]

There are two general types of topography in which the formation is displayed. Where it is clean and well sorted it stands in steep cliffs with rounded shoulders and in huge domes, such as are so characteristic of the Navajo sandstone. Where it is more earthy or less well cemented it crops out in a steep slope, though in many places it weathers down much like a shale.

Lithology and thickness.—The thickness of the Entrada sandstone is variable. At the type locality it is 312 feet, but toward the south it increases greatly. At Muddy River, on the west flank of the Swell, it is 844 feet, and Moore found 1,430 feet in the Circle Cliffs, though he probably includes at the top a few feet of strata equivalent to the Summerville formation. To the east of the Swell the thickness is more nearly constant for many miles, being 405 feet at Black Dragon Canyon, 498 feet at the mouth of San Rafael River, 375 feet near Courthouse mail station, 401 feet in Salt Valley, and 360 feet at the mouth of Dolores River.

There are two lithologic facies of the formation. Both consist dominantly of sandstone, but the one exposed to the east of the Swell is composed largely of clean well-sorted material, and the more westerly facies is somewhat finer grained and silty. Gilbert's description of the "Flaming Gorge group," a larger unit in which the equivalents of the Entrada greatly preponderate, applies very well to the Entrada sandstone over most of the San Rafael Swell.[9]

> The rock of the Flaming Gorge group is of a peculiar character. It is ordinarily so soft that in its manner of weathering

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[95] Howell, E. E., U. S. Geog. and Geol. Expl. W. 100th Mer. Rept., vol. 3, p. 281, 1875. Gilbert, G. K., idem, pp. 159, 174.

[96] Dake, C. L., op. cit., p. 636.

[97] Emery, W. B., op. cit., p. 568.

[98] Lupton, C. T., op. cit. (Bull. 628), p. 24.

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

[1] Gregory, H. E., op. cit., p. 52 and elsewhere. Dake, C. L., op. cit., p. 637. Lee, W. T., Smithsonian Misc. Coll., vol. 69, No. 4, p. 12. Moore, R. C., op. cit., p. 216.

[2] Coffin, R. C., op. cit.

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

[4] Emery, W. B., op. cit., p. 567.

[5] Dake, C. L., op. cit., pp. 644–646.

[6] Gilbert, G. K., The geology of the Henry Mountains, pp. 6–7, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[7] Moore, R. C., op. cit., pp. 219–221.

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

[9] Gilbert, G. K., op. cit., p. 6.

Correlation of the stratigraphic subdivisions of this paper with the classifications of previous workers in the region

Age	Gregory, 1917; Navajo country	Gilbert, 1877; Henry Mountains	Moore, 1922; Circle Cliffs	Gilluly and Reeside, 1926; southeastern Utah	Dake, 1919; Waterpocket fold	Cross, 1907, and Paige, 1924	Emery, 1918; Green River Desert	Longwell and others, 1923; southeastern Utah
Upper Cretaceous.	Dakota sandstone.	Henrys Fork group.	Dakota sandstone.	Dakota sandstone (locally absent).	Dakota sandstone (locally absent).	Dakota sandstone.	Dakota sandstone.	Dakota sandstone.
Cretaceous(?).	McElmo formation.	Flaming Gorge group.	McElmo formation.	Morrison formation. Salt Wash sandstone member.	McElmo group Upper McElmo. Salt Wash member.	McElmo formation.	McElmo formation. Salt Wash member.	McElmo formation.
Upper Jurassic.	Hiatus. Undifferentiated McElmo and Navajo.		"Upper Not present. Jurassic sandstone." "Gypsiferous zone."	Summerville formation. Curtis formation. Entrada sandstone. Carmel formation. —(?)—	Lower McElmo (Sundance?).	Hiatus. La Plata group. Upper La Plata. Middle La Plata. Lower La Plata.	La Plata group Navajo sandstone. —(?)— Todilto (?) formation. —(?)—	Varicolored sandstones and shales [Curtis not present]. Gypsiferous shales and sandstones.
Jurassic(?).	La Plata group. Navajo sandstone. Todilto formation. Wingate sandstone.	Gray Cliff group. Vermilion Cliff group.	La Plata group. Navajo sandstone. Todilto formation. Wingate sandstone.	Navajo sandstone. Todilto formation. Wingate sandstone.	La Plata group. Navajo sandstone. Todilto formation. Wingate sandstone.	Dolores formation. Vermilion Cliff sandstone.	Wingate sandstone.	Navajo sandstone. Todilto formation. Wingate sandstone.
Upper Triassic.	Chinle formation.	Shinarump, "division a."	Chinle formation.	Chinle formation.	Dolores formation.	Lower Dolores.	Chinle formation.	Chinle formation.

it appears to be a shale. It is eroded so much more rapidly than the Henry's Fork conglomerate above it that the latter is undermined and always appears in the topography as the cap of a cliff. Nevertheless, it is not, strictly speaking, a shale. The chief product of its weathering is sand, and wherever it can be examined in an unweathered condition it is found to be a fine-grained sandstone, massive and cross laminated like those of the Gray and Vermilion Cliffs but devoid of a firm cement. In a number of localities it has acquired, locally and accidentally, a cement, and it is there hardly distinguishable from the firmer sandstones which underlie it.

The chief modification this description requires is that the sandstones are really not free from silt but contain a good deal. This is readily swept away by the winds, however, and is not seen in the talus from the formation. Its presence gives the sandstones a peculiar character, so that they weather like a granite into bosses and rounded forms—a most characteristic feature of the formation. The term "earthy sandstone" seems best to describe the rock.

To the east of the Swell the Entrada sandstone becomes much less earthy and better cemented, taking on the appearance of the underlying Navajo and Wingate sandstone. At the mouth of San Rafael River it forms huge domes 325 feet high, but the bedding is nearly parallel at a number of horizons within this thickness, and the earthy character of the basal 30 feet and the 140 feet overlying the domes shows the affinities with the San Rafael Entrada which the stratigraphic position would indicate.

Farther east the earthy character is even less prominent but is still seen in a 15-foot zone included as the base of the formation at the mouth of Dolores River, though it might perhaps be assigned to the Carmel formation. This basal earthy portion is in many places highly contorted, as described on page 74, in a manner difficult to explain, for the overlying and underlying strata are well exposed and undisturbed. This contorted character is a constant feature of the base of the formation over the plateau east of the San Rafael Swell and is seen at points so widely separated as Bluff, Dry Valley, and Salt Valley, as well as at the places already mentioned. Lee[10] has recognized this zone still farther south in northern New Mexico.

Although the Entrada sandstone is massive and thick bedded in the western localities, it contains many shaly layers a few inches thick and exceedingly persistent. The partings between the thick beds are as a rule very even and traceable over wide areas. Toward the east it is more massive, though there also the even bedding divisions are continuous for long distances.

Conditions of deposition.—The Entrada sandstone in the western areas is almost surely entirely water-laid. The even bedding and continuity of single zones seems to point to a marine origin, though this inference is not yet confirmed by fossil evidence. Toward the east, also, it is largely water-laid, though it there appears to be more highly and variably cross-bedded as well as cleaner and less silty, and some beds suggest an eolian origin, or at least conditions comparable to those prevailing in Navajo time.

Age and correlation.—The Upper Jurassic age of the Entrada formation is proved by its position between fossiliferous strata of that time. It is correlated with the Upper Jurassic sandstone of the Circle Cliffs and is equivalent to a part of the group in southern Utah called "varicolored sandstones and shales" by Longwell and others. In the San Rafael Swell it is part of the "McElmo formation" of Lupton[11] and was included (with some overlying beds) in the Navajo by Emery.[12] Traced toward the east it is found to be the zone in Dry Valley and near Moab called "Upper La Plata" by Cross.[13] Dake[14] follows Gilbert[15] in referring the sandstone to the "Flaming Gorge group," adding that this is practically equivalent to the "McElmo" of more recent writers. Prommel[16] called the corresponding strata in the Salt Valley anticline "Upper Navajo sandstone" and referred them to the La Plata "group," but, as is now known from tracing, they occur above the true Navajo, though equivalent to the upper part of the La Plata sandstone of Colorado.

CURTIS FORMATION

General character.—In the San Rafael Swell an erosional unconformity displaying irregularities of as much as 50 feet in height occurs at the top of the Entrada sandstone. Resting on this channeled surface is the Curtis formation, here named from its excellent exposures on Curtis Point, near the head of Cottonwood Springs Wash, on the northeast side of the Swell. It is a series of greenish-gray glauconitic conglomerates, sandstones, and shales and contains Upper Jurassic fossils.

Distribution and topographic expression.—About the north end of the San Rafael Swell and well down the west side the Curtis formation forms the crest of a cliff and the dip slope behind it. Farther south the conglomeratic facies of the formation becomes less prominent and the whole formation thins greatly, so that in the south end of the Swell, south of Starvation Creek, it forms a hardly noticeable shoulder in the steep slopes above the Entrada formation, while in the north end of the Waterpocket Fold it is a thin greenish-gray shaly sandstone which lenses out completely a short distance to the south. To the east of the Swell also it becomes more shaly and, though still present as a ledge former near the mouth of San Rafael River,

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[10] Lee, W. T., U. S. Dept. Interior Mem. for the Press, March 30, 1926.

[11] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, pp. 125-126, 1914; Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, pp. 21, 23-24, 1916.

[12] Emery, W. B., op. cit., pp. 570-572, 1918.

[13] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15 pp. 644-651, 1907.

[14] Dake, C. L., op. cit., pp. 644-646.

[15] Gilbert, G. K., op. cit., p. 6.

[16] Prommel, H. W. C., op. cit., pp. 387, 392.

is no longer recognizable near Courthouse mail station, where its horizon is exposed. The formation is not known east or south of the extreme localities mentioned, and so far as known it is a restricted phase of the marine Jurassic.

Lithology and thickness.—The Curtis formation, unlike most of the other strata of the plateau, may be identified usually by color alone. All its members have a peculiar greenish-gray color on fresh fracture, due to the glauconite contained in them. Weathering causes them to turn brownish, but very dark colors are not common.

At or near the base there is commonly from 3 to 20 feet of conglomerate, containing well-rounded pebbles as much as 1½ inches in diameter, mostly varicolored chert and flint, in a gritty matrix. Most of the formation, however, is a fine sandstone, in beds from 6 inches to 3 or 4 feet thick, cross-bedded and ripple marked throughout and commonly containing sporadic pellets of green shale. (See pl. 20, *B*.) Lime cement with some iron is irregularly distributed, and the sandstones commonly weather into biscuit-like or loglike forms owing to this differential cementation and to exfoliation. The shales that make up most of the upper part of the formation are well laminated, flaky, and limy.

The Curtis formation is 193 feet thick at the type locality and 252 feet at Summerville Point, at the north end of the Swell. Down the west side of the Swell it diminishes to 166 feet at Horn Silver Gulch and to 76 feet just south of the junction of Last Chance and Starvation Creeks. At Sand Creek, in the northern part of the Waterpocket Fold, it is very shaly and was estimated as about 40 feet thick. The formation was not noted by Moore [17] in his work near the Circle Cliffs. Just across Fremont River from Hanksville it is about 70 feet thick, but the formation is not recognizable in the description of the stratigraphy of the Henry Mountains by Gilbert.

At Black Dragon Wash the Curtis formation is 170 feet thick; near the mouth of San Rafael River, 50 feet. It is probably represented by the 40 feet of "sandstone, red below and gray above, very calcareous; contains many small nodules," described by Lupton [18] in his section of the "McElmo" formation on Salt Wash. It is not recognizable at any of the more easterly points visited by the writers.

Conditions of deposition.—The fossils collected from the Curtis formation at several places in the San Rafael Swell prove its marine origin. Its narrow areal distribution and its upper gradational boundary with the Summerville formation, which is much more widespread, seem to indicate that it never extended as a distinct deposit much farther south and east. Nothing definite is known of its northern or western limits. Certainly its coarse basal facies and the ripple marks throughout the formation afford convincing evidence that it is a shallow-water deposit. The presence of its pebbles in crevices in the upper surface of the Entrada seems to point to its origin as a basal conglomerate, deposited by the sea encroaching on a land surface.

Age and correlation.—The assignment of the Curtis formation to the Upper Jurassic is based upon the fossils shown in the following table, mostly collected in the northern part of the Swell:

Fossils of the Curtis formation

	12568	12569	12571	12576	12579
Cidaris sp	×	×	----	----	×
Pentacrinus asteriscus Meek and Hayden	×	×	----	----	×
Eumicrotis curta Hall	----	×	----	----	----
Ostrea strigilecula White	×	×	----	----	×
Camptonectes stygius White	×	----	----	----	----
Tancredia inornata (Whitfield)	----	----	----	×	----
Ammonite, indeterminable	----	----	×	----	----

12568. Saleratus Creek, 1 mile south of Lost Springs, in Saleratus Wash, Emery County, Utah; lower part of formation. Collected by E. M. Spieker.

12569. One mile north of Lost Spring, Emery County, Utah; highest grit, about middle of formation. Collected by E. M. Spieker.

12571. Lost Spring, Emery County, Utah. Collected by E. M. Spieker.

12576. One mile north of Lost Spring, Emery County, Utah; 5 feet below top of formation. Collected by John B. Reeside, jr.

12579. Humbug Wash, Emery County, Utah; base of formation. Collected by John B. Reeside, jr.

The species named above, like those of the Carmel formation, all occur in the Sundance formation of Wyoming, and it seems assured that the time of at least the lower three formations of the San Rafael group is included in the interval represented by the Sundance formation. It is not yet possible, however, to say precisely what parts of the San Rafael group are represented in the marine Upper Jurassic deposits of southwestern and central Utah, nor in the Twin Creek limestone of the Uinta Mountain region.

It should be noted that the Curtis formation on the west flank of the Swell was called the Salt Wash sandstone member of the "McElmo" by Lupton.[19] The true horizon of the Salt Wash sandstone member, as shown by detailed mapping and sections in the intervening areas between the west flank of the Swell and the type locality of the member, is 335 feet higher, the 8-foot conglomerate of Lupton's measured section being the equivalent of the true Salt Wash.

SUMMERVILLE FORMATION

Distribution and topographic expression.—In the San Rafael Swell the Curtis formation passes upward with a gradational boundary into the even-bedded

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

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

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

red and white sandstones and maroon shales of the Summerville formation, so named from its excellent exposures on Summerville Point, just southeast of the head of Summerville Wash, in the north end of the Swell. This formation has a much greater areal extent than the Curtis and is found in the Waterpocket Fold,[20] in the Henry Mountains, and throughout the region between the Swell and the mouth of Dolores River, wherever beds at its horizon are exposed. Very similar beds occur in Dry Valley and just north of Bluff, but detailed mapping would be required before exact equivalence can be confidently affirmed. It is ordinarily exposed in a steep slope, though in some places in a vertical cliff capped by the conglomeratic Salt Wash sandstone member of the overlying Morrison ("McElmo") formation. The zone of thin alternations of shale and sandstone weathers in rounded slopes that resemble those of shale badlands in appearance but are so hard and so thickly covered with small sandstone fragments that it is very difficult to maintain one's footing on even moderate slopes.

Thickness and lithology.—The type section of the Summerville formation includes 163 feet of thin alternating beds of chocolate-colored gypsiferous mudstone and well-laminated sandstone, with some red clays toward the base. Even bedding is not so characteristic as it is in the Woodside anticline, on the northeast flank of the Swell, but the beds are fairly persistent and regular. To the south the formation increases in thickness for some distance, being 258 feet thick at Horn Silver Gulch and 331 feet near Drunk Man's Point. Still farther south it thins considerably, so that near the junction of Starvation and Last Chance Creeks it is only 184 feet thick. The formation is not everywhere evenly laminated but contains a series of lenticular sandstones and shales of very irregular thickness, though the group as a whole changes only gradually from place to place. No measurement was made at Sand Creek, in the northern part of the Waterpocket Fold, but the formation was estimated to be much thinner there, perhaps only 100 feet thick. Eastward from the northern part of the Swell the formation is on the average somewhat thinner than in the type locality, being 128 feet thick in the Woodside anticline, 125 feet on Cottonwood Springs Wash in sec. 34, T. 19 S., R. 13 E. (unsurveyed), 210 feet at Black Dragon Wash, on the east side of the Swell, and 125 feet near the junction of San Rafael and Green Rivers. Strata 120 feet thick just below the Salt Wash sandstone member of Lupton's Salt Wash section[21] appear to represent the Summerville. Near Courthouse mail station about 60 feet of the Summerville formation rests directly upon the Entrada, the Curtis not being recognizable there. In similar manner at Salt Valley 55 feet of the Summerville, and near Dolores River 90 feet, is present directly above the Entrada sandstone.

In these more easterly localities the bedding resembles that in the southerly exposures in the Swell—that is, it is marked by interlensing thin sandstones and maroon mudstones and shales. Chalcedony concretions are present over the entire area of exposure of the Summerville, and bedded gypsum is likewise very common though not persistent.

Conditions of deposition.—In the north end of the Swell the Summerville formation appears to represent deposition in rather quiet shallow waters, but it is ripple-marked and sun-cracked throughout, and its sandstones contain pellets of the interbedded shales. The apparent conformity with the marine Curtis formation renders it probable that the Summerville likewise was deposited in an arm of the sea, though the gypsum beds, as well as the shallow-water features just mentioned, seem to indicate lack of free access thereto. Both to the south and to the east, however, the irregular lenticular nature of the sandstones seems to point to continental deposition, perhaps on a flat shelving plain whose lower portion was covered by the shallow marine water in which were deposited the even sediments of the northern San Rafael Swell. This conception would agree with the general evidence tending to show that the Jurassic sea retreated toward the northwest.

The chalcedony concretions are undoubtedly secondary for the most part. Perhaps they are to be accounted for by vadose circulating waters during the exposure of these beds prior to the deposition of the unconformably overlying Salt Wash sandstone member of the Morrison formation.

Age and correlation.—The conformable relation of the Summerville with the Curtis formation, which is of known Upper Jurassic age, together with the unconformity at the top beneath the Morrison formation (pl. 20, *C*), whose Cretaceous age is questioned, renders it probable that the Summerville formation likewise belongs to the Upper Jurassic. No fossils have yet been found upon which to base a more unequivocal assignment.

Correlation with beds in other areas must remain very tentative in view of the absence of fossils, the unconformity just above the Summerville, and the rapid lateral variations of the overlying Morrison. It is possible that the sandstones of the "lower McElmo" of Coffin[22] (the "carnotite beds") represent equivalents of the Summerville in western Colorado, though they may possibly lie in the Salt Wash sandstone member of the Morrison formation.

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

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

[22] Coffin, R. C., op. cit., pp. 77-97

CRETACEOUS (?) SYSTEM

LOWER CRETACEOUS (?) SERIES

MORRISON FORMATION

Lower contact.—There is an unconformity, both angular and erosional, at the top of the Summerville formation. (See pls. 20, *C*, and 21, *C*.) The angular discordance of the beds above and below is not everywhere apparent, and at no point observed in the San Rafael Swell does it exceed 4°, though in the Henry Mountains a divergence of approximately 8° was observed on the road between Hanksville and the Granite ranch, on the northeast foothills of Mount Ellen. However, the erosional unconformity is everywhere present. An unconformity at this horizon has been suggested by Emery [23] and Dake.[24]

Lithology and thickness.—The Morrison formation consists of mudstones and clays of variegated colors (pl. 21, *B*), with many channel conglomerates, sandstones, and lenticular limestones and at least locally some volcanic ash. On the east flank of the Swell, in the Green River Desert, and to the east there is at the base of the formation a variable thickness, ranging from about 50 feet to 200 feet or more, of thick lenticular conglomeratic sandstones with subordinate interbedded shales and mudstones—the Salt Wash sandstone member. (See pl. 21, *C*.) To the west and south this member rapidly diminishes in thickness and in the southwestern part of the Swell is present only at irregular intervals. These variations are almost surely due solely to variations in original deposition, as the lenticular nature of the individual beds of the conglomerate is very evident, and the interbedded mudstones are identical with those of the higher parts of the Morrison.

The mudstones of the Morrison formation are of various colors, as is usual with the unit elsewhere. Green, gray, white, maroon, purple, red, and many other colors are represented in irregular and discontinued development. Most of the mudstones are limy, and lenticular limestones occur here and there at several horizons within them.

In the northern part of the San Rafael Swell a persistent conglomerate from 3 to 40 feet thick containing many rounded pebbles of black chert occurs about 250 to 300 feet below the top, but it was not observed as a continuous bed either to the south or to the east. Lenses of similar conglomerate, however, recur to the east, though not at a constant horizon. Lee [25] believed that in the region from Moab eastward conglomerates similar to these may correspond to the basal conglomerate of the Cloverly formation of Wyoming and should be grouped with overlying highly colored shades and still higher beds of sandstone and locally coal-bearing strata as the Dakota (?) formation. He interprets the conglomerates in that region to be unconformable on the older beds and the overlying strata to be unbroken. The inconstancy of the conglomerates, the identical character of the overlying and underlying highly colored mudstones, and the practical impossibility of recognizing a dividing plane where the conglomerate is absent have led to the inclusion of the beds in the Morrison for the San Rafael Swell, especially as dinosaur bones were seen in the most persistent of these conglomerates. The designation Dakota (?) is applied in this paper only to the strata immediately beneath the Mancos shale and unconformably above the highly colored shales.

The thickness of the Morrison formation varies greatly, both because of original irregularities of deposition and because of the notable unconformity at the top. East of the Woodside anticline, in the northern part of the Swell, it is 725 feet thick; at Horn Silver Gulch, on the west flank, 847 feet. Just south of Willow Springs Draw, on the west flank, it is only 415 feet thick, and it was estimated to be of about the same thickness in the north end of the Waterpocket Fold.

Near Green River the Morrison includes, according to the measurements of Lupton,[26] 475 to 525 feet of strata, for the lower 700 feet of his "McElmo formation" constitutes the San Rafael group of the present report. In the Salt Valley anticline 640 feet of the Morrison is exposed.

Conditions of deposition.—The Morrison formation has long been considered an example of a flood-plain deposit, laid down by aggrading, wandering streams. On this hypothesis the lenticular conglomerates and sandstones represent old stream channels; the mudstones represent the deposits away from the main channels; and the limestones are believed to be fresh-water pond deposits. All the fossil evidence seems to harmonize with this interpretation as thoroughly as the physical evidence, and it is here accepted.

Age and correlation.—The Morrison is assigned with question by the Geological Survey to the Cretaceous system. Many vertebrate remains were seen in the area, but only one collection was made. This was examined by C. W. Gilmore, who furnished the following information:

> The fossil bones apparently belong to one individual and are identified as pertaining to the well-known genus *Diplodocus*. *Diplodocus* 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.

The limestone layers at places contain poorly preserved shells. One collection, made on Humbug Wash from limestones in mudstones between the lenses of conglomeratic sandstone of the Salt Wash member,

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[23] Emery, W. B., op. cit., p. 573.

[24] Dake, C. L., op. cit., p. 646.

[25] Lee, W. T., U. S. Dept. Interior Mem. for the Press, March 30, 1926.

[26] Lupton, C. E., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, p. 124, 1914.

contains a *Unio* much like the Morrison *Unio nucalis* Meek and calcareous tubes of an undetermined organism, perhaps an annelid.

As the fauna of the formation as observed in this area is similar to that of the type Morrison formation and the lithology is practically identical, the name Morrison formation is here applied to the strata. Previously the beds have formed part of the "McElmo" formation, but that name is abandoned here because the "McElmo" formation probably contains at the type locality[27] beds equivalent to the Summerville formation and more particularly because the term "McElmo" has been used by several authors to include, in different parts of the plateau province, (1) all the strata between the base of the Carmel formation and the base of the Dakota sandstone, (2) the beds between the base of the Entrada and the base of the Dakota, and (3) the beds between the top of the Entrada and the base of the Dakota. Such confusion has greatly impaired the usefulness of the name.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

DAKOTA (?) SANDSTONE

Distribution and topographic expression.—The Dakota (?) sandstone is present around most of the northern part of the San Rafael Swell, where the beds at its horizon are exposed, but toward the south it becomes less prominent and is absent near Caineville and at many of the southwestern exposures along the Swell. To the east it is nearly everywhere present within the area covered by this study.

The Dakota (?) sandstone invariably crops out either as a cuesta or as a mesa, for it is interbedded with weak mudstones and shales.

Stratigraphy.—The Dakota (?) sandstone rests unconformably on the eroded surface of the Morrison formation. In places it is lacking entirely; in places it may reach as much as 60 feet in thickness; everywhere it is extremely variable in constitution. It is ordinarily a rather friable buff to brown conglomerate, containing well-rounded pebbles of white, brown, black, and red quartz and chert in a matrix of coarse-grained cross-bedded sandstone. In some places it is very firmly cemented with silica and is a quartzite; but in most exposures it is cemented with lime, in places rather loosely.

Age and correlation.—Richardson collected typical Dakota plants from the sandstone near Elgin and near Woodside.[28] These fix the age of the beds as in the early part of the Upper Cretaceous, but although the stratigraphic succession and lithology are similar to those of beds widely accepted as Dakota, the likelihood of differences in age at so great distances from the original Dakota locality and the difference of opinion as to how much shall be included under the name make it seem best to apply a question mark to the correlation.

MANCOS SHALE

The Mancos shale overlies the Dakota (?) sandstone with apparent conformity, usually with transitional contact. It crops out over a large area in Castle Valley, the broad plain south of the Book Cliffs and north of the Henry Mountains. It is everywhere a soft, easily eroded formation and forms wide valleys with badland slopes leading back to steep cliffs which are formed by resistant sandstone members within the shale or overlying it.

The relations of the Mancos shale and the overlying rocks in the region of Castle Valley and the Wasatch Plateau have been recently summarized.[29] Only casual attention was given to them in the present work, as only negligible areas of Mancos were included in the district mapped.

LOCAL SECTIONS

The measured sections on which the much generalized descriptions and the interpretations given above are largely based are presented in detail below. The localities are shown by corresponding numbers on Figure 2.

1. *Section 2 miles south of junction of Starvation and Last Chance Creeks, in southern part of San Rafael Swell, Utah*

	Feet
Morrison formation: Gypsum and limy sandstones of various colors, conglomerate at base.	
Unconformity; surface scoured into hollows 4 feet deep, in which occurs the conglomerate at the base of the Morrison.	
Summerville formation:	
1. Sandstone, chocolate-red, shaly; thin bedded (average 1 inch), well laminated in the large but irregularly in the hand specimen; interbedded with some thin green-gray sandstone as much as 4 inches thick; much seamed with gypsum, which is probably all secondary	184
Curtis formation:	
2. Sandstone, green-gray, glauconitic, gritty; becomes shaly toward the top; firmly cemented at base, softer above; gradation to Summerville through about 4 feet of interbedded red-brown and green-gray sandstone	76
Unconformity, not obviously angular; sharp lithologic change; upper surface of the Entrada sandstone bleached to a depth of about 6 inches.	
Entrada sandstone:	
3. Sandstone, red-brown, shaly, in beds as much as 20 feet thick, alternating with poorly bedded lumpy chocolate-brown sandy shale in beds as much as 18 inches thick; the whole weathers in a horizontally fluted cliff, in which the individual beds are traceable for very long distances	299

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

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

[29] Spieker, E. M., and Reeside, J. B., jr., Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. America Bull., vol. 36, No. 3, pp. 435–454, 1925.

	Feet
Entrada sandstone—Continued.	
4. Sandstone, red-brown, massive, cross-bedded; weathers in rounded exfoliating masses and forms a strong ledge	14
5. Chocolate-brown sandy shale and thin cross-bedded micaceous shaly sandstone; beds about 4 inches thick; stands in a horizontally fluted cliff	23
6. Sandstone, shaly, massive, cross-bedded, resistant; weathers in a strong rounded ledge traceable for long distances	2
7. Sandstone and shale, like No. 3, except that there are no sharp divisions between the more sandy and the less sandy beds and the sandstones weather into "stone babies" and rounded masses; much seamed with secondary gypsum	337
Total Entrada sandstone	675
Apparent conformity.	
Carmel formation:	
8. Mudstone, orange-brown, very soft; with some interbedded green silt and much selenite veining	8
9. Silt, light green, and gypsum, containing seams of white and nodules of red-brown selenite; forms an irregular ledge with some interbedded lavender shale at some places; thickness variable	2
10. Shale, light green, soft; forms slope	6½
11. Silt, light green, and shale, banded with gypsum; forms low ledge	29
12. Shale, light grayish green, limy, with some slightly ripple-bedded shaly limestone	41½
13. Interbedded green and chocolate-red gypsiferous silt and mudstone, much seamed with selenite; forms a slope	6½
14. Mudstone, reddish brown, poorly consolidated	1
15. Silt, grayish green, and gypsum	½
16. Mudstone, like No. 14	2
17. Shale, light grayish green, limy, with some thin alabaster gypsum beds in a 4-foot zone about the middle of the member	27½
18. Silt, like No. 15, except that there is more gypsum in nodules toward the base	3
19. Shale, like No. 12	2
20. Gypsum, in some places with light-green silt, elsewhere constituting the entire unit	3
21. Shale, light green; gypsiferous, containing many seams of selenite averaging half an inch to 1 inch thick; bedding contorted, highly folded; upper 1 to 4 feet a continuous ledge	11
22. Shale, light greenish gray, limy	15½
23. Gypsum, white; forms a ledge	1
24. Silt, light grayish green, gypsiferous	1
25. Shale, grayish green, limy, interbedded with shaly limestone; forms a slope	10
26. Limestone, light greenish gray finely laminated; weathers into thin plates; forms a low ledge	1
27. Shale, light greenish gray, with seams of gypsum as much as half an inch thick	2½
28. Silt, reddish brown	1½
29. Silt, light yellowish green and grayish green, with some limy shale	17½
30. Silt, like No. 28	1
31. Silt and shale, like No. 29	2
32. Limestone, light greenish gray, less shaly toward the top; weathers in thin plates	5
Carmel formation—Continued.	
33. Gypsum (alabaster)	1
34. Shale, light green, limy; weathers light yellowish green	5
35. Silt, light greenish yellow; gypsiferous, grading toward the top into white gypsum with subordinate silt	36½
36. Gypsum, white	3
37. Silt, light grayish green, gypsiferous; shaly in places	3
38. Gypsum, white, including a minor amount of light greenish-gray limestone	3
39. Silt, light yellowish green and reddish brown, gypsiferous	8
40. Gypsum and limestone, like No. 38	5
41. Gypsum, white, resistant; forms a ledge	7
42. Silt, greenish yellow and reddish brown; gypsiferous, especially toward the top	1
43. Silt, reddish brown and brick-red, gypsiferous	7½
44. Limestone, light greenish gray, somewhat shaly, partly replaced (?) by gypsum	4½
45. Limestone, light greenish gray to bright yellow, somewhat sandy, ripple-marked; gypsum along joint planes; weathers in thin platy slabs in lower part	27
46. Limestone, light and dark gray, massive, blocky, ledge-forming	1½
47. Limestone, light and dark gray, thin bedded, platy; forms slope	3
48. Limestone, like No. 46	6½
49. Limestone, resistant, banded light gray and light yellow	2
50. Limestone, gray, weathering brownish yellow; platy, cross-bedded on a small scale in lower and upper parts; middle massive; forms resistant ledge	34
51. Mudstone, reddish brown, soft	1
52. Limestone, gray, thinly laminated, soft	1
53. Limestone, light greenish gray, sandy; ripple-marked and ripple-bedded; platy, except upper 5 feet, which forms massive ledge	22½
54. Limestone, very light gray, slabby, nonresistant	3
55. Limestone, white, ledge-forming; in places somewhat sandy; irregular in thickness	3
56. Sandstone, greenish gray, fine grained, limy; lower 1 to 4 feet finely laminated, ripple-bedded; middle part weathers in rounded forms; upper part massive, forms irregular ledge	23
57. Silt, green and yellow, unconsolidated	5
58. Sandstone, bright yellow, limy, soft	5
59. Shale, sandy, light green	1
60. Sandstone, like No. 58	1
61. Sandstone, white to light yellow, limy, fine grained, soft; forms a slope except uppermost 2 feet	11½
62. Shale, light greenish gray and yellowish	½
63. Sandstone and mudstone, yellow to brown, soft to hard; forms variable ledge and slope	4
64. Mudstone, chocolate-colored, with some light greenish gray shale at base	1
65. Sandstone, light gray, massive, fine grained, limy; forms ledge	1
66. Mudstone, like No. 57	2
67. Sandstone, light greenish gray, fine grained, thinly laminated, ripple-bedded, lime-cemented; ledge former but variable along exposure	1

Carmel formation—Continued.	Feet
68. Mudstone, maroon to dark gray, flaky	½
69. Sandstone, gray to yellow, fine grained, hard, sugary; reworked Navajo sandstones, cross-bedded on a small scale	2½
Total Carmel formation	449½

Unconformity.
Navajo sandstone.

2. *Section on cliffs south of Muddy River, in southwestern part of Sinbad, San Rafael Swell, Utah*

Wingate sandstone:	Feet
1. Sandstone, buff to yellow, fine grained, limy, friable, highly cross-bedded	300+

Unconformity, marked by channeled surface, into the depressions of which the overlying sandstone is deposited.

Chinle formation:	
2. Shale, green, sandy, not very well laminated; top surface shows channeling to depth of 1 foot or more	3
3. Sandstone in beds 2 to 3 feet thick; red-brown except top foot, which is green; earthy; weathers in rounded forms	11
4. Mudstone, limy, variegated purple and maroon, indistinctly laminated; forms a slope	13½
5. Sandstone, gray, limy, fine grained, ripple-marked, thin bedded; lenticular, not persent in section 100 yards away	5
6. Lower part mudstone, blocky, limy, in nearly vertical cliff; checks into small angular fragments; upper part alternately more and less shaly mudstone containing particles of grit and fragments of green shale	62
7. Basal part shale, maroon, well laminated; upper part variegated mudstone like upper part of No. 6 and even earthy sandstone	38
8. Sandstone, shaly, well bedded, olive-green, passing upward into well-laminated biotite-bearing sandstone which is cross-bedded at high angles; thins to less than 1 foot within 100 yards along the exposure	4½
9. Sandstone, greenish gray, highly cross-bedded, coarse grained; contains shale pellets	1
10. Shale, olive-green, flaky, somewhat sandy	1
11. Sandstone, like No. 9	1
12. Shale, like No. 10	1½
Total Chinle formation	141½

Contact apparently conformable.

Shinarump conglomerate:	Feet
13. Conglomerate, extremely variable, cross-bedded; pebbles largely of quartzite, white quartz, and white, black, gray, and cream-colored chert as much as three-fourths inch in diameter; matrix a coarse sandstone with much mudstone locally (probably transported as mud balls). Along the exposure the conglomerate is everywhere a cliff; in some places it is all in one bed; in others it occurs in many 2 to 3 foot beds separated by mudstone lenses. Carbonaceous material is abundant	58
14. Mudstone, green, sandy	7
15. Mudstone, shaly, mottled purple and green, showing slickensides on a small scale in nearly every plane; forms a ledge	10
16. Mudstone, very limy, mottled purple, green, and yellow; contains some angular fragments of yellow quartz a quarter of an inch or less in diameter	23
17. Shale, variegated green, brown, ocher, and purple; color changes unrelated to bedding; forms a smooth slope	16
Total Shinarump conglomerate	114

Unconformity, smooth surface, sharply cutting between decidedly different lithologic types. No angular discordance is discernible.

Moenkopi formation:	Feet
18. Alternating thin beds of red-brown micaceous shale and fine-grained limy red-brown micaceous sandstone, very well bedded; thick sandstones at 16–19, 32–36, 205–208, and 212–217 feet above the base. Gypsum nodules occur in some of the sandstones, and seams of selenite are very common. Individual beds are traceable for long distances—the sandstones as ledges, the shales as rounded sunken surfaces	291
19. Sandstone, very limy, cross-bedded, in 6-inch beds; contains some shale partings and some 2-inch gypsum seams near the base; forms a persistent ledge	6½
20. Shale, maroon, flaky, evenly bedded, with a few thin limy sandstone beds at 12 to 14 feet from the base	21
21. Sandstone, micaceous, very limy; forms a strong persistent ledge, ripple-marked and cross-bedded throughout	6½
22. Shale, micaceous, evenly bedded, with subordinate shaly sandstones that weather into rounded forms; much selenite in seams	46
23. Alternating shale and sandstone, like No. 18, except that the heavy sandstones occur between 27 and 30 feet above the base and in the top 4 feet of the unit	47½
24. Sandstone, red-brown, ripple-marked, very evenly bedded, micaceous; upper foot slabby; persistent ledge former	5½
25. Shale and sandstone, like No. 18, but without heavy sandstones	21
26. Sandstone, like No. 24	2
27. Shale, red-brown, slightly sandy, micaceous	½
28. Sandstone, like No. 24	1
29. Shale, like No. 27	2½
30. Sandstone, like No. 24	25½
31. Alternating shale and sandstone, like No. 18	41
Sinbad limestone member:	
32. Limestone, gray, ripple-marked, sandy, cross-bedded; lower half in one bed, upper part in beds 6 inches or less in thickness	6½
33. Shale, green-gray to blue-gray, well laminated; no sand present	1
34. Limestone, like No. 32	8½
35. Shale, like No. 33	6½
36. Limestone, gray; weathers to cream-colored or yellow; in beds 2 inches to 3 feet thick; slightly sandy, somewhat cross-bedded; vuggy and cherty in places, especially toward the top, where the nodules lie in layers parallel to the bedding; some thin shale partings 1 to 2 inches thick; oolitic to dense, fossiliferous at a few horizons; silicified in places; contains blebs of asphalt. Usually in one vertical ledge, but locally in a series of vertical steps	68½

	Feet
Moenkopi formation—Continued.	
Sinbad limestone member—Continued.	
37. Sandstone, green-gray, limy, petroliferous, shaly, with a few partings of green shale; a number of selenite seams, and some gypsum nodules at the base; becomes sandier upward; at 12 feet above the base becomes a red-brown earthy, limy sandstone, well bedded, ripple-marked, micaceous, very fine grained. Weathers into ledge below and rounded slope above. Partings of red-brown shale, mottled with green, begin at 27 feet above base and increase to top of unit, though the sandstone facies predominates	62
Total Sinbad limestone member	153
38. Sandstone, shaly, tan; limy, increasingly so toward top; ripple-marked and ripple-bedded throughout; thin bedded, more shaly and less shaly beds alternate in slopes and subordinate ledges; one 2-inch bed of very black petroliferous sandstone 33 feet above the base; in upper part, gypsiferous yellow-brown shale alternates with the sandstone; a 3-foot bed of very clean blue-green shale occurs 3 feet above the base	39
39. Conglomeratic sandstone and conglomerate in beds 1 inch to several feet thick; pebbles, largely of milk-blue chert derived from the Kaibab, greatest diameter noted, 1 inch	4
40. Sandstone, shaly, containing chert particles; interbedded with sandy green-gray limy micaceous shale	9
41. Sandstone, gray, gritty, quartzose, cross-bedded; variable along exposure; contains pebbles like those of No. 23 except that greatest size is three-eighths inch; also waterworn asphalt grains	1 to ½
42. Shale, green-gray, gypsiferous, sandy	½
43. Sandstone, like No. 41	1 to ½
44. Sandstone, tan, gritty; very thin bedded, with some thin sandy shale; weathers in a slope	6½
45. Conglomerate, like No. 39	½
46. Sandstone, green-gray, shaly, very limy; contains chert particles and is not conglomeratic; interbedded with micaceous sandy shale	2½
Total Moenkopi formation	734
Unconformity, irregular erosion surface with apparent relief of about 10 feet in an area of 2 or 3 acres.	
Kaibab limestone: Top bed is a very limy sandstone, gray with some black; weathers into rounded forms.	

3. *Section near The Tanks, in southern part of Sinbad, San Rafael Swell, Utah*

	Feet
Moenkopi formation: Chert conglomerate, containing much silt and passing upward into gypsiferous shale.	
Erosional unconformity with relief of 40 feet in a few acres of exposure.	
Kaibab limestone: Chiefly cream-colored to gray sandy limestone with many shaly nodules, crinoid fragments, and milk-blue chert nodules as much as 1½ inches in diameter; beds 1 to 4 feet thick. Part near top is less sandy and darker gray and shows cleavage facets of calcite as much as one-eighth inch in diameter. Basal 10 feet a fine-grained, limy sandstone, somewhat shaly, passing laterally and vertically into the limestone facies. No sharp lithologic change within the formation	69
Contact, apparently transitional and indefinite within 2 feet.	
Coconino sandstone: Sandstone, commonly gray to white but blotched with yellow-brown and rarely maroon; fine grained, sugary; the quartz grains clean, rounded to subrounded, with many "frosted" surfaces; highly cross-bedded and jointed without any apparent system; exposed	50+

4. *Section on Muddy River, San Rafael Swell, Utah, between mouth of Salt Gulch and mouth of Willow Springs Wash*

	Feet
Curtis formation (basal part):	
1. Conglomerate of pebbles of gray chert, jasper, flint, gray limestone, and green chert, rather well rounded, ranging from one-sixteenth inch to 1½ inches in diameter; matrix of green-gray glauconitic sandstone	2
Unconformity, slightly wavy; the material below cracked and bleached for a few inches and sharply different from that above.	
Entrada sandstone:	
2. Mudstone, chocolate-brown, slightly sandy, with some ripple-bedded sandstone	14
3. Sandstone, red-brown, massive, ripple-bedded	1½
4. Sandstone, shaly, ripple-marked, soft; forms a slope	3
5. Sandstone, shaly, massive, concretionary	4
6. Sandstone, soft, red-brown, with subordinate chocolate-colored mudstones; indistinctly bedded; weathers into a slope like shale	16
7. Sandstone, red-brown, earthy, massive; weathers into "stone babies"; not well exposed	142
8. Sandstone, fine to coarse grained, ripple-marked and cross-bedded; purple, green-gray, chocolate-brown; seamed with gypsum; forms a strong persistent ledge	11½
9. Mudstone, chocolate-brown, sandy, soft, indistinctly bedded; forms a slope broken by subdued ledges of slightly more sandy beds	33
10. Sandstone, red-brown, fine grained, somewhat shaly, ripple-bedded; gritty in parts, almost approaching a fine conglomerate; cross-bedded, somewhat lenticular; forms an irregular ledge	2½
11. Sandstone, brick-red and gray, thin bedded, ripple-bedded, alternating with chocolate-brown mudstone and shale in beds about 3 inches thick; upper 12 feet massive, poorly bedded and slightly contorted	68
12. Sandstone, massive, very gypsiferous; forms a ledge	2½
13. Silt, dark chocolate-brown, soft, sandy	4
14. Sandstone, shaly, massive, limy, seamed somewhat with selenite; toward top almost a sandy gypsum; forms a ledge	6
15. Sandstone, brick-red and gray, thin bedded, ripple-bedded, alternating with chocolate-brown mudstone and shale in beds averaging 3 inches in thickness except for a 2-foot sandstone ledge 16 feet from the base	48

Entrada sandstone—Continued.	Feet
16. Gypsum (alabaster), sandy; forms a ledge, though friable; selenite common in seams	1½
17. Sandstone, soft, friable; red-brown, earthy, fine grained, cross-bedded; weathers in rounded forms	3½
18. Sandstone, brick-red and gray, thin bedded, ripple-bedded, alternating with chocolate-brown mudstone and shale in thin beds	24
19. Gypsum, like No. 16	2½
20. Series of alternating beds of poorly bedded red silty sandstone, forming ledges, and dark chocolate-brown blocky, shaly sandstone which forms niches; a few ½-inch limestones. Each individual layer is poorly bedded but persistent, giving the cliff the appearance of the edges of the leaves of a book	12
21. Gypsum like No. 16	2
22. Alternating beds like No. 20	19
23. Sandstone, red-brown, massive; forms a slope	32
24. Sandstone, red-brown, massive; forms a ledge	10
25. Sandstone, dark red-brown, shaly; bedding apparent and very even when viewed in the large but invisible in the hand specimen; a very gypsiferous zone at 42 feet above the base	61
26. Concealed by valley fill	155
27. Sandstone, light brick-red, ledge-forming, can be traced for miles	29
28. Sandstone, dominantly brown, but with some gray shaly layers; gypsiferous, soft, friable; weathers into a banded slope like a shale; at places along strike stands in cliffs	136
Total Entrada sandstone	843½

Contact conformable; a sharp lithologic change only at this horizon.

Carmel formation:	Feet
29. Gypsum, orange-red, porous, silty	3½
30. Silt, red-brown, with some purple shale and much secondary gypsum	3
31. Sandstone, shaly, red-brown; forms a ledge	½
32. Shale, green-gray, flaky	10½
33. Gypsum, pink, with some green silt and chert	½
34. Silt, red-brown, passing into green-gray shale	3½
35. Gypsum, porous, impure, and green silt with much secondary chert	½
36. Shale and sandstone, greenish gray, ripple-bedded, lenticular	5
37. Gypsum and silt, like No. 35	1
38. Shale and sandstone, like No. 36	10
39. Silt, red-brown, gypsiferous	7
40. Gypsum, impure, with much green silt; bedding highly contorted	4½
41. Silt, red-brown at base, passing up into greenish-gray flaky, somewhat sandy shale, with some ripple-bedded lenticular sandstone at about 25 feet above the base	31
42. Gypsum, impure, banded with green silt; some pink selenite crystals	6
Carmel formation—Continued.	
43. Shale, green, alternating with a minor amount of chocolate-brown silt; some selenite seams	5
44. Alternating green sandstone and shale, thin bedded, ripple-bedded throughout; shale predominant. Ripples trend N. 60° E., of current type and indicating current from west	19
45. Silt, chocolate-brown, unconsolidated	2
46. Gypsum, contaminated with much red and green silt	1
47. Shale, greenish gray, well laminated, with some lenses of sandstone	1½
48. Sandstone, limy, thin bedded (average one-fourth inch), oscillation-ripple marked throughout (trend N. 40° E.)	1
49. Shale, greenish gray; with subordinate very thin sandstone lenses; ripple-bedded throughout	11
50. Sandstone, friable, poorly bedded, oscillation-ripple marked, somewhat shaly; contains both light and dark mica and includes a few thin lenses of greenish shale	20
51. Shale, green, maroon, and chocolate-brown, alternating	6½
52. Gypsum, impure, with much green silt and secondary jasper	1½
53. Silt, red	9
54. Shale, green	7
55. Gypsum, impure, with green and red silt and jasper crusts	2½
56. Silt, reddish brown, gypsiferous	2
57. Gypsum, pink, impure	1
58. Shale, green	6
59. Gypsum, greenish, impure, with green silt and some pink selenite	2½
60. Shale, green	4½
61. Gypsum, like No. 59	1
62. Shale, green	9
63. Gypsum with much interbedded green shale	1
64. Shale, green	2
65. Alternating gypsum, green-gray rippled sandstone, and subordinate flaky green-gray shale; more gypsiferous in upper part	7
66. Shale, green, becoming sandier upward and passing into poorly bedded shaly sandstone at the top	51
67. Gypsum, snow-white, mottled with small aggregates of greenish and red silt; many selenite seams 1 inch thick cutting across and parallel to the bedding planes	4½
68. Shale, greenish, with some blue; highly gypsiferous and seamed with selenite	18
69. Gypsum, impure, largely reddish brown with some green, persistent	6
70. Shale, green, with some soft greenish-yellow fine-grained sandstone; about 70 per cent shale	32
71. Gypsum, impure, with irregular beds of green limestone and shale at the base; a layer of soft yellow shaly unconsolidated sand 10 to 12 feet above the base; white gypsum containing pockets of yellow sand above that to top of member	28
72. Shale, lenticular, greenish gray, flaky	2

Carmel formation—Continued.	Feet
73. Sandstone, yellow, soft, fine grained, very friable except at the top; weathers a peculiar yellow-brown	1
74. Gypsum, spongy, crystalline, white, with much yellow clay and silt distributed through it	11
75. Shale and shaly limestone, greenish gray, veined with gypsum along and across the bedding; passes completely into limestone within 100 feet along exposure and then into gypsum 150 feet farther on	3½
76. Shale, greenish gray, limy, with some secondary gypsum	7½
77. Gypsum, largely pink selenite, streaked with green silt	1½
78. Silt, unconsolidated, red-brown, highly gypsiferous	5
79. Shale, green-gray, limy, seamed with greenish gypsum, especially near the top	7
80. Gypsum (alabaster) containing isolated crystals of selenite as much as three-eighths inch long; thickness variable	3–7½
81. Mudstone, reddish brown, much fractured and jointed; cracks filled with fibrous selenite, at some places 2½ inches thick, associated with jasper crusts; some greenish shale and sandstone in upper part	12
82. Gypsum (impure alabaster) with shale streaks and selenite, as in No. 80	5
83. Shale, green	3½
84. Gypsum, like No. 82	6
85. Shale, limy, platy, very thin bedded	13
86. Sandstone, greenish gray, fine grained, ripple-bedded, with some green silt along the bedding surfaces; finely laminated in upper part; forms ledge	2½
87. Shale, gray, limy, platy, weathering almost white, and thin lenses of ripple-bedded greenish-gray sandstone, increasing upward. Unit seamed with selenite, some of which has altered to chert	22
88. Limestone, variable; in places oolitic, in places dense or sandy, even a shaly sandstone; passes from one phase to the other both across and along the bedding; forms a strong ledge, the top 8 feet being a persistent dense limestone; breaks into slivers usually, though locally platy; fossiliferous; *Trigonia* and *Camptonectes* especially plentiful	78
89. Gypsum and green-gray sandy shale and sandstone, greatly contorted on a small scale, especially around gypsum nodules in the shale and sandstone; about 25 per cent gypsum	2
90. Sandstone, greenish gray, weathering brown, shaly, very fine grained, poorly bedded; weathers into rounded forms. Some subordinate layers of clean sandstone show cross-bedding on a small scale	12
91. Sandstone, gray, clean, mostly limy but siliceous in places, thin bedded, cross-bedded on a small scale; forms strong ledge	2½
92. Shale, greenish gray, micaceous, unctuous, and some subordinate thin lenses of greenish-gray limy ripple-bedded sandstone	9
93. Conglomerate or breccia, largely of flint pebbles but with some clear and some milky quartz 1 inch in largest dimension, poorly sorted; unit cavernous but firmly cemented	½
94. Gypsum, impure, yellowish gray, with much limestone and shale; somewhat spongy in texture	2½
95. Sandstone, reddish brown, fine grained; soft, almost unconsolidated in lower part; gray and slightly better cemented above	18
96. Sandstone, yellowish gray, very irregularly bedded and including pockets of maroon shale; soft at base, harder and better bedded toward top, a hard, limy greenish-gray ledge 2½ feet thick	12½
97. Sandstone, shaly, poorly bedded; weathers into rounded forms below and slabs above; persistent limy zone at top	14
98. Sandstone, blue-gray weathering dark brown; hard, limy, somewhat shaly but resistant; beds about 2 inches thick	3
99. Shale, dark blue-gray, carbonaceous, with some thin, very limy ripple-bedded lenticular sandstones and sandy limestones; some reddish-brown iron concretions near the base; shale constitutes 85 per cent of unit	7
100. Limestone (a coquina in places) and shale, alternating in beds about 2 inches thick; some rill marks in the limestone, which is very vuggy	1
101. Shale, greenish gray, carbonaceous, well laminated, almost black on fresh exposure, weathering with dark reddish-brown streaks	1
102. Limestone, dense, very hard, with some shale containing red calcite blebs; forms a strong ledge; fossiliferous; *Trigonia* and *Camptonectes* especially common	2
103. Shale, green-gray, carbonaceous, limy, in some places slightly sandy; blocky in lower part, platy above; forms a slope	7½
104. Sandstone, dark reddish brown, limy, varying to sandy limestone and in some places a clean, dense purple limestone, extremely fossiliferous; forms a strong persistent ledge	2½
105. Limestone, gray, dense in some places, oolitic in others; very hard; forms a ledge; fossiliferous, locally almost a coquina	1
106. Shale, limy, gray, varying to soft, well-laminated shaly limestone; fossiliferous; forms a slope	4
107. Shale, sandy, greenish gray, varying to thin-bedded soft sandstone; both limy and veined with selenite; fossiliferous; forms a slope	2½
108. Sandstone, evenly bedded, fine grained, tan, limy, very resistant; forms a ledge; composed of reworked Navajo sandstone	11
Total Carmel formation	648–652½

Unconformity, cutting cross-bedding of Navajo sharply.

5. *Section of Dakota (?) sandstone and Morrison formation in terrace 2 miles south of Willow Springs Wash, west flank of San Rafael Swell, Utah*

Mancos shale.

Apparent conformity.

Dakota (?) sandstone:	Feet
1. Sandstone, yellow-gray, cross-bedded, ripple-marked, gritty; in two beds separated by 3 feet of dark-gray carbonaceous shale	13

Unconformity; contact a scoured surface.

Morrison formation:	
2. Mudstone, purple variegated with white, bluish gray, maroon, and reddish brown; contains many small lenses of nodular silicified limestone, caliche-like zones, and thin sandstone lenses, some conglomeratic, none over 2 feet thick and a few scores of feet wide	189
3. Conglomerate and sandstone, brownish gray, very hard, lenticular	8
4. Mudstone, like No. 2, rather limy; at 46 and 55 feet above the base nodular jasper lenses 1 foot thick	124½
5. Chert and jasper, nodular; interbedded with bentonitic (?) clay and poorly bedded light-gray coarse sandstone, which is only partly cemented	5½
6. Mudstone, dominantly purple, gray, and maroon; contains some thin nodular silicified limestone, a few thin lenticular sandstones, and at 12 feet above the base a persistent 2 to 4 foot limestone	86
7. Sandstone of lenticular "channel" type; very limy and cherty	1–5
Total Morrison formation	414–418

Summerville formation: Thin-bedded orange-red shaly sandstone and sandy shale with some interbedded thin gray limy sandstones.

6. *Section in gulch southwest of Drunk Man's Point, San Rafael Swell, Utah*

Summerville formation (part):	Feet
1. Alternating thin-bedded lilac to brick-red clays and soft gray sandstone	18

Curtis formation:	Feet
2. Sandstone, gray, soft; forms a slope except the bottom 6 inches, which is platy and forms a ledge; some thin dark-green cross-bedded sandstones and a little purple shale are interbedded; upper 3 inches contains shale pellets	11
3. Sandstone, green-gray, soft except for a basal ledge-forming bed	6
4. Sandstone, green-gray, soft, with a few harder beds but no ledges; forms slope	11½
5. Sandstone, green-gray, concretionary, limy; forms ledge	1
6. Sandstone, light greenish gray, soft, nonpersistent	8
7. Sandstone, green-gray, weathering brown, ripple-bedded, very hard and limy, concretionary; forms a ledge	1
8. Sandstone, green-gray, weathering brown, medium to coarse grained, massive; bedding indistinct, with some ripple-marked surfaces; weathers into biscuit-shaped limy masses; contains some carbonaceous seams, and a rather resistant 4-foot bed about 30 feet above the base; cross-bedding more evident above this bed than below it	88
9. Sandstone, shaly, greenish gray, soft, much cross-bedded; true bedding irregular, rarely evident; carbonaceous, especially along certain seams; secondary seams of selenite common; some rusty strata interbedded	9½
10. Sandstone, green-gray, very hard, firmly cemented, medium grained; contains pellets of green shale as much as 1 inch long and three-eighths inch thick and much carbonized vegetable matter; forms ledge	3½
11. Sandstone, greenish gray, fine grained, blocky; no evident bedding	2½
12. Shale, green-gray, poorly laminated; limy, with some concretions and many selenite seams; some thin ripple-bedded sandstone lenses as much as three-fourths inch thick	5
13. Sandstone, massive, silty, cross-bedded throughout, lime-cemented, some secondary gypsum seams; carbonaceous in places	4
14. Shale, greenish gray, and lenticular ripple-bedded sandstone alternating in thin beds; unit sandier toward the top	6
15. Sandstone, very limy, ripple-bedded; upper half forms a ledge; lower half soft and slightly shaly; not persistent	1½
16. Shale, green-gray, in places concretionary, containing many beds about half an inch thick of lenticular cross-bedded fine gray sandstone. This unit grades into sandstone within a quarter of a mile along the exposure	15
Total Curtis formation	173½

Unconformity; surface of Entrada sandstone covered with veneer of pebbles of black chert and gray limestone, which are somewhat embedded in the sandstone in places; the surface was exposed to weathering and then reconsolidated. Contact surface strikes N. 7° E. and dips 3½° W.

Entrada sandstone: Sandstone, red-brown, earthy, massive, thick bedded, strike N. 20° E., dip 2½° W., exposed to level of Salt Gulch, at least 400 feet.

7. *Section in Saddle Horse Canyon, San Rafael Swell, Utah*

Navajo sandstone: Sandstone, buff to yellow-gray, massive; cross-bedded on a very large scale; forms vertical cliff.

Transitional contact.

Todilto (?) formation:	Ft.	in.
1. Shale, green, very sandy	1	
2. Sandstone, white to greenish gray, much cross-bedded; contains a few shale pellets, shale lenses, and small limonite concretions	4	3
3. Shale, green, passing by gradation into No. 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

Todilto (?) formation—Continued.	Ft.	in.
5. Shale, maroon, clayey		6
6. Sandstone, like No. 4		6
7. Shale, green at base, passing up into maroon; flaky		8
8. Sandstone, buff, tangentially cross-bedded; weathers into benches and slopes—the benches made by thin laminæ containing small shale particles and spherical limy nodules one-sixteenth to one-fourth inch in diameter	12	6
9. Sandstone, white and tan, containing green shale pellets; 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 a foot	8	
11. Sandstone, white, very micaceous, ripple-marked throughout, cross-bedded, with chiefly angular but some tangential cross-bedding at angles as great as 28°; contains many comminuted fragments of green shale	2	
12. Shale parting, green		2
13. Sandstone, pink, in beds averaging 6 to 8 inches thick with thinner bedding at bottom and top	5	
14. Sandstone, in alternating laminae of pale red and white, carrying small fragments of green shale; fine grained, cross-bedded; has a very limy layer with hummocky surface about 6 inches below the top; top 6 inches a micaceous shale conglomerate with shale pebbles as much as 2 inches in diameter, though the average is about three-eighths inch	6	
15. Shale, maroon, slightly sandy	1	
16. Sandstone, light red, with a few partings of maroon shale; carries pellets and flakes of allochthonous green shale; top 2 inches bleached white	2	
17. Shale, maroon, like No. 15		6
18. Sandstone, of the channel type, torrentially cross-bedded, and containing flakes of green shale as large as 2 inches by three-eighths of an inch; extremely variable along the strike; very resistant; forms a ledge	2	6
19. Sandstone; lower 40 feet massive, gray, coarse grained, tangentially cross-bedded, containing large flakes of muscovite and a few shale pellets, which lie at all angles to the bedding, though prevailingly parallel to it. The massive sandstone passes into red micaceous very thin-bedded sandstones and above them through much cross-bedded material carrying flakes of green shale into well and evenly bedded, dominantly light brick-red sandstone with alternating white bands a quarter of an inch to 10 inches thick. This red and white sandstone is rather friable and contains fragments of a green mineral, quartz, magnetite, sporadic mica, and some chlorite with very little silt; in uppermost 15 feet lamination is poorer and ferruginous and limy concretions occur	87	6
20. Sandstone, brick-red, bleached green along joints and in uppermost foot; very micaceous, very fine grained, extremely thin bedded but well bedded; ripple-marked on a small scale. The unit is cut out by scour within a quarter of a mile in one direction from the point of measurement and within 2,000 feet in the other, the sandstone above descending in both directions; bedding surfaces in the uppermost foot continuous from the normal red to the green weathered layers, though the green layers are somewhat brecciated from weathering	9	
21. Sandstone, white, friable; has a surficial pink tinge due to wash from upper part of Todilto (?) formation; contains throughout pellets of green shale ranging from those of microscopic size to pieces 3 inches by half an inch; these weather out on the surfaces and leave pits; bedding thick, somewhat thinner at bottom; unit shows angular cross-bedding at angles as high as 17° and some tangential cross-bedding. In basal part of unit the sand is interlaminated with shale and there are channels as much as 5 feet deep cut in unit 22. At 15 feet above base a short lens of green shale and at same horizon a shale conglomerate with chunks 6 inches long. Unit forms a persistent ledge crowning the Wingate sandstone cliff for miles	31	
22. Shale, green, flaky, persistent; ranges in thickness from 2 feet to 2 inches	1	
Total Todilto (?) formation	181	5

Contact shows some channeling, but no observable angular unconformity.

Wingate sandstone:	Ft.	in.
23. Sandstone, buff, cross-bedded; massive, except for a few thin water-laid beds; forms sheer cliff	139	
24. Sandstone, gray, in one cliff-forming bed with tangential cross-bedding	34	
25. Sandstone, soft, thin bedded, almost laminated; alternating yellow-gray and light red in thin lenses; contains bands of cone-in-cone calcite	7	
26. Sandstone, buff; massive, with tangential cross-bedding	43	6
27. Sandstone, white, thin and thick bedded, softer than most of the formation; forms a distinct bench	12	
28. Sandstone, buff, with tangential cross-bedding cut off at all angles; almost certainly wind-laid	73	
29. Sandstone, buff, thick bedded, calcareous, with some subordinate thin-bedded water-laid material. A few thin lenses of dense cherty limestone occur on the opposite side of the canyon at this horizon but do not appear on the near side	11	
30. Sandstone, gray-buff, composed of rounded grains; cross-bedded very irregularly on a large scale; a typical dune deposit	30	6
Total Wingate sandstone	350	

	Ft.	in.
Unconformity, channeled surface.		
Chinle formation:		
31. Clay shale, light blue-green, passing up into green sandstone in 2-inch beds and shale, capped by a 2-inch bed of bright-green sandstone	7	2
32. Shale, flaky, dark red; contains no sand; a thin band of green shale at the base	3	6
33. Sandstone, red, containing shale pellets as much as 1 inch in diameter, ripple-marked throughout, cross-bedded. This bed increases to about 15 feet in thickness within 300 feet along the outcrop	4	
34. Limestone conglomerate; contains fragments of green and red shale and sandstone	1	3
35. Shale, maroon, micaceous, with the mica along the bedding planes	5	3
36. Sandstone, red, in beds one-sixteenth to one-fourth inch thick, ripple-bedded and cross-bedded throughout; very micaceous	5	
37. Shale and sandstone, the shale brick-red; the sandstone green and very subordinate, no bed thicker than about 1 inch, except for a 1-foot sandstone ledge at 11 feet from the base. This member lenses out completely within 300 feet along the outcrop	20	
38. Sandstone, gritty, containing shale pellets; the lower 2 feet massive and red, then a red shale parting, and the upper foot thin bedded and red, with 1 inch of green-gray sandstone at the top	3	
39. Shale, brick-red	3	
40. Sandstone, gritty, at some places all one bed, at others in 6-foot to 8-foot beds; contains conglomerate lenses composed of limestone pebbles half an inch long, micaceous green sandstone fragments 1 inch long, and shale pellets and flakes as much as 3 inches long; a green mineral prominent; forms a persistent ledge	18	
41. Sandstone, dark greenish gray, weathering purple; blocky, limy, extremely fine grained, massive; weathers into mammillary forms; upper contact wavy, the irregularities as much as 3 inches in height	3	
42. Alternating green sandstone and brick-red shale, becoming more limy upward	9	
43. Sandstone, greenish gray, in beds less than one-sixteenth inch thick, very fine grained, ripple-marked and cross-bedded throughout; individual beds lens in and out very rapidly, 6-inch beds disappear within 8 feet; some angular and some tangential cross-bedding present; bedding is much contorted and bends down as much as 3 inches beneath limy lumps; manganese dendrites common	2	
44. Shale; lower third dark green, weathering to purple, almost black; upper two-thirds brick-red, weathering brown-red; very limy throughout	25	6
45. Sandstone, mottled brick-red and green, the green color apparently confined to walls of fractures; very fine grained, very limy; massive, forms ledge; passes upward by gradation into No. 44	7	
46. Shales and sandstone, brick-red; the shale blocky, somewhat sandy, very calcareous, and in beds three times as thick as the sandstone beds	2	
Chinle formation—Continued.		
47. Sandstone, very fine grained, very hard, limy		8
48. Sandstone and shale, alternating; about 80 per cent sandstone, dark brown and chocolate-red, thin bedded, ripple-marked, limy; 20 per cent maroon shale	6	
49. Sandstone, green-gray, rippled, and cross-bedded		4
50. Shale, maroon	2	
51. Sandstone, red, micaceous, fine grained, cross-bedded; at the top weathers gray, and contains green flakes resembling chlorite and muscovite, the muscovite flakes as much as one-sixteenth inch long; one lens with beds less than half an inch thick, all the rest thick bedded. At 50 feet away along the strike, this sandstone and the underlying conglomerate, No. 52, are one bed of sandstone with a thin conglomerate lens in the middle, the whole 6 feet thick	3	
52. Conglomerate; contains quartz grains; very limy, subangular and well-rounded pellets of red shale nearly three-fourths inch in maximum diameter; much crystalline calcite; and a few chert pebbles; beds 2 to 6 inches thick; unit locally massive	2	
53. Shale, maroon in distant view, reddish chocolate-colored in the hand specimen; biotitic, muscovitic, slightly sandy; broken at 3, 5, and 18 feet above the base by sandstone beds 8 inches to a foot thick	29	3
54. Sandstone, green-gray, stained somewhat with limonite; hard, ripple-marked, slabby, in beds one-eighth to one-fourth inch thick; contains rose quartz, muscovite, and magnetite	2	2
55. Shale, green-gray, flaky; slightly sandy, with a few thin gray sandstones—one bed 3 inches thick, with shale flakes in it as much as 2 inches long, cross-bedded and rippled. This sandstone on fresh fracture is mottled gray and brown (the brown from limonite) and contains quartz, muscovite, and a green mineral as common constituents	5	
Total Chinle formation	169	1
Contact apparently conformable.		
Shinarump conglomerate:		
56. Sandstone, gray, medium grained, thick bedded, siliceous, resistant	8	
57. Conglomerate, dark brown, extremely hard and well cemented with silica and lime; pebbles as much as 4 by 2 inches but averaging half an inch in diameter, predominantly of well-rounded white chert with milky quartz, gray crystalline limestone, opaline silica, brown chert, rose quartz, jasper, flint, gray sandstone, and green shale in angular fragments. Rock breaks across the pebbles at many places and forms a strong ledge. Many plant and bark fragments as much as several inches in length, some carbonized, are present, and carnotite stains are associated with the siliceous and carbonized wood	9	6
58. Shale, green-gray, flaky, without sand, and with broken carbonized plant remains	5	6

Shinarump conglomerate—Continued.	Ft.	in.
59. Sandstone lens, gray, massive; thins out laterally	6	
60. Conglomerate, like No. 57	1	6
61. Sandstone, gray, weathering light brown; massive, grading into No. 62	5	
62. Conglomerate, like No. 57, grading up into No. 61	2	
63. Sandstone, like No. 57, but with fewer and smaller pebbles	5	
64. Shale, gray, nearly a clay; forms a slope	9	
65. Sandstone, gray, like No. 61	2	
66. Sandstone and conglomerate alternating; varies much laterally and vertically; beds average perhaps 3 feet in thickness; top 6 inches is thin bedded and shows ripple marks and cross-bedding. Unit forms a strong ledge	9	6
67. Sandstone, medium to fine grained, made up largely of quartz and some black grains not determinable with the hand lens; somewhat softer than the beds above and below	3	8
68. Sandstone, gritty, with sporadic pebbles of same sort as in No. 57, cross-bedded at angles with the true bedding as high as 20°, well cemented, somewhat mottled with brown on gray, highly variable along the strike	1	6
69. Conglomerate, only partly consolidated, many pieces of silicified wood 4 inches or less in diameter and pebbles like those in No. 57. A white efflorescence as much as half an inch thick occurs at the top and bottom of this member and also in reticulating veinlets through it	2	2
Total Shinarump conglomerate	70	4

Unconformity; surface wavy, with a relief of about 6 inches in a length of 10 feet.

Moenkopi formation:		
70. Shale, gray and purple; a persistent zone seen throughout the area just below the Shinarump conglomerate, not typical of Moenkopi lithology, but here assigned to that formation	10	
71. Sandstone, red, typical Moenkopi, not measured.		

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

Mancos shale.

Dakota (?) sandstone:	Ft.	in.
1. Grit, gray, limy, cross-bedded, with iron concretions up to 1 foot in diameter; and conglomerate of 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	

Morrison formation:	Ft.	in.
2. Mudstone, variegated, light gray, blue-gray, and greenish gray	96	
3. Sandstone, slightly gritty, light gray, slightly friable, lime-cemented; subrounded grains of rose quartz, white quartz, and biotite make up the rocks; lenses out within 200 yards	3	6
4. Mudstone, very poorly laminated, light gray, gypsiferous	42	

Morrison formation—Continued.	Ft.	in.
5. Conglomerate lens, disappears within half a mile in one direction and 300 feet in the other; very little sandstone present	4	
6. Shale and clay, dominantly light gray banded with purple and mauve and with numerous 4-inch bands of dense blue-gray nodular limestone; forms a slope strewn with limestone and silicified limestone balls derived from these beds	93	
7. Conglomerate, with lenses of sand constituting as much as a third of the unit; persistent; contains well-rounded pebbles of flint with some jasper and brown chert, averaging three-eighths inch in diameter but as large as 2½ inches. Thickness varies by inclusion of lenses of shale and clay at some places and increases locally to 20 feet	6	
8. Shale and clay, variegated indigo-gray, light gray, and maroon; with some thin limestones, as in No. 6	66	
9. Limestone, green-gray, dense; much silicified, with chert lenses roughly parallel to the bedding and following joints, the chert evidently a weathering product; the bed is a lens disappearing within 100 yards along the strike	3	6
10. Clay, variegated gray, purple, red, and brown, with purple, maroon, white, and gray marl, brick-red shale, and sandstone in a few thin lenses 6 inches to 1 foot thick and rarely over 200 feet long, though at the corresponding horizon 100 yards away there are several thick sandstones which lens out before reaching this section	134	6
11. Sandstone, slightly gritty, cross-bedded; very lenticular, exposure less than 150 feet long	1	6
12. Marl, white	7	6
13. Clay, purple, limy, varying to slightly clayey limestone	9	
14. Shale and clay, variable, purple, micaceous, gypsiferous, passing along the strike into sandstone; fractured, with a white material resembling bentonite along the cracks and apparently interbedded with the clay	2	
15. Clay, white, brick-red, and purple, with a few thin limestones; passes upward into dead-white marl with a few shaly maroon limestones; under the microscope the clay proves to be an altered volcanic ash, approaching bentonite in structure	31	6
16. Sandstone, lenticular, grayish red, fine grained, irregular; contains lumps of marl and clay	1	6
17. Clay, red	9	
18. Clay, gray, with a bench of purple limestone at 15 feet from the base and a few thin sandstone lenses	22	
19. Marl, purple, containing limestone lumps	1	
20. Clay, gray-green, with lenticular thin sandstones and an 8-inch limestone	21	
21. Channel sandstone, cross-bedded, conglomeratic, with a siliceous cement; base irregular, with a relief of 2½ feet in a short distance; dinosaur bones at the top. Capping a winding ridge, the sandstone lens, nowhere over 100 yards wide, can be traced with northeast trend for miles and is clearly a fossil stream channel	9	6

Morrison formation—Continued.	Ft.	in.
22. Clay, light green-gray; at 7 feet above the base a persistent 6-inch ledge of blue-gray limestone, weathering brown	48	
23. Limestone, shaly, gray, weathering brown	1	6
24. Clay, gray	51	
25. Sandstone, conglomeratic, like No. 21; extremely variable along its northeast trend and lenticular across it; thins out and disappears in about an eighth of a mile along its course in one direction from the point of measurement, though it continues in the other for a long distance	13	6
26. Clay, gray with some purple; contains some lumpy marl weathering brownish purple	34	
27. Channel sandstone, like No. 21 but lensing out in both directions along its trend	13	9
28. Clay, gray, like No. 26; contains a 3-inch sandstone at 16 feet above the base	23	6
29. Channel sandstone, very lenticular; like No. 21 but not persistent; as much as 6 feet thick and lensing completely out within 500 feet	2	
30. Clay, light green-gray, pinkish gray, purple-gray, and tan; very subordinate shaly limestone and brown marl	6	
31. Channel sandstone with grit lenses; lenticular, although this horizon is sandy for long distances; some of the conglomerate pebbles are three-fourths inch in diameter, though the average is much less; a thin short lens of sandy marl 11 feet above the base	14	
32. Sandstone, white, friable; poorly bedded, somewhat shaly, lenticular, vanishing within a few score feet	1	6
33. Clay, blue-gray, becoming sandier upward and passing into No. 32	3	
34. Sandstone, like No. 32	1	3
35. Clay, gray, with some shaly limestone and thin sandstone lenses 4 inches thick and 30 feet long	16	6
36. Sandstone, cross-bedded, conglomeratic, pebbles as much as a quarter of an inch in diameter, largely of flint and gray chert	4	
37. Clay, like No. 30	21	
38. Limestone lens, nodular, sandy, with small chert pebbles scattered through it; thickens to 1½ feet and then lenses out in a short distance		6
39. Clay, gypsiferous, gray	4	
40. Gypsum (alabaster), with thin seams of green clay, contorted perhaps by hydration of the gypsum; contains jasper chert crusts of irregular shape as much as 2 inches in length, some with hollow centers filled with crystalline quartz; lower 10 feet forms a ledge, the upper part a slope	24	
Total Morrison formation	847	

Unconformity, angular and erosional; the gypsum cuts down across the bedding of the red shale and sandstone of the Summerville formation as much as 3 feet in 30 feet of outcrop.

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

9. *Section in gulch north of Horn Silver Gulch, in secs. 28–29, T. 20 S., R. 9 E., San Rafael Swell, Utah*

	Ft.	in.
Curtis formation (part): Conglomerate of pebbles of gray sandstone as much as 1½ inches long and well-rounded chert pebbles in a green-gray sandstone matrix, cross-bedded and interfingering with thin shales.		
Unconformity, angular and erosional.		
Entrada sandstone:		
1. Sandstone, green and red, top part scoured and checked, containing pebbles of chert and shale; a consolidated soil	3	
2. Shale, green, flaky		2
3. Sandstone, shaly, massive, limy; weathers in rounded forms	9	
4. Shale, maroon, with a few thin lenses of green-gray sandstone	7	6
5. Sandstone, red-brown, very shaly and soft, thin bedded; top few inches bleached green-gray	6	
6. Sandstone, clean, very fine grained, cross-bedded and ripple-marked		2
7. Shale, maroon, with a few lenses of very fine grained green-gray sandstone one-eighth to one-sixteenth inch thick	1	3
8. Sandstone, mostly red-brown but green at top and bottom; a 2-foot subdued ledge at the base, shaly and thin bedded above	11	
9. Shale, maroon	1	
10. Sandstone, shaly, red except the top, which is bleached	7	
11. Sandstone, red-brown except for gray bleached zone at the bottom; upper 3 feet is shaly and thin bedded, forming a slope; remainder massive	15	3
12. Clay, purple, limy		6
13. Sandstone, red-brown except at the top, where it is greenish gray; massive and weathers in rounded forms like a granite	4	6
14. Sandstone, red-brown, very silty, massive; forms a bench	20	
15. Shale parting		1
16. Sandstone, red-brown, massive, soft and silty but forms a bench	9	6
17. Sandstone, thin bedded; forms a slope	3	
18. Sandstone, massive, like No. 14	55	
19. Sandstone, very soft and shaly, brown-red	3	
20. Sandstone, dark red, with cavities containing calcite and chert	1	6
21. Sandstone and shale, thin bedded, extremely wavy, limy; contains crusts of red chert in geodes and along fractures	2	
22. Sandstone, like No. 14	6	
23. Sandstone, dark red, thick bedded except 1 foot of shaly material at the top	28	6
24. Shaly sandstone with much red chert in crusts and geodes	1	
25. Sandstone, like No. 14, except that the upper foot is a strong ledge	4	6
26. Sandstone, red-brown, poorly bedded, ripple-marked; cross-bedded; top surface hummocky; uppermost 2 feet forms a ledge; remainder shalier	5	
27. Sandstone, light gray, ripple-marked, fine grained	2	6
28. Sandstone, shaly, red-brown; contains a ledge of green-gray cross-bedded, current-rippled cleaner sandstone; coarse grained, with some large well-rounded quartz grains and fine chert, almost a fine grit	12	

Entrada sandstone—Continued.	Ft.	in.
29. Sandstone, red-brown, mostly shaly but with a 2-foot ledge at the top	13	
30. Sandstone, brownish gray, shaly, poorly bedded, gypsiferous; lenticular, thinning within a few feet along the strike	2	
31. Shale, very thin bedded, micaceous, slightly sandy; contains some greenish gray and some red sandstone, poorly bedded, soft, limy	10	
32. Sandstone, gray-brown, gypsiferous, limy; very irregular lower boundary, with relief of 1 foot in 10 feet, perhaps due to variable cementation but not to channeling; forms a ledge	2	
33. Sandstone, shaly, dark red-brown, thin bedded, lenticular	9	6
34. Sandstone, brown-gray, gypsiferous, shaly, cross-bedded; in thin irregular beds 1 inch thick but weathers as one massive layer	6	6
35. Shale parting		8
36. Sandstone, gypsiferous, shaly, cross-bedded; like No. 34	1	6
37. Shales, micaceous, chocolate-brown, in beds from 6 to 18 inches thick; alternating with green-gray sandstone in beds less than 2 inches thick, ripple-marked, cross-bedded, lenticular; gypsum seams, largely parallel to the bedding, as much as three-eighths inch thick, are abundant in the upper part	13	
38. Sandstone, gray, thin bedded, cross-bedded, with gypsum seams, lenses out along the bedding	2	6
39. Sandstone, red, thin bedded, shaly, with numerous seams of secondary gypsum; cross-bedded and ripple-marked throughout	62	6
40. Shale, dark brown, micaceous, slightly sandy		2
41. Sandstone, white, coarse grained, capped by silicified platy layer; forms a very persistent ledge		6
42. Sandstone, red, thin bedded, apparently thick bedded toward the top	26	6
43. Sandstone, white, ripple-marked, cross-bedded, medium grained; contains large plates of biotite and also selenite crystals in cavities; forms a small ledge		3
44. Sandstone, soft, red, thin bedded, with much secondary gypsum	116	
45. Concealed interval interpreted as the basal part of the formation, as the next outcrops are gypsum beds typical of the Carmel formation	32	
Total Entrada sandstone	518	6

Carmel formation.

10. *Section on south side of Sawtooth Butte, San Rafael Swell, Utah*

Chinle formation (part):	Ft.	in.
1. Shale, maroon, micaceous; contains a number of thin lenses of green-gray ripple-marked fine-grained, extremely micaceous sandstone	5	

Contact displays no angular discordance or notable erosion.

Shinarump conglomerate:	Ft.	in.
2. Sandstone, conglomeratic at the top, and shale; beds very lenticular and much channeled; unit shows tangential and angular cross-bedding; forms a strong ledge. Beds of conglomerate and sandstone from 6 inches to 3 feet thick, very hard, with lime cement; pebbles of the conglomerate include quartz, chert, green shale, and fine sandstone. Shale lenses green, very lenticular, well laminated; contain rounded quartz pebbles around which the laminae are curved	7	
3. Shale, micaceous, maroon except the top 6 inches, which is green	8	
4. Sandstone, thin bedded, cross-bedded, medium grained; increases to 4 feet in thickness in 100 feet along the strike; forms strong ledge	2	
5. Sandstone, gray, medium grained, with silicified wood; thin parting of red shale in the middle	5	6
6. Conglomeratic sandstone, medium gray, with much dark mineral (biotite?) in the sand; cross-bedded, with laminae of alternating coarse and fine sand with sporadic pebbles of black chert, and red, white, and colorless quartz as much as 1½ inches in diameter. Upper surface irregular, relief of 6 inches in a length of 6 or 8 feet. A persistent layer at the top contains chunks of shale as large as 6 by 6 inches by 1 foot	2	3
7. Conglomerate; pebbles of quartz and limestone 1½ inches or less in diameter in a matrix of coarse granular sandstone	2	6
8. Clay, limy, lumpy, approaching a marl; dark blue except top 1½ feet which is greenish gray	13	6
9. Grit, light gray, weathering reddish brown, cross-bedded; individual beds not persistent, averaging 6 inches thick and 30 feet long; very hard, cemented with both calcite and silica; forms a ledge	1	
10. Shale parting, green		6
11. Grit, like No. 9	2	6
12. Grit, reddish brown except where leached and and blotched with white and green; unconsolidated, the sand grains about one-sixteenth inch in diameter and largely white, colorless, and rose quartz; contains much clay, which seems to be in transported lumps and breaks with very brilliant fracture surfaces; upper surface irregular	3	
13. Sandstone, with angular quartz grains, very light pinkish gray, cross-bedded; decidedly lenticular, pinching out in 50 feet; forms a ledge	1	
14. Grit, not well consolidated, micaceous, with some shale particles; purple-gray, somewhat mottled	1	3
15. Sandstone, very light gray, fine grained, very limy; forms a ledge	4	
16. Clay, sandy, nodular, in lumps about the size of an egg; purple, mottled with blue and brown, probably colored by manganese and iron; wavy, irregular upper surface	21	6

Shinarump conglomerate—Continued.	Ft.	in.
17. Sandstone, reddish brown spotted with gray, limy and ferruginous; in concretionary masses 1 foot by 2 inches; largely quartz, stained with some yellow mineral	6	
18. Clay, sandy; purple at a distance, mottled gray on close view, with some yellow mineral stains	5	
19. Conglomerate, very carbonaceous, not very well cemented; chiefly of coarse angular quartz with some gray detrital calcite, some carbonized wood fragments as large as 2 by 7 inches, some detrital asphaltite with stringers of red mineral fragments and some thin shale lenses with plant remains	13	
20. Shale, black, carbonaceous, gypsiferous, with carbonized wood fragments and leaves and some yellow mineral stain	3	
21. Shale, fine-grained sandstone, and medium-grained sandstone, in interfingering lenses as much as 4 inches thick; much carbonized wood and sedimentary asphaltite; sand grains and asphaltite particles largely angular	2	
Total thickness of Shinarump conglomerate	104	6

Contact with no angular discordance nor marked erosion.

Moenkopi formation: Shales and sandstones, gray, ripple-marked, limy, with small fragments of carbonized wood.

11. *Section at mouth of Buckhorn Wash, San Rafael Swell, Utah*

Wingate sandstone: Sandstone, tinged with green at the base for 2 feet, above which it is buff; stained red on the surface with wash; massive, cross-bedded, with only 8 or 10 bedding planes in over 350 feet of strata.

Unconformity. The lower few feet of the overlying formation is shaly and lenticular, in some places occupying scoured channels in the lower beds. There is no evidence in the San Rafael Swell of any diastrophism having occurred in the interval between the deposition of the Chinle and that of the Wingate formation.

Chinle formation:	Ft.	in.
1. Shale, limy, green and purple; showing scour, filling with sand, and later scour and filling with shale		4
2. Sandstone, greenish gray, ripple-marked, very micaceous, very limy; with a few shaly lenticular partings; shale flakes numerous	8	6
3. Shale, mottled greenish gray and chocolate-brown, well laminated; mud cracks evident		2
4. Sandstone, greenish gray, ripple-marked		2
5. Shale, like No. 3, much squeezed	2	
6. Sandstone, brick-red, becoming green-gray upward; limy and shaly; weathering into rounded forms	3	
7. Sandstone, green-gray, mud-cracked, ripple-marked; some shale pellets along bedding planes and some thin shale partings; the shale pellets reach 3 by 1 by one-fourth inch in size	1	6
8. Shale, maroon, with a few lenses as much as 2 inches thick of ripple-marked and rill-marked thin-bedded greenish-gray sandstone	3	
Chinle formation—Continued.	Ft.	in.
9. Sandstone, tan, fine grained, with some shale partings and numerous shale flakes one-half by one-half by one-eighth inch in maximum size; micaceous, limy, thin bedded, cross-bedded; forms a strong ledge, except the top 3 feet, which is very thin bedded and nonresistant	12	
10. Shale, red-brown, micaceous, and thin bedded ripple-bedded sandstone, alternating	1	6
11. Sandstone, greenish gray, very limy, with calcite along the fractured surfaces; ripple-bedded, rill-marked; containing many small shale pellets; upper surface mud-cracked	1	
12. Shale and sandstone, alternating, red-brown except along some joints, where they are leached to greenish-gray; sandstone micaceous, ripple-marked, cross-bedded; shale blocky, poorly laminated	2	6
13. Sandstone, green-gray, hard, limy, ripple-marked and rill-marked; calcite along joint surfaces; contains animal borings one-eighth to one-sixteenth inch in diameter	1	
14. Shale and sandstone, like No. 12	3	6
15. Sandstone, reddish gray at base, greenish gray at top; very fine grained, ripple-bedded, very limy; contains shale pellets as much as a quarter of an inch in diameter; forms a small ledge	2	
16. Sandstone, shaly, greenish gray; lenses out in 8 feet	1	6
17. Sandstone, reddish gray; massive in some places, one-fourth inch bedding in others; ripple-marked, mud-cracked, micaceous; forms ledge	3	
18. Mudstone, very sandy, chocolate-brown, micaceous	4	6
19. 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 an apparently massive but really thin-bedded ripple-marked, rill-marked greenish-gray sandstone with several shale conglomerate lenses whose shale fragments are less than 2 inches in diameter; in some places weathers into rounded forms, in others into thin plates due to the rippling; forms a ledge	12	
20. Shale, maroon, micaceous, lenticular; fades out laterally; upper surface scoured	1	6
21. 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	
22. Shale, maroon, micaceous, well laminated	11	
23. Sandstone, greenish, mottled with light red in places; contains fragments of green shale one-half by one-eighth inch scattered throughout; mud-cracked, rill-marked; thin bedded in lower part (one-eighth to one-fourth inch bedding), massive above, where it weathers into rounded forms; much calcite along joint surfaces; forms a ledge	16	6

Chinle formation—Continued.	Ft.	in.
24. Shales, green-gray, purple, and maroon, all well laminated; some are micaceous and have sheen, perhaps due to desiccation; mud-cracked; about one-fifth of bed is dark reddish-gray, fine-grained ripple-bedded sandstone, in lenses one thirty-second to one-fourth inch thick	4	
25. Sandstone, greenish gray, very limy, micaceous, ripple-marked, massive; lower contact is irregular, owing to reworking of No. 26; forms a ledge	1	
26. Limestone conglomerate, mottled purple and ash-gray, with some drab; limestone pebbles light gray and purple, the largest 2 inches in length; matrix a limy sandstone; whole bed forms cliff, weathers into nodular forms, and is much fractured and jointed	6	
27. Marl, red-brown, soft, slightly sandy, becoming sandier upward and containing some sand lenses; weathers into a slope	5	
28. 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	
29. 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 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; unit forms a slope	21	
30. Sandstone, drab, weathering light greenish gray; cross-bedded both angularly and tangentially; unit in one bed at this point, but 10 feet away along the strike it is all thin bedded; farther on it is interbedded with shale; forms a ledge	2	
31. Sandstone, reddish brown, thin bedded, ripple-bedded, with some greenish-gray lenses half an inch to 3 inches thick; interbedded with maroon micaceous shale; unit is 70 per cent sandstone; forms slope	5	
32. Sandstone, red-brown, blotched with green due to leaching; thinly laminated, ripple-marked, cross-bedded, very fine grained; weathers into small curved plates about a quarter of an inch thick; forms a ledge	3	6
33. Shale, brick-red, weathering chocolate-brown	7	6
34. Sandstone, drab, weathering light greenish gray, medium grained; carries muscovite, biotite, and magnetite but consists chiefly of rounded quartz; very limy, ripple-marked; in one massive blocky bed forming a ledge	1	9
35. Shale, maroon, micaceous, with many glistening surfaces, perhaps indicating desiccation	14	
Total Chinle formation	167	11

Contact a 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 which become less numerous upward.

12. *Section of Wingate sandstone in Cane Wash, San Rafael Swell, Utah*

Todilto (?) formation:	Ft.	in.
1. Sandstone, buff, in beds 5 to 10 feet thick, separated by thinner-bedded zone of alternating buff sandstone and green shale. The heavier sandstones are cross-bedded tangentially at steep angles, and in some places the bedding is much contorted as if by slumping due to water scour. Local shale conglomerates of chunks as much as 8 inches long arranged at all angles to the bedding, as well as thin green shale lenses as much as 12 feet long, formed in place, prove that this series was at least in part deposited in water	30+	
Contact gradational.		
Wingate sandstone:		
2. Sandstone, tangentially cross-bedded; very dark brown, nearly black, with impregnated petroleum	21	
3. Shale, green, well laminated, persistent for some distance		2
4. Sandstone and shale conglomerate; the angular shale chunks, arranged at all angles to the bedding, reach sizes of 1 foot by 5 inches by one-half inch, but most of the fragments are about a quarter of an inch long	5	6
5. Green shale and sandstone, containing much muscovite and chlorite, gypsiferous, thin bedded, very well laminated, lenticular, grades upward into No. 4	2	
6. Sandstone, buff, with a few black layers showing spots of asphalt (?) stain	71	
7. Sandstone, with tangential cross-bedding on a large scale, dominantly buff, but with much black, the cross-bedding surfaces separating the two colors	15	
8. Sandstone, mostly black but in part buff, with tangential cross-bedding dipping S. 80° E., S. 30° W., and N. 55° E., in various parts of the bed; some small black iron concretions at the top	39	
9. Sandstone, buff and black, in part tangentially cross-bedded and in part horizontally bedded; rippled 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
10. Sandstone, white, with lenses of black material, sharply cut off on horizontal surfaces by tangential cross-bedding in different directions	1	
11. Sandstone, black with subordinate buff; tangential cross-bedding	4	
12. Sandstone, buff, with a few black bands, not noticeably cross-bedded	12	6
13. Sandstone, black and buff, tangentially cross-bedded; forms a strong ledge	6	6
14. Sandstone, buff, with very subordinate black bands in lower part; tangentially cross-bedded, the planes dipping N. 60° W., S. 10° W., and N. 65° E.	20	
15. Sandstone, black, interbedded with buff; tangentially cross-bedded; varies somewhat in thickness but is persistent laterally	13	

Wingate sandstone—Continued.	Ft.	in.
16. Sandstone, buff, massive, with only two true bedding planes, one at 20 feet, the other at 83 feet above the base; strong tangential cross-bedding with the planes dipping in so many directions that no system is apparent; forms a bench	95	
17. Sandstone, light red, separable from No. 18 only by the color differences; tangentially cross-bedded at high angles; not persistent for more than 300 feet	10	6
18. Sandstone, buff, tangentially cross-bedded at high angles, the cross-bedding planes dipping S. 60° E., S. 40° W., and N. 20° E.; true bedding surfaces rare, one at 3 feet, one at 10 feet, and one at 23 feet above the base being the only breaks in an otherwise massive member	44	
(Beds 16, 17, and 18 are all deeply pitted with solution cavities, ranging in size from very small pits to hollows 3 feet in diameter, which apparently start along bedding surfaces but are not controlled by them in their development.)		
Total Wingate sandstone	364	8
Unconformity (?); contact shows only slight channeling.		
Chinle formation (part):		
19. Shale and thin sandstone, green, well bedded		6
20. Sandstone, buff, massive, limy, medium to fine grained, composed of quartz and an unidentified dark mineral; cross-bedded tangentially	3	
21. Sandstone, ripple-bedded, green-gray; and shale, well bedded, green.		

13. *Section of Moenkopi formation at north end of San Rafael Swell, Utah*

[Units 1 to 26 measured at mouth of Red Canyon; remainder north from head of Black Box Canyon]

		Feet
Shinarump conglomerate: Conglomerate and coarse sand; forms a vertical ledge.		
Contact shows no noticeable angular or erosional unconformity.		
Moenkopi formation:		
1. Clayey sand and sandy clay, 80 to 90 per cent sand; soft, forms slope		20
2. Sandstone, mottled gray and red, the red perhaps due to wash; very fine grained, composed chiefly of well-rounded quartz sand, mostly colorless, with sporadic large frosted glassy grains and some mica; flaggy in the middle, with a shale parting, but massive at top and bottom		24
3. Shale, dark red-brown, micaceous; very well laminated, ripple-marked and mud-cracked		2
4. Mudstone, chocolate-brown, with a few thin bands of green-gray sandy shale and red and green micaceous gypsiferous sandstone; secondary seams of gypsum as much as 1 inch in thickness		11
5. Sandstone, red-brown, flaggy, micaceous		5
6. Mudstone and sandstone, like No. 4		6
7. Sandstone, red-brown, limy, massive, ledge-forming		4
8. Mudstone and sandstone, like No. 4		16
9. Sandstone, like No. 5		4
10. Mudstone and sandstone, like No. 4		79
Moenkopi formation—Continued.		
11. Sandstone, like No. 7		10
12. Mudstone and sandstone, like No. 4		25
13. Sandstone, like No. 7		4
14. Mudstone and sandstone, like No. 4		15
15. Sandstone, like No. 7		3
16. Sandstone and mudstone, like No. 4		9
17. Sandstone, like No. 7		5
18. Mudstone and sandstone, like No. 4		61
19. Sandstone, dark gray, weathering light gray, micaceous; contains black, brown, and green grains, some of them perhaps hydrocarbons; concretionary, in beds half an inch to 4 inches thick with a few thin shale partings		42½
20. Shale, chocolate-brown to brick-red, micaceous, containing a few thin lentils of hard limy gypsiferous sandstone; the finer material darker than the coarser; 6-inch ledge of gray sandstone 64 feet above the base		126
21. Sandstone, red-brown, ripple-bedded, limy, micaceous, quartzose, with heavy iron stain; forms a strong ledge		9
22. Sandstone, buff at the bottom, brick-red above, with a wavy boundary between the colors; thin bedded except for one 2-foot blocky massive bed; lime-cemented, symmetrically ripple-marked		37
23. Shale, green-gray, micaceous, gypsiferous, well laminated; includes thin lentils of sandstone which constitute about 10 per cent of the member		21
24. Sandstone, gray, fine grained, shaly, gypsiferous, limy, ripple-marked; beds separated by green-gray well-laminated shale, which makes up about a fourth of the material at the base but is less abundant toward the top		27
25. Sandstone, brown-gray on fresh fracture, weathering dark brown, massive, fine grained, lime-cemented, cross-bedded on a small scale; weathers to a semiplaty débris but forms a strong ledge		9
26. Sandstone like No. 22, with about the same distribution of the colors		36
Sinbad limestone member:		
27. Limestone with a minor amount of sandstone, the two phases not sharply separated and passing gradually one into the other; the sandstone micaceous but not well bedded; the limestone dense, light gray to buff, stylolitic, containing dendrites of manganese and numerous rounded grains of quartz one-sixteenth of an inch in diameter; pelecypods and cephalopods abundant in some layers; unit contains oolite-like grains of asphalt	19	
28. Sandstone, gray, weathering brown, fine grained, micaceous, with calcite cement; massive, cross-bedded; weathers into thin plates and has a shaly parting in the middle	15	
29. Limestone, massive, dirty purplish gray, weathering light gray; dense, in part crystalline; breaks in irregular angular fragments; strongly petroliferous; very fossiliferous, brachiopods and mollusks numerous	11½	
Total Sinbad limestone member		45½

Moenkopi formation—Continued.	Feet
30. Shale, buff-yellow, limy and sandy; contains some edgewise conglomerate and is seamed and veined with gypsum; contorted on a small scale; forms a slope	7
31. Shale, gray, slightly sandy, gypsiferous, making up three-fourths of the unit; alternates in thin beds with dark-gray sandstone, weathering medium gray, ripple-bedded by symmetrical ripples 1½ inches long, and weathering into platy fragments. Except for dominantly sandy zones between 60 and 90 feet and between 120 and 130 feet above the base, no sandy beds exceed a few inches in thickness. The unit as a whole is soft, a slope former	146
32. Sandstone, buff-brown, limy, thin bedded, ripple-bedded, seamed with gypsum; fine grained, with about 30 per cent brown grains; forms a ledge	2½
33. Sandstone, yellowish-stained gypsum, and shale; the sandstone friable, of the type of No. 6	24½
34. Sandstone, light gray, thin bedded, fine grained, friable, limy; composed dominantly of white quartz with scattered grains of limonite; weathers into platy fragments	1½
35. Gypsum, yellow, interbedded with blue-gray well-laminated micaceous limy, sandy shale, which makes up about one-third of the unit	2
Total Moenkopi formation	839½

Unconformity, not well exposed.

Kaibab limestone.

14. *Section in Black Box Canyon, San Rafael River, San Rafael Swell, Utah*

Kaibab limestone.

Contact apparently conformable.

Coconino sandstone:	Feet
1. Sandstone, white to buff, sugary, in beds from 1 to 15 feet thick, cross-bedded, very uneven grained; gritty and definitely water-laid at the base, finer grained upward; very much jointed and weathering like an igneous rock, owing to the jointing and the inconspicuous bedding. The canyon receives its name from the prominent coating of desert varnish on the cliffs formed by this unit	662
2. Sandstone, buff, very limy, sugary and friable; gritty, with rounded grains of quartz and feldspar as much as one-eighth inch in diameter, set in a finer-grained matrix	3
3. Sandstone, buff, very limy at base, less so at the top; grades into No. 2 without a sharp break; fine grained, with much mica and some thin limestone lenses at the base	22
4. Limestone, buff, with some buff sandstone, largely massive, with some parts thin bedded; varies from sandstone to limestone along the strike, with some shaly material in both types; a 6-inch zone of limestone conglomerate 6 feet above the exposed base; quartz and calcite-filled geodes numerous, and some limonite pseudomorphs after pyrite; exposed to water's edge	26
Total Coconino sandstone exposed	713

15. *Section half a mile south of the head of Black Box Canyon of San Rafael River, San Rafael Swell, Utah*

	Feet
Moenkopi formation: Conglomerate, fine to coarse, with many angular and subangular chert and quartz pebbles; in 1-foot lenses, locally recurring in two beds 1 to 1½ feet thick separated by 5 feet of buff gypsiferous shale.	
Erosional unconformity, with a relief of about 15 feet in an area of 5 acres. The conglomerate occurs only in the hollows, the higher points being covered with green-gray gypsiferous shale. In some of the depressions a gritty white clay occurs, probably being derived from the decomposition of the Kaibab limestone in pre-Moenkopi time.	

Kaibab limestone:	
1. Limestone, light gray to cream-colored, weathering dark to light gray, containing some limy sandstone beds 1 to 9 feet thick which grade into true limestone; surface pitted; contains abundant nodules which range from half an inch to 5 inches in diameter, though mostly about an inch, and which are chert on the outside, lined with crystalline milky quartz, and filled at the center with large calcite crystals. Toward the middle of the unit iron concretions are numerous, their sharp angular outlines in strong contrast with the mammillary surfaces of the quartzose nodules. Thickness varies owing to erosion surface at the top	61–76
2. Sandstone, gray, weathering nearly white; massive, in two or three beds; very limy, micaceous; very unevenly granular, grains one-sixteenth inch in maximum diameter	5
3. Limestone, sandstone, and shale, thin bedded and interfingering; the limestone practically all altered to white, chalky-appearing chert, with scattered gray nodules as much as 3 inches in diameter; the limestone beds average half an inch in thickness; the shale and sandstone lenses are thinner, averaging perhaps a quarter of an inch, though a few are as much as 4 inches thick; some angular chert in these thicker layers is perhaps clastic, but the whole bed is so checked and broken that it may have been formed in place	3–4½
Total Kaibab limestone	69–85½

Contact gently rolling; conformity probable but uncertain.

Coconino sandstone: Sandstone, heavy bedded, cross-bedded, white, sugary.

16. *Section on south side of Cedar Mountain, in sec. 10, T. 19 S., R. 11 E., San Rafael Swell, Utah*

Entrada sandstone (part): Sandstone, maroon, fine grained, gypsiferous, cliff former.

Carmel formation:	Ft.	in.
1. Gypsum, green, bedded, with much selenite veining; forms a ledge	4	
2. Sand, green-gray	1	6
3. Sand, maroon, with gypsum veins and layers	3	
4. Gypsum, green stained	1	
5. Shale and sandstone, sandier upward; green	5	3
6. Sand, maroon, much veined with secondary selenite	2	
7. Gypsum, white		10
8. Sand, red and green, gypsiferous, unconsolidated	1	
9. Gypsum, white		3
10. Shale, green	4	3
11. Sand, red, gypsiferous	2	6
12. Gypsum, clean white, bedded	1	6
13. Sand, gypsiferous, red	3	9

Carmel formation—Continued.	Ft.	in.
14. Gypsum, massive	5	
15. Shale, green	11	6
16. Sand, red, gypsiferous	2	6
17. Gypsum		6
18. Shale, gray-green, sandier toward the top	32	6
19. Gypsum	2	
20. Sandstone, gray, gypsiferous, thin bedded	4	
21. Gypsum		4
22. Shale, green	4	
23. Sand, red, gypsiferous	1	6
24. Shale and thin sandstone; gray, flaky, ripple-marked; thin gypsum parting at the top	21	6
25. Sand, maroon, shaly	1	
26. Gypsum, clean white alabaster, massive	5	3
27. Sand, maroon, shaly, soft	1	
28. Gray shale and sandstone, alternating; interbedded gypsum bands 4 feet above the base; much secondary selenite along cracks	6	
29. Gypsum, green-white	3	
30. Sand, green-gray, highly gypsiferous; a few black grains disseminated through it	1	
31. Sand, red, highly gypsiferous	1	6
32. Sand, like No. 30	1	
33. Gypsum, white, soft, pure; forms a flat bench	5	
34. Gypsum, interbedded with gray dense crystalline limestone in lenses from a quarter of an inch to 30 feet long and from paper-thin to 2 inches in thickness; the gypsum very clean and hard; no limestone in the upper 10 feet, which forms a persistent ledge	16	9
35. Clay, gray-green and chocolate-red, highly gypsiferous	1	6
36. Gypsum, clean white, practically free from silt		10
37. Sandstone, gray, gypsiferous, very soft and friable	2	6
38. Clay, red, very gypsiferous, slightly sandy	7	
39. Shales and sandstones, gray; highly micaceous, some biotite flakes one-eighth inch long; clean gray quartz sand and gray clay, with secondary gypsum seams as much as 1 inch in thickness	6	
40. Gypsum (alabaster), stained green; weathers cavernous and hummocky; bedding apparent on distant view but not prominent in detail; fibrous seams of selenite as much as 1¼ inches thick cut diagonally across the bedding but more commonly lie parallel to it; forms a ledge	6	3
41. Sandstone, green-gray, fine grained, ripple-marked, cross-bedded, composed of rounded grains of quartz; upper 8 feet massive and cut by many gypsum seams as much as half an inch thick, which have a tendency to follow the bedding planes but cut across them at places; the fibers of gypsum are neither parallel to the bedding nor perpendicular to the walls of the veinlets; some of the veinlets show comb structure, and most of them die out downward but upward enlarge into nodules of alabaster gypsum as much as 1 inch thick and 3½ inches long; these nodules are flattened roughly parallel to the bedding; forms a ledge	20	9
42. Limestone, oolitic, containing shell fragments		2
43. Shale, drab	3	

Carmel formation—Continued.	Ft.	in.
44. Limestone, shaly, gray, hard, thin bedded, platy; breaks into chips one-eighth to one-half inch thick and 3 to 5 inches across; forms a ledge	3	6
45. Limestone, massive, gray, very dense, blocky; irregular leached cavities numerous in the middle part; forms a persistent ledge; a few fossils in the upper part	1	10
46. Shale, hard, limy; drab, weathering creamy gray; in beds one-fourth to one-half inch thick, slabby, ripple-marked; sandy to varying degree, in the upper part approaching a sandstone	32	
47. Sandstone, gray, platy, fossiliferous; breaks into shelly fragments 2 to 6 inches across, one-eighth to 1 inch thick; forms a strong ledge	6	
48. Sandstone, thin bedded, ripple-marked, cross-bedded; in small lenses one-eighth to 1 inch thick and three-fourths to 4 inches long; the top 1 foot unconsolidated sand; forms a slope	7	
49. Sandstone, very limy, buff; oolitic at the top, with coarser grains as much as one-eighth inch in diameter; variable between the limy and the sandy facies by gradation along the bed, not by discontinuous lensing	2	6
50. Limestone, shaly, changing upward to a sandy, limy shale, greenish gray, weathering buff; forms a slope	15	6
51. Limestone, light gray, dense, breaking with conchoidal fracture; somewhat sandy in the middle, shaly and platy at the top; fossiliferous throughout; forms a strong ledge	5	6
52. Conglomeratic limestone, containing numerous chert pebbles as much as three-eighths inch in diameter and small, nearly spherical gray oolites; *Camptonectes*, *Trigonia*, and *Ostrea* numerous		2
53. Limestone, blocky; massive at both top and bottom, with a thin-bedded shaly zone in the middle; *Camptonectes*, *Trigonia*, and *Ostrea* abundant, lie at many places at right angles to the bedding; one shell observed with valves vertical and umbo down	3	6
54. Sandstone, greenish gray, extremely limy; in paper-thin to 4-inch beds, ripple-marked, tangentially cross-bedded; has a 2-inch parting of green shale at the top; forms a ledge	2	2
55. Shale, greenish gray, slightly sandy, not very well laminated; contains some soft gray thin-bedded fine-grained ripple-marked cross-bedded limy sandstone toward the top; uppermost 1 foot sandstone; forms a slope	11	9
56. Sandstone, fine grained, gray, weathering drab; contains lenses of dense gray ripple-marked limestone, weathering white; beds from paper-thin to 3 inches in thickness; oscillation ripples on top, wave length 6 inches, amplitude half an inch	5	1
57. Shale, from greenish gray to almost black, slightly sandy, not very well laminated; contains some thin lenses of sandstone; forms a slope	4	9

Carmel formation—Continued.

	Ft.	in.
58. Sandstone, buff, weathering brown, the upper part much stained with desert varnish; very hard and limy; at some places massive, at others in one-half to 6 inch beds; cross-bedded and ripple-marked throughout; fine grained, consisting chiefly of white quartz grains; some of the beds with high concentration of dark minerals, among them biotite; forms a very persistent ledge	5	9
59. Sandstone, buff, weathering light brown, fine grained, very limy, probably chloritic; and shale, dominantly greenish gray with some thin maroon bands, especially toward the bottom, well laminated, flaky, and pure; interbedded in lenses 1 foot long and 3 inches thick; unit variable, ripple-marked throughout	2	8
60. Sandstone, red, possibly owing to wash from the overlying beds, as fresh fracture shows green-gray with only a few red blotches; extremely limy, vuggy; fractured surfaces show broad facets of calcite; beds a quarter of an inch to 5 inches thick; two chocolate-red shale partings 2 inches thick in the upper part; very fossiliferous, in part approaching a coquina; forms a ledge	3	
61. Parting of red and green shale		2
62. Sandstone, maroon, grading into limestone; fine grained, largely recrystallized; contains prolate-spheroidal red oolites from 0.25 to 0.75 millimeter in diameter and very irregular in distribution, also vugs of calcite; shows facets of calcite on fracture; alternates with beds of shale one-quarter to 3 inches thick, decidedly ripple-marked, and lensing in and out along the strike; fossils abundant, including *Ostrea*, *Camptonectes*, and *Trigonia*	2	4
63. Shale and sandstone, alternating in beds one-sixteenth to 1 inch in thickness; the sandstone yellow-gray, weathering brown; the shale green with a brown tinge, making up 70 per cent of unit; the upper surface of the unit ripple-marked	1	
64. Sandstone, yellow, weathering brown; in beds 1 to 3 inches thick; composed of fine-grained clean white and pink quartz sand; stained by limonite and manganese; hard, very limy, showing facets of calcite on fracture surfaces; forms a ledge		10
65. Shale, blocky, greenish, with limonite stains along the bedding planes and around incipient concretionary centers; very limy; contains muscovite but no sand		8
66. Sandstone, yellow, weathering brown, very fine grained, shaly, rather friable, with a few thin shale partings through the bed	1	6
Total Carmel formation	324	10

Unconformity; rolling surface, rather broadly irregular.

Navajo sandstone: Sandstone, buff, massive, cross-bedded; exposed to a thickness of 30 feet.

17. *Type section of the Entrada sandstone at Entrada Point, northern San Rafael Swell, Utah*

Curtis formation: Conglomerate of chert pebbles in a green gray sandstone matrix.

Erosional unconformity, shown in a rolling surface of low relief.

Entrada sandstone:

	Feet
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 laminated, massive in places	3½
4. Sandstone, chocolate-brown, medium to fine-grained, massive; weathers into rounded forms	13
5. Sandstone, light red, coarse, gritty	2
6. Shales, 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; unit sandier toward the top	2½
9. Sandstone, chocolate-red, fine grained, massive; forms a bench; in the upper 4 feet many angular and subrounded fragments of fine-grained green-gray sandstone, ranging from half an inch to 15 inches in length, disposed at all angles to the bedding	29
10. Sandstone and shale; sandstone micaceous, mottled red and green; shale sandy and chocolate-red	5½
11. Sandstone, chocolate-red, massive, fine grained, cross-bedded in thin laminae	4
12. Sandstone, fine grained, and shale, variegated	2
13. Sandstone, chocolate-red, massive, fine grained; weathers into rounded forms	14
14. Sandstone, chocolate-red, thin bedded, medium to fine grained	15
15. Sandstone, chocolate-red, very fine grained, variable along the strike; massive, cliff-forming in some places, terraced 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 grains near the base; almost surely water-laid; forms a ledge	30
18. Sandstone, light gray, fine grained	2
19. Sandstone, red, fine grained, massive; forms a cliff	18
20. Sandstone, chocolate-brown, thin bedded, medium to fine grained	7
21. Sandstone, chocolate-red, in beds from 2 to 8 inches thick	5
22. Shale, chocolate-red, well laminated	1
23. Sandstone, gray, red in places, medium grained, massive; concretionary toward the top	3
24. Shale, micaceous, and sandstone, thin bedded, chocolate-brown to red, with greenish streaks through it	3

Entrada sandstone—Continued.	Feet
25. Sandstone, light gray to pink, medium grained, massive; with discontinuous shaly partings; cemented with lime	5
26. Sandstone, dark brown, thinly laminated; weathers like shale	2
27. Sandstone, chocolate-brown, cross-bedded, massive, fine grained; upper and lower surfaces irregular	5
28. Sandstone, chocolate-brown with a few gray bands, coarse grained at the 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, loosely cemented with lime, somewhat friable and with a shale parting at 7½ feet above the base	11
30. Sandstone, reddish brown, medium grained, massive, cross-bedded toward the top; the upper surface rolling, with a relief of 1 foot; weathers into rounded forms	22
31. Sandstone, gray, mottled, thin bedded, shaly	7
32. Sandstone, reddish brown, medium grained	1
33. Sandstone, greenish gray, shaly, fine grained; contains many red grains, probably of agate	20
Total Entrada sandstone	312

Carmel formation.

18. *Section of Summerville and Curtis formations at Summerville Point, near head of Summerville Wash, northern San Rafael Swell, Utah*

Morrison formation (part):	Feet
1. Clay, chocolate-colored, containing many lumps of gypsum as much as 4 inches in diameter; passes, by a zone 6 inches thick, into a gray shaly sand containing some carbonaceous matter	4
Unconformity, not prominent.	
Summerville formation (type section):	
2. Sandstone, chocolate-colored, thin bedded	2
3. Clay, with several thin sandstones	4½
4. Sandstone, thin bedded, cross-bedded, ripple-marked, micaceous	2
5. Clay, sandy, chocolate-colored	2
6. Sandstone, gray, fine grained, minutely cross-bedded and showing current-rippling	3
7. Clay, sandy, chocolate-colored; interbedded with gypsum; with well-laminated brown sandstones in beds less than 2 inches thick and gray sandstones in beds less than 1 inch thick; 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
8. Gypsum, chocolate-colored mottled with green; weathering in gnarled, lumpy shapes	¼
9. Clay, chocolate-colored; interbedded with talc-like gray silt, with thin limy chocolate-colored sandstone in beds nowhere over 2 inches thick and usually thinner	32
10. Sandstone, chocolate-colored, very fine grained, very limy, breaking with conchoidal fracture	1
11. Clay, reddish, interbedded with thin limy green-gray sandstone, mostly very thin-bedded but with some layers 8 inches thick	14
Total Summerville formation	163¾
Transitional boundary.	Feet
Curtis formation:	
12. Limestone, sandy, gray, weathering brown; contains many geodes lined with chalcedony, rock crystal, and calcite	¾
13. Sandstone, gray, weathering brown, fine grained, very limy; with thin-bedded zones 5 to 10 feet apart between which the bedding is massive; contains many small black grains (biotite?) and green grains	73½
14. Sandstone, green-gray, medium grained; green grains numerous; bedding irregular, ripple-marked; cross-bedded, breaking into smooth slabs along the planes; more massive toward top and weathering into large disks; contains thin lentils of chlorite-bearing shale	124½
15. Sandstone, green-gray, very limy; coarse, nearly a grit, with well-rounded grains; green grains numerous and clay balls as large as 2 by 1½ inches by three-fourths inch, usually containing carbonaceous material	1
16. Sandstone, greenish gray, weathering brown, fine to medium grained; beds from one-eighth inch to 18 inches thick, irregularly cemented; cross-bedded; clay fragments sparingly scattered throughout, in places associated with carbonaceous material	20
17. Sandstone, medium grained, containing angular clay flakes usually parallel to the bedding; carbonaceous material in irregular lenses	1
18. Sandstone, with some shale, thin bedded, irregularly bedded, fine grained	12½
19. Sandstone and shale, in alternating lenses	2
20. Shale, gray-green, well laminated	14
21. Conglomerate of black, brown, and red chert pebbles one-fourth inch in maximum diameter	⅔
22. Shale, green-gray, clayey, well laminated	½
23. Conglomerate, cross-bedded at angles as great as 30° with the true bedding; same types of pebbles as in unit 21, but more scattered	1
24. Sandstone, gray	1
Total Curtis formation	252½

Unconformity; erosion and angular discordance of 4°.
Entrada sandstone: Sandstone, red, thin bedded.

19. *Section on Curtis Point, Saleratus (Lost Springs) Wash, sec. 34, T. 19 S., R. 13 E., San Rafael Swell, Utah*

Morrison formation (part):	Ft.	in.
1. Sandstone lens, channel type.		
2. Limestone, crystalline, gray, containing much nodular jasper, shattered and veined like septaria; beds about 7 inches thick	4	
Unconformity not apparent at this point.		
Summerville formation:		
3. Sandstone, gray, fine grained; in part massive, weathering brown; in part thin bedded, weathering brick-red; interbedded with chocolate-colored sandy clay; a 6-inch bed of jasper at top; forms a slope	5	6
4. Sandstone, gray, weathering brown, fine grained, limy, thin bedded, ripple-bedded, containing some small clay pellets, variable along strike; forms a subdued ledge	2	
5. Mudstones, somewhat sandy, chocolate-colored; with many 1 to 2 inch beds of cross-bedded calcareous chocolate-brown sandstone	75	6

Summerville formation—Continued.	Ft.	in.
6. Sandstone, gray, weathering chocolate-colored; rather fine, well-rounded grains, some black and some red; massive bed	1	4
7. Mudstone, chocolate-colored, with many thin ledges of very limy sandstone, mostly chocolate-colored but with some green-gray and constituting about 10 per cent of the unit; many balls of gypsum as large as baseballs weather out and are strewn over the surface	23	6
8. Mudstone, sandy, green-gray; passes upward into a variable series of green-gray thin-bedded calcareous, very fine-grained sandstone; highly calcareous gray sandstones which form low ledges; and at about the middle of the unit red sandy clays	17	6
Total Summerville formation	125	4
Curtis formation (type section):		
9. Sandstone, green-gray, weathering brown; very limy, fine grained, thin, platy; cross-bedded in 6-inch layers between heavier layers of slightly coarser, less limy sandstone, which does not weather brown	21	
10. Sandstone, green-gray, medium grained; weathers in rounded forms due to exfoliation and differential cementation	40	6
11. Sandstone, green-gray, fine grained, friable; clay pellets and loglike iron-stained concretions at various horizons; forms steep ledgy slope	24	
12. Sandstone, green-gray, weathering brown; much carbon at some horizons, clay pellets at others; weathers into rounded forms as in No. 10 and forms ledge	20	
13. Sandstone, green-gray, of fine-grained quartz with some black and green grains; thin bedded, lenticular; interfingers with lenses of green gritty sandstone, which weathers buff, contains many red grains as well as the green and black, and is cross-bedded throughout, with individual beds 4 inches to 2 feet thick; unit forms vertical cliff, capped by projecting ledge	10	6
14. Grit, green-gray, with sporadic pebbles; cross-bedding not as general as in the lower beds and with planes dipping north; 2-inch shale parting in the middle; lenses out within 100 yards	2	2
15. Shale, green-gray, flaky	5	
16. Conglomerate, green-gray, of pebbles of brown, gray, and white chert, and jasper as much as half an inch in diameter but mostly less than a quarter of an inch; very limy; cross-bedded, with planes dipping south at angles as great as 22°, directly opposite to the dip in No. 14	3	
17. Shale, like No. 15	15	6
18. Conglomerate, like No. 16, containing echinoid spines	1	
19. Shale, green-gray, flaky	2	6
20. Conglomerate, like No. 16, but with cross-bedding on a smaller scale; within 100 yards to the north base cuts downward and unit is 12 feet thick	4	6
21. Shale parting, dark gray		6
Curtis formation (type section)—Continued.		
22. Grit, grains nearly all smaller than wheat grains		6
23. Shale, slightly sandy, dark gray, fissile	7	6
24. Sandstone, gray, weathering buff; limy, with a few thin shale lenses	4	9
25. Shale, sandy, dark gray; includes thin lenses of well-bedded rippled fine-grained limy sandstone which make up about 25 per cent of the member; carbonaceous toward the top	7	
26. Sandstone, buff, massive, fine grained, limy	3	
27. Sandstone, limy, clayey, fine grained, mouse-colored, with red tinge here and there; alternates with sandy shale of the same color; the sandstone especially predominant at bottom and top; gypsiferous in upper part	20	
28. Shale, gray and green-gray, with a little red along some beds; well laminated		8
Total Curtis formation	193	4
Erosional unconformity.		
Entrada sandstone (part):		
29. Sandstone, red, thin bedded, very fine grained	10+	

20. *Section on east flank of Woodside anticline, San Rafael Swell, secs. 17 and 18, T. 19 S., R. 14 E., Utah*

	Feet
Dakota (?) sandstone:	
1. Grit, ill exposed, at base of Mancos shale	2
Morrison formation:	
2. Clay, variegated yellow, cream-colored, chocolate-colored, bluish gray, greenish gray, brick-red, etc.; contains discontinuous bands of gritty medium-gray limestone which weather dark brown. The limestones contain sporadic grains, one-sixteenth to one-eighth inch in diameter, of jasper and black chert and smaller grains of translucent quartz; seams of secondary calcite common	25
3. Sandstone, light gray, fine grained, with calcareous cement, cross-bedded, much stained with desert varnish; conglomerate at base containing pebbles as much as 3 inches in diameter of clay, chert, limestone, and jasper	11
4. Shale, marly, medium gray with greenish cast	20
5. Limestone, dense but badly shattered; medium gray with greenish tinge and some lilac-red spots; much iron stain along joints; grades upward into a dirty-purplish shaly limestone	6
6. Clay, variegated, like No. 2; limy bands have considerable secondary calcite	33½
7. Sandstone, light gray, fine grained, with limy cement, cross-bedded; conglomeratic at base, with pebbles of limestone, chert, and jasper; much desert varnish on surface	5
8. Clay, variegated, like No. 2; contains a parting of fine-grained thin-bedded greenish limy sandstone made up largely of quartz and jasper	28¼
9. Sandstone, light gray, much cross-bedded; contains several bands of fine conglomerate, cemented with silica; pebbles as much as 1 inch in diameter but mostly about three-eighths inch, chiefly black and gray chert with a few of firm clay including grains of secondary quartz (apparently weathered igneous rock); unit contains also a clay parting at 13½ to 17 feet above base; much desert varnish	18

Morrison formation—Continued.	Ft.	in.
10. Clay, variegated, like No. 2; the gritty limestone bands in places give way to a calcareous grit or a limestone conglomerate with chert pebbles as much as 1 inch in diameter, in part angular, in part smoothed, of many colors; unit weathers into steep slopes covered with jagged pebbles	64	
11. Sandstone, lenticular, like No. 9	3	
12. Clay, like No. 10	18½	
13. Limestone, medium gray, lenticular but more extensive than usual as it is traceable for over half a mile; contains much secondary bluish-white chert, calcite, and rock crystal; weathers into nodular masses from 6 inches to 1 foot across and in places makes a slight bench	4½	
14. Clay, like No. 10	52	
15. Grit and conglomerate, cemented firmly with silica; in places fractures across the pebbles, in places limy with secondary calcite along fractures; lower 4 feet a fine conglomerate with brown, gray, green, white, red, and black chert pebbles averaging three-eighths inch in diameter, and limestone and sandstone pebbles as much as 3 inches in diameter; upper 5 feet a grit which blends with the lower part, very irregular in thickness, and bearing much desert varnish	9	
16. Clay, like No. 2 except that limestone lenses are confined to the upper part	25½	
17. Sandstone, light gray, limy; grains about 0.25 millimeter in diameter, of translucent quartz with some muscovite and a few dark minerals; massive, breaking into angular joint blocks about 1 foot on a side; in part firmly cemented; stained on outcrop by blotches of limonite	5	
18. Conglomerate, cemented with silica, largely of chert pebbles, but with some pebbles of sandstone as much as 4 by 2 inches; layers of cross-bedded sandstone and grit as much as 4 feet thick included; stream-bedded throughout. This is the conglomerate capping Cedar Mountain and forming the prominent hogback west of the Denver & Rio Grande Western Railroad south of Woodside, Utah	19	
19. Shale, limy, greenish gray	3	
20. Clay, purplish on close view, bluish gray at a distance; rather flaky toward the top, approaching a shale in fissility but breaking into angular fragments	4½	
21. Conglomerate, mottled purple and gray, with limestone pebbles as much as 1¼ inches in diameter	½	
22. Clay, drab to green-gray; weathers into steep slopes	45	
23. Sandstone, light gray, with some limonite stain; tangentially cross-bedded; lime-cemented, very friable	3	
24. Clay, gray, with faint greenish-yellow tinge	8½	
25. Sandstone, light gray, weathering drab to brown, friable, lime-cemented, thin bedded, cross-bedded; varies in constitution along strike, at some places gritty and containing subrounded grains as much as one-eighth inch in diameter of gray chert, jasper, and translucent quartz; at other places shaly	2½	

Morrison formation—Continued.	Ft.	in.
26. Clay, drab or gray, with faint greenish-yellow tinge, soft, structureless	16	
27. Sandstone, medium gray, generally friable, lime-cemented, cross-bedded; grains 1 to 2 millimeters in diameter, many coated with limonite; contains small lenses of quartzite and at base a fine conglomerate of clay and chert pebbles	5½	
28. Clay, light greenish gray	19	
29. Sandstone, light gray, limy; cross-bedded, with planes inclined as much as 32° to the true bedding, and no consistent direction apparent; grains about 0.75 millimeter in diameter, chiefly of well-rounded clear quartz, with some jasper and brown chert; clay pellets up to 1.5 millimeters in diameter at bottom of ripples	12	
30. Clay, variegated, dominantly light greenish gray with tinges of red	9	
31. Limestone, dark green, dense, cherty	1	
32. Clay, like No. 30	21	
33. Sandstone, dark green, calcareous, friable, very lenticular	1	
34. Shale, variegated, somewhat fissile	3	
35. Sandstone, lenticular, dark green	½	
36. Clay, like No. 30	3½	
37. Limestone, light, greenish gray, dense, siliceous	1½	
38. Clay, like No. 30	19	
39. Limestone, very dense, green-gray; weathers into nodular forms; much stained with limonite, probably impure	1	
40. Clay, like No. 30	6	
41. Clay and sandstone, alternating; the clay of the type of No. 30; the sandstone limy, greenish gray, weathering brown, in cross-bedded lenses half an inch to 10 inches thick, averaging 4 inches. The unit is about 80 per cent clay and 20 per cent sandstone, and a short distance away one of the sandstone lenses reaches a thickness of 4 feet	14	
Salt Wash sandstone member:		
42. Sandstone, light gray; fine, nearly pure quartz sand cemented by lime; beds as much as 12 feet thick; cross-bedding common, and in the cross-bedded parts, especially toward the top, some layers of fine grit or even fine conglomerate; clay in partings and seams as much as 1 foot thick, especially near the base, constituting 20 per cent of entire unit; unit weathers into a limonite-stained friable rock in rounded forms and makes a strong bench half a mile wide	74	
43. Clay, light medium gray with slight greenish cast, in part variegated; polished pebbles ("gastroliths") on this slope	11	
44. Sandstone, light gray, friable on weathering; largely medium grained; contains a few clay pellets as much as a quarter of an inch in diameter	2½	
45. Clay, like No. 43	6	

Morrison formation—Continued.	Feet
Salt Wash sandstone member—Continued.	
46. Clay, like No. 43, and sandstone, like No. 44. The sandstone constitutes about one-third of the unit, in ledges 6 inches to 2 feet or more thick, weathering light brown; very hard, probably cemented with silica; 11 feet above the base of unit a 1-foot bed of quartzitic grit containing grains of jasper, rock crystal, brown, green, and black chert; sandstone at top of the unit makes a bench 50 feet wide	27
47. Clay, light medium gray with a greenish cast, but in part variegated with a dirty purplish tinge; probably limy	7
48. Clay, like No. 47, and limestone. Limestone constitutes one-third of the unit, 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	18½
49. Gypsiferous clay, mainly green-gray, with many seams of fibrous white secondary gypsum; near top a few thin sandstone layers	11
50. Gypsiferous sandstone, grading upward into No. 49; greenish gray, friable, with much secondary fibrous gypsum; apparently a resistant stratum, as it caps a rather extensive bench	15
51. Gypsum, massive and fibrous; contaminated with clay and sand; cherry-red, pink, and white; forms a strong ledge	5½
Total Salt Wash sandstone member	177½
Total Morrison formation	724¾
Unconformity not apparent, though elsewhere a low angular discordance and some erosion are visible at this horizon.	
Summerville formation:	
52. Sandstone, dirty brick-red, friable, clayey, gypsiferous; upper 2 feet with fibrous white secondary gypsum in numerous seams nearly parallel to the bedding planes	4½
53. Mudstone, limy, sandy, brownish red with chocolate-brown tinge at close range, brick-red in distant view; massive, nonfissile, breaking into angular fragments, and weathering in part into ellipsoidal masses; contains some thin bands which range in texture from dense medium-gray limestone to coarsely crystalline pinkish or white calcite and which weather into nodules and irregular fragments covering the slope; many of these nodules cherty	1
54. Sandstone, medium gray with a greenish cast, very thin bedded, fine grained, clayey, lime-cemented; includes some red mudstone partings	1
55. Mudstone, like No. 53	3
Summerville formation—Continued.	
56. Sandstone, like No. 54	1½
57. Mudstone, like No. 53	1
58. Sandstone, like No. 54	½
59. Mudstone, like No. 53	8½
60. Sandstone, like No. 54	1½
61. Mudstone, like No. 53, with about 10 per cent sandstone	16
62. Sandstone, like No. 54	4
63. Mudstone, like No. 53	8
64. Sandstone, like No. 54	3
65. Mudstone, like No. 53	8
66. Sandstone, like No. 54	3
67. Mudstone, like No. 53, but a few thin sandstone beds of a medium greenish-gray color, like No. 54	5½
68. Sandstone, like No. 54	4
69. Mudstone, like No. 67, except that the sandy ledges are confined to the upper part	27
70. Limestone, medium gray with red cast, finely crystalline, ripple-marked on upper surface	½
71. Mudstone, approaching a shale in fissility in some places and containing some thin sandstone beds. None of the mudstones above this unit carry more than a few per cent of limestone; in this there is more lime, perhaps 10 per cent	21
72. Limestone, brownish red, dense; contains stringers of quartz sandstone and seams as much as one-eighth inch thick of fibrous gypsum; weathers dark brown; forms a ledge	1
73. Mudstone, like No. 53	1
74. Limestone, like No. 72	½
75. Mudstone, like No. 53	3
Total Summerville formation	128
Curtis formation:	
76. Sandstone, medium gray with slight greenish tinge, weathering rich medium brown; very fine grained, fairly well cemented with lime; beds as much as 6 inches thick, with partings of shale of same color; ripple-marked; composed largely of quartz with some black and some red minerals; contains vugs and cavities lined with jasper, milky chalcedony, and rock crystal. Some of the vugs occur in limestone lenses which reach 6 inches in thickness and several feet in length	128

21. *Section in Cottonwood Springs Draw, sec. 10, T. 20 S., R. 13 E., San Rafael Swell, Utah*

Curtis formation (part):	Feet
1. Sandstone, gray, medium grained, lime-cemented; massive except for a few thin beds toward the top	3½
Unconformity, not strongly expressed here, but 1 mile to the west an angular discordance of 4° and erosional irregularities.	
Entrada sandstone:	
2. Sandstone, chocolate-brown, very massive; in general fine grained but gritty in the lower foot or so and containing subangular grains of gray, red, and yellow quartz and some biotite (?); weathers into rounded ledges and cliffs	49
3. Sandstone, buff, fine to medium grained, the larger grains well rounded, many of red quartz, some of blue	11½

	Feet
Entrada sandstone—Continued.	
4. Sandstone, chocolate-brown, shaly, thin bedded, micaceous; composed principally of red and yellow quartz grains; some dark, possibly carbonaceous streaks toward the middle and top of the unit	3
5. Sandstone, chocolate-brown, massive, fine grained; forms a ledge	4
6. Sandstone, chocolate-brown, friable, medium to fine grained, with sporadic large well-rounded quartz grains; 2-inch parting, at about the middle, of fine-grained cross-bedded gray sandstone with many yellow and red quartz grains	8
7. Sandstone, gray, massive, hard, medium grained, lime-cemented; composed of well-rounded white quartz grains with a few of red	1½
8. Sandstone, clayey, chocolate-brown; incloses lenses half an inch to 4 inches thick of very fine grained gray biotite-bearing lime-cemented thin-bedded and cross-bedded sandstone marked by current ripples of small size; lenses make up about 30 per cent of the rock	11½
9. Sandstone, chocolate-brown, massive, medium to fine grained, lime-cemented; contains some muscovite and a few large yellow quartz grains; forms a rounded slope	17½
10. Sandstone, clayey, chocolate-brown, with subordinate thin lenses of friable gray sandstone	4½
11. Sandstone, massive, gray, medium fine grained; composed chiefly of well-rounded white quartz grains, with some biotite; weathers yellow-gray in a rounded ledge	5½
12. Sand, gray, alternating with friable thin-bedded gray sandstone of fine grain; weathers to a slope	13½
13. Sandstone gray, massive; well-rounded sand grains, chiefly white, yellow, and red quartz, subordinate; black, green, and blue grains; weathers into rounded shapes ("stone babies") several feet long; forms a ledge	12
14. Sandstone, in three thin beds, medium grained, limy, fairly hard	2
15. Sandstone, gray, weathering yellow-gray; thin bedded, with a more massive zone at the top; composed of well-rounded white quartz, with sporadic yellow and red quartz, biotite, and some scattered specks of limonite	29
16. Sandstone, chocolate-brown, massive, lime-cemented; fine grained but with a few coarse, well-rounded grains	6
17. Sandstone, chocolate-brown, friable; basal 2 feet very friable, shaly, and red; above this, three very hard, well-cemented 1-foot beds composed of white and brown subangular quartz grains	19
18. Sandstone, brown, medium grained, composed of subangular quartz with much dark mica; in two heavy beds with 6-inch shaly parting between	2½
19. Sand, shaly, slightly gypsiferous; includes at intervals of 3 and 5 feet three beds of friable chocolate-brown sandstone, about 8 inches thick, forming ledges in the slope made by the unit as a whole	14
20. Shale, sandy, gray, gypsiferous, becoming more sandy upward; uppermost foot nearly a sandstone	8
21. Sandstone, gray, friable, medium coarse grained, finer toward top; made up chiefly of rounded and subangular quartz grains; cross-bedded, planes dipping generally southeast; in beds about 4 feet thick; forms a gentle slope	19
22. Sandstone, gray, weathering yellow-gray, chocolate-red in upper part, sugary, very friable, lime-cemented, cross-bedded, massive, medium to coarse grained; largely of white quartz, with some red and yellow; forms vertical cliff	24
Total Entrada sandstone	265
Contact gradational.	
Carmel formation:	
23. Shale, chocolate-brown, becoming sandier toward top	9½
24. Shale, maroon, gypsiferous	2½
25. Gypsum, clean	4½
26. Shale, chocolate-red, with gypsum beds as much as 1 foot thick distributed throughout	11
27. Gypsum, clean	3
28. Clays, greenish gray, gypsiferous	5
29. Gypsum, clean, white	2
30. Shales, green-gray and red, gypsiferous	16
31. Concealed, probably gypsiferous clay and shale	35
32. Sandstone, gray, thin, platy; shows symmetrical ripples, with wave length 2½ inches, amplitude one-fourth to one-half inch, and crest trending generally N. 75° E	2
33. Shale and sandstone, gray, in very thin alternations	8
34. Gypsum, white weathering yellow	3½
35. Shale, red at base, tan toward top, highly gypsiferous	8½
36. Gypsum (alabaster)	1
37. Sandstone and shale, alternating; chocolate-brown, with some clean maroon clays	11
38. Sandstone, blocky at base and thin, platy, highly micaceous toward top	½
39. Shale, sandy, chocolate-red	2½
40. Shale, slightly sandy	2
41. Sandstone, very shaly, green-gray, thin bedded, platy	2½
42. Sandstone, gray, weathering yellow-brown, medium grained, composed chiefly of subrounded quartz, cross-bedded at top; forms strong ledge	3½
43. Sandstone, shaly, light gray, ripple-bedded	10
44. Concealed	2
45. Sandstone, gray, fine grained, very limy, concretionary; cross ripples form a rhombic pattern on surfaces	7
46. Shale, slightly sandy, gray, soft	3½
47. Limestone, gray, shaly, fossiliferous	½
48. Sandstone, gray, thin bedded, platy, limy, with many grains of a black mineral (biotite?); makes low slope	9½
49. Sandstone, shaly at base, green-gray, fine grained, in beds 1 to 3 feet thick at base, thin bedded and flaggy toward the top; symmetrical ripple bedding throughout; forms strong ledge	19

Carmel formation—Continued.	Feet
50. Sandstone, greenish drab, very fine grained, dense; shaly and thin bedded toward base, cleaner and more massive in the middle, platy toward top (beds one-sixteenth inch thick); somewhat variable along the strike	10½
51. Limestone, gray, dense; usually platy but at some places, blocky	2½
52. Shale, very limy, blocky, hard	2½
53. Limestone, gray, dense, massive, very hard; contains calcite-incrusted geodes; many fossils, especially oysters	1¼
54. Shale, green, soft, unctuous	⅔
55. Limestone, chocolate-brown; partly oolitic, partly dense, crystalline; beds one-fourth inch to 6 inches in thickness; contains oysters and other fossils	5
56. Sandstone, green, with a 1-foot chocolate-brown bed toward middle, separated by sharp but wavy boundaries; flaggy and cross-bedded toward top, massive and blocky in lower 2 to 3 feet	6
57. Shale, green to tan, blocky, gypsiferous, very limy, sandy toward top; upper surface wavy, with relief of 2 inches; basal 4 inches dark brown from limonite	2–2½
58. Sandstone, shaly at base, gypsiferous, green, weathering brown, biotite or chlorite plentiful, fine grained, very limy; very irregular upper surface suggesting wave form	2½
59. Shale, green, fissile, containing sandstone lenses 8 to 10 inches thick; lower bedding planes follow irregularities of lower surfaces, but upper planes smooth out and are regular; much secondary gypsum, in seams cutting across the bedding	1–2½
Total Carmel formation	219–221
Unconformity (?), wavy surface, with relief of 1½ feet and wave length 3 to 8 feet. Apparently there is here no reworked Navajo sandstone in the basal part of Carmel formation, as is usual elsewhere.	
Navajo sandstone:	
60. Sandstone, tan, massive, tangentially cross-bedded on large scale	400+

22. *Section at Black Dragon Canyon and Straight Wash, San Rafael Swell, Utah*

[Beds 1 to 6 measured east of Straight Wash Canyon; remainder along Black Dragon Wash]

	Feet
Morrison formation: Thick white alabaster gypsum beds at base, followed by conglomeratic "channel" sandstones and varicolored mudstones, marls, and shales.	
Unconformity, a channeled irregular surface in the hollows of which the overlying gypsum was deposited.	
Summerville formation:	
1. Shale, sandy, thin bedded, dark reddish brown; contains many thin lenses of greenish-gray sandstone, especially in the upper part, and many beds of pinkish-white alabaster gypsum as much as 6 inches thick; crusts of red chert, probably secondary, weather out on the slope; unit much seamed with secondary selenite veins	63
2. Gypsum, a massive greenish-white alabaster; a persistent bed	2½
3. Shale, sandy, dark red-brown, with a few gray sandstones 2 inches thick in the lower part; ripple-marked; above a horizon 65 feet from the base, nodules and beds as much as 6 inches thick of pink gypsum occur at 6-foot intervals to the top of the unit; in the upper 50 feet much more sandy than shaly—in fact, a blocky thin-bedded shaly sandstone, much seamed with secondary selenite; crusts of red chert strewn over the slope, as in No. 1	146
Total Summerville formation	211
Curtis formation:	
4. Shale and sandstone, alternating, green-gray, thin bedded; dominantly sandstone below and shale above and passing by gradation into the overlying Summerville formation	47
5. Sandstone, green-gray, weathering brown, lime-cemented, friable, massive, very thick bedded, cross-bedded, ripple-marked; includes some angular shale fragments and weathers into concretionary bosses and "biscuits"	65
6. Shale, green-gray, glauconitic, in layers chiefly less than 2 inches thick though as much as 6 inches, ripple-marked and separated by thin-bedded sandstone; the sandstone constitutes perhaps 5 per cent of the bulk of the unit	58
Total Curtis formation	170
Erosional unconformity with relief of several feet.	
Entrada sandstone:	
7. Sandstone, massive, earthy, red-brown; over 50 feet in one bed, the rest thick bedded but with shaly partings a few inches thick	84
8. Sandstone, yellow-gray, tangentially cross-bedded	11
9. Sandstone, earthy, red-brown, with many thin maroon sandy shale zones; weathers into "bobbins"	25
10. Sandstone, yellow, highly cross-bedded, even grained but somewhat earthy, especially in upper part	7
11. Sandstone, at base shaly and thinly, poorly bedded but passing upward into earthy, exfoliating ("bobbin weathering") type; buff in lower 3 feet, red-brown above	19
12. Sandstone, red-brown, earthy at base, buff and clean above; weathers in rounded forms, tangentially cross-bedded, especially in upper part; a green shale parting 17 feet above base	26
13. Sandstone, shaly, yellow-brown, interlensing with clean maroon shale; average lens 2 inches or less in thickness; wavy surfaces and ripple marks throughout	2½
14. Sandstone, yellow-gray and tan, tangentially cross-bedded, limy, friable; a few thin partings of maroon shale and green sandy shale; except for the shale the unit is of the type characteristic of the Navajo sandstone	31½
15. Shale, maroon, clean, well laminated	1½
16. Sandstone, yellow-gray, tangentially cross-bedded, limy, friable; uppermost 6 inches shaly	6

	Feet
Entrada sandstone—Continued.	
17. Sandstone, red-brown, earthy, limy, containing at several horizons well-bedded red-brown shale a few inches thick. The unit is a series of more shaly and less shaly beds, poorly bedded, contorted and rippled throughout	35½
18. Sandstone, shaly, micaceous, drab, weathering buff; very poorly bedded	8½
19. Sandstone, like No. 14	75
20. Sandstone, red-brown, earthy, limy, massive, irregularly bedded; contains some very irregular lenses of green shale fragments; bedding in the large slightly contorted; weathers into "bobbins"	73
Total Entrada sandstone	405½
Carmel formation:	
21. Gypsum and green-gray shaly sandstone, highly contorted and inseparably mixed owing to slumping	32
22. Gypsum, white alabaster	2
23. Sandstone, like No. 20 except that it is less massive; checks into angular fragments the size of a pea	5
24. Gypsum, white alabaster	1½
25. Sandstone, like No. 23	8
26. Gypsum, white alabaster	2
27. Sandstone, earthy, like No. 23	18
28. Sandstone, gray, earthy, obscurely bedded at base; some sandy shale in the middle of the member; greenish gray, platy, ripple-marked and ripple-bedded toward the top; sharp lithologic change at top, transition at base; weathers into rounded forms	19
29. Sandstone, gray with greenish tinge, limy at base, passing up into fine-grained sandy limestone; cross-bedded and ripple-marked throughout; platy at top	6
30. Limy shale, somewhat sandy, not well bedded, varies laterally and across the bedding into true limestone and passes upward by gradation into No. 29; poorly exposed	26
31. Sandstone, yellow, with lenses of gray shaly limestone; ripple-marked and cross-bedded; becomes more limy upward and is a true limestone in upper 3 feet; forms a ledge	21
32. Sandstone, buff, very limy, fine grained, poorly bedded; very shaly in middle; weathers in rounded forms toward the top; ripple-marked throughout; forms a slope	18
33. Limestone, gray with purple bands in lower part, all purple toward the top; beds 2 inches to 1 foot thick, slabby; usually dense but sandy in some places; very fossiliferous, *Camptonectes* and *Trigonia* especially common; forms a strong ledge	2½
34. Sandstone, red-brown, evenly bedded, fine grained, very limy; beds half an inch to 3 inches thick; passes into No. 33 by gradation, and along strike into a sandy limestone	3
35. Sandstone, red-brown, fine grained, earthy; weathers into a notch, and passes by gradation into No. 34	5
Total Carmel formation	169
Possible unconformity.	
Navajo sandstone:	
36. Sandstone, massive, light gray, even grained, with both tangential and angular cross-bedding	520
Todilto (?) formation:	
37. A series of poorly bedded, thin to medium bedded pink sandstones, weathering white to light gray and containing a few beds and many thin partings of finely laminated chocolate-colored sandy shale and brown sandstone. Both upper and lower boundaries are transitional and indefinite	239
Wingate sandstone:	
38. Sandstone, very thick bedded, light gray to red-brown, weathering brown; beds average 6 to 15 feet thick, but all resemble one another, and parting planes do not appear to be significant	323
Unconformity.	
Chinle formation: Top member is chocolate-colored earthy sandstone, in upper part varying to mudstone, soft, poorly exposed; forms a slope.	

23. *Section in Green River Desert near mouth of San Rafael River, Utah*

	Feet
Morrison formation: Varicolored shales and mudstones, and conglomeratic "channel" sandstone lenses.	
Unconformity; angular discordance not evident but a very sharp, widespread lithologic change.	
Summerville formation:	
1. Limestone, sandy, gray, containing irregular masses of reddish chert and geodes lined with crystalline quartz; forms a very widespread bench	2
2. Alternating shaly sandstone and mudstone, chocolate-brown and red-brown; includes some thin beds of greenish-gray sandstone; thin bedded and ripple-marked throughout	70
3. Mudstone and shaly sandstone, chocolate-colored, interbedded with orange-red silt and forming a fairly conspicuous band traceable for some distance	12
4. Shale, alternating grayish green and chocolate-colored, with a few thin purple beds, grading into sandy shale, shaly sandstone, and greenish-gray thin-bedded sandstone in upper part	12
5. Mudstone, somewhat laminated but not a shale, chocolate-brown and orange-colored, with a few thin beds of greenish-gray sandstone	7
6. Shale, very thin bedded, chocolate-colored, greenish-gray, and some purple; chocolate-colored mudstone; and some thinly laminated grayish-green sandstone	25
Total Summerville formation	128
Curtis formation:	
7. Shale, sandy shale, and thinly laminated ripple-bedded sandstone, greenish-gray; includes a few thin beds of chocolate-colored and purple shale of the type of the Summerville formation; upper foot forms a continuous sandstone ledge	18
8. Sandstone, very thin bedded, greenish gray, shaly, with greenish-gray sandy shale and subordinate chocolate-colored shale, shaly mudstone, and concretionary ripple-bedded greenish-gray sandstone; a zone 2 to 3 inches thick of purple carbonaceous shale about 8 feet above the base	20

Curtis formation—Continued.	Feet
9. Sandstone, reddish brown, shaly, thin bedded, even bedded, soft; weathers in low slope	11
10. Sandstone, red-brown, limy, even bedded, very hard; forms persistent strong ledge capping Entrada cliff and cutting across irregularities in the Entrada	2
Total Curtis formation	51
Unconformity; strike N. 45° E., dip 2° NW., above; strike N. 45° W., dip 1° NE. below.	
Entrada sandstone:	
11. Sandstone, earthy, red-brown; weathers into "bobbins"; beds 2 to 5 feet thick with very thin maroon shale partings continuous in the large, though individual beds vary noticeably in thickness; cross-bedded obscurely on a small scale. From a distance contortion of bedding is noticeable, the contortion being cut off smoothly beneath the ledge at the base of the Curtis formation	142
(Part of section above this horizon measured in cliffs 4 miles north of the San Rafael River crossing of Elaterite Basin road, and remainder 2 miles south of the crossing. Some uncertainty exists as to the identity of the base of bed 11 with the top of bed 12, the uppermost horizon south of the river, but the error is probably less than 20 feet and almost certainly not over 40 feet.)	
12. Sandstone, clean; the lower 3 feet thin bedded but passing up into massive, highly cross-bedded pinkish sandstone, which weathers into rusty-brown domes and arches	126
13. Sandstone, clean, yellow to tan, weathering brown; thin bedded in lower few feet but very thick bedded above; tangentially cross-bedded; forming domes in upper part	88
14. Sandstone, clean, massive, only slightly cross-bedded, almost surely water-laid	111
15. Sandstone, earthy, somewhat limy; weathers into "bobbins"; highly irregular contorted bedding so that both upper and lower boundaries vary in position nearly 20 feet; average thickness about	31
Total Entrada sandstone	498
Carmel formation:	
16. Shale, gray, mostly pure but with slight amounts of sand in some layers and a few thin beds of earthy sandstone intercalated	12
17. Sandstone, gray to buff, weathering very light gray, limy, rather clean, composed of well-rounded sand grains but with some small chert fragments and many mud pellets; very irregularly bedded, with some mud cracks and ripple marks; forms a ledge	3
18. Sandstone, red-brown, earthy, soft, irregularly bedded, with some platy layers and subordinate red-brown shale; some thin brown-stained but really clean gray sandstones as much as 6 inches thick occur but are not prominent or numerous; forms a slope	29
19. Sandstone, gray, limy, stained brown by wash; forms a ledge	1½
20. Sandstone, red-brown, earthy, somewhat platy in some places	4½

Carmel formation—Continued.	Feet
21. Sandstone, gray, very limy, very irregularly cross-bedded; nodular chert and gypsum common; forms a strong ledge	1
22. Sandstone, red-brown, limy, in part platy, in part earthy and irregularly bedded; forms a slope	13
23. Sandstone, gray, stained red-brown, very limy; contains many mud pellets; top and bottom are wavy surfaces, but the bed is not notably lenticular; forms a ledge	1½
24. Sandstone, red-brown, earthy, except toward top, where it is cleaner and platy; forms a slope	11
25. Sandstone, gray, limy, cross-bedded and irregularly bedded; weathers into nodular shapes and forms continuous ledge over a wide area	1½
26. Sandstone, red-brown; earthy, in some places almost a sandy mudstone; unevenly bedded, lime-cemented; weathers in a slope, with a few subordinate clean red sandstone ledges which weather brown	18
Total Carmel formation	95
Unconformity, an even surface separating very distinct lithologic types.	
Navajo sandstone, traced from Miller Canyon, about 15 miles to the south (east of Keg Springs); exposed	200±

24. *Section west of Thompsons-Moab road, 2¾ miles south of Courthouse mail station, Utah, just west of big fault which brings the Morrison formation into contact with the Moenkopi formation*

Summerville formation (not measured).

Unconformity.

Entrada sandstone:	Feet
1. Sandstone, white, clean, not prominently cross-bedded, probably water-laid; covers very wide dip slopes both here and east of the fault to and beyond Salt Valley; thickness can not be measured here; estimated	50±
2. Sandstone, massive, gray, weathering red-brown; clean, except for a few small lenses of "bobbin" sandstone, and forming arches and domes; not prominently cross-bedded; stands here in vertical cliff in which some of the bedding-planes can be followed for a few hundred yards, but none are persistent nor do the beds above and below them differ in composition. Alidade measurement	207
3. Shale, maroon, very evenly bedded, extremely persistent; can be followed for miles. Above this zone the bedding is even and regular; below it, contorted and very irregular	2½
4. Sandstone, red-brown, earthy; weathers into bobbins and rounded forms; bedding very highly contorted, the top cut off sharply by No. 3; a few thin discontinuous bands of red-brown shale constitute perhaps 1 per cent of the unit; forms very steep rounded slopes and vertical cliffs. Alidade measurement	105½
Total Entrada sandstone	365±
Carmel formation:	
5. Sandstone, white, limy, very much cross-bedded and hummocky on surfaces; lenses out along the exposure	10

Carmel formation—Continued.	Feet
6. Sandstone, red-brown, shaly, thin bedded, cross-bedded, ripple-marked, soft; forms a slope; lenticular with very hummocky upper surface having relief of about 2 feet	11
7. Sandstone, white, limy, very much cross-bedded and irregularly bedded, ripple-marked, lenticular	9
8. Sandstone, red-brown, very shaly, thin bedded, cross-bedded, ripple-marked, soft; forms slope; lenticular, nonpersistent	17
Total Carmel formation	47
Unconformity.	
Navajo sandstone:	
9. Sandstone, gray to buff, clean, quartzose; very thick and even bedded; weathers in large rounded masses but not into "bobbins" or "stone babies"	41
10. Sandstone, gray, thick bedded, highly cross-bedded; contains a few thin partings of shaly ripple-marked even-bedded sandstone, nowhere thick enough to conceal the dominantly tangential cross-bedding of the unit as a whole	117
Total Navajo sandstone	158
Todilto (?) formation:	
11. Sandstone, gray; a 2-foot hard cross-bedded ledge at base followed by thin-bedded ripple-marked sandstone, cross-bedded on a small scale and including a few red shale partings; unit transitional to the Navajo sandstone	13
12. Sandstone and shale, irregularly interbedded, dominantly soft shaly micaceous maroon sandstone with a minor amount of clean maroon shale and clean gray sandstone	30
13. Sandstone, red to gray, in beds 1 to 3 inches thick, limy, ripple-marked, cross-bedded throughout; includes some very discontinuous lenses of red limestone and of shale conglomerate; red shaly partings are very numerous, and the whole mass is very lenticular, so that thicknesses of individual beds vary much along the outcrops; local unconformities numerous but probably insignificant	76
14. Sandstone, gray, in beds about 3 feet thick, cross-bedded, containing some green shale partings; forms a strong ledge	19
15. Sandstone, red to gray, fine grained, ripple-bedded, in beds about 2 inches thick; forms a persistent bench, and passes gradually into No. 14	22
Total Todilto (?) formation	160
Wingate sandstone:	
16. Sandstone, gray, in beds 1 to 2 inches thick at top and bottom but 7 to 8 feet thick in middle, where it is highly cross-bedded; ripple-marked, very irregularly bedded; no sharp boundaries above or below; much thinner bedded than usual for the Wingate sandstone	91
17. Sandstone, pink to buff, composed of clean quartz; unevenly bedded at base, with some red-brown shale in bulbous, discontinuous lenses and passing upward into clean sandstone, very highly cross-bedded and probably wind-laid	97
18. Sandstone, red-brown, earthy, ripple-marked, fine grained, very limy, containing many discontinuous beds of dark red-brown shale about 2 inches thick; weathers in much modified "stone babies"; upper surface ripple-marked	6
19. Sandstone, buff to pink, in beds about 3 inches thick in lower part, and in beds as much as 6 feet thick in upper part; ripple-marked; many green shale pellets and green sandy lenticular mudstone partings between the beds	16
Total Wingate sandstone	210

Unconformity; rippled and mud-cracked surface, channels in which are filled by the basal Wingate sandstone.

Chinle formation: Red-brown mudstones, limestone conglomerate, green-gray shale and thin-bedded micaceous red-brown sandstone, the sandstone forming the top bed, which is 3 feet thick.

25. *Section in Salt Valley, about 6 miles south of road from Thompsons to Green River, Utah*

Dakota (?) sandstone:	Feet
1. Sandstone, white and light gray, containing at the base a conglomerate with black chert pebbles. The sandstone is carbonaceous and ferruginous, is much stained with limonite, and forms a strong ledge	9
2. Shale and sandstone; the lower 15 feet in layers less than 1 foot thick of interbedded sandstone and shale, in which *Halymenites* and plant impressions are common, but no carbonaceous matter was seen; above the basal 15 feet the member consists dominantly of gray shale with only thin sandstone lenses	51
3. Conglomerate, cross-bedded, containing yellow, black, white, and gray chert pebbles as much as three-fourths inch in diameter	10
Total Dakota (?) sandstone	70
Unconformity.	
Morrison formation:	
4. Clay, light gray with a green tinge, typical of the Morrison and containing marly layers, limestone nodules, and some grit lenses	68
5. Gritty sandstone, of which the lower 50 feet passes into clay within a few hundred feet laterally. Half a mile away this unit consists of only 8 feet of coarse light-gray sandstone, conglomeratic at the top and persistent for some distance; pebbles in the conglomerate are black chert and limestone	58
6. Clay, variegated, maroon, gray, and purple, with more gray toward the base and more maroon toward the top, the maroon color stronger than is usual in the Morrison; unit contains many grit and sandstone lenses, more numerous and thicker in the upper 50 feet; much chert and mottled chalcedony strewn over the surface and in place	337
7. Conglomeratic grit and conglomerate, light gray, containing many black, orange, white, and gray chert pebbles; a fairly persistent bed	22
8. Alternating red shale and thin gray sandstone, not well exposed	22
9. Channel sandstone, rather gritty and with some shale lenses in places	17

	Feet
Morrison formation—Continued.	
10. Interval mostly concealed, with some maroon and green shales exposed	41
11. Persistent gritty channel sandstone, containing pebbles as much as a quarter of an inch in diameter	13
12. Sandstone, gray, thin bedded, ripple-marked, cross-bedded, and interbedded red shale	17
13. Channel sandstone, gray	18
14. Variegated shale, with a sandy marl containing green shale lumps at the top and with interfingering drab shale lenses, limestone, and grit	14
15. Coarse channel sandstone	8
16. Variegated gray and purple sandy mudstone	5
Total Morrison formation	640
Unconformity, not prominent.	
Summerville formation:	
17. Poorly exposed red and green sandstone and shale, with limy and siliceous lumps on the surface; forms a slope	34
18. Grit, hard, fine grained, cross-bedded, white	2
19. Sandstone, red, somewhat shaly, thin bedded, medium grained	6
20. Sandstone, white, hard, fine grained	2
21. Sandstone, light yellow-gray, somewhat friable, thin bedded, poorly bedded, medium grained	11
Total Summerville formation	55
Unconformity.	
Entrada sandstone:	
22. Sandstone, white, massive in upper 50 feet, thin bedded in lower 20 feet; cross-bedded, fine grained, very limy toward the base	70
23. Sandstone, massive, brick-red, decidedly cross-bedded, strongly jointed, weathering into chimneys and alcoves; a few shale pockets present; sandstone somewhat shaly at the base, upper part clean and well-sorted	290±
24. Sandstone, red-brown, thick bedded, weathering into rounded masses and containing irregular shale pockets	41
Total Entrada sandstone	401±
Carmel formation:	
25. Interval largely concealed, probably mostly shale but with massive 6-foot sandstone at the top and at least one nodular bed of calcareous gypsum about 2 feet thick	60
Navajo sandstone:	
26. Sandstone, light buff to gray, cross-bedded at high angles, very massive	170
Todilto (?) formation and Wingate sandstone, not measured separately:	
27. Sandstone, massive, thick bedded, cross-bedded; bedding roughly parallel, probably water-laid throughout; some beds 12 feet thick, others as little as 1 foot; a few carry conglomerate of shale fragments as much as 6 inches long; at top a massive cross-bedded calcareous sandstone, red and gray, 12 feet thick; color of whole unit streaked red and light gray	350

Shale slope about 30 feet high to base of exposure.

26. *Section one-half to 1 mile below Dewey Bridge, on Colorado River just below the mouth of Dolores River, Utah*

	Ft.	in.
Morrison formation: Variable series 121 feet thick of gritty ripple-marked cross-bedded sandstones in beds as much as 8 feet thick, interbedded with red and green sandy shale. This series capped by a 20-foot gray sandstone ledge, followed by several hundred feet of variegated mudstones and channel sandstones.		
Unconformity.		
Summerville formation:		
1. Sandstone, irregularly bedded, red-brown, shaly, very limy in places; dense purple limestone; nodular limestone; and some red-brown shale. Nodules of lime and crusts of chert are common on the slope. In the upper part a few lenses of limy fine-grained irregularly bedded white sandstone, ranging in thickness from 2 feet to a few inches within short intervals. The unit forms a slope	47	
2. Sandstone, gray, gritty, of clean quartz with grains of gray and white chert and flint one-sixteenth inch in maximum diameter; a few lenses of shale and some shale pellets; thickness and bedding vary along the strike; very limy, hard, and forming a persistent ledge	8	6
3. Mudstone, red, sandy, micaceous, with thin lenses of green-gray sandstone, nowhere over half an inch thick; a number of thin lenses and one persistent 2-inch bed of dense pink sandy limestone are present; the upper surfaces show mud cracks and curled shale fragments, indicating with certainty exposure to the air	1	6
4. Sandstone, pink, quartzose, slightly earthy, and very limy; contains flakes of green shale at the bottom and has wavy contact, both at bottom and top; thickness somewhat variable; forms a persistent ledge	2	
5. Shale, sandy, reddish brown, with a very sharp, even separation from the gray sandstone of the Entrada formation below; contains many thin lenses of gray limy ripple-marked cross-bedded fine-grained sandstone with pellets of green shale; unit about 60 per cent shale, though not perfectly exposed	31	6
Total Summerville formation	90	6
Unconformity.		
Entrada sandstone:		
6. Sandstone, gray, all in one bed; highly cross-bedded, with tangential type of bedding throughout; composed of clean quartz with lime cement	57	
7. Shale parting, maroon, very persistent, can be traced as far as the stratigraphic horizon is visible, several miles		1

	Ft.	in.
Entrada sandstone—Continued.		
8. Sandstone, pink below, gray above; dominantly even bedded in lower half, highly cross-bedded and very thick-bedded like the upper half of the Navajo sandstone	268	
9. Sandstone, nodular, earthy, very irregularly and obscurely bedded, containing many bulbous lenses of red-brown mudstone; both boundaries extremely indefinite and variable; tongues of the overlying clean sandstone penetrate into the upper surface of this unit, but there is apparently no significant unconformity. Basal 10 feet of this unit may be the Carmel formation	36	
Total Entrada sandstone	361	
Unconformity (?).		
Navajo sandstone:		
10. Sandstone, clean, quartzose, with lime cement, pink in places but mainly gray, highly cross-bedded, the bedding cutting off at all angles and without apparent system	127	
11. Limestone, dense, silicified; a short lens, vanishing within less than 100 feet in one direction, concealed in the other	1	6
12. Sandstone, white, weathering buff, fine grained, clean, hard, well cemented, and containing many small pellets of green shale at the base; cross-bedded regularly up to about 28 feet above base and very irregularly above that horizon; a 5-inch parting of maroon shale 5 feet above the base and several very thin partings of green shale in the lower 15 feet of the unit; this part is cut out down the dip by bed 13, owing to evident local erosional unconformity	115	
Total Navajo sandstone	243	6
Todilto (?) formation:		
13. Sandstone, red, very shaly; thin bedded, with a few lenses of limy sandstone as much as 1 foot thick; mud-cracked and ripple-marked throughout; in places a sandy, poorly laminated shale; upper surface channeled; forms a slope	31	
14. Sandstone, pink, weathering red-brown; in beds 6 inches to 10 feet thick, lensing into one another and not persistent over long distances; contains thin, irregular lenses of red-brown sandy shale, mudstone, and shale conglomerate, but these are all subordinate to the sandstone	165±	
Total Todilto (?) formation	196±	
(Section continued on left bank of the Colorado half a mile downstream.)		
Wingate sandstone:		
15. Sandstone, pink, weathering dark red-brown, fine grained, lime-cemented, in beds mostly 3 to 8 feet thick, ripple-marked; cross-bedding not prominent except in a few layers; maroon shale partings, 1 inch or less in thickness, separate the heavy beds of clean sandstone; upper 40 feet in one massive, highly cross-bedded unit without partings and capping an abrupt cliff	246	
Chinle formation: Red shales, sandstones, and limestone conglomerates, forming below the Orange Cliffs a slope to river level.		