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ART. XXIII.—*The Green River Desert Section, Utah*;^{*}
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GENERAL STATEMENT.

The charm of the Southwest and of its geology ever lingers with me, and so it was with considerable pleasure that in 1917 I again undertook work in this region for the U. S. Geological Survey, after several seasons spent elsewhere. The examination in hand, which was a reconnaissance to determine the oil possibilities of the Green River Desert, Utah, necessitated a more or less detailed study of the stratigraphy of the area, and it is the results of this phase of the investigation that I shall present in the following pages. These results constitute further evidence of the remarkable similarity in lithologic character and stratigraphic sequence of the thick series of sedimentary beds exposed broadly over the vast area of the Colorado Plateaus. Very frequent comparison will be made with the rocks of the Navajo Country in the southern Colorado Plateaus, for it is with the stratigraphy of this region, embracing many hundred square miles in southern Utah, northern Arizona, and northwestern New Mexico, that I have first-hand knowledge, acquired during a long field season in 1913, while assistant to Professor Herbert E. Gregory, in his studies there for the United States Geological Survey.

Green River Desert is situated in east-central Utah and embraces that portion of the Colorado Plateaus which is in Emery and Wayne counties, between the Den-

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ver and Rio Grande Railroad, Dirty Devil River, San Rafael Reef, and the canyon of Green River (fig. 1). The rocks exposed in the Desert range in age from Penn-

FIG. 1.

INDEX MAP

sylvanian (?) to Upper Cretaceous and embrace a thick series of sandstones with some shale and a very little limestone. The oldest bed examined was a white sandstone of Pennsylvanian (?) age which is extremely cross-bedded and is saturated with petroleum. Above it lies, probably unconformably, the Moenkopi formation (here

assigned to the Lower Triassic), constituted principally of red-brown sandstone and shale, but containing at its base a prominent zone of buff shale and sandstone. The Moenkopi is unconformably overlain by the Shinarump conglomerate (Triassic), which is a very valuable key formation for correlation purposes, because of its peculiar lithologic character and widespread distribution. The variegated shales of the Chinle formation (Triassic) which lie perhaps unconformably above the Shinarump, are succeeded, also perhaps unconformably, by the massive, much cross-bedded sandstones of the Wingate (Jurassic). There is some evidence to indicate that the overlying beds, here tentatively correlated with the Todilto formation (Jurassic), rest unconformably on the Wingate. The Todilto (?) in addition to a rather heterogeneous mass of reddish shale and dirty gypsum, contains near its base a dense limestone which is fossiliferous and is therefore an invaluable key bed, as it occurs in the midst of a considerable thickness of unfossiliferous strata. The Navajo sandstone (Jurassic) succeeds the Todilto (?) and is composed of massive red sandstone at the base, with thinner-bedded red sandstone and sandy shale above and a prominent thick belt of gypsum at the top. The Wingate, Todilto (?), and Navajo together form what has been called the La Plata groups of rocks. The McElmo formation (Cretaceous?) comes next above the Navajo and consists of coarse white sandstone and conglomerate at the base (the Salt Wash sandstone member), variegated shales containing dinosaur bones and well polished pebbles resembling gastroliths in the middle portion, and at the top, coarse sandstones and conglomerates with minor quantities of variegated shale. The McElmo is believed to rest unconformably on the Navajo. An unconformity occurs also at the top of the McElmo, for it is in places overlain by a thin bed of Dakota sandstone (Upper Cretaceous) but is elsewhere in contact with the Mancos shale (Upper Cretaceous). This shale, which is several thousand feet thick, is blue-gray to drab in color and fossiliferous at numerous horizons. It is an important stratigraphic marker because of its lithologic character and fossil content.

The areal distribution of these formations in the Green River Desert is shown in the geologic sketch map

(fig. 2), and their correlation with beds in adjacent areas is shown in the table on page 556.

PENNSYLVANIAN(?) SANDSTONE.

A sandstone of Pennsylvanian(?) age which is exposed in Elaterite Basin and also outcrops rather broadly in San Rafael Swell behind "The Reef," is the lowest formation I had the opportunity of seeing in the Green River Desert. It is heavily impregnated with oil on the outcrop and is probably oil-bearing throughout its areal extent in this region.

This sandstone, which is composed mostly of translucent quartz grains held together by calcareous cement, is coarse-grained, massive, very cross-bedded, and rather soft. Where not impregnated with petroleum it is white both on the fresh face and on weathered surfaces, but where filled with oil is a steel gray at the surface but dark brown to black on fresh fracture. It commonly weathers into deep pockets, constituting excellent rain water reservoirs, and is further characterized in San Rafael Swell by scarlet spots and blotches on the weathered surfaces.

Near Temple Mountain, San Rafael Swell, fully 100 feet, and in Elaterite Basin about 50 feet of the Pennsylvanian (?) sandstone are exposed. In both localities the sand is heavily saturated with oil from top to bottom, but the oil is definitely confined to certain, probably more porous layers, for I saw no sign of oil in clean white laminae in direct contact with dark petroliferous laminae.

At the top of the Pennsylvanian (?) near Temple Mountain is a very distinctive bed containing quartzite pebbles and irregular areas of calcite and having the appearance of a coarse, irregular conglomerate. It attains a maximum thickness of 7 feet, but is locally absent, which with its conglomeratic character is indicative of an unconformity at this horizon. The presence of an unconformity at the top of the Pennsylvanian (?) is

LEGEND (FIG. 2).

Table of Correlations.

Age	Navajo Country <i>a/</i>	Henry Mountains <i>b/</i>	Green River Desert	Green River oil field <i>c/</i>
Cretaceous (Upper)	Mancos shale	? — ?	Mancos shale	Mancos shale
	Dakota sandstone		Dakota sandstone	Dakota sandstone
	Unconformity		Unconformity	Unconformity
Cretaceous ?	McElmo formation	Flaming Gorge group	McElmo formation Salt Wash sandstone member	McElmo formation Salt Wash sandstone member
	Unconformity?		Unconformity	
Jurassic	Navajo sandstone	Gray Cliff group	Navajo sandstone	La Plata sandstone
	Todilto formation		Unconformity?	
	Wingate sandstone	Vermilion Cliff group	Todilto (?) formation	
	Unconformity?		Unconformity?	
	Unconformity?		Wingate sandstone	
Triassic	Chinle formation	Shinarump group	Chinle formation	
	Unconformity?		Unconformity?	
	Shinarump conglomerate		Shinarump conglomerate	
	Unconformity	"c" division	Unconformity	
	DeChelly sandstone		Absent	
	Moenkopi formation		Moenkopi formation	
Pennsylvanian	Unconformity		Unconformity?	
	Undifferentiated Pennsylvanian		Pennsylvanian (?)	

a (= 1) Gregory, H. E., Geology of the Navajo country, U. S. Geol. Survey, Prof. Paper 93, pp. 15-16, 1917.

b (= 2) Gilbert, G. K., Report on the geology of the Henry Mountains, U. S. Geog. and Geol. Survey of the Rocky Mountain region, p. 6, 1877.

c (= 3) Lupton, C. T., Oil and gas near Green River, Grand County, Utah, U. S. Geol. Survey, Bull. 541, p. 124, 1914.

also suggested by the apparent absence of the white, petroliferous sandstone described above in a number of places toward the junction of the Grand and Green rivers, for though I did not have the opportunity of examining this area in detail, from a distance it appears that this oil sand is locally absent.

The sandstone just described underlies the beds referred by Gilbert to the lower member of what he termed the Shinarump group in the Henry Mountains region⁴ and which is now known as the Moenkopi formation in the Navajo Country to the south.⁵ In the northern part of that area the beds directly below the Moenkopi are known as the Goodridge formation, and from the physical character and sequence it appears likely that this white Pennsylvanian (?) sandstone is equivalent to the top of the Goodridge. The fact that the Pennsylvanian (?) sandstone is oil-bearing in Green River Desert as is the Goodridge near Bluff on the San Juan River in southern Utah, affords further evidence of the validity of such a correlation. The Goodridge formation in the San Juan field was definitely determined to be Pennsylvanian in age on the basis of fossils collected there by Woodruff.⁶ A brief examination in the Green River Desert revealed no fossils in the white sandstone, but because of its stratigraphic position it is here provisionally referred to the Pennsylvanian.

MOENKOPI FORMATION (TRIASSIC).

The Moenkopi formation here includes the series of reddish shales and sandstones between the white Pennsylvanian (?) sandstone below and the Shinarump conglomerate above, the intervening De Chelly sandstone not being present in this area. The Moenkopi is exposed in the heart of San Rafael Swell and under The Ledge between the Dirty Devil and Green rivers, where it forms the "riser" to the "step" made by the overlying Shinarump conglomerate.

The Moenkopi formation is arenaceous throughout. At

⁴ Gilbert, G. K., *Geology of the Henry Mountains*, U. S. Geol. and Geol. Survey of the Terr., p. 6, 1877.

⁵ Gregory, H. E., *Geology of the Navajo country*, U. S. Geol. Survey, Prof. Paper 93, P. III, 1917.

⁶ Woodruff, E. G., *Geology of the San Juan oil field, Utah*, U. S. Geol. Survey, Bull. 471, p. 85, 1912.

the base are 60 to 75 feet of white to brownish buff sandy shale with numerous interbedded thin sandstones of the same color. This part of the formation makes a rather conspicuous feature of the landscape, for it is in sharp contrast to the nearly dead white color of the underlying Pennsylvanian (?) sandstone and to the alternating red sandstones and shales of the upper Moenkopi. The sandstone in the Moenkopi consists of fairly well-rounded small quartz grains, held together by a calcareous cement. The finer, more thinly bedded sandstones are beautifully ripple-marked.

About 140 feet above the base of the section near Temple Mountain is a thin layer of very calcareous buff sandstone, with a coquina-like appearance, containing many fossil fragments. A hurried examination revealed no identifiable specimens, but Mr. Walt M. Small, consulting geologist, of Tulsa, Oklahoma, who was with me when I visited this section, informs me that he later obtained collections from this horizon on the west side of the Swell.

The character of the Moenkopi is shown in the following detailed sections:

Section of Moenkopi formation, North Temple Wash, 1 mile $\pm$ north of Temple Mountain, San Rafael Swell, Utah.

(Measured with the assistance of Milton Anderson and Walt M. Small of Tulsa, Okla.)

Unconformity

1. Sandstone, reddish brown, medium grained with some purple shale at top	128'
2. Sandstone and shale, buff to ecru. Contains a lensing oil sand 4' thick from 30' to 40' above base	117'
3. Sandstone, red-brown, medium grained, thin to massive bedded, cross-bedded, ripple-marked, contains some shale	193'
4. Sandstone, weathers steel gray, darker gray-brown on fresh fracture, lenticular, saturated with petroleum	5-8'
5. Sandstone, buff to ecru, very limy; contains broken fossils; weathered surface resembles coquina...	4'
6. Sandstone and shale, buff, thin-bedded	61'
7. Shale, very sandy, white	75'

Unconformity

Section of Moenkopi formation near Elaterite Spring, Elaterite Basin, Utah.

1. Conglomerate and coarse light sandstone. Shinarump conglomerate.

Unconformity

2. Sandstone with shale becoming more prominent toward top; red-brown, upper two-thirds almost all shale. One foot of leached greenish shale and sandstone at top 102'
3. Sandstone, buff, weathers red-brown, fine-grained, massive—a single bed, prominent ledge maker .. 17'
4. Shale, sandy, red-brown, chocolate, and cream-colored toward top with considerable red-brown sandstone in thin layers, ripple-marked 62'
5. Sandstone, red-brown, weathering to flakes; thicker bedded than that below 3'
6. Sandstone, red-brown, ripple-marked, fine-grained, with interbedded red-brown shale 24'
7. Sandstone, red-brown, fine-grained, honey-comb weathering in places. Ledge maker. Lower 4' a single bedded. Thinner bedded above 9'
8. Shale, red-brown, sandy, with some minor cream-colored, sandy shale and with numerous interbedded, thin-bedded sandstone—red-brown, medium to fine-grained, much ripple-marked. Weathers to flakes 78'
9. Sandstone, thin-bedded to beds 3' thick, brown, weathering light brown to buff, with interbedded shale like (10). Ledge maker 16'
10. Shale, sandy, with some thin sandstone; cream colored 45'
11. Sandstone, white, coarse-grained, impregnated with petroleum. Pennsylvanian(?) sandstone.

356'

The beds just described are limited both above and below by unconformities. They constitute the (c) division or lowest member of Gilbert's Shinarump group in the Henry Mountains region, which together with a thick series of overlying beds were referred provisionally to the Jura-Trias by him. Though these beds have not been actually traced into the Moenkopi formation of the Navajo Reservation, I think the correlation is amply warranted on the ground of position in the sequence, for they underlie the Shinarump conglomerate, which is an excel-

lent distinctive horizon that Gregory⁷ has shown is equivalent in northeastern Arizona with the similar bed in the Henry Mountains, and overlies beds of probable Pennsylvanian age. The equivalence is further emphasized by likeness in lithology, every lithologic feature of the series in the Green River Desert being, I believe, susceptible of duplication on the Navajo Reservation. The De Chelly sandstone, present in places between the Moenkopi and Shinarump on the Reservation, is absent in Green River Desert.

The brief examination of the Moenkopi formation on the borders of Green River Desert did not result in the collection of identifiable fossil forms, though a limy bed containing shell fragments was noted in the lower part of the formation near Temple Mountain. Butler has, however, collected fossils on Miners Mountain near Fruita, about 45 miles southwest of Temple Mountain, from a limestone about 300 feet below the Shinarump conglomerate, which Girty has determined to be Triassic (probably to be correlated with the Lower Triassic, Thaynes and Woodside formations of the Wasatch range).⁸ This fossiliferous limestone is interbedded in a series of reddish sandstones and shale, which, because of lithology and stratigraphic position, I believe correlative with the Moenkopi of the Green River Desert. The Moenkopi is accordingly here referred to the Triassic, though the Moenkopi of the Navajo Reservation was referred by Gregory to the Permian (?), because in that area the various bits of fossil evidence obtained were contradictory.⁹

SHINARUMP CONGLOMERATE (TRIASSIC).

The Shinarump conglomerate, which unconformably overlies the Moenkopi formation, is more resistant to erosion than are the beds above and below, and where inclined at low angles as it is under The Ledge, makes a prominent bench in the topography. In San Rafael Swell it is sharply upturned and forms a small "hog-back."

The Shinarump, from 80 to 100 feet thick, is generally

⁷ Gregory, H. E., op. cit.

⁸ Butler, B. S., Ore deposits of Utah, U. S. Geol. Survey, Prof. Paper 111, in press.

⁹ Gregory, H. E., op. cit., pp. 30-31.

light-colored, having a somewhat Nile-greenish tinge on exposed faces, though locally it weathers almost black. It is composed of very coarse-textured, cross-bedded and massive sandstone and conglomerate. The conglomerate is of two types, the one consisting of water-worn black and brown quartz pebbles one-eighth to one-fourth of an inch or more in diameter, the other of angular yellow and drab limestone and shale pebbles. Limestone pebbles appear to be absent under The Ledge, but are distributed from top to bottom of the formation near Temple Mountain and are especially prominent at the top. A diagnostic feature is the abundance of fossil wood, some of it of large size, as for example, a single trunk on Black Mesa near West Pass, Elaterite Basin, which measures 15 feet in length by 1 foot in diameter. The Shinarump is in places saturated with petroleum. In the Temple Mountain region, it is the source of the radium-bearing ores which occur in pockets associated with fossil wood. The Temple Mountain mine is the type locality of uvanite, a new vanadium-bearing mineral described by Hess and Schaller.¹⁰

The beds just described unconformably overlie the Moenkopi and constitute the "b" division or middle conglomerate member of Gilbert's Shinarump group in the Henry Mountain region and the Shinarump conglomerate of other authors in the Colorado Plateaus. The Shinarump is a most valuable marker, for its very distinct characteristics with their remarkable similarity over a wide area render it an unmistakable key-bed for correlation purposes. No fossils were observed in the Shinarump in Green River Desert, and their exceeding rarity in other places makes determination of the age of the formation difficult. It has, however, been tentatively regarded by Gregory¹¹ as probably of Upper Triassic age on the basis of stratigraphic position and on such meager fossil collections as have been made, and this determination is accepted here.

CHINLE FORMATION (TRIASSIC).

The Chinle formation embraces the variegated shales and red sandstones between the Shinarump conglomerate

¹⁰ Hess, F. L., and Schaller, W. S., Pintadoite and Uvanite, two new vanadium-bearing minerals from Utah, Jour. Wash. Acad. Sci., 4, p. 578, 1914.

¹¹ Gregory, H. E., op. cit.

and the massive Wingate sandstone. It is exposed in The Ledge and upstream in the canyon of Green River to within a few miles of the mouth of the San Rafael and comes to the surface again back of San Rafael Reef. Where the beds are inclined at low angles the Chinle weathers back to a steep slope underlying the vertical cliff of the massive lower portion of the La Plata group, but where not capped by La Plata weathers into badland forms.

Shale predominates in the lower part of the Chinle formation but gives way to sandstone above. The shale is very argillaceous, rather firmly cemented, hard, friable, and of variegated colors, including heliotrope, lavender, mauve, turquoise, dove, cream, and white, and with it are interbedded thin sandstones similar to those constituting the upper part of the formation. The shale rather gradually loses its "marl"-like character becoming more and more sandy until finally in the upper part of the formation the beds are sandstone rather than shale. This sandstone is fine-grained, massive, cross-bedded, and in the San Rafael Swell region its color is maroon with a terra-cotta cast, but under The Ledge the color partakes more of an orange-terra-cotta, the maroon tinge being absent.

In the section measured in Elaterite Basin a limestone conglomerate such as occurs in this formation in the Navajo country, where it is a diagnostic feature, is present in the Chinle about 35 feet above its base. Near Temple Mountain, however, the Chinle consists entirely of sandstone and shale, but limestone conglomerate like that which elsewhere occurs in the body of the formation is present at the base.

A detailed section of the Chinle was not measured in Temple Wash, near Temple Mountain, San Rafael Swell, but its thickness was determined as 210 feet. In this locality approximately the lower one-half of the section is composed of variegated, heliotrope, lavender, mauve, and red-brown argillaceous shale containing thin beds of sandstone, while the upper part is composed principally of sandstone which is medium-grained, much cross-bedded, lenticular and terra-cotta maroon in color. A detailed section of the Chinle rocks measured along the trail over The Ledge between French Spring and Elaterite Spring follows:

Section of Chinle formation in The Ledge along trail from French Spring to Elaterite Spring.

1. Sandstone, red-brown, massive, cross-bedded—Wingate sandstone.	
2. Shale, very sandy, becoming increasingly so toward top; red-brown in color; grades into overlying Wingate sandstone	150'
3. Shale, hard, friable, variegated lavender, heliotrope, mauve, blue, white and cream	115'
4. Shale, sandy, greenish, coarse, with dark limestone conglomerate at top	35'
5. Conglomerate and coarse sandstone, Shinarump conglomerate.	
	<hr/> 300'

The Chinle is lithologically strongly in contrast with the underlying Shinarump conglomerate, which is significant, and which may indicate an unconformity though this does not necessarily follow. At the top of the Chinle along The Ledge there is no evidence of unconformity for the Chinle seems to grade insensibly into the massive Wingate sandstone above. On the other hand, near Temple Mountain there is a marked lithologic difference in the Chinle and La Plata which may perhaps indicate a time break. In the Navajo country east of Carrizo Mountain in extreme northeastern Arizona I found evidence of such a break between the Chinle and overlying Wingate sandstone, and Gregory obtained evidence of unconformity at this horizon at several other places in the Navajo country.¹² Thus it appears likely that the Chinle may be unconformably limited at the top and bottom.

That the beds described above are to be correlated with the Chinle formation on the Navajo Reservation I think there is no reason to doubt. The peculiar lithologic characters of the Chinle in the Reservation, including the presence of limestone conglomerate, are duplicated in Green River Desert, and this together with its position between such prominent and unmistakable key-beds as the Shinarump below and the massive Wingate sandstone above, makes the correlation of the formations in the two localities imperative. The Chinle is identical with the beds referred by Gilbert to the (c) or upper division of his Shinarump group in the Henry Mountains region.¹³ It is Triassic in age.

¹² Gregory, H. E., op. cit., p. 48.

¹³ Gilbert, G. K., op. cit., p. 6, stratigraphic section.

LA PLATA GROUP (JURASSIC).

The La Plata group, which consists of three formations, includes all the beds between the Chinle and McElmo and is probably limited both above and below by unconformities. The lowest formation of the group is the Wingate sandstone, about 900 feet thick and composed of massive cross-bedded, quartz-sandstone beds. Above it lie 100-300 feet of shale and gypsum, with a thin marine limestone containing fossil invertebrates of Jurassic age near the base, which are believed to represent the Todilto formation of the Navajo Reservation. Massive cross-bedded red sandstone and thinner bedded red sandstone and sandy shale aggregating about 700 feet in thickness constitute the Navajo sandstone, which lies above the Todilto (?) and is the highest formation of the La Plata group. The group as developed in Colorado, Arizona, and New Mexico has been referred to the Jurassic on account of stratigraphic position, and that reference is now confirmed by the distinctive marine Jurassic invertebrates in the Todilto (?) formation.

WINGATE SANDSTONE (JURASSIC).

The Wingate sandstone, the lowest formation in the La Plata group, embraces all the massive cross-bedded sandstone between the Chinle and the overlying Todilto (?) formation. It is widely exposed in Green River Desert, forming the canyon walls of Green River from the mouth of San Rafael River to Horseshoe Canyon and capping The Ledge from there to the Dirty Devil. The wonderfully impressive crags of San Rafael Reef are formed from the Wingate sandstone.

The Wingate is a remarkably uniform series of extremely massive, very cross-bedded, medium to fine-grained sandstones, averaging in this region about 900 feet in thickness. The name Orange Cliffs, which appears on the Land Office base (1915) along what is locally and more expressly known as The Ledge, is a descriptive term derived from the color of the lower part of the Wingate which forms these cliffs. The upper part of the formation near The Ledge is white. A similar color scheme is seen in the Wingate in San Rafael Reef in the vicinity of San Rafael River, but at other places

along the Reef the formation is white throughout its entire thickness. Such inconstancy of color seems to preclude its use as a diagnostic character, although it was regarded as distinctive by Powell, Dutton, and Gilbert in their early reconnaissance work in Utah. The extreme massiveness and cross-bedding of these sandstones, which features were of course recognized and emphasized by these writers, seem indeed to be diagnostic and to afford much safer ground for correlation purposes than does color.

There is generally a weaker zone between the massive and resistant upper and lower portions of the Wingate in both The Ledge and San Rafael Reef, but this zone occurs at different stratigraphic positions in each section. In the section at The Ledge it is 250 feet thick and starts 375 feet above the base of the formation, whereas in the Temple Wash section it is only about 200 feet thick and starts 150 feet above the base of the formation. The beds in this zone are sandstones similar to those above and below in all respects except that they are less massive, and so less resistant to erosion. There is no shale or gypsum in this zone, but within a few feet of the top of it in the Temple Wash section are two beds of conglomerate each less than 4 feet thick containing angular limestone and shale pebbles. These conglomerates lie about 550 feet below the top of the formation in this area. In the section at The Ledge similar conglomerate was noted about 100 feet below the top of the Wingate in the midst of a thick series of very massive sandstones, but no such conglomerate is present here in the less massive middle portion of the formation. Near the "Bowknot" loop of the Green fragments of fossil wood are present in similar conglomerate in the upper part of the Wingate. The conglomerate is apparently only locally developed and is such as one would expect to form by the breaking up of limestone and shale deposits laid down in little fresh water lagoons. It marks no single definite horizon nor do the less massive sandstone beds in the middle portion of the Wingate represent a single period of widespread deposition of this type. Rather they indicate that at different times in different places conditions were right for the deposition of more thinly bedded sandstone than were laid down before or after.

The following sections illustrate the character of the Wingate sandstone:

Section of Wingate sandstone in The Ledge near French Spring.

1. Sandstone, white, weathering light buff to white, medium grained, very massive, cliff maker; cross-bedded, contains bed of limestone conglomerate about 100' below top	285'+
2. Sandstone, lighter in color than underlying sandstone, grading into white above, less massive than (1) and (4), cross-bedded	145'
3. Sandstone like (4) but less massive	105'
4. Sandstone, orange-terra-cotta in color, weathering red-brown, very massive, a single bed; cross-bedded, very prominent ledge maker	375'
5. Sandstone and shale, red-brown, Chinle formation,	
	<hr/> 910'+

Section of Wingate sandstone, North Temple Wash.

(Measured with the aid of Milton Anderson and Walt M. Small of Tulsa, Okla.)

1. Shale and fossiliferous limestone, Todilto (?) formation.	
2. Sandstone, white, massive, cross-bedded, forms dip slope of San Rafael Reef	517'
3. Sandstone, white, less massively bedded than member above, but having similar characters. Contains two thin beds of limestone conglomerate within 25' of top	213'
4. Sandstone, light buff, very massive, cross-bedded, cliff maker, supports San Rafael Reef; oil sand at base	150'
5. Sandstone, red-brown, and variegated shale, Chinle formation.	
	<hr/> 880'

The beds described above were divided by Gilbert into two formations, the "Vermilion Cliff" and the "Gray Cliff," apparently largely because of color differences, but that such a division was attended with difficulties is evident from Gilbert's statements quoted below:¹⁴

"The Gray Cliff and Vermilion Cliff sandstones are often difficult to distinguish, but the latter is usually the firmer, standing in bold relief in topography, with level top, and at its edge a precipitous face. The former is apt to weather into a wilderness

¹⁴ Gilbert, G. K., op. cit., p. 7.

of dome-like pinnacles so steep sided that they cannot often be scaled by the experienced mountaineer, and separated by narrow clefts which are equally impassible."

And again:

"Standing upon one of the summits of the Henry Mountains and looking eastward I found myself unable to distinguish the Gray Cliff Sandstone by color either from the lower part of the Flaming Gorge Group or from the Vermilion Cliff Sandstone."

The distinction of two formations in these massive sandstones is equally as difficult in the Green River Desert as in the Henry Mountain region. As already shown, color in these beds is not a sure ground for the drawing of formational boundaries, and in the absence of fossils I can see no basis for drawing such a boundary in the midst of a series lithologically similar from top to bottom. In my opinion the "Vermilion Cliff" and "Gray Cliff" sandstones constitute a single stratigraphic unit, which is equivalent to the Wingate sandstone of the Navajo Reservation. This correlation is based on the position of the unit between the Chinle formation below and a series of limestone, shale, sandstone, and gypsum beds above which is believed equivalent to the Todilto as mapped by Gregory in the western part of the Navajo Reservation, and further upon its lithologic character, especially its massiveness and cross-bedding, which duplicate that found in the Wingate in Arizona. This interpretation differs from that of Gregory,¹⁵ who correlated the Wingate sandstone with only the lower part of the series, the "Vermilion Cliff" portion, and who regarded the Todilto as the equivalent of the less massive zone present in the "Vermilion Cliff"—"White Cliff" series of beds in the High Plateaus. It has been shown above that this less massive zone is not constant in stratigraphic position in Green River Desert, but does in fact occur at various horizons in the series, and is not a formation or definite member of a formation. The present interpretation differs also from that of Doctor Cross, who in eastern Utah correlated the upper ("White Cliff") portion of the series with the La Plata,¹⁶ and regarded the "Vermilion Cliff" sandstone as older than La Plata. The present interpretation differs also from

¹⁵ Gregory, H. E., op. cit., plate III.

¹⁶ Cross, Whitman, Stratigraphic results of a reconnaissance in Western Colorado and Eastern Utah, Bull. Geol. Soc. America, 15, p. 642, 1907.

that of Lupton, who in the course of a study of the Cretaceous beds in Castle Valley and again in Grand County near Greenriver, also briefly examined the underlying rocks and reached the conclusion that the massive Jurassic sandstones ("Vermilion Cliff" and "Gray Cliff") represented the entire La Plata group.¹⁷

TODILTO (?) FORMATION (JURASSIC).

The rocks here called Todilto (?) formation constitute the middle portion of the La Plata group and comprise a heterogeneous and extremely variable series of shale, sandstone, limestone, and gypsum, but is a perfectly definite unit between the Wingate sandstone below and the Navajo sandstone above. It is broadly exposed in Green River Desert just east of San Rafael Reef, and again back from the canyon of Green River and The Ledge.

The Todilto (?) formation, characterized by its extreme variability, which is in fact diagnostic, in places appears as an unbedded jumbled mass of reddish shales associated with dirty gypsum and irregular bunches of massive sandstone, as in the Dugout Creek area about 8 miles above the mouth of San Rafael River, but elsewhere comprises a series of regularly bedded shales, sandstones, limestone, and gypsum, as for example, along Green River south of San Rafael River and in places along San Rafael Reef. The formation varies from 100 to about 300 feet in thickness.

Near San Rafael Reef where the Todilto (?) is rather regularly bedded a persistent blue-gray, compact limestone 2 to 4 feet thick lies from 12 to 15 feet above the base of the formation. This limestone is very fossiliferous and in a collection made with the assistance of Dr. Harvey Bassler along the Greenriver-Hanksville road 2 miles south of Straight Wash the following species have been identified by Dr. T. W. Stanton, who states they are marine invertebrates of Jurassic age:

Ostrea strigilecula White
Camptonectes sp.
Camptonectes stygius White
Plicatula sp.

Gervillia (?) sp.
Trigonia quadrangularis
 Hall and Whitfield
Cyprina (?) sp.

¹⁷ Lupton, C. T., Oil and Gas near Green River, Grand County, Utah, U. S. Geol. Survey, Bull. 541, p. 125, 1914.

In driving from Castledale to Greenriver, Mr. H. S. Palmer and I noted fossils at this horizon at the north end of the Swell and Lupton reports this limestone to be fossiliferous in Castle Valley on the west side of the Swell, where in addition to the species listed above he found *Modiola subrimicata* Meek.¹⁸

Along Green River south of San Rafael River the limestone of the Todilto (?) directly overlies the massive Wingate sandstone. The limestone is here barren of fossils and is 4 feet thick, blue-gray, and dense in texture though it is possible to see flashes from crystal faces when a hand specimen is turned in the sun. With the limestone is interbedded chert, and in places there are irregular patches of calcite. This limestone strongly reminds me of the Todilto limestone in the type locality at Todilto Park, north of Fort Defiance, Ariz.

The sharp lithologic contrast of the Todilto (?) and Wingate and especially the much disturbed character of the lower beds of Todilto (?) in some places suggests that these formations are separated by an unconformity. The pronounced irregular surface of the top of the Todilto (?) into which the overlying Navajo fits, suggests that the Todilto (?) is also limited above by an unconformity.

The following detailed section furnishes an idea of the character of the Todilto (?) formation in the Green River Desert:

*Section of Todilto (?) formation in sec. 28 T. 24 S.,
R. 16 E., Salt Lake Meridian, Utah.*

1. Sandstone, red, massive, cross-bedded Navajo sandstone. Erosional unconformity?	
2. Sandstone, like (4), contact with massive red sandstone is irregular	16'
3. Sandstone, light-colored, weathering light green; coarse-grained, irregularly bedded	11'
4. Sandstone, dark red, coarse-grained, rather irregularly bedded, with ripple-marked layers 4"-15" thick	68'
5. Sandstone, pinkish gray, massive, cross-bedded Wingate sandstone.	

95'

¹⁸ Lupton, C. T., Geology and coal resources of Castle Valley, in Carbon, Emery, and Sevier counties, Utah, U. S. Geol. Survey, Bull. 628, p. 24, 1916.

Of the Jurassic age of the rocks just described there can be no doubt, for it is amply shown by the fossil content. They are lithologically similar to beds referred by Gregory to the Todilto in Piute Canyon and near Navajo Mountain, and like those beds lie between massive Wingate sandstone, below, which is an excellent key formation, and the Navajo sandstone above. Gregory, however, states that the expression of the beds in the northwest part of the Navajo Reservation is so unlike the Todilto of the type locality that the correlation can only be considered a working field hypothesis.¹⁹ So while it is recognized that the beds between the Wingate and Navajo in Green River Desert are the equivalent of similar beds near Navajo Mountain they are referred to the Todilto with a question mark because later work may show that the Navajo Mountain Todilto is not indeed the equivalent of the type Todilto.

The Todilto (?) constitutes the lower part of what Gilbert termed the "Flaming Gorge group" in the vicinity of Henry Mountains and has been included by Lupton in the McElmo in Grand County and in Castle Valley. Lupton, however, was aware that the inclusion of these beds in the McElmo might not stand the test of more detailed work than the time at his command and the exigences of his examination permitted, for in this connection, quoting a list of fossils found in the limestone mentioned above, he said:

"As the McElmo formation in its type area is not known to include any marine strata, it is possible that the bed containing this fauna is older than the basal beds of the typical McElmo."²⁰

NAVAJO SANDSTONE (JURASSIC).

The Navajo sandstone includes the beds between the Todilto (?) formation and the variegated shale and coarse sandstone and conglomerate of the Salt Wash member of the McElmo. It is broadly exposed in Green River Desert outcropping along San Rafael River and also in the region of the Flat Tops.

In the field two members of the Navajo sandstone were mapped on lithologic grounds. The lower of these is about 300 feet thick and consists of medium-grained sand-

¹⁹ Gregory, H. E., op. cit., p. 56.

²⁰ Lupton, C. T., *Geology and coal resources of Castle Valley, in Carbon, Emery, and Sevier counties, Utah*, U. S. Geol. Survey, Bull. 628, p. 24, 1916.

stone, massive in character, and much cross-bedded and held together by calcareous cement. True bedding is so irregular as to make it next to impossible to obtain a valuable dip reading with the clinometer and the irregularity is especially marked near the contact with the Todilto (?) into the irregularities of which the lower Navajo beds fit. The irregularity along this contact suggests an unconformity at this horizon. In general the color of the lower massive Navajo is brick-red but in places near the "Reef" the rocks vary in color from café-au-lait to straw. This part of the formation weathers into prominent cliffs with rounded, impassable faces, or into deep pockets which catch and retain rain water. A rather local and striking feature of weathering is that near Gillis's ranch on San Rafael River where the formation is veined with calcite—probably associated with minor faulting, and weathers into low walls which "fence" in circular areas.

The thin-bedded upper part of the Navajo contrasts strongly with the massive lower part just described. The beds are sandstone and sandy shale and are for the most part brick-red in color, but near the middle of the series is a conspicuous zone of light-colored beds which though of similar lithology to the associated beds, differ in that they are light greenish in color. With them are associated irregular bunches of quartz which weather into small rounded red balls or lozenges resembling in appearance red rubber bath sponges. These "sponges" may be seen in profusion along the Hanksville road two miles or so south of San Rafael bridge. The very top of the upper Navajo sandstone is characterized by a 90-foot cliff of sandy shale interbedded with dirty gypsum. There is about 15 feet of almost solid gypsum just below the McElmo, which is thought to unconformably overlie the Navajo.

The character of the Navajo sandstone is shown by the following section:

*Section of the Navajo sandstone near Gillis's ranch,
San Rafael River, Utah.*

1. Shale and thin sandstone with much interbedded gypsum, 15' of gypsum at top makes a vertical cliff	90'
2. Shale, sandy, brownish, with interbedded gypsum, forms steep slope to cliffs above	63'

3. Sandstone and sandy shale, light brown below, greenish above, thin-bedded, some beds 1/16" thick, with veins and interbedded layers of gypsum 6" to 18" thick in middle portion	144'
4. Sandstone, fine-grained, reddish brown on weathered surface, somewhat lighter on fresh fracture, lower part massive, upper part more thinly bedded ...	127'
5. Sandstone, massive, cross-bedded, red-brown to yellow. Estimated	300'
	<hr/> 724'

The beds described above were included by Gilbert²¹ in the "Flaming Gorge group" and have been referred by Lupton²² to the McElmo formation. Their lithologic character and stratigraphic position are suggestive of the Navajo sandstone of northeastern Arizona, and accordingly all the beds in Green River Desert between the Todilto (?) and the Salt Wash member of the McElmo have been referred to that formation. The limits of the Navajo as thus drawn are very definite in Green River Desert, but it is realized that the upper limit here may differ somewhat from that on the Reservation where Gregory states that the boundary between the Navajo and McElmo can not be too finely drawn.²³ That the contact in the two areas is not identical seems likely for Gregory has included the beds of Theater Rock in the McElmo while what appear to be similar beds in Green River Desert are here referred to the Navajo. Realizing that in northeastern Arizona there is apparently no counterpart of the Salt Wash member of the McElmo, which I believe indicates an unconformity, and realizing that the contact of the Navajo and McElmo is therefore uncertain in some degree, I have drawn the boundary as sharply as possible in Green River Desert. As so drawn, the Navajo contains all the red cross-bedded sandstone and red sandy shale above the Todilto (?); the McElmo includes light-colored coarse sandstone and variegated shales entirely different in character from the beds in the Navajo.

McELMO FORMATION. (CRETACEOUS?)

The McElmo formation overlies the Navajo sandstone and includes all the beds between it and the Dakota sand-

²¹ Gilbert, G. K., *op. cit.*, p. 6.

²² Lupton, C. T., *op. cit.*

²³ Gregory, H. E., *op. cit.*

stone, or Mancos shale where the Dakota is absent. The formation embraces a series of coarse sandstones, conglomerates and variegated marl-like shale, and may be divided into three parts on the basis of lithology. Of these the lowest consists of coarse sandstone and conglomerate with minor amounts of light shale and has been called the Salt Wash member, by Lupton.²⁴ The middle portion embraces a series of variegated shales with local thin sandstones, and the upper portion consists of hard sandstone which weathers dark and has associated with it small amounts of variegated shale.

At the base of the Salt Wash member of the McElmo formation is 15 to 20 feet of light variegated shale which contrasts strongly in lithology and color with the underlying Navajo sandstone. The Salt Wash member is 200 feet thick, and with the exception of the basal shale, consists of coarse sandstone composed of loosely cemented, rather well rounded quartz grains mostly translucent with a small per cent of weathered feldspar. It also includes considerable poorly cemented conglomerate. These rocks are light-colored on fresh fracture and in many places weather nearly white, though elsewhere they weather a light brownish color. Fragments of light-colored petrified wood are present in this series and with them are associated in a number of places yellow streaks in irregular blotches of carnotite, and other uranium and vanadium ores. Many uranium claims have been located on the outcrop of this part of the formation in the vicinity of San Rafael River and numerous prospect holes have been opened. The Salt Wash member also includes numerous fragments of *dinosaur bones* which differ from the dinosaur bones in the overlying beds in that they are smaller.

The presence of shale very different in character from the underlying Navajo beds, and the further presence of a considerable thickness of conglomerate and coarse sandstone indicates that deposition in Salt Wash time took place under conditions entirely different than those prevailing before that time. The evidence indicates that Salt Wash deposition was separated from the Navajo by a time break, and that the contact of the Navajo and McElmo is unconformable.

²⁴ Lupton, C. T., Oil and gas near Green River, Grand County, Utah, U. S. Geol. Survey, Bull. 541-D, p. 15, 1914.

A detailed section showing the character of the Salt Wash member of the McElmo is given below.

*Section of the Salt Wash sandstone member of the
McElmo formation.*

On north side of San Rafael River two miles below San Rafael bridge.

1. Sandstone, coarse-grained, loosely cemented; contains fragments of fossil wood	20'
2. Shale, green to gray in color and streaked with brown; irregularly bedded; streaked with yellow at top and bottom indicating presence of carnotite	5'
3. Sandstone, light-colored on fresh fracture, weathering dark brown medium to coarse-grained, loosely cemented, soft, cross-bedded, massive ..	55'
4. Shale, variegated light and maroon	17'
5. Sandstone, light-colored, fine-grained, ledge-making but not as hard as sandstones lower in section ..	6'
6. Shale, mostly light-colored but with some maroon, and with one sandstone bed one-half way up which is here 1½ feet thick, but elsewhere 5' thick	30'
7. Sandstone, like 9, ledge-making in places	8'
8. Shale, like that lower in section, mostly maroon ...	15'
9. Sandstone, like 11 and 13, somewhat irregularly bedded and streaked with maroon shale	9'
10. Shale, mostly maroon but with some light colors, and with local sandstone	11'
11. Sandstone, like 13	3'
12. Shale, like 14 but with more maroon	9'
13. Sandstone, nearly white on fresh fracture, weathers light brown, hard, compact, very fine-grained, a single bed with thin laminae	5'
14. Shale, variegated light green with some maroon and contains some thin sandstone, Base of Salt Wash sandstone member	5'
	198'

Above the Salt Wash member of the McElmo lies a series of variegated clay shales 170 to 200 feet thick, which weather into steep cliffs and are very conspicuous because of their gray, purple, and maroon colors. The shales contain numerous well-polished pebbles ¼ to 2 inches in diameter, resembling gastroliths, which are

found in profusion strewing weathered surfaces, and also contain toward the top bones of large dinosaurs. The variegated shales are capped by a bed of coarse sandstone or conglomerate which forms a prominent bench, and above which is a series of coarse sandstones and conglomerates with small amounts of gray or pale-tinted variegated shale. This part of the section is extremely variable in lithology and color but is in general characterized by a predominance of sandstone which, though light on fresh surface, is somber gray or black in color on the weathered face due to desert varnish. The accompanying stratigraphic section gives details of the beds in the McElmo formation above the Salt Wash member.

Section of upper part of the McElmo formation three-fourths mile west of Jesse's Twist in the Greenriver-Hanksville road.

(Measured by Milton Anderson.)

1. Conglomerate, light-colored, massive, cross-bedded	15'
2. Shale, light-colored, sandy, containing beds of grayish sandstone	75'
3. Conglomerate, grayish in general color, but containing well worn, red, blue, black quartz pebbles, loosely cemented, makes a ledge	25'
4. Shale, grayish purple, containing four thin beds of sandstone and capped by layer of white shale two feet thick	38'
5. Sandstone, brownish gray in color, in beds 18" thick alternating with purple and gray shales	15'
6. Sandstone, brownish gray, coarse-grained, irregularly bedded, ledge maker	20'
7. Shale, variegated purple, gray, red, containing well-polished pebbles resembling gastroliths, with local thin sandstone beds	170'
Total	358'

The beds just described and included by Gilbert²⁵ in the "Flaming Gorge group," were referred to the McElmo by Lupton,²⁶ who also placed in this formation the underlying Navajo and Todilto. In the present paper these two formations have been referred to the La Plata group of rocks (Jurassic) for reasons already presented. The lower limit of the McElmo (Cretaceous?)

²⁵ Gilbert, G. K., op. cit.

²⁶ Lupton, C. T., op. cit.

is placed at the base of the Salt Wash member of this formation because there is at this horizon a distinct lithologic and color break, which with the presence of a thick series of coarse sandstone is indicative of a time break and unconformity. The upper limit of the McElmo is the Dakota sandstone, or Mancos shale where the Dakota is absent. As so defined the McElmo appears to be in accord with the description of the McElmo at the type locality along the creek of that name in southwestern Colorado where it consists principally of marl-like variegated shales.

DAKOTA SANDSTONE (CRETACEOUS).

The Dakota sandstone is exposed near the Greenriver-Hanksville road in the vicinity of Greenriver where it reaches a maximum thickness of about 40 feet but is absent elsewhere in the northern part of Green River Desert. It consists of loosely cemented and friable, coarse sandstone layers and lenticular beds of coarse conglomerate containing rather well rounded translucent, gray, black, and red quartz pebbles. On fresh fracture the color is buff but the rock commonly weathers to a rusty dark brown. No coal was observed in the Dakota in the Greenriver region nor were any fossils collected in the rather cursory examination of the formation, but Richardson²⁷ who studied the Dakota in this vicinity as well as over a large area to the east and west found characteristic Dakota plants (Cretaceous) in it near Elgin, and therefore has correlated it with the Dakota of the Rocky Mountain region. It is unconformable on the underlying variegated shales and sandstone of the McElmo.

MANCOS SHALE (CRETACEOUS).

The Mancos shale overlies the Dakota sandstone and is broadly exposed in the vicinity of Greenriver and along the base of the Book Cliffs for many miles east and west of that town. It comprises a series of rather uniform drab to dark gray clay shales, which are calcareous throughout, in places to such an extent as to be almost limestones. About 200 feet above the base of the formation and forming a prominent escarpment is 15 to 20 feet

²⁷ Richardson, G. B., Reconnaissance of the Book Cliffs Coal field, U. S. Geol. Survey, Bull. 371, p. 14, 1909.

of shale more resistant than the rest of the formation and which erodes into small lozenges, steel gray on the weathered face. This together with the tendency of the shale to ring when trod upon leads one to suspect that it may represent the Mowry shale of Wyoming which lies in a somewhat stratigraphically similar position. With this resistant shale are associated, near Tidwell, minor sandstones containing sparsely distributed, small black quartz pebbles with which were found fragments of *Inoceramus* sp. and sharks' teeth belonging to *Lamna* and possibly other genera. The black quartz pebbles suggest that these beds may represent in this region the sandstones of the Frontier formation of Wyoming.

The following species identified by Doctor Stanton as Benton in age were collected from calcareous sandstone nodules in the shale about 50 feet above the base of the formation 3 miles northwest of the Greenriver-Hanksville road:

<i>Gryphaea newberryi</i> Stanton	<i>Exogyra suborbiculata</i> Lamarck?
<i>Plicatula?</i> sp.	
<i>Cardium pauperculum</i> Meek	<i>Veniella martoni</i> M. and H.

Gryphaea newberryi Stanton occurs profusely at the very base of the formation and fragments of *Inoceramus* sp. are widely distributed through the lower part of the series.

Richardson, Lupton and others who have studied this shale near Greenriver have correlated it with the Mancos, and fossil evidence amply confirms the correlation. The more resistant band of shale described as lying about 200 feet above the base of the formation is to be correlated I think with the Ferron sandstone member of the Mancos,²⁸ for although this part of the shale cannot be actually traced into the Ferron east of Greenriver yet the distance between the two outcrops is so small and their stratigraphic position is such that there can be no doubt of the correlation.

²⁸ Lupton, C. T., op. cit.

ART. XXIV.—*The Law of Dissipation of Motion*; by
ERNST JONSON.

In order to explain the physical aspect of the universe it is assumed that matter consists of separate particles tied together by forces in such a manner that when the particles move motion is transmitted from one particle to another. Transmission of motion is mechanically conceivable only if we assume that a force acts on the two particles between which transmission of motion takes place, *i. e.*, when the two particles are the points of application of a force.

When two stars revolve about their common center of gravity there occurs a continuous transmission of motion from each one to the other. Such transmission of motion involves permanent action of force. When a water molecule collides with an iron molecule in the wall of a steam cylinder the resulting transmission of motion is momentary because the force acts only for an instant. The revolution of masses of matter about each other is a comparatively stable condition. Most natural changes evidently are due to transmission of motion through collision. In the mechanics of collision then must be found the final explanation of all those natural phenomena which result from the transmission of molecular energy.

The following derivation of the Law of Dissipation of Motion is a contribution to this branch of mechanics. The chief immediate interest in this law arises from the fact that it explains the Law of Dissipation of Energy by rendering its mode of operation mechanically presentable.

When a collision occurs between two particles and the motions of the colliding particles are not parallel, each motion may be resolved into two perpendicular components in such a way that each component of one motion is parallel with one of the components of the other motion, and so that the two components which have the same direction also have the same size. The momentum AB in figure 1 is resolved into the momenta AD and DB, and the momentum CB into the momenta CD and DB. The two coinciding components of the original motions represent the common motion of the two particles and have therefore nothing to do with the collision. The collision of the two particles results, of course, entirely from their relative motion. This relative motion is represented by