STRATIGRAPHIC RESULTS OF A RECONNAISSANCE IN WESTERN COLORADO AND EASTERN UTAH[1]

WHITMAN CROSS

One of the principal features of interest in the study of the sedimentary formations of the western mountain slopes of Colorado is their correlation with the formations of the Plateau Province to the west. I have already introduced the discussion of this subject in an article on the Red Beds of Colorado (**8**)[2], but without first-hand information as to the Plateau country. I am now able to review and affirm the correlation there suggested, on the basis of observations made during the summer of 1905, in the course of a reconnaissance from Mancos, on the southwestern flank of the San Juan Mountains, in Colorado, to the vicinity of Moab, on Grand River, in Utah, returning to the northern slope of the San Juan at Montrose. Other members of the party engaged in this reconnaissance were Messrs. L. H. Woolsey, W. H. Emmons, and Geo. F. Kay, all of whom had seen, or were to see later in the season, the stratigraphic succession of formations in the San Juan region. I wish to acknowledge my indebtedness to all these gentlemen for observations recorded with my own in the following pages.

Itinerary.—The party proceeded west from Mancos to Cortez, in the Montezuma Valley; thence northwesterly across the headwaters of various branches of Montezuma Creek to the northeast base of the Abajo or Blue Mountains, in Utah. From this point the route northward lay mainly in Dry Valley which extends nearly to the La Sal Mountains. This part of the journey was near the line followed by Newberry in 1859 (**28**). Turning westward down Spanish Valley to Moab, extensive sections were examined on both sides of Grand River. From Moab we proceeded up the Canyon of Grand River, some 20 miles, and then turned east, passing over the northern slopes of the La Sal Mountains, and thence south through Sindbad and

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[2] Numbers in parentheses refer to the bibliographic list at the end of this paper.

Paradox Valleys. The Dolores River was crossed in Paradox Valley and from that point the route turned again northward following the crest of Uncompahgre Plateau to Unaweep Canyon, the remarkable transverse gorge examined by Peale (**29**). The section exposed in West Creek near Dolores River was studied in some detail. From Unaweep Canyon we retraced our course along the Uncompahgre Plateau and passed down its eastern slope to Montrose. During this journey, of about 450 miles, occupying 30 days, excellent opportunities were presented for observing the stratigraphic relations of formations ranging from the Pennsylvania Carboniferous to the Mancos shale of the Cretaceous.

It will be a great aid to the reader in comprehending the significance of the recorded observations if he will refer to Sheets XIV and XV of the Hayden *Atlas of Colorado* and adjacent parts of Utah, which represent the whole of the area traversed, with the exception of the vicinity of Moab.

GENERAL CORRELATION OF FORMATIONS

The plan of presentation will be to take up the formations of each system in turn and give the evidence which identifies the stratigraphic units adopted in the Colorado folios with certain ones found in the Plateau region, with suggestions, more or less definite as the case may be, as to correlation with the terminology of Peale, Holmes, and other geologists who have written upon the region visited. The table of correlation appearing on the following page is presented as a guide in following the discussion.

CRETACEOUS FORMATIONS

The floor of the main plain or plateau between the San Juan Mountains and Grand River Canyon in Utah, variously designated on the Hayden maps, in adjacent areas, as San Miguel Plateau, Dolores Plateau, and Great Sage Plain, is immediately underlain by the Dakota sandstone. Speaking of the very district traversed by our party on the outward journey, Holmes remarks that "over hundreds of square miles these sandstones lie comparatively unbroken, while the loose series of shales above have been swept off like so much dust from a great floor" (**17**, p. 259).

CORRELATION OF FORMATIONS

San Juan Folios, U. S. G. S.			Peale	Holmes	Powell
Cretaceous	Mancos				
	Dakota		Dakota or Upper Dakota	Upper Dakota	Henry's Fork
Jurassic	Gunnison	McElmo	Lower Dakota	Lower Dakota	Flaming Gorge
			Jurassic		
		La Plata	Triassic	Triassic	White Cliff
Triassic	Dolores				Vermilion Cliff
Carboniferous	Permian ?	Cutler	Permean Permo-Carboniferous, or Upper Carboniferous		Shinarump Group (All assigned to Triassic)
	Pennsylvanian	Hermosa	Middle Upper Carboniferous		Aubrey

The continuity of exposures, the persistence of lithologic characters, and the simplicity of stratigraphic relations place it beyond question that the section under discussion has for its upper members the Dakota sandstone and a variable remnant of Cretaceous shales, everywhere of the same general characteristics. The shale formation has been named after the town and valley of Mancos, our starting point, and I am aware of no reason why that name should not apply to the portions of that formation remaining above the Dakota, over the entire Plateau Province east of the Colorado and Grand Rivers, if not, indeed, still farther westward.

The formation here called Dakota is that designated as "Upper Dakota" on Sheets XIV and XV of the Hayden *Atlas of Colorado*, covering the portion of Colorado and Utah with which this discussion has to do. The "Lower Dakota" of those maps was a division established by Holmes for strata below the commonly recognized Dakota, as will shortly be explained.

While this reconnaissance was in progress Stanton and others were demonstrating that the beds hitherto referred to the Dakota to the east of the mountains, in the Arkansas Valley, were in part of the Comanche or Lower Cretaceous Series (**36**). Our observations were not directed to this point, but a re-examination in 1906 of the Dakota on the south flank of the San Juan failed to reveal ground for assigning any part of the formation called the Dakota in the San Juan folios to the Comanche Series.

JURASSIC FORMATIONS

All geologists who have examined the Mesozoic section of western Colorado have been impressed with the strong lithologic resemblance exhibited by several hundred feet of strata, occurring immediately below the Dakota to the fresh-water Jurassic beds found along the eastern base of the Front Range and characterized by the wonderful Dinosaurian fauna exploited by Marsh and others. With one exception, tc be considered below, this lithologic similarity and corresponding stratigraphic position have been considered sufficient to warrant the assignment of the western slope beds to the Jurassic.

The first to give a formation name to those strata was Eldridge (**13**), who called them the Gunnison formation. In the San Juan region it was found better to divide the Gunnison into the McElmo and La Plata formations, the former to include the alternating sandstones and variously colored marls and shales of the upper part of the section, and the latter the heavy sandstones of the lower portion.

THE McELMO FORMATION

Before the McElmo beds were so named (**3**) they had been studied in the Telluride quadrangle at the head of San Miguel and Dolores Valley, and had been traced for some distance down each stream.

They are continuously exposed down the canyon of the former to the Dolores River and have a wide distribution in the Uncompahgre Plateau, about the La Sal Mountains and in the lower Dolores and the Grand River valleys. This is clearly stated by Peale in the *Report* for 1875 (**29**). But the Hayden map covering the area just mentioned shows "Lower Dakota" beds as present beneath the plateau-making Dakota proper, and in Peale's *Report* for 1876 (**30**) he divides the

beds formerly called Jurassic into "Lower Dakota" and Jurassic, consistent with the map. It may be well to make a summary statement in this place concerning the origin and application of the term "Lower Dakota," since the use of the Hayden map is rather confusing without explanation. Moreover, the McElmo beds were named from a locality where the Hayden map shows no Jurassic beds.

While surveying the Rico quadrangle the Dakota and subjacent strata were traced southwesterly down the Dolores Valley to the great bend of the river, where it turns due north. But a few miles west of that point several branches of McElmo Creek, a large tributary of San Juan River, cut below the Dakota sandstone into the underlying Jurassic beds. Flowing at first in narrow canyons rimmed by the Dakota, these various forks finally widen into valleys presenting broad exposures of the strata in question. In 1897, H. S. Gane, who had been my assistant in the Telluride quadrangle work, traversed the main McElmo Valley from its head to the San Juan River and upon his report the name McElmo was chosen for the Jurassic formation beneath the Dakota.

The Hayden map, Sheet XV of the *Atlas of Colorado*, represents the "Lower Dakota" as the principal formation below the plateau sandstone, in McElmo and Montezuma Valleys and in the adjacent portion of the broad San Juan Valley. Apparently the "Lower Dakota" of that map represents in fact the general distribution of the McElmo formation. No Jurassic formation is shown upon the Hayden map of that region.

This cartographic representation is based on the work of W. H. Holmes, and its explanation is to be found in his report for 1875 (**17**, p. 260). Describing in general terms the section below the Dakota proper Holmes says "The variegated series which succeeds it [downward] I at first felt inclined to call Jurassic, since it resembles so closely the variegated beds that on the eastern slope of the mountains have usually been credited to that age." After mentioning details of differences in lithologic character, Holmes refers to a much more important basis for his conclusion. He states (**17**, p. 261) that: "In Middle Western Colorado Dr. Peale has found Cretaceous fossils in a stratum of sandstone some three or four hundred feet beneath the bed of conglomerate [referring to the basal Dakota conglomerate],

and also beneath a series of variegated beds that resemble these in this section." No mention of even the general character of these fossils is made, nor can I find any further reference to them in the publications of the Hayden Survey. Personal inquiry of both Messrs. Holmes and Peale brings out the fact that after the lapse of many years spent in other lines of work, neither geologist is able to recall the basis for the statement that such fossils had been discovered, nor can records in regard to them be found. As the observations of the last 30 years do not indicate the existence of Cretaceous fossils in the position referred to, it must be assumed that the statement is an error, the origin of which cannot now be fixed.

The McElmo beds in characteristic development were seen by us in Dry Valley and on the eastern flanks of La Sal Mountains, in Dolores Valley, and in many places on Uncompahgre Plateau, as far north as Unaweep Canyon. To the north from that locality Peale refers to the formation as maintaining the same general character. No representative of the Marine Jurassic reported by Powell (**33**) and others from Utah was observed by us.

Rumors of large bones, presumably in the McElmo beds, have come to my attention several times in recent years, but never with exact locality named, and no trace of such remains has been found in the San Juan region.

The McElmo beds of Dry Valley are fossiliferous, locally, at least, as proven by Newberry, who found saurian bones in place at about 500 feet below the Dakota (**28**, p. 91), in the southeastern branch of Dry Valley, named by him Cañon Pintado or Painted Cañon. From Newberry's description of the locality and our own observations of the Cañon Pintado from the mesa to the west, as well as on the route traversed through Dry Valley, it is certain that the saurian bones came from the McElmo. Newberry expressed no positive opinion as to the age of the bone-bearing horizon, but called it "Jurassic(?)" in his "General section of the Valley of the Colorado" (**28**, p. 99).

The saurian bones found by Newberry were described by Cope (**2**, p. 31) as the type of *Dystrophæus viæmalæ*, and were said in positive, but quite unwarrantable, terms to have come from the Triassic, with no suggestion of the provisional assignment to the Jurassic by

Newberry. Cope states that Newberry excavated the bones of Dystrophæus "from the red and green rocks usually referred to the Trias, hence from the same formation which yielded the *Typothorax* already described." The *Typothorax* in question was found in New Mexico with belodont crocodile and other forms almost demonstrating that its horizon is the fossiliferous zone of the Dolores Triassic formation, the place of which in the Grand River section is nearly, or quite, 1,000 feet below the McElmo beds, as will be shown in a later section. Cope adds emphasis to his error as follows: "More than usual interest attaches to this fossil. It is the first one found in the Triassic beds of the Rocky Mountain region. . . . ." "The rock is described by Professor Newberry as the same as that which I have identified in New Mexico as the Trias and is of the usual red color" (**2**, p. 36*a*). In harmony with the occurrence of *Distrophæus viænalæ* in the McElmo beds it has recently been pointed out by F. von Huene that its affinities are Jurassic rather than Triassic (**20**).

That the McElmo beds contain the vertebrate fauna of the "*Atlanta-saurus* beds" of Marsh has been demonstrated by Riggs who discovered many dinosaurian remains in that formation near the junction of the Grand and Gunnison Rivers at the northeastern base of the Uncompahgre Plateau (**34**, p. 651). While this vertebrate fauna has not as yet been described, it is referred to by Riggs as clearly the same which characterizes the Jurassic beds of Wyoming and the eastern base of the Front Range in Colorado. It is said that "Representatives of a single genus (*Morosaurus*) have been observed to range through the entire series," meaning a section some 500 or 600 feet in thickness below the Dakota.

It is to be regretted that Riggs did not make the importance of his discovery in the correlation of the Colorado Jurassic more evident to the general reader by a reference to the literature concerning occurrences of supposed Jurassic in western Colorado. There is no mention of the beds for which Eldridge proposed the term Gunnison in the Anthracite-Crested Butte folio (1894), nor to my division of the Gunnison into McElmo and La Plata formations in the Telluride folio (1899). Riggs applies the term "Como beds" to the "Dinosaur beds" of Wyoming and Colorado, although Morrison (Eldridge, 1894)

and Gunnison both antedate Como by several years, if I am correct in thinking that the first definite proposition to use Como as a formation name was made by Scott (**35**, p. 477) in 1897.[1]

Beneath the vertebrate-bearing fresh water Jura are 100 to 120 feet of "bluish and grayish gypsum-bearing clays in which thin layers of fine-grained sandstone and nodular ledges of limestone are interspersed." These Riggs refers to the "marine Jura," although they are destitute of fossils. This assignment must be considered questionable in view of the fact that no marine Jurassic beds are known in Colorado except in the northwestern part where they apparently are to be correlated with occurrences in Utah and Wyoming. The few hundred feet of reddish sandstones below the "marine Jura" are referred by Riggs to the Trias, in accordance with Peale's view. This assignment will be discussed in the next section. The underlying pre-Cambrian granite is spoken of (perhaps inadvertently) as "intrusive" in the sandstones.

LA PLATA FORMATION

The term La Plata formation has been applied in the San Juan folios and other publications to the lower part of what Eldridge described as the Gunnison formation (**13**).

The La Plata consists of two massive sandstone members with an intermediate member of more thinly-bedded sandstones and a variable amount of bluish freshwater limestone. The sandstones are commonly not indurated as in the Elk Mountains; instead they are rather friable and crumbling, although of homogeneous texture. Cross-bedding is a marked feature, and not infrequently a massive ledge as much as 100 feet in thickness has no prominent division planes. Of the two sandstone members the lower is commonly thicker and much more massive than the upper. The latter is in fact occasionally thin-bedded and shaly and may be inconspicuous.

The calcareous member is very variable in character. On the San Miguel River, in the Telluride quadrangle, it is in some places

[1] The reference by Knight to the Como beds as *marine* (*American Journal of Science*, 3d Series, Vol. V, 1898, p. 380) is clearly a mistake as he later names the *marine* Jura of Wyoming the Shirley beds, reserving the term Como beds for the *freshwater* strata above the Shirley (*Bulletin of the Geological Society of America*, Vol. XI, 1900, p. 377).

a pure massive blue-gray limestone in several beds and with almost no shale. Usually dark calcareous and bituminous shales and thin-bedded sandstones, with more or less of massive limestone, occur between the two main sandstones and sometimes reach a thickness of nearly 100 feet.

The total thickness of the La Plata formation varies, in the area we have examined, from about 100 feet in the Ouray and Telluride quadrangles to 500 or more in the La Plata mountains, and it is known that to the west all members increase still further in thickness.

The sandstones are almost wholly quartzose, and their normal color adjacent to the San Juan Mountains is white or gray; but yellow, orange, and red tints have been observed in that region. The cement is often calcite.

In the Red Beds paper (**8**) were given the observations of Spencer, who traced the La Plata sandstones to Paradox and Sindbad valleys, west of the Dolores, and of Gane, who followed them down the San Juan Valley to the Colorado Canyon. Both noted the prevalence of orange or pink color in the lower country.

On the strength of these observations and a study of literature it was concluded that "the La Plata Formation is seemingly equivalent to the White Cliff sandstone. Its local assumption of red color has led to confusion with the Vermilion Cliff in certain districts and a reference to the Trias." This correlation is considered to be amply substantiated by the recent observations. As this matter is of much importance to an understanding of Plateau geology the grounds for this correlation will be given in some detail.

The first point to be considered will be the relation of the La Plata sandstones of the San Juan slopes to the "Triassic" of Peale in the Uncompahgre Plateau and lower Dolores Valley. The continuity of the La Plata exposures from the Telluride area northwesterly through the San Miguel Canyon and Plateau to the slopes of the higher Uncompahgre Plateau leaves no room for doubt that the upper part of Peale's "Triassic" consists of the La Plata. Moreover, a careful examination of Peale's descriptions of the "Triassic" sandstone shows that characterization to be fully in harmony with this idea. He repeatedly emphasizes a distinction between the upper, light-colored and the lower dark-red sandstones. To illustrate this

the following quotations among many that might be made will suffice. Speaking of the "Triassic" at the head of the Little Dolores, the north end of the Uncompahgre Plateau, he says: "The upper beds of the formation, as usual, are lighter colored than those below. Near the heads of the creeks they are orange-yellow, becoming pink as we go north. Immediately beneath them we have blood-red sandstones which rest on gneissic rocks (**29**, p. 48). In the Unaweep Canyon he says that: "The white or orange-colored, cross-bedded, massive sandstone forms the top of the series" (**29**, p. 81). And again the expression, "the cross-bedded, white sandstone of the Upper Trias," is used (**29**, p. 82).

In characterizing the sandstones on the west side of the Plateau north of San Miguel River he remarks: "The upper portion of the Triassic beds in this region are light colored; in fact in many places they are almost white, and it is only by noticing their structure, which remains the same whatever the color, and watching the change in color, with their position in relation to the remaining strata, that we can identify them. Another point to be noted here is that they are directly superimposed on the Archean rocks" (**29**, p. 55). This last sentence refers to the unconformity between the La Plata and the red Triassic sandstone, which will be discussed farther on in this paper.

From the Dolores Valley the La Plata sandstones are continuously exposed, through Paradox and Sindbad valleys, around the northern and western slopes of the La Sal Mountains to the broad plateaus bordering Grand River Canyon below Moab. Peale examined this area from the summits of the La Sal Mountains (**29**, p. 60), and Holmes viewed them from the similar commanding peaks of the Abajo group. The simple stratigraphy of the area, as far as the section from the Dakota to the Trias is concerned, was an open book to these experienced field observers, and they agreed in extending the units of the areas they had examined in detail through the low country which was hurriedly traversed by Peale.

As the La Plata formation can be traced to the walls of Grand River Canyon below Moab, there is little room to doubt its further extension to the junction with Green River, some 30 miles, and thence down the Colorado to the mouth of the San Juan Valley, 70 miles further, to the point where it was traced by Gane, as mentioned.

As far as I am aware no geologist has described the wonderland lying between Grand River and the Cretaceous divide between the La Sal and Abajo Mountains since the vivid pen pictures of Newberry in his report of the Macomb expedition (**28**). Nor can one easily equal the clearness with which the broader features of this fascinating region are portrayed. To one familiar with the formations Newberry's descriptions are for the most part easily interpreted.

Descending from the Great Sage Plain, with its Dakota floor, one passes first some 500–600 feet over the steep slope where the soft sandstones and red or green shales of the McElmo occur, but are seldom well exposed. Below them is the upper sandstone of the La Plata, about 300 feet in thickness, which forms low mesas or ridges between the branches of Dry Valley, the main floor of which, over wide stretches, is near the upper surface of the lower La Plata sandstone. The upper member is a fine and even-grained massive sandstone, strongly cross-bedded, of yellowish or pinkish color, and lends itself to a very characteristic sculpturing. We fell at once into the habit of calling this member of the La Plata in Dry Valley the *alcove sandstone*, from the numerous recesses exhibited in nearly all its cliff exposures. Newberry illustrates this feature of a hill called by him "Casa Colorado," and in the files of the Geological Survey is a photograph by W. H. Jackson, clearly of the same subject, reproduced here as Fig. 1.

Certain remnants of the alcove sandstone now standing as isolated hills are very striking. One of these, known as Looking-glass Rock, is situated southwest of the La Sal Mountains near and east of the road from Monticello to Moab. It is represented in Fig. 2. Another remnant of erosion is shown in Fig. 3. Near the base of this knoll a band of marked red color transgresses the stratification very markedly, serving to show the secondary origin of the red color in this case.

The massive character of the upper La Plata sandstone is further illustrated by Fig. 4, representing the cliffs of the upper La Plata in the canyon of Grand River a few miles above the Moab ferry. The incipient alcoves at this point seem largely due to jointing.

The middle calcareous member of the La Plata is apparently represented in Dry Valley by less than 100 feet of thinly-bedded strata, sandstones for the most part, with shaly and impure cal-

careous layers between. The latter are often nodular in development and a pure blue limestone like that of the San Juan region was not seen. In color these beds are apt to be darker red than the massive sandstones above and below, but some layers are gray or yellowish. These beds are seen in Fig. 3 at the base of the sandstone mass.

Below the floor of Dry Valley is the lower La Plata sandstone in a thickness of about 250 feet. It is well shown in Cañon Colorado,[1] (Newberry) and its branches, through which the drainage of Dry

FIG. 1.—"Casa Colorado" (Newberry). In Dry Valley, Utah, near Cañon Pintado. Made of friable sandstones of the upper La Plata formation, Jurassic. Exhibits the alcoves which are very common in this sandstone in the Grand River district. Photograph by W. H. Jackson.

Valley and the southwest slope of the La Sal Mountains enters Grand River.

The lower La Plata sandstone of the Grand River region is more indurated than the upper and is specially distinguished by its cross-bedding. It is light pink or gray, of even fine grain, but is not so notably uniform as the upper. Fig. 5 illustrates a characteristic bank of this sandstone on a small tributary of Cañon Colorado.

[1] The Hayden *Atlas* maps apply this term to the broad shallow part of Dry Valley but on the sketch map of Peale's report for 1875 the name is applied in accordance with Newberry's usage.

Newberry's descriptions and sketches show how strong these characters are in the greatly dissected country adjacent to Grand River.

The base of the La Plata sandstone is probably to be taken as at the horizon where the light-colored, cross-bedded, massive strata give way to dark red sandstones of the Trias. The unconformity or stratigraphic break below the La Plata, discussed in the next section, is not always in evidence in the Plateau country and indeed there is in many places as near an approach to perfect conformity as is commonly found within a given formation between sandstones of different textures.

On the northern side of Cañon Colorado, near its head, the La Plata rests on thin-bedded reddish sandstones of fine grain near the top of which are calcareous layers. Some of the beds contain small chert fragments. In Fig. 6 is shown the nearly white, cavernous, cross-bedded strata, at the base of the La Plata, immediately beneath which are the strongly calcareous sandstones of dark-red color which on weathering yield large nodular masses, such as those in foreground. This is believed to be the line between the Jurassic and Triassic beds at this point.

The continuity of the La Plata sandstone from the San Juan Mountain flanks down the Dolores and San Miguel valleys, around the La Sal Mountains to Grand River Valley, may be said to be perfectly plain and incontestible. In this distance the most notable change in the formation is its increased thickness. The massive texture and even grain of many strata, cross-bedding, variation in color, and other marked features are but emphasized by the greater, volume. The intermediate strata are most variable in character, yet everywhere the two great massive sandstone members are separated by beds distinguishable through their thin bedding, darker color, and richness in calcareous cement or development of limestone.

From the district covered by our reconnaissance the ledges of gray, pink, or orange La Plata sandstone can be seen stretching to the west and south into the belt traversed by Green and Colorado Rivers, where Powell has described the White Cliff sandstone. This great unit in the Plateau country section was never described accurately nor in detail for any given locality, but there seems to be no ground for questioning the assertion of Powell that this formation is continu-

ous with persistent characters from northeastern Utah to the great esplanade bordered by the White Cliffs in southern Utah facing the Grand Canyon. The characters of the White Cliff repeatedly emphasized are its massiveness, "oblique lamination" or "false stratification," and its white, golden, orange, or light-red colors, which are so brilliant in the desert air.

The upper boundary of the White Cliff is the basal marine limestone of the Flaming Gorge Group, of Powell (**33**). The lower

FIG. 2.—Looking-glass Rock. Near southwest base of La Sal Mountains, Utah, to east of road from Monticello to Moab. Formed of alcove-making upper sandstone of La Plata formation. At rear of recess is an opening through to other side of rock. The scale is indicated by figures of two men outlined against sky through opening.

boundary is less clearly defined in the statements of Powell and others, but, with recognition of the stratigraphic break soon to be mentioned and the marked color line apparently everywhere present at the summit of the Triassic sandstones, it may be hoped that no great difficulties in drawing the base of the White Cliff will be experienced when the attempt is seriously made.

UNCONFORMITY BELOW THE LA PLATA SANDSTONE

The far-reaching unconformity below the fresh-water Jurassic beds of central Colorado, by which they overlap all older Mesozoic

and Paleozoic beds and in many places rest on the pre-Cambrian granites and schists, is well illustrated by the Hayden maps. This overlap is particularly well exhibited in the southern Elk Mountains and some of its details are shown in the Anthracite-Crested Butte folio (**13**).

The fact that no Paleozoic formations are present in the Uncompahgre Plateau was recognized by Peale and expressed on the Hayden map. If, however, the greater part of Peale's "Triassic" in that area be now referred to the La Plata Jurassic, as has been done in the preceding discussion, the question arises as to whether evidence of erosional unconformity between the La Plata and the underlying Dolores Triassic exists in that area or not. Our observations on this point were quite limited but tend to show that such a break does occur. It is certain that in the vicinity of the Unaweep Canyon the dark-red Triassic strata are much thinner than in the Dolores Valley to the west and this decreased thickness appears to be principally due to erosion of the massive red sandstone forming the upper part of the Triassic.

On the north side of West Creek, which is the western stream flowing out of Unaweep Canyon, Messrs. Emmons and Kay found the La Plata to rest on granite near the shore line of the Permian (?) beds which will be discussed in another part of this article. At the head of West Side Creek a few miles south of the Unaweep the pink La Plata sandstone rests on thin-bedded sandstones and shales belonging to the lower part of the Dolores formation, as shown by the pressence of the fossiliferous "Saurian conglomerate." Near the head of Atkinson Creek on the western side of Uncompahgre Plateau, the La Plata seems to rest on gneiss, according to the statement of Peale cited on p. 643.

These facts and the evident variation in thickness of the massive Dolores sandstone, which we noticed at many places, seem to speak for a relation of the La Plata and Dolores very similar to that existing on the western and southwestern slopes of the San Juan Mountains. But much more careful observation is needed in the Uncompahgre Plateau to determine to what extent the absence or variable thickness of the Triassic beds is due to pre-La Plata erosion. Personally, I believe that the Triassic beds were originally deposited over the Uncom-

pahgre Plateau and indeed all of western Colorado, and that they were in some places entirely removed by the erosion under discussion, but this view is not yet supported by enough evidence to warrant a positive assertion.

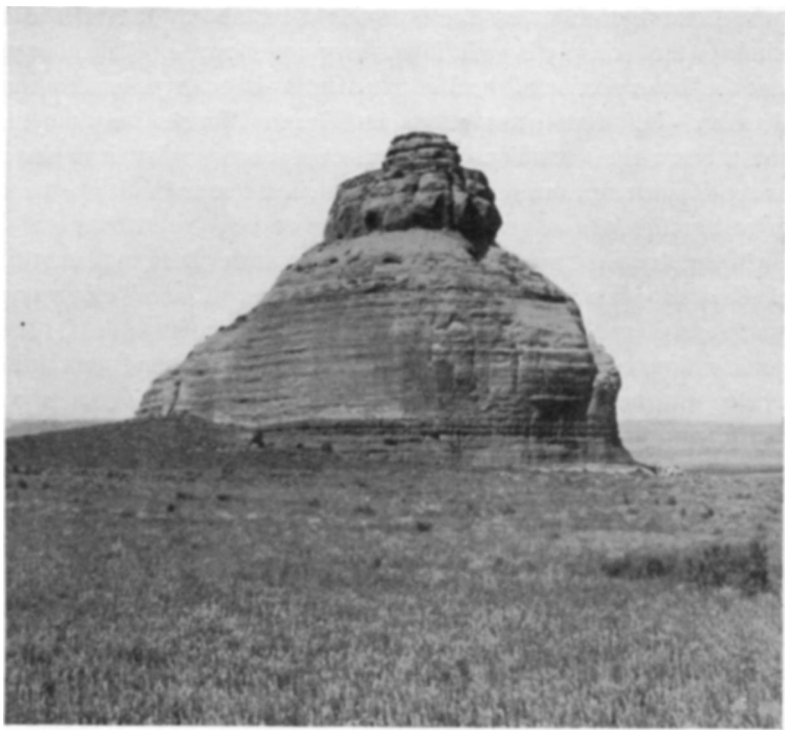

FIG. 3.—A remnant of upper La Plata sandstone in Dry Valley, Utah. The lower massive sandstone is zone generally characterized by alcoves. The weathering forms shown in cap of hill are very characteristic.

TRIASSIC FORMATIONS

Immediately below the White Cliff sandstone of the Plateau country comes another wonderful formation named by Powell the Vermilion Cliff sandstone (**31**) which has been recognized by Gilbert, Dutton, and other explorers of the region. Its continuity from the Uinta Mountains to the Vermilion Cliff, which forms the next great step below the White Cliff, facing the Grand Canyon of the

Colorado, is unquestioned, and all observers have referred it to the Trias. It is characteristically developed on Grand River.

Below the Vermilion Cliff sandstone of the classic Plateau section comes a series of beds originally called by Powell (**33**) the "Shinarump group," and for it the early observers claimed the same widespread distribution as for the overlying formations. Referred as a whole to the Trias by Powell, it was long ago shown by Walcott (**37**) that the lower portion of the Shinarump group of the type locality was Permian (?). Our observations on Grand River show that the strata below the Vermilion Cliff sandstone, corresponding in position to the Shinarump, are of very different character from those of the typical section of that group.

In the Red Beds paper (**8**), I suggested that the Dolores formation of Colorado includes diminished equivalents of the Shinarump group and Vermilion Cliff sandstone of the plateau province. With qualifications as to the Shinarump this view has been substantiated. The importance of the relations discovered on Grand River requires a preliminary review of the essential features of the Dolores formation as an aid to a comprehension of the new data.

The Dolores formation of the San Juan region.—The name Dolores Formation has been proposed for the Triassic portion of the Red Beds of southwestern Colorado. It is now known to embrace but a few hundred feet of strata, with stratigraphic breaks, represented in some localities by definite unconformities, both above and below. In the San Juan country the Dolores consists of an upper, dark red, fine-grained sandstone, of variable thickness, in consequence of the pre-La Plata erosion just discussed, and of a lower sparingly fossiliferous succession of sandstones, shales, and peculiar conglomerates.

The thoroughly diagnostic element of the Dolores formation is a certain kind of fine-grained reddish or grayish conglomerate, occurring constantly at its base and repeated in variable development at several horizons in the lower 200 or 300 feet of sandstones and shales. The pebbles of these peculiar conglomerates are commonly very small in some places, resembling pisolitic grains, and appear to be derived from the breaking-up of limestone beds in process of formation; at least, they are not from the bluish fossiliferous limestones of the

Carboniferous section and they are rarely associated with pebbles of other rocks.

In this limestone conglomerate occur almost everywhere small fragments of bone and occasional teeth, vertebrae or other small bones, which have been identified by Lucas as belonging to belodont crocodiles, or to dinosaurs of megalosauroid types. Unios, gasteropods, and plant remains are sparingly associated with the vertebrates.

In the Red Beds paper (**8**) the wide distribution of this fossil-bearing conglomerate was pointed out and the even greater extent

FIG. 4.—The La Plata sandstone. In Canyon of Grand River a few miles above ferry at Moab, Utah. The massive beddings are specially marked in this vicinity. Through irregular jointing rude alcoves have been initiated, suggesting one of the processes involved in their formation.

of the fauna it carries. It is necessary here merely to repeat that the peculiar conglomerate with its upper Triassic fauna, marks a horizon of great importance in the stratigraphic column of the Plateau country and the adjacent mountain slopes. The importance of this horizon is further emphasized by the fact that at Ouray, on the north flank of the San Juan Mountains, the "saurian conglomerate" is found to rest unconformably on the Permian (?) red beds and on the fossiliferous Pennsylvanian section below them, testifying to an important stratigraphic break.

Statement of new observations.—In the Grand River Valley a deep red sandstone, which is clearly the Vermilion Cliff, occurs everywhere in its appropriate place beneath the White Cliff or La Plata sandstone. It was first noted by us in the canyon which appears to be the Cañon Colorado of Newberry, where it presents the aspect shown in Fig. 7—the point of view being within a few yards of that of Fig. 6. The massive wall of this canyon is of a fine-grained, dull, deep-red sandstone, about 200 feet in thickness. The thinner-bedded strata, seen in the view above the massive portions, are of a similiar dark-red color. The basal beds of the La Plata are represented in the knoll on the sky line at the left hand.

The dark-red sandstone seen in the gorge of Fig. 7 has ample opportunity to display its cliff-making capacity in the Grand River Valley, as illustrated in the views of Figs. 8 and 9. The massive sandstone is there seldom more than 200 (?) feet thick, but a vertical jointing, common in the formation, leads to vertical cliffs in many places. As noted by Powell and Dutton the more massive part is almost always overlain by about 100 feet of beds of nearly identical character except for the thin-bedding and local tendency to shaly development. Similar strata underlie the cliff-making portion of the formation, as seen in Figs. 8 and 9.

Not more than 100 feet below the cliff sandstone there occurs on Grand River a thin conglomerate, chiefly of limestone, carrying sparingly, but constantly, fragments of bones and teeth of belodont crocodilean or dinosaurian animals. Both in details of character of the conglomerate and of the fossils it carries, as well as in stratigraphic position, this stratum is clearly identical with that at the base of the Dolores formation in the San Juan region. It is present in corresponding position wherever we examined sections carefully, near Moab, in the Grand River Canyon some miles above Moab, on the north slope of the La Sal Mountains, in Paradox Valley, and on West Creek.

The assertion that the fauna contained in the Triassic beds of Grand River is identical with that occurring in the Dolores formation of Colorado is frankly not supported positively by a large amount of evidence in the form of identifiable fossils. On the east side of Grand River near the road to the ferry, Mr. Kay obtained a vertebra con-

cerning which Mr. J. M. Gidley of the U. S. National Museum reports that "though somewhat crushed and weathered, it is recognizable as belonging, probably, to a Triassic form of carnivorous Dinosaur, although it may possibly be referable to a genus of Belodont. It is certainly reptilian and of a more advanced type than any I know from the Permian."

On West Side Creek, a branch of West Creek, where the Trias is represented only by its lower beds, resting on the Archean (see p. 648),

FIG. 5.—This cross-bedded lower La Plata sandstone. View in a ravine tributary to Cañon Colorado. This cross-bedding stands out prominently in most cliff exposures.

a fragment of bone was found in the limestone conglomerate, which Mr. Gidley considers with reasonable certainty to be "a portion of a fibula (lacking the distal end) of a carnivorous Dinosaur probably of Triassic age."

Ill-preserved Unio shells were found in association with the vertebra mentioned. Much better material was obtained in 1901 by Mr. L. M. Prindle, now of the U. S. Geological Survey, in certain of the reddish sandstones between the Vermilion Cliff and limestone con-

glomerate, and through his kindness I am able to give the report made upon these fossils by Mr. T. W. Stanton, as follows:

The collection of invertebrates collected by Mr. L. M. Prindle contains many good casts and imprints of Unio, apparently belonging to three or more species. These are comparable and possibly identical with *Unio cristonensis* Meek, *U. dockumensis* Simpson, and *U. dumblei* Simpson, all of which come from supposed Triassic beds. *Unio cristonensis* was described with two other species from fragmentary specimens obtained by Cope on Callinas Creek, New Mexico. The Moab specimens are much larger than the types but they agree in outline and general proportions. The other two species above mentioned were obtained by the Texas Geological Survey in the Dockum beds of northwest Texas. These beds have yielded four species of Unio, which, with the three species from about the same horizon in New Mexico, are the oldest known representatives of the genus. The species in the Moab collection seem to belong to the same Unio fauna.

That in this vicinity a stratigraphic break of much importance occurs just below the "saurian conglomerate," as it has been called in the San Juan region, is evident on Grand River and at other places. On the west side of Grand River opposite Moab the bone-bearing conglomerate is separated from fossiliferous Pennsylvanian beds by only about 50 feet of shaly sandstone, and it is possible that these beds also belong to the Pennsylvanian series. Details of the section at this point are given on p. 669.

Near Moab, on the northeast side of Spanish Valley, a poorly exposed section reveals about 250 feet of strata, mainly reddish sandy shales, between the "saurian conglomerate" and the uppermost Pennsylvania limestone. On Grand River about 1 mile above the Moab ferry the "saurian conglomerate" reappears above the level of the river, and, as it rises gradually to the northeast for several miles, a larger and larger section of the pre-Dolores strata is exposed, but nowhere so far as our observations go, do the Pennsylvanian beds appear, all the sub-Dolores section belonging to the upper (Permian?) series of the Carboniferous. This is itself evidence of a great break immediately below the "saurian conglomerate." That the break represents uplift and erosion producing angular unconformity is well illustrated on both sides of Grand River about 10 or 12 miles northeast of the ferry and just below the mouth of Castle Creek, a stream heading on the west side of the La Sal Mountains. Fig. 8

illustrates this unconformity, which may be traced for about half a mile, and it was estimated that at least 600 or 800 feet of beds are visibly truncated by the conglomerate in one continuous exposure. The occurrence of an extensive section of gypsiferous sandstones and shales beneath the Dolores conglomerate in Fisher Valley on the northwest side of the La Sal Mountain adds so much to the beds trangressed; and a still higher series of sandstones and conglomerates is known, so that, altogether, it is estimated that not less than 1,500

FIG. 6.—The lowest strata of the La Plata sandstone, north side of Cañon Colorado near its head. Shows the characteristic cross-bedding and cavernous weathering. Nodular masses on level floor of foreground belong to upper beds of Vermilion Cliff (Dolores) sandstone (p. 646).

and possibly 2,000 feet of Permian (?) or upper unfossiliferous Pennsylvanian beds have been eroded in the locality of the section first mentioned, opposite Moab.

On West Creek, the western stream from Unaweep Canyon, the "saurian conglomerate" is seen overlapping from the heavy conglomerates of the Permian (?) to the granite-gneiss-schist complex of Uncompahgre Plateau. This is the overlap represented on the Hayden Map of western Colorado, and interpreted by Peale as a part of the overlap of all formations from the upper Carboniferous to the

Dakota about an island of ancient rocks which he believed to have never been completely submerged until the Dakota epoch (**29**). This view is manifestly not wholly correct, in that it does not recognize the extent of the denudation of the intervals preceding and following the Dolores epoch. Only the latter of these was known to Peale. As for the uppermost Paleozoic beds of West Creek there is evidence (presented on p. 662) that they do there abut against the granite of a continental mass, as noted by Peale. The point of interest here is that the Dolores conglomerate has no such boundary and was probably deposited on the granites, gneisses, etc., over the whole area of the Uncompahgre Plateau, its absence in any given locality being satisfactorily explained by the pre-La Plata erosion.

From the facts presented, it would seem established that the Dolores formation is represented in the Grand River Valley by the Vermilion Cliff sandstone, together with about 100 feet of thin-bedded sandstones, shales, and limestone conglomerate below it.

Relation of the Dolores conglomerate to the Shinarump conglomerate.—The discovery of the "saurian conglomerate" and the unconformity below it makes it necessary to trace that horizon with care through the Plateau province. There seems to be no suggestion of such a conglomerate in the statements of any writer on the geology of the region, except Newberry. In his "General Section of the Valley of the Colorado" (**28**, p. 99) there is a member, 92 feet in thickness, described as, "Greenish gray micaceous conglomerate and gray sandstone, separated by red and purple shales." This occurs below 350 feet of red sandstone which I correlate with the Vermilion Cliff sandstone, and there is evidently a general correspondence to the 104 feet of strata below the Vermilion Cliff west of Moab. As Newberry measured this member of his section only a few miles below Moab it seems almost necessary to assume that the 92 feet of strata here referred to belong to the lower part of the Dolores, and include the fossiliferous conglomerate. Between this conglomerate and fossiliferous Pennsylvanian limestone Newberry found 514 feet of sandstone described as liver-colored, brick red, or white, with shale partings. Clearly the gypsiferous series of Fisher Creek, the overlying conglomerates and sandstones, and a considerable part of the underlying Permian (?) beds are absent on the line of Newberry's

section, implying a stratigraphic break comparable to that we found, and the probable horizon of the break is below the conglomerate.

The question as to the correlation of the Dolores formation with some portion of the Plateau section generally assigned to the

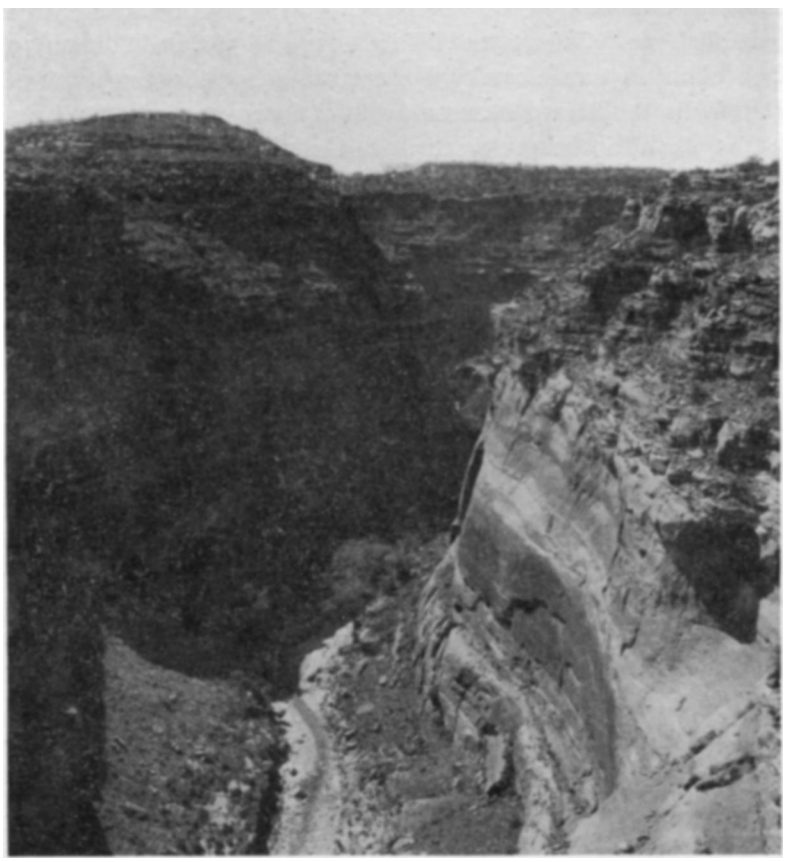

FIG. 7.—Near head of Cañon Colorado, Utah. Shows massive Vermilion Cliff (Dolores) Triassic sandstone, thinner sandstones above, and, in knoll on left hand, the lowest sandstones of the La Plata Jurassic.

Trias becomes mainly a study of what has been called the "Shinarump Group" by Powell and particularly of the relatively thin bed called the "Shinarump conglomerate." I have made such a study and

embodied the result in a paper which will appear in this journal during the current year. A brief summary of certain facts and conclusions will suffice in this place.

The Shinarump conglomerate, named by Powell (**31**), is in the midst of a series of strata well shown to the north of the Grand Canyon called the Shinarump Group by Powell (**33**), who believed the whole to be Triassic. Gilbert (**14**), Walcott (**37** and **38**), and Dutton (**9**) have observed unconformity by erosion below the conglomerate, while Walcott obtained Permian fossils in the lower part of the group in the typical Kanab section, and since that discovery geologists generally have adopted Walcott's view that the Shinarump conglomerate should be taken as the base of the Trias of the Plateau Province.

The correspondence in stratigraphic position between the Shinarump and the lower conglomerate of the Dolores formation naturally suggests their identity and I am strongly inclined to believe that they will ultimately be found to occur at the same horizon. There are, however, some discrepancies and apparent differences between the observed sections that must be explained before this opinion can be accepted.

It has been asserted by Powell and Dutton in almost unqualified terms that the Shinarump group extends from the Grand Canyon district to the Uinta Mountains, and Dutton has named the junction of the Grand and Green rivers as a locality where the whole group is present in typical development (**9**, p. 144) and where the conglomerate bed exhibits the same characters as in the Shinarump Cliff of southern Utah (**10**, p. 208). Both assertions seem to have been based on insufficient knowledge of the section below the Vermilion Cliff sandstone, for no descriptive data appear in the reports of these geologists to substantiate the claim. As far as I can ascertain, no geologist except Powell has examined the section near the confluence of the Grand and Green Rivers and he gives in his reports only general statements concerning the strata between the Vermilion Cliff sandstone and the Carboniferous beds referred to the Aubrey.

In the vicinity of the Henry Mountains Gilbert reports (**14**) a stratum correlated by him with the Shinarump conglomerate at 350 feet below the Vermilion Cliff sandstone, and some miles southeast of the Henry Mountains at Clay Hill divide, H. S. Gane found (**7**)

a Triassic crocodile, *Heterodontosuchus ganei* Lucas (**24**) with fossil wood in limestone conglomerate near the base of the Dolores formation. Gane was familiar with this formation and traced it to Clay Hill from southwestern Colorado. The beds are apparently continuous westward to Glen Canyon of the Colorado about 20 miles. This observation of Gane is most important as bringing what I think can be unhesitatingly considered to be the fossiliferous zone of the Dolores formation into the heart of the Plateau country. Actual

FIG. 8.—View in canyon of Grand River about 12 miles above ferry at Moab, Utah. Looking west across river; to show angular unconformity at base of Dolores Triassic beds. Cliffs of columnar rock are formed of Vermilion Cliff sandstone. Beds beneath unconformity are considered to belong to Permian (?).

demonstration of the relation of the Clay Hill fossil-bearing conglomerate to the Shinarump conglomerate is yet to be furnished.

One can scarcely question that Powell, Dutton, Walcott, and others have applied the name Shinarump conglomerate to a single bed or formation commonly less than 100 feet thick, as far as the country west of the Colorado is concerned, from the mouth of Paria Creek to the vicinity of St. George, Utah. No fossils have been found

in it and it has not been described in detail as to the character, size, and abundance of the pebbles. But from the mouth of Paria River southeast, below the Echo Cliffs, which are mainly formed of the Vermilion Cliff sandstone, the Shinarump conglomerate has unfortunately not been absolutely traced, so that its relation to the vertebrate-bearing beds found by Ward in the Little Colorado Valley is uncertain. The vertebrate fauna obtained by Ward and Brown (**39**, **40**) from several localities near the Little Colorado from the midst of the strata, rich in fossil wood, is clearly the same as, or similar to, that so widely known in the Dolores formation, the most common form being the crocodile of which the type was found by Gane in the Dolores at Clay Hill. Ward does not identify the Shinarump conglomerate as a single marked bed, but applied the term to 800 feet of strata entirely below the vertebrate-bearing horizon (**40**). Dutton, on the other hand, has thought to recognize the Shinarump conglomerate in typical development as far east as the Zuni Plateau in New Mexico (**11**).

At the present time, it seems to me not improbable that the horizon of the original Shinarump conglomerate of the Shinarump Cliffs is near, if not equivalent to, the vertebrate-bearing strata of the Little Colorado Valley, being there perhaps less conspicuously conglomeratic than in the type locality. The "conglomerate" is usually described by Dutton and others as really a coarse sandstone with pebbles irregularly scattered through it. Dutton ascribes a fluviatile origin to it, and such is also clearly the mode of formation of the Dolores conglomerates, which vary greatly in character in different places. It is surely not unlikely that beds of this character, but of different horizon, have been mistaken for the same by reconnaissance observers at widely separated points. This might be suspected from the character of the so-called conglomerate alone, and is rendered quite plausible by Ward, who found sandstones containing some pebbles variably developed in different sections through some 800 feet of strata (**40**).

The occurrence of a vertebrate fauna of upper Triassic age over a wide expanse of country, in Arizona, Utah, Wyoming, Colorado, New Mexico, and probably also in Texas, seems the most definite fact from which to start in studying the problem of the western Trias.

CARBONIFEROUS FORMATIONS

Sedimentary formations of the Carboniferous System are but sparingly exposed in the eastern part of the Plateau country, erosion having penetrated to them in only a few places. They were found by

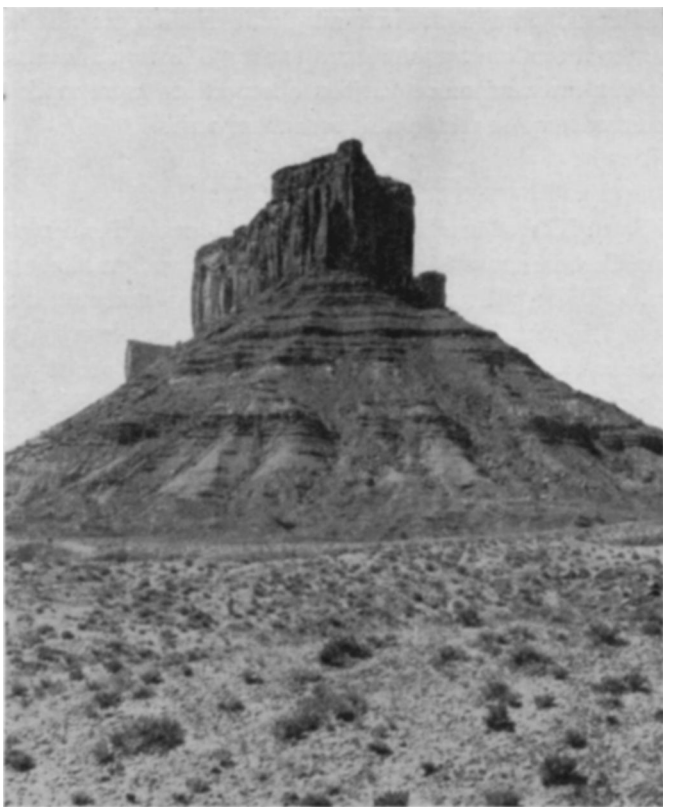

FIG. 9.—View in Grand River Canyon at mouth of Castle Creek, Utah. Shows characteristic scarp of Vermilion Cliff sandstone. Probably about 100 feet of thin-bedded strata below belong to Triassic and remainder to Permian (?), the unconformity between them not being exhibited.

Peale in the valleys of Grand and Dolores Rivers and in Paradox and Sindbad Valleys. While the Triassic and other Mesozoic rocks of the Plateau district can be traced continuously to the mountains of Colorado, the correlation of the Paleozoic formations depends entirely

upon stratigraphic position in different areas and on inherent characters.

In the area under discussion, Peale distinguished an unfossiliferous series of red beds lying below the Trias, and a fossiliferous series of still lower horizon. The former he mapped as "Upper Carboniferous," though often referring to it, in his reports, as possibly Permian, and the latter was referred to the "Middle Carboniferous." During our reconnaissance various observations were made touching the character and relations of both these series.

THE PERMIAN (?) RED BEDS

On Sheet XIV of the Hayden *Atlas of Colorado*, Peale represents "Upper Carboniferous" beds abutting against granite on West Creek near Dolores River, and thence extending westerly to the canyon of Grand River in Utah. The same formation is shown in Paradox and Sindbad Valleys. While the general distribution of the pre-Triassic red beds is no doubt fairly represented on the Hayden map, Peale was unable to make sufficiently detailed study of the formation to correlate the various partial sections examined. Our observations were also far too incomplete to permit of a satisfactory description of the whole section. This is the more difficult because of a gradual change in the character of the formation as distance from its eastern border increases.

It was observed by Peale that the "Upper Carboniferous" beds near the granite on West Creek were conglomerates rich in granite, "proving that during their deposition there was adjacent land of which the rocks were granite" (**29**, p. 56). He also represents a shore-line near this locality, in profile sections across the Uncompahgre Plateau (**29**, Plate IV). Owing to "a steep dip" of the conglomerates away from the granite Peale does not place the shore-line immediately at the contact seen crossing West Creek; but, as no "Middle Carboniferous" strata are present adjoining the granite the boundary does in fact represent correctly the overlap.

That the strata in the vicinity of the granite do dip westward at angles of 15° or more is true, but in a ravine on the south side of West Creek and about ½ mile from it, I observed grits to rest directly on granite with a westerly dip of 12° to 15°, exhibited in strata near

the base. No fault was found, and it seems to me improbable that the boundary is of that nature in the vicinity of West Creek. Where the sediment was seen resting on granite, the lower layers consisted

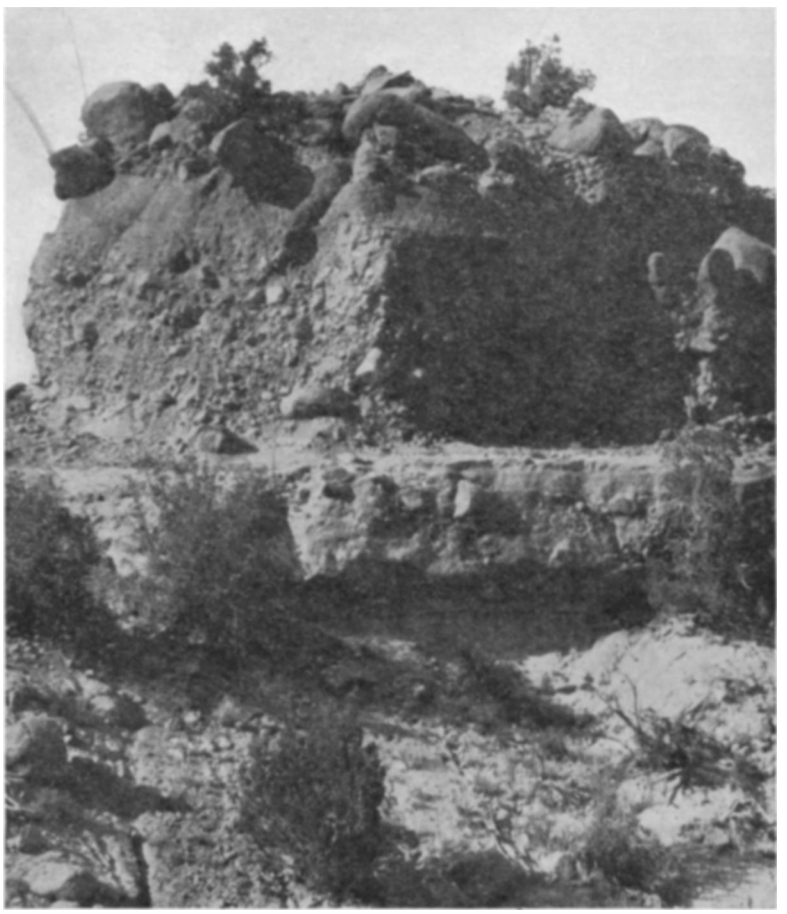

FIG. 10.—In a ravine on south side of West Creek, Colorado, about 5 miles east of Dolores River. To show character of Permian (?) conglomerates and grits very near granite mass of Uncompahgre Plateau from which they were derived (p. 662).

of coarse, angular gravel, scarcely bedded at all. At a distance of a few feet above the granite bedding planes become more distinct, through alternation of finer and coarser material aided by color differ-

ences, the finer-grained material being reddish. At 25 feet above the granite the characteristic alternation of grit and conglomerate began. But the distribution of pebbles and bowlders is very irregular, the latter are often subangular, and the whole is so little consolidated that the disintegrated beds seem like surface gravels. Fig. 10 shows the appearance of the beds in the ravine in question. It is but a few hundred feet from this point to the contact which was seen.

FIG. 11.—Looking southward across West Creek, Colorado, near mouth. Canyon of Dolores River faintly outlined on right. The upper cliffs of view are caused by massive La Plata sandstone (Jurassic). Next lower cliffs and headlands on right are formed of Dolores or Vermilion Cliff Triassic sandstone. Below latter, section is that discussed on p. 667, and referred to Cutler Permian (?).

Similar coarse conglomerates occur along the road on the north side of West Creek, seeming there like partially consolidated stream gravels, but examination shows them interbedded with finer grits of the series.

At about 3 miles west of the granite line on the south side of West Creek, Mr. Woolsey measured the following section of sub-Triassic strata, the locality being below the central point seen in Fig. 11.

SECTION ON SOUTH SIDE OF WEST CREEK (L. H. WOOLSEY)

		FEET
	Top. Triassic red beds.	
20.	Conglomeratic grit, fine-grained, pinkish	50
19.	Interval, mainly covered by talus, but with pinkish grit revealed here and there	140
18.	Interbedded arkose and shale grading upward into shale	8
17.	Conglomerate, containing pebbles 4–5 inches in diameter, of various granites, in matrix of red arkose sand	2
16.	Covered interval	30
15.	Friable grits not well exposed and probably very similar to No. 14	80
14.	Conglomerate and fine arkose, interbedded, the pebbles generally of coarse granite and gneiss, up to 12 inches in diameter	35
13.	Covered by talus	75
12.	Arkose, red, fine-grained, with occasional pebbles of granite or greenstone, 3 inches diameter	42
11.	Concealed by talus	13
10.	Conglomerate of gneiss and coarse granite; bowlders up to 12 inches diameter; arkose matrix	5
9.	Concealed by débris, but apparently like	20
8.	Conglomerate arkose, alternating fine and coarse; the finer-grained parts are similar to No. 7; the conglomerate carrying bowlders of various granites up to 6 inches diameter	30
7.	Arkose, reddish, mostly fine-grained with pebbles 1 inch or less in diameter; occasional bowlders of different granites to 9 inches; toward top becomes interbedded with thin red shale layers, but lenses of bowlders are also present in this upper part	135
6.	Conglomerate, coarse, the granite and gneiss bowlders reaching 1½ feet in diameter, the largest ones near top, rests unconformably on 5	5
5.	Arkose grit and red shale alternating; 4 feet of fine-grained arkose at base, with thin seams of shale; these become more and more prominent toward top; coarse lenses of conglomerate at several horizons; isolated bowlders occur in certain shale layers	15
4.	Arkose grit, reddish, grading into coarse conglomerate at top, containing some bowlders 1½ feet in diameter	10
3.	Shale, red and green, irregular in thickness, owing to erosion	2
2.	Arkose grit, dark reddish, conglomeratic and seldom cross-bedded, the coarser parts in lenticular bodies; granite pebbles reach 6 inches diameter; a few pebbles of greenstone, the great majority being granite or gneiss	32
1.	Grit-conglomerate, gray, pink, or purplish, in massive cross-bedded banks, with numerous layers of fine grain, and usually darker color	150
	Total	879

The pebbles of the conglomerate strata of this section are principally of granite and the most abundant variety is the very coarse-textured one with large orthoclase crystals occurring in the nearest exposures of the Uncompaghre Plateau. Among the pebbles are some of greenstone schist which indicate that the pre-Cambrian complex furnishing this material is similar to that from which the Cutler conglomerate of the San Juan was derived. Similar greenstones were observed in the conglomerates of Grand River Valley.

Below the measured section there may be several hundred feet of similar strata, for the somewhat deeper cutting of Dolores River does not reveal the base of the succession of grits and conglomerates. The next lower formation is probably a series of gypsiferous shales and sandstones and the nearest locality at which such strata are known to occur is in Sindbad Valley, 12 miles south from West Creek. A fault running near the base of the northeastern scarp prevents a clear determination of the relations but the gypsiferous beds are manifestly older than the strata below the Dolores. These belong no doubt in the series measured on West Creek. Owing to complex folding and faulting to be discussed on another page, the extent and relations of the gypsum-bearing beds cannot be ascertained, but they are apparently some hundreds of feet in thickness.

That the gypsiferous section occurs between two series of sandstones, shales, and conglomerates, is indicated by the observations on Grand River (p. 654). In discussing the unconformity at the base of the Dolores, it was stated that going northeast from Moab, up Grand River, a succession of shales, sandstones, and conglomerates appears between the fossiliferous Pennsylvanian beds and the Dolores. The structure brought out in Fig. 8 shows that the intermediate beds rest on the Pennsylvanian.

At the time we traversed Grand River Valley, we did not know of the existence of the gypsiferous beds in that region, but on the way to the northern stope of the La Sal Mountains in the valley of Fisher Creek a considerable thickness of such strata was found. As in Sindbad Valley, a zone of faulting and folding interferes with an accurate determination of relationship on the line of travel.

No doubt the detailed nature of the section between the Pennsylvanian and Triassic can be fully determined in Grand River Canyon,

and without difficulty. A few miles above the point at which we left Grand River, Boutwell found a section of "light pinkish-purple, shaly sandstones which include coarse cross-bedded sandstones and conglomerates with well-rounded granite and porphyry pebbles" under a massive sandstone which corresponds to the Vermilion Cliff (**1**). These might belong to the section resting on the Pennsylvanian beds near Moab, but seem much more probably to represent strata above the gypsiferous beds and roughly equivalent to those seen on West Creek.

Comparing the strata known on Grand River between the Dolores base and the Pennsylvanian limestones with the Cutler formation (Permian ?) of the San Juan Mountains it is clear that the gypsiferous part of the series has no similar representative in the mountain district. If such beds ever existed in the San Juan region, they were removed prior to the deposition of the saurian conglomerate, and this does not seem at all unlikely, for gypsiferous beds are known in the Paleozoic red beds of northwestern Colorado, as reported by Peale (**29**).

The grits and conglomerates of West Creek are so near their source that they differ from the Cutler beds in being much coarser and more strongly arkose, but the section seen on Grand River and Fisher Creek certainly resembles in lithologic character the Cutler beds of the Uncompahgre Valley below Ouray, and appears to occupy the same stratigraphic position.

The Cutler formation and the pre-Dolores red-bed strata of Grand River clearly correspond to the lower part of Powell's Shinarump Group, that is, to the "Permo-Carboniferous" of the Wasatch and Uinta Mountains, according to the nomenclature of the Fortieth Parallel Survey, or to the Permian of Dutton, in the Grand Canyon monograph. Fossils indicating a Permian or Permo-Pennsylvanian age were found by the Fortieth Parallel geologists in the Wasatch Mountains and by Walcott in the Kanab Valley of northern Arizona. The apparent absence of fossils in most localities where these beds have been examined is no doubt due to the fact that they are mainly continental deposits, an origin indicated by their texture.

The site of one of the land masses from which these deposits were derived is shown by the relations existing on West Creek. Peale assumed that this plateau belonged to an island extending eastward

through the area now traversed by the Gunnison Canyon, where Mesozoic beds rest on the pre-Cambrian complex. This may be true, but it must be borne in mind that the pre-Dolores and pre-La Plata uplifts with their succeeding denudations may have removed the entire Paleozoic section from much of this tract.

As distance from the mountain source of these clastic materials increases, the beds are naturally finer grained and grade into shales and marls, and correlation of widely separated sections becomes difficult. It is evident that the sub-Dolores and probably Paleozoic red beds need much closer study as to their structural relations to the overlying Triassic, as well as careful record of sections at favorable points, before correlation can be made satisfactory.

PENNSYLVANIAN SERIES

Fossiliferous Carboniferous strata were found by Newberry in 1859 in Grand River Canyon and in the lower part of Cañon Colorado. The section referred by him to the Carboniferous was described as follows in the "General Section of the Valley of the Colorado" (**28**, p, 99).

		FEET
14.	Blue limestone, somewhat cherty. Fossils: *Spirifer cameratus, Athyris subtilita, Productus semi-reticulatus*	110
15.	Bluish-white, red, or mottled sandy limestone, with partings of red shale	95
16.	Hard, blue cherty limestone. Fossils same as No. 14	36
17.	Alternations of blue limestone, red and gray sandstone, to bottom of cañon	1,000

On the map accompanying Newberry's report the point at which he reached Grand River is located only about 6 miles above the junc tion with Green River, whereas according to the La Sal sheet of the U. S. Geological Survey, Cañon Colorado, the name of the side gorge descended by Newberry, joins Grand River Canyon at 9 miles below Moab and 24 miles above the union with Green River. Whether Newberry's locality be near the junction of the Grand and the Green, or but a few miles below Moab, it is natural to assume that a fossiliferous Pennsylvanian Carboniferous section discovered by us on the northwest side of Grand River, opposite Moab, is identical stratigraphically with some part of that found by Newberry. The faunal

evidence, however, makes this conclusion more or less open to question, as will appear from the ensuing discussion.

At about three fourths of a mile northwest of Grand River and on the southwest side of the valley traversed by the stage road from Moab to Thompson station on the Rio Grande Western Railroad, there is an excellent section of the strata for several hundred feet below the Vermilion Cliff sandstone. The beds dip gently to the southwest, and it is believed that no fault crosses the line of the section, although its base is immediately adjacent to the southwestern fault of a zone traversing Spanish Valley. The following section, including some of the Triassic beds, was measured by W. H. Emmons and L. H. Woolsey.

SECTION NEAR GRAND RIVER, OPPOSITE MOAB, UTAH

		FEET
	Top	
32.	Sandstone, massive or shaly, dark red at base and bright red at top	20
31.	Shaly, conglomeratic sandstone, reddish limestone pebbles, the size of a pea or smaller, with few bone fragments	6
	Dolores Triassic	
30.	Sandy shale, red and green	5
29.	Débris slope, of red shale fragments	20
28.	Limestone conglomerate, with a few inches of limestone at top, fossil, wood, and bone fragments; pebbles less than 2 inches diameter	10
27.	Sandstone, gray, massive	20
26.	Limestone conglomerate grading into sandstone	1½
25.	Sandstone, gray, massive becoming shaly near top	23
24.	Calcareous sandstone and fine-grained conglomerate, mainly sandy, with conglomerate near base and top. Pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of peas to several inches	9
	Permian (?)	
23.	Red sandy shales, alternating with sandstone	8
22.	Conglomerate, containing pebbles of limestone and sandstone	1
21.	Sandstone and shale alternating, red and green, the shales sandy and friable	35
	Hermosa Pennsylvanian	
20.	Blue limestone, weathering dirty buff; near top a layer contains pipe coral	10
19.	Sandstone, thin bedded, some crumbling, some massive, red or gray	40
18.	Gnarly looking bluish limestone, sandy	3
17.	Sandstone, pink to gray, massive, friable	23

16.	Sandstone and limestone in alternating thin layers, crumbling	25
15.	Limestone, blue, weathering buff; crinoid stems near base, corals above	40
14.	Sandstone, light red, fine-grained, cross-bedded	30
13.	Sandstone, gray, massive, calcareous	5
12.	Sandstone and shale with a few thin limestone layers; nodular forms of weathering common	60
11.	Limestone, blue, gnarly looking, massive	1½
10.	Sandstone red and green layers alternating	12
9.	Sandstone, red, micaceous, alternating with sandy shales	60
8.	Limestone, sandy near base, gnarly, fossiliferous	6
7.	Shale and sandstone, red	10
6.	Sandstone, red	8
5.	Shales, purplish, sandy micaceous, very thin-bedded	4
4.	Limestone, bluish, in hard dense beds, 1 to 2 feet thick, fossiliferous	6
3.	Sandstones, thin-bedded, alternating with purplish sandy shales; sandstone layers less than 3 feet thick	15
2.	Sandstone, bluish-gray, friable, micaceous, cross-bedded	7
1.	Sandstone, gray, green, or purplish red	15
		539

Above this section comes a cliff of red, pink, and gray sandstones apparently embracing the Vermilion Cliff sandstone and possibly a part of the White Cliff sandstone, not examined in detail. No lower beds are exposed in the valley.

The upper 104½ feet of the section represents the fossiliferous Triassic beds immediately below the Vermilion Cliff sandstone which is here well developed. The next 44 feet of beds is provisionally referred to the Permian, and in that case represents the basal portion of that series. It may possibly belong with the underlying Pennsylvanian Series, or partly to the overlying Triassic, if the conglomerate, No. 22 of the section, be taken as the base of that series.

From the limestones of the Pennsylvanian portion of the section, Nos. 1 to 20, inclusive, we obtained the fossils shown by column IV of the table on p. 672. Probably no other exposure near near Moab reveals so great a thickness of the Pennsylvanian strata as that we examined, but doubtless the upper fossil-bearing limestones may be found in Spanish Valley. It is not known whether they are continuously exposed in the canyon of Grand River from Moab to the mouth of Cañon Colorado. The southwesterly dip of the Spanish

Valley anticline brings the Triassic beds to the river level at a short distance below Moab.

Another collection of fossils was made in 1901 by Mr. L. M. Prindle, on the road about half a mile northwest of the locality we studied, from strata visibly belonging to the section given. By Mr. Prindle's courtesy, I am permitted to indicate the forms identified by Mr. Girty in his collection, in column III of the table.

The only other locality where we observed fossiliferous Pennsylvanian beds is on the southwestern side of Sindbad Valley at the same point where Peale found bluish limestone carrying Producti, Crinoid, and Corals. The specimens collected by him were abandoned during an attack by Indians, so that the definite character of this fauna was not determined. In his report, Peale gives a section (**29**, p.71) in which the fossil-bearing strata are placed beneath shaly sandstones having an estimated thickness of 3,500 feet, and above these are the gypsiferous strata of the valley floor. The fault zone parallel to the axis of the valley is more complex than Peale supposed, and it seems probable that the fossil-bearing strata form a narrow and vertically upturned block thrust up almost to the level of the Vermilion Cliff sandstone, and that no continuous section exists in the valley by which the position of these fossiliferous beds in the whole section can be established. They are bounded by a fault on the northeast, as well as on the southwest. These fossil-bearing beds were also examined by Mr. A. C. Spencer in 1899, and a collection of fossils was made.

From the bluish limestone ledges of Sindbad Valley the fossils indicated in column V of the table, p. 672, were obtained, either by Mr. Spencer or by our party.

In view of the meager statements of Powell and Newberry as to the sections examined by them, and the isolation of the Moab and Sindbad Valley occurrences, the most satisfactory basis for a correlation of these Pennsylvanian sections lies in comparing the fossils collected at the several localities. Through the kind assistance of Mr. G. H. Girty, who has examined all the material except the collection by Newberry, I am able to present in tabular form the lists of all known fossils from the localities named. For comparison the known occurrence of the species of the lists in the Hermosa forma-

tion, or in probable equivalents of that formation in central Colorado, is also indicated.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO

	I	II	III	IV	V	VI
Syringopora multattenuata				×		
Syringopora sp.			×			
Lophophyllum profundum				?	×	×
Zaphrentis sp.				×		?
Campophyllum torquium			×	×		×
Axophyllum rude				×		
Eupachycrinus platybasis*	×					
Erisocrinus typus	×					
Ceriocrinus inflexus	×					
Echinocrinus cratis	×					CB
Echinocrinus trudifer ?			×			L
Echinocrinus Dinnini ?			×			
Echinocrinus sp.					×	
Fenestella aff. tenax			×			×
Fenestella sp			×			×
Polypora sp.			×	×	×	?
Goniocladia sp.*	×					
Fistulipora sp.			×	×		?
Rhombopora lepidodendroides			×			×
Lingulidiscina sp.					×	
Derbya crassa ?		×*	×	×		?
Derbya aff. robusta	×					
Meekella striaticostata	×					×
Orthotichia Schuchertensis					×	
Enteletes hemiplicatus					×	
Chonetes granulifer	×				×	
Productus semireticulatus	×	×			?	?
Productus semireticulatus var.	×					
Productus Portlockianus					×	
Productus punctatus	×	×	×	×	×	×
Productus Nebraskensis	×	×†	×	×	×	×
Productus aff. Humboldti*	×					
Productus aff. porrectus*	×					
Productus scabriculus*		×				
Productus cora	×			×		×
Productus nodosus*		×				
Productus multistriatus*	×					
Productus subhorridus*	×					
Marginifera Lasallensis				×		CB ?
Marginifera Wabashensis ?	×			×		?
Marginifera ? sp.	×					
Spirifer cameratus	?	×		×	×	×
Spirifer Rockymontanus	×					×
Squamularia perplexa				×		×
Spiriferina Kentuckyensis	×					×
Composita subtilita	×	×		×	×	×
Hustedia Meormoni				×		CB
Puguax sp.				×		CB ?
Drelasma bovidens				×		CB
Deltopecten Van-vleeti			×			

* Orthisina umbraculum of Newberry. † P. Rogersi of Newberry.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO—*Continued*

	I	II	III	IV	V	VI
Myalina Kansasensis			?		×	
Myalina ampla		×				
Myalina subquadrata	u§					?
Myalina Apachesi*	u					
Myalina Wyomingensis ?	u					L ?
Edmondia subtruncata	×					×
Edmondia Mortonensis ?					×	
Allerisma terminale	×	×‡	×			×
Choenomya Leavenworthensis					×	×
Schizodus Wheeleri	×					
Schizodus sp	×					?
Pleurophorus sp	×					
Bellerophon majusculus*	×					
Bellerophon sp	×	×				?
Bellerophon percarinatus					×	?
Patellostium aff. Montfortianum	u					?
Euconispira excelsa*	×	×				
Euconispira sp					×	?
Worthenia tabulata ?					×	
Euomphalus catilloides	×			×	×	×
Euomphalus sp	×					
Naticopsis remex	×					
Naticopsis Altonensis ?					×	?
Naticopsis monilifera				×	×	×

* Orthisina umbraculum of Newberry.

† P. Rogersi of Newberry. ‡ A. Subcuneatum of Newberry.

§ Species designated by White as from the "Upper Aubrey" are marked "u."

I. Confluence of Grand and Green Rivers, Utah; collected by Powell expedition, determined by C. A. White (**32**, pp. 88–92).

II. In or near Canyon of Grand River, below Moab; collected by J. S. Newberry, 1859 (**27**, p. 98).

III. On road about 4 miles northwest of Moab, Utah; collected by L. M. Prindle, 1901.

IV. Cliff about 3½ miles northwest of Moab, Utah; collected by Cross party, 1905.

V. Sindbad Valley, on Colorado-Utah line; collected by A. C. Spencer, 1899, or Cross party, 1905.

VI. Occurrence of species of this table in the Hermosa formation of southwestern Colorado, indicated by species not yet found in the Hermosa formation but known from the Crested Butte quadrangle, Colorado, or the Leadville district, are also indicated, by CB or L respectively.

Concerning the faunal relations indicated by this table, Mr. Girty has kindly given me the following comments for publications:

Powell's collection at the junction of the Grand and Green Rivers shows a fauna probably equivalent to that of the Aubrey formation. Many of the charac-

teristic Aubrey forms are, however, lacking (*Productus occidentalis*, *P. Ivesi*, *Allerisma capax*, etc.). This fauna is more like that of the Weber quartzite formation of Bingham, Utah, which, at the present time, I provisionally correlate with the Aubrey. Newberry's list making the necessary synonymic changes is almost identical with Powell's, as far as it goes. The collection is smaller, and, of course, lacks many forms which might be obtained on further search. Considering the Powell and Newberry collections together, it is notable that they contain a considerable number of species which may be called distinctive western types, as compared with the Pennsylvanian fauna of Colorado and of the Mississippi Valley. These species are marked by an asterisk following the names in the list. In some cases nothing at all closely related to the types indicated is known from the region to the east. In other instances there are more or less similar species known which are not yet regarded as identical with western forms, although they may prove to be so.

The collections from Moab consist entirely of typical Pennsylvanian species, lacking the forms specified as characteristic of the far western areas. The distinctly Pennsylvanian forms found at the junction of the Green and the Grand occur, however, at Moab. The Sindbad Valley fauna is very closely related to that from Moab.

In view of the fact that none of these collections can be considered as exhaustive for the localities, numerical comparisons are more or less untrustworthy; yet the table brings out certain contrasts or resemblances which seem worthy of note. Out of 42 species represented in the Powell and Newberry collections but 9 have been found at Moab, or in Sindbad Valley, while out of 43 species obtained in these latter localities 25 are known from the Pennsylvanian rocks of southwestern or central Colorado.

On the basis of the fossil evidence alone there can be no hesitation in considering the Moab and Sindbad Valley sections as belonging to the Hermosa formation rather than to the Aubrey, as represented in the lower Grand River Valley.

The strong similarity which Mr. Girty has pointed out between known faunas of the Moab district and of Sindbad Valley to that of the Hermosa formation of Colorado, and the contrast with the faunas collected by Newberry and Powell, require some explanation.

As stated on p. 668 the collection made by Newberry was obtained less than 10 miles below Moab, if the Cañon Colorado of recent maps is the same as the canyon of that name through which Newberry descended to Grand River. If he reached Grand River as near to the junction of the Green as he himself supposed, the locality of Newberry's collection was still in all probability not more than 25 miles from Moab. One explanation of the difference between the Moab

collections and those of the lower Grand River lies in the assumption of insufficiency of collections at Moab, which by chance failed to include a large number of the species of the Powell collection. In view of the fact that the collections from Moab and Sindbad Valley were made by several different collectors at different times, this explanation seems hardly a plausible one. Another interpretation is that there may be a stratigraphic break, due to uplift and erosion, through which the Aubrey strata found by Powell and Newberry have been removed at Moab, in the Sindbad Valley, and to the mountain region to the east. This implies that the Hermosa beds of Moab are present beneath the section examined by Powell and Newberry. Such a break must occur at the base of the Paleozoic "Red Beds," and no suggestion of such a hiatus has come from observations in Colorado; but it is to be remembered in this connection that in southern Utah and northern Arizona, Powell, Gilbert, Dutton, Walcott, and others have noted a persistent unconformity by erosion between the Aubrey and the succeeding strata now commonly referred to the Permian through Walcott's discovery of fossils in the Kanab Valley (**37**). All of the above-named geologists have observed a conglomerate more or less widely distributed at the base of the Permian series, composed in large part of pebbles derived from the Aubrey rocks, as shown by fossils contained in them. It is, of course, possible that the denudation at this horizon may have been much more extensive than the observations thus far reported would suggest. The situation is really not very different from that concerning the unconformity and stratigraphic break now known below the Dolores Triassic formation, which a few years ago was supposed to consist in comparatively slight unconformity by erosion.

The foregoing suggestion is in some degree confirmed by the fact, determined in the Colorado region, that the Hermosa fauna is succeeded by one having a distinct, and apparently a younger, facies (**16**, pp. 245–56), that of the Rico formation, which has not been found at Moab. Mr. Girty informs me that recent data tend to correlate Rico with the Aubrey formation (in part) through the Manzano group of New Mexico. In its lithologic, stratigraphic, and faunal relations the Rico is said to be suggestive of the Manzano group, which

in turn can be correlated with the Aubrey. The Manzano fauna comprises a certain number of species which occur also in the Rico, together with others not yet found in the Rico, which are more or less characteristic of the Aubrey.[1] There is also some confirmation of the relations thus suggested in the fact brought to my attention by Mr. Girty that the Hermosa fauna bears a noteworthy resemblance to that of the upper part of the Red Wall limestone of the Grand Canyon, while markedly different from that of the Aubrey. No great emphasis can be laid upon this at present, however, since the collections upon which Meeks' list of Red Wall forms given to Gilbert (**14**, p. 178) have been lost and further study of the Red Wall fauna is necessary to elucidate this matter. There is clearly a field requiring much further investigation as to the relations of the Red Wall, Aubrey, Hermosa, and Rico faunas.

THE PRE-CAMBRIAN COMPLEX

The ancient rocks of the Uncompahgre Plateau were described by Peale as in the main granites and gneisses with a subordinate amount of various schists. He called them Archean, considered them to be derived by metamorphism from sediments, and correlated them with the complex so well exposed in the Canyon of Gunnison River to the east (**29**).

There is every reason to suppose that the rocks in question do belong to the same great pre-Cambrian complex which is well known in other parts of Colorado. Our limited observations in Unaweep and West Creek Canyons and at other points indicate that the old rocks of the Uncompahgre Plateau are comparable in most elements with those of the Needle Mountains and the Gunnison Canyon. There are many gneisses and schists, the origin of which is not wholly evident. Some gneisses are granitic in composition and may plausibly be considered as mashed or sheared granite. But there are many very dark hornblendic schists and others containing both hornblende and biotite. Such gneisses and schists are probably the oldest rocks of the district and are naturally referable to the Archean.

The gneissoid and schistose rocks are cut by many bodies of coarse

[1] The relations of the Manzano group will be discussed in a forthcoming bulletin of the Survey by W. T. Lee and G. H. Girty.

or fine-grained granite, little modified by movement or pressure, and these seem plausibly to be equivalent in age to the massive granites of the Needle Mountains, which are later than the quartzites of the Uncompahgre formation referred to the Algonkian in the Needle Mountains and Ouray folios.

That the Uncompahgre quartzites are also present in the West Creek area is indicated by two observations. In West Unaweep Canyon, near the west end, a patch of white quartzite, some hundreds of feet in visible extent occurs on the north side of the valley a few hundred yards north of the road. Mr. Kay visited this outcrop and found it to consist of quartzite of fine, even grain, for the most part, if not wholly, surrounded by granite.

Another occurrence of quartzite was discovered by Mr. Woolsey within the area of Permian (?) sediments very near the granite line on the south side of West Creek and several hundred feet above the stream. These quartzites were surrounded and in part covered by the Permian (?) grits, and they apparently form a pinnacle or knoll which has been buried and is now again exposed by erosion. Small quartzite fragments were observed in the adjacent granite.

These quartzite occurrences, of which scarcely more than notice of their existence can now be said, are very suggestive in the matter of the correlation of the extensive Uncompahgre formation of the San Juan region with the still greater series of ancient quartzites in the Uinta Mountains. Both have been referred to the Algonkian and their similarity emphasized. The quartzites of West Creek are about 90 miles from the type locality for the Uncompahgre quartzites at Ouray on the north side of the San Juan Mountains, and 150 miles from the Uinta Mountains. They are thus so nearly intermediate as to add weight to the correlation suggested.

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