CONTRIBUTIONS TO THE STRATIGRAPHY OF SOUTHWESTERN COLORADO.

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INTRODUCTION.

In the course of field work of the United States Geological Survey in the San Juan region of Colorado observations have been made in the last three seasons that considerably extend our knowledge of the great stratigraphic break below the La Plata sandstone, which is currently assumed to be of Jurassic age. The new data pertain partly to the relations existing in the Gunnison Valley, north of the San Juan Mountains, where the unconformity marking this break was already known at certain places, and partly to the conditions in the Piedra Valley, on the south side of the mountains, where the unconformity had not before been noted. The Piedra Valley is of special interest, and it seems well to call attention to the relations observed even though they were examined only in a reconnaissance. The first part of this paper is devoted to the evidence of the overlap of the La Plata sandstone; the second to the stratigraphic relations in the Piedra Valley.

The section of sedimentary formations in Piedra Canyon is of much interest because none of the pre-La Plata formations are known east of this locality on the south side of the San Juan Mountains. Most of these formations exhibit a notably different facies where they reappear from beneath the overlying beds at their nearest exposures in New Mexico, southeast of the Piedra Valley. It is believed that the character of the formations in the Piedra section should be recorded for the benefit of geologists who may be studying the Paleozoic and Mesozoic rocks of New Mexico, and accordingly the second part of the paper presents details of the structure and the stratigraphic section of Piedra Valley.

THE STRATIGRAPHIC BREAK BELOW THE LA PLATA SANDSTONE.

GENERAL RESULTS OF THE HAYDEN SURVEY.

The Hayden Geological Survey established the existence of great stratigraphic breaks in the central and western mountain regions of Colorado below both Triassic and Jurassic formations, and a corresponding overlap is also represented on the Hayden map of western Colorado as occurring at the base of the Dakota Cretaceous. The map represents this break as being particularly prominent along the Gunnison Canyon, between the town of Gunnison and Vernal Mesa. The shales of Colorado age, belonging to the formation now distinguished in western Colorado as the Mancos shale, are also represented as overlying the pre-Cambrian rocks east of Gunnison, on both sides of Tomichi Creek, and as abutting against the gneisses and schists of Vernal Mesa in primary contact.

The overlap of the Cretaceous formations upon the pre-Cambrian in this region, as shown on the Hayden map, is in accord with the view expressed by A. C. Peale,[2] that "The Archean area along the northern edge of the San Juan Mountains and south of the Gunnison River probably formed a shore line in Cretaceous times."

F. M. Endlich was the geologist who visited the area within which the "Colorado" shales are represented by the Hayden map as lying on granite, in the valley of Tomichi Creek, for a distance of about 15 miles above Gunnison. As we shall explain more fully later on, he found other sediments beneath the shales of this area, which are not shown on the map.

[1] The authors wish to acknowledge the efficient assistance of J. Fred Hunter in the field work on which this paper is based.

[2] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1875, p. 69, 1877.

The contact of Cretaceous shales and pre-Cambrian rocks on Vernal Mesa, thought by Peale [1] to be of primary origin, is now known to be a fault contact in a zone of complex folding and fracturing, the details of which have been shown by the tunnel of the Uncompahgre irrigation project.

THE OVERLAP IN THE GUNNISON VALLEY.

The assumed overlap of the Dakota sandstone in the Gunnison Valley is unquestionably explained by the fact that Peale and other Hayden Survey geologists included in the Dakota several hundred feet of beds that belong in the Gunnison formation (Jurassic?) of Eldridge, embracing equivalents of the McElmo and La Plata formations of the San Juan region, a fact clearly shown by Peale's section of the assumed Dakota occurring in Gunnison Canyon about a mile above Sapinero.[2] This section embraces 536 feet of strata, which are described as predominantly sandstone, with some shaly beds and thin limestones. The upper member of Peale's section, 100 feet thick and described as "massive yellow siliceous sandstone," is all that, in our opinion, belongs in the Dakota. In mapping the Uncompahgre quadrangle we have examined this and many other sections of the Gunnison Canyon, and we assign to the Dakota a thickness of about 100 feet. It has the character common to it over large areas of western Colorado, which have been examined by several parties of the Geological Survey in recent years. A thin remnant of Mancos shale in some places lies between the Dakota and overlying volcanic rocks.

The beds beneath the Dakota sandstone in the Gunnison Valley are largely sandy, as Peale has stated, but shaly beds of red, lilac, green, or yellowish colors are in many places well developed between the sandstones. At its base the sandstone is thicker and more massive, and this portion undoubtedly corresponds to the La Plata sandstone, as distinguished in the San Juan Mountains area and the adjacent portions of the plateau country to the west. The La Plata is also well developed in the Uncompahgre Plateau and the Uncompahgre Valley.

In the wild lower canyon of the Gunnison, between Cimarron Creek and Smiths Fork, the Hayden map represents a thin Jurassic formation as appearing between the Dakota sandstone and the gneisses and schists, but farther down the canyon a thin Triassic formation appears in similar manner between the Jurassic and the crystalline rocks. This makes the section of the lower Gunnison Canyon correspond with that of the eastern flanks of the Uncompahgre Plateau, 30 miles to the west. But though Peale[3] refers to his Jurassic formation as appearing beneath the Dakota at a certain point and thickening toward the north, he was unable to examine the section in detail, and it seems reasonable to assume that if these beds are Jurassic they belong in the Gunnison formation with the greater part of the section above them, included by Peale in the Dakota. They may illustrate the progressive overlap of succeeding beds of the Gunnison on an uneven floor of crystalline rocks.

The age of the supposed Triassic rocks of the lower Gunnison Canyon has not been determined by fossils or by close lithologic correlation with known Triassic rocks of similar position in the Uncompahgre Plateau, and it must be remembered that Eldridge found that the Gunnison formation in the southern Elk Mountains (=La Plata+McElmo) rests unconformably on red strata of the Maroon conglomerate (Carboniferous),[4] and in the Uncompahgre Valley below Ouray both Triassic and Permian (?) beds occur between the La Plata and the Carboniferous.[5]

Coming now to new data bearing on the character of the great overlap shown in the Gunnison Valley, we may say that our observations during the last few years have demonstrated the presence of the Gunnison formation between the Dakota and the pre-Cambrian all along the Gunnison Canyon and also in the valley of Cebolla Creek, the southern tributary of the Gunnison called "White Earth River" on the Hayden map. During the survey of the Uncompahgre quadrangle in 1911 it was found that the lower member of that formation, now

[1] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 132 and Pl. VII; fig. 2, facing p. 97, 1876.

[2] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 131, 1876. The section is referred to as "beneath station 73"; the location is shown on the map facing p. 170 and the profile in fig. 1, Pl. XIV, facing p. 169.

[3] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 126, 1876.

[4] U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

[5] Idem, Ouray folio (No. 153), 1907.

called the La Plata sandstone, extends for 16 miles up the ridge east of the Cebolla, overlying a variety of pre-Cambrian rocks. In some places the McElmo beds are preserved above it; in a few others there are also remnants of the Dakota sandstone. Tertiary volcanic rocks overlie all these sediments.

East of Cebolla Creek the Gunnison beds probably extend continuously underneath the volcanic rocks to the valley of Cochetopa Creek. They are exposed north of Agency Peak and on the ridge west of the Cochetopa, where the Hayden map represents the volcanic rocks. About 12 miles south of Tomichi Creek the Gunnison beds cross the Cochetopa and pass under the Dakota sandstone on its eastern bank, in the area where the Hayden map represents Colorado shales as resting on granite. The shales occur in this region but are restricted to the higher country several miles south of the Tomichi.

In Razor Creek valley, next east of the Cochetopa, nearly 1,000 feet of Mancos shale is locally preserved beneath the volcanic rocks. In an eastern branch of that stream not shown on the Hayden map a fault brings up the Dakota, the Gunnison, and the underlying granite in a small area nearly surrounded by volcanic rocks.

In the extreme eastern part of this sedimentary area, which is traversed by Tomichi Creek, the Dakota and Gunnison formations are everywhere present beneath the Mancos shale. Moreover, these formations occupy a somewhat larger area than is assigned to them on the Hayden map, especially on the north and east. The hills and smooth-sloped ridges near the Tomichi are in most places formed of the soft McElmo strata, though rhyolitic tuff occurs in certain hills. The Dakota maintains its usual character and thickness, and from its superior induration it is everywhere the most prominent of these formations. On the northwest slope of Tomichi Dome it has a measured thickness of 80 feet.

Near Tomichi Creek some low cliffs, which appear at about the horizon where the Dakota might be expected, are of rhyolite. The volcanic rocks rest on a very uneven surface and are not readily recognizable at a distance. Moreover, the sediments are gently folded, and this adds to the difficulty of tracing formation boundaries in reconnaissance work.

The Gunnison formation is rarely well exposed. The lower sandstones, which in the western part of the area are so prominent as to suggest a correlation with the La Plata sandstone, are thin or entirely absent in the eastern part. The formation here exceeds 200 feet in thickness in but few places. Northwest of Tomichi Dome its thickness was found to be 150 to 175 feet. It consists chiefly of reddish and greenish shales, sandstone being very subordinate.

The decided thinning of the Gunnison formation eastward suggests that it may not have been everywhere present beneath the Dakota in the central mountain region of Colorado. The change in lithologic character here noted indicates that this thinning was due to nondeposition of the normal section in the area under discussion and not to unconformity caused by erosion.

As to the structure exhibited by the Mesozoic formations in the basin of Tomichi Creek it is sufficient to say that for about 20 miles east of Gunnison the creek flows in a syncline, the strata dipping at high angles toward it from the north and south. But the limitation of the formations on the east is due to a steep upturning of the beds. The Dakota and Gunnison beds assume westerly dips of 80° or more and are in some places overturned. On the north side of Tomichi Creek the gradual change from a low southerly dip can be observed in the area northeast of Tomichi Dome, but on the south side of the creek the lower beds hold their steep dips until they disappear beneath the volcanic rocks.

In regard to the Paleozoic sediments, the representation on the Hayden map of Tomichi Dome as "Lower Carboniferous" is incorrect, for the dome is made up of a plug of rhyolite, about a mile across, intruding Mancos shale. Moreover, Paleozoic sediments, not shown on the Hayden map, form most of the basin of Indian Creek, the fork of Marshall Creek which enters from the north about 4 miles southeast of the town of Sargents. The Paleozoic beds are thus known within 5 miles of Marshall Pass. About 600 feet of these beds are exposed over the pre-Cambrian in this area, and the section is similar to that of Fossil Ridge, where the Carboniferous is represented on the Hayden map. The beds dip about 20° S. and on the east, west, and south are overlain by volcanic rocks, while on the north they overlie the pre-Cambrian rocks.

The error of the Hayden map in representing Colorado shales on pre-Cambrian east of Cochetopa Creek is perhaps entirely cartographic. It is certainly not entirely due to incorrect observation, for the map does not agree with Endlich's statements concerning the distribution of the Cretaceous formations in Cochetopa and Tomichi valleys, nor with his profile sections through this region.[1] He repeatedly refers to quartzites under the shales as probably "Lower Cretaceous," but they were omitted from the map prepared some years later. The name Dakota does not appear to have been applied to these sandstones at the time of Endlich's report.

SAN JUAN MOUNTAINS AREA.

The representation of the Hayden map by which Triassic, Jurassic, and Dakota Cretaceous beds are shown to overlap and in turn come in contact with the pre-Cambrian in canyon branches of Cimarron Creek, north of Uncompahgre Peak, is wholly hypothetical. There are no such exposures in these canyons, for the volcanic rocks descend to the streams. Yet an overlap of this general character for the La Plata sandstone must exist beneath the volcanic rocks between the Gunnison Canyon at the mouth of Blue Creek and the Uncompahgre Valley below Ouray. Endlich, who was responsible for this part of the Hayden map, understood the nature of the overlap existing beneath the volcanic rocks, but drew on his imagination for the exposures to express it. In the Ouray quadrangle the La Plata is found on the Dolores (Triassic) formation, and beneath the Dolores is the complete known sedimentary section of the San Juan region from the Cutler formation (Permian?) to the Ignacio quartzite (Cambrian). The beginning of the overlap is near the Uncompahgre, however, for on Cow Creek, one of its eastern tributaries, the La Plata rests with angular unconformity on Cutler beds, the Dolores and an unknown amount of the Cutler being missing.

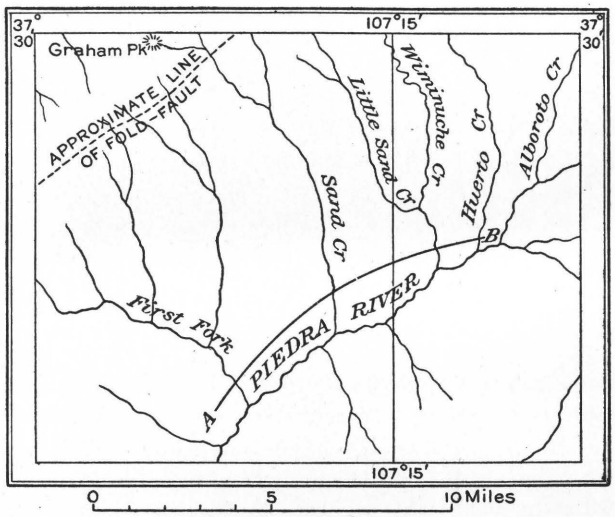


FIGURE 2.—Drainage map of a part of the Piedra Valley, Colo.

The sedimentary sections of the San Juan Mountains district from the Uncompahgre Valley, on the north, around the western slopes and eastward on the southern side as far as Pine River agree in showing the La Plata sandstone resting on the Triassic red beds (Dolores formation), the full Paleozoic sequence of the region occurring in most places. The details of these relations are described in the Ouray, Telluride, Rico, La Plata, and Engineer Mountain folios of the United States Geological Survey. At many localities, however, the sandstone of the Dolores formation beneath the La Plata has been much eroded, causing local unconformities.

As stated in the Engineer Mountain and Needle Mountains folios, the great overlaps shown on the Hayden map in the Animas Valley and east of it are not to be found as represented. Our recent work has shown, however, that about 25 miles east of the Animas, on the west side of Wiminuche Creek, both faulting and earlier overlap are plainly exhibited nearly on the northeast-southwest line where the Hayden map represents "Upper Dakota" beds in original contact with "Metamorphic granite." In the small portion of this area that lies in the San Cristobal quadrangle, north of 37° 30′, the fault mentioned brings Dolores (Triassic), La Plata (Jurassic), and McElmo (Jurassic?) beds successively into vertical or steeply inclined position against pre-Cambrian rocks on the northwest. A coarse granite is the chief of these older formations, but gneiss and Algonkian quartzite also appear in Wiminuche Valley near the point where the fault disappears under the later volcanics. The relations of Wiminuche Creek, Piedra Canyon, and other localities mentioned are shown in figure 2.

[1] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, Pl. XIV, pp. 341-342, 1874.

Farther southwest this fault is lost under glacial drift and a thick forest cover, but on the east and southeast slopes of Graham Peak, a granite mountain near by, which is unnamed on the Hayden map but assigned an elevation of 12,836 feet, small remnants of quartzite and greenish shales rest on the granite northwest of the fault line. These beds dip gently to the southeast. Their character suggested to us that they belong to the La Plata and McElmo formations, and the exposures of the Piedra Canyon, to be described, practically prove this correlation to be correct. The fault probably passes into a fold within the area shown in figure 2, but time was not available for an examination of the district where this change presumably occurs, nor were we able to examine the country southwest of Graham Peak, where the overlap of the La Plata sandstone over the whole section of older sedimentary formations must apparently occur within a few miles.

The Hayden map is also incorrect in its representation of the geology of Piedra Canyon and lower Wiminuche Valley and of the slope between Piedra River and the granite divide to the northwest, which is colored as entirely occupied by the "Upper Dakota." Endlich, who mapped this district, usually applied this term to the strata still called the Dakota sandstone, and at most a few hundred feet of lower beds. In the area referred to, however, the valleys and canyons on the dip slope have a depth of more than 1,000 feet, and as the true Dakota is less than 200 feet thick in this region lower formations are naturally exposed. It is in the canyon sections that the overlap to be described is so clearly exhibited.

A traverse down Wiminuche Creek to Piedra River and down the canyon of the Piedra for 6 miles to the mouth of the second large tributary from the northwest, called "First Fork," revealed a most interesting structural and stratigraphic complexity, which is described in some detail on pages 44–46 of this paper. Within a few miles the river cuts across a monocline and two anticlinal uplifts, exposing three areas of pre-Cambrian rocks, which are overlain by somewhat different sections of the Paleozoic and Triassic formations, and these in turn are covered in marked unconformity by the La Plata sandstone. Above this come the McElmo and Dakota formations, the Dakota forming the rim rock of a warped and dissected plateau.

The northeastern of these eroded uplifts reveals the La Plata resting on granite or Algonkian schist; the middle one exposes the same pre-Cambrian formations but shows a varying Paleozoic section between them and the La Plata; the southwestern uplift was seen only from a distance, but it also appears to have a pre-Cambrian core in the rugged canyon below First Fork, and Paleozoic formations must be present, though perhaps in an incomplete section.

RÉSUMÉ.

From the evidence here presented it appears that the overlap of the Gunnison formation on the pre-Cambrian rocks extends at least 50 miles farther up the valleys of the Gunnison and Tomichi than was represented for the Jurassic beds on the Hayden map. It takes the place of the assumed transgressions of the Dakota sandstone and "Colorado" shale. Eldridge has shown that the Gunnison extends northward through the Elk Mountains in marked unconformity with the Paleozoic formations.[1] The relations in the Piedra Valley suggest that the La Plata sandstone overlapped earlier sediments and came into contact with the pre-Cambrian rocks along a general north and south line, crossing the San Juan Mountains area. Piedra Canyon is about 75 miles south of Gunnison River, and it seems not unlikely that the area of the La Plata overlap extended eastward through the present mountain district to the San Luis Valley. The suggestion has been entertained that the strata known as the Gunnison formation on the western slope and the Morrison formation on the eastern slope were once continuous deposits, having been connected across the area of the Sawatch Mountains and perhaps also across the areas of the Sangre de Cristo, the Arkansas Valley, and the district south of South Park. Although it is difficult to outline land areas in central and southern Colorado where the Morrison or Gunnison beds were not deposited, or to prove that there were any such areas, the thinning of the Gunnison formation eastward, as described on page 41, indicates that the two formations may never have been continuous.

[1] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

It is the current practice of the Geological Survey to refer the La Plata sandstone to the Jurassic because strata believed to be its equivalent occur in Utah beneath marine Jurassic beds. This reference does not require the assignment of the McElmo and Morrison formations to the Jurassic. It seems, however, to indicate that sedimentation may have continued in Colorado, with no considerable interruption, from Jurassic through Lower Cretaceous time.

STRATIGRAPHIC RELATIONS IN THE PIEDRA VALLEY.

STRUCTURE OF THE UPPER MESOZOIC FORMATIONS.

The Mesozoic formations exposed in the lowlands adjacent to the San Juan Mountains, in the area traversed by San Juan and Piedra rivers, exhibit many gentle folds and minor faults which can be grouped in no definite systems. These structural features are brought out by the Dakota sandstone in characteristic ledge outcrops on steep slopes and along the walls of small canyons, or by undulations where it serves as the sustaining floor of many nearly level stretches between streams near the mountains. Such rolls and small faults are especially well shown near Pagosa Springs, where several small streams have cut through a thin mantle of Mancos shale and revealed the underlying Dakota.

The McElmo and La Plata formations must take part in these minor structures, but erosion has not revealed them, so far as known, in the valleys east of the Piedra. The structure shown immediately adjacent to Piedra Canyon is rudely expressed in figure 3. It will be noted that the La Plata, and with it the overlying beds, has been warped by three low folds. The one best shown in the figure lies between Sand Creek and First Fork. The fold southwest of First Fork is probably still more striking, for it is plain that the La Plata, McElmo, and Dakota formations must all disappear beneath the Piedra, by southwesterly dips or faulting, within 4 or 5 miles of First Fork. These low folds of the La Plata are located, at least in a general way, above more pronounced folds of pre-Jurassic formations, to be described under the next heading.

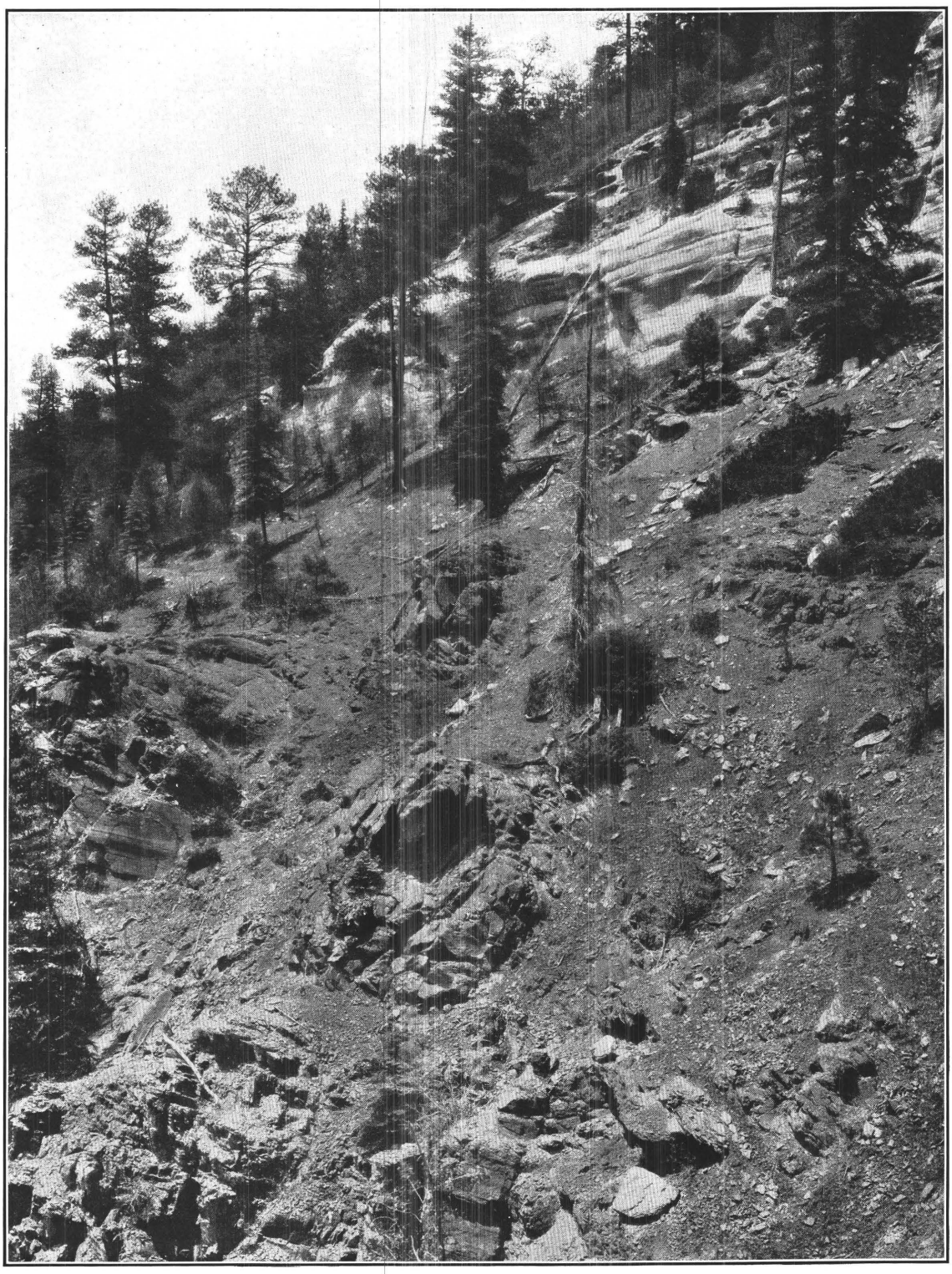
The structure of the underlying beds probably had much to do with the location of the later minor folds of the La Plata along the Piedra, for many small faults in younger formations in the San Juan region represent renewed movement on fault planes along which older formations have been more extensively dislocated at some much earlier period. It seems reasonable to suppose that the same is true of the folds, and the gentle flexures of the Piedra appear to be the results of such repeated movement, but further study is necessary to ascertain definitely the relations of the folds in this region.

Mention has been made (p. 42) of a major fold-fault of southwest-northeast trend that crosses the Wiminuche north of the area shown in figure 2. Whether this movement was synchronous with the minor flexures here referred to is not known.

THE UNCONFORMITY BELOW THE LA PLATA SANDSTONE.

The character of the unconformity may be more clearly brought out by describing in somewhat greater detail the relations so well exhibited in the Piedra Valley and its branches below the mouth of Wiminuche Creek. The Piedra itself first cuts through the La Plata sandstone about a mile above the mouth of that creek. The La Plata there dips very slightly to the southeast and rests on steeply upturned shales, schists, and thin quartzites of the Uncompahgre (Algonkian) formation. These relations are brought out by the view given in Plate VIII. The schists are much decomposed and their appearance indicates that they had long been subjected to weathering before the deposition of the La Plata.

In the angle between Piedra and Wiminuche Creek the base of the La Plata lies about 200 feet above the junction of the streams. It runs up the Wiminuche with nearly regular position, crossing it at about a quarter of a mile above Little Sand Creek, and in this distance it crosses an ill-exposed contact between the Uncompahgre strata and a great intrusive mass of coarsely porphyritic granite, regarded as a part of the Eolus granite, which occupies a large area in the Needle Mountains. There may be a fault contact at this point.



LA PLATA SANDSTONE ON SCHIST OF UNCOMPAHGRE FORMATION ON NORTH BANK OF PIEDRA RIVER, COLO.

Below Wiminuche Creek the base of the La Plata descends gradually, with very gentle undulations, keeping from 100 to 200 feet above the river, to the point of the ridge east of Sand Creek. The Uncompahgre beds underlie the La Plata in the Piedra Canyon with a general northwestern dip of 43°–45°, to a point about a mile below the mouth of Wiminuche Creek, where they disappear beneath the lower Paleozoic formations, which dip about 11° SW. These beds belong to the northeastern limb of a shallow syncline, the opposite side of which rises more steeply beyond Sand Creek.

Owing to this older structure the La Plata overlaps discordantly the formations from the Elbert? (Devonian?) to the Hermosa (Pennsylvanian), and at the point of the ridge east of Sand Creek it lies on Hermosa beds several hundred feet above the base of the formation, with an angular unconformity rudely illustrated by figure 3.

Sand Creek is nearly in the trough of the syncline just referred to, and it has cut below the La Plata for its entire length. The gradient of the stream is equal to the southeastern dip of the La Plata sandstone, about 4°, so that the base of the sandstone keeps its position, from 100 to 200 feet above the stream, for over 7 miles from the Piedra. The underlying Hermosa also persists until the great fold-fault alluded to on page 42 is approached. Where the lower beds turn up adjacent to that fold the creek cuts through them into granite.

Somewhere in the region near Graham Peak the La Plata again overlaps the lower Paleozoic formations, but a heavy cover of forest and old glacial gravels obscure these relations and no

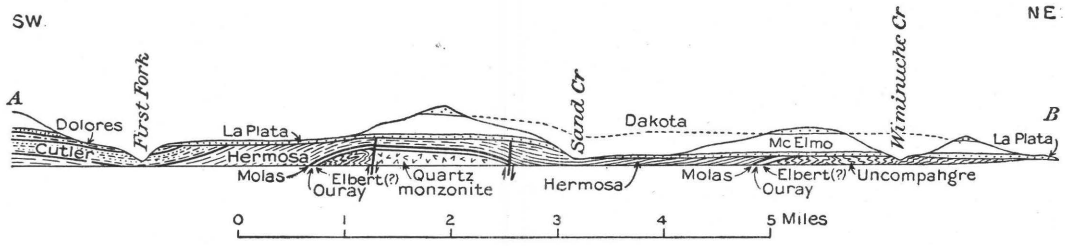


FIGURE 3.—Diagrammatic section along the northwest side of Piedra Canyon, Colo.

exposures of the unconformity were found. Erosion may have removed the La Plata from the rather narrow zone in which it might otherwise be present.

The divide at the head of Sand Creek and farther north is in the Eolus granite, and the base of the La Plata turns up sharply on the higher slopes and swings around to the northeast where the fold merges into the Wiminuche fault. On some of the ridges of these upper slopes northwest of the fault remnants of the La Plata sandstone overlie the granite.

Below the mouth of Sand Creek the La Plata sandstone assumes a northeastern dip and in a distance of less than a mile its base rises 1,000 feet above the bed of Piedra River. It then turns gently to the southwest and east of the mouth of First Fork, which is the next main stream, it is again only a few hundred feet above the Piedra. As shown in figure 3, there is an older and more pronounced fold in the pre-Jurassic strata between Sand Creek and First Fork and the La Plata truncates these older formations, the overlap being very plainly demonstrated by the section displayed in Piedra Canyon and the valley of First Fork.

As the Piedra cuts across this anticline it first reveals the Eolus granite beneath the sediments, but on the southwest side a fault brings schists of the Uncompahgre formation once more to view. The river flows through these pre-Cambrian formations in a rugged canyon. The Hermosa and earlier Paleozoic formations are well exposed on the northwest side of the canyon.

First Fork also flows in a synclinal trough and for at least several miles above its mouth cuts below the La Plata. In the lower part of the valley bright-red sandstones are prominent in the southwest bank and also appear on the southeast side of the Piedra. These beds and 300 to 400 feet of variously colored grits, sandstones, shales, and nodular limestones which overlie them, clearly belong to the Permian (?) Cutler formation, for they are in turn overlain by

the Triassic Dolores formation. The characteristic fine-grained "saurian conglomerate" of the Dolores, carrying fragments of bones and teeth and made up mainly of small pebbles of gray limestone, is exposed on the northeast side of First Fork, halfway to the principal forks of the stream shown in figure 2, and also in the ridge between the forks.

The white La Plata sandstone occurs 300 to 350 feet above the forks, being clearly shown in the main ridge to the northeast. It thus appears in First Fork in about the same position relative to the underlying section of Triassic and Paleozoic formations that it holds throughout the San Juan region, to the west, as described in the published folios. Except for a part of the Dolores formation the overlap from Triassic to pre-Cambrian rocks is complete between First Fork and Wiminuche Creek.

Below the mouth of First Fork the canyon of the Piedra has been seen only from a distance. The canyon closes in and the walls are high and rugged. The Paleozoic beds form a sharp anticline, with very steep dips on the southwest limb, and the pre-Cambrian rocks are probably again exposed in the canyon. The La Plata and overlying beds are also folded, but less sharply than are the underlying rocks, the conditions resembling those above First Fork. Within a few miles down the river all pre-Dakota formations disappear beneath the surface by southerly dips.

The overlap of the La Plata has been described with special reference to the exposures examined on the northwest side of the Piedra, but the same general relations are shown on the opposite side, as could be seen from many good points of view. But the structure exhibited by the older formation southeast of the Piedra is more complex than has been described. Pre-Cambrian rocks rise about 1,000 feet above the river in an amphitheater nearly opposite Sand Creek, and are there immediately overlain by the La Plata sandstone. A more detailed study than we could make is necessary in order to determine fully the structural relations of the formations in this area.

PRE-DAKOTA SECTION OF PIEDRA VALLEY.

JURASSIC (?) SYSTEM.

McELMO FORMATION.

The McElmo strata, occurring between the Dakota and La Plata sandstones, are widely distributed in the Piedra and adjacent valleys, but owing to their soft, friable nature are well exposed at few places. The only good section observed is in the little canyon of Wiminuche Creek, about 5½ miles north of the area shown in figure 2, where the stream cuts across the strata adjacent to the fault mentioned on page 42. In this canyon 470 feet of McElmo strata are exposed in vertical position.

At the base of this McElmo section is a dark-red marly shale, such as occurs at many places in this position. It is succeeded by wavy friable sandstones, sandy shales, and clay shales, in beds that are rarely more than a few feet thick, without marked change in character. On slopes the harder sandstones form ribs separating shale depressions. The colors, especially those of the shaly layers, exhibit the variegation characteristic of the formation, from red, through pink, green, lilac, and yellow, to gray.

It seems probable that this section does not show the true thickness of the formation, owing to squeezing and shearing near the fault, and that the softer beds in particular are thinner than is normal. No fossils have been observed in the McElmo formation.

JURASSIC SYSTEM.

LA PLATA SANDSTONE.

General character.—The La Plata of the Piedra Valley exhibits variations which are natural in a region of overlap upon an uneven topography. In other parts of the San Juan region the La Plata consists of two thick members of white massive cross-bedded quartzose sandstone, separated by a subordinate and variable calcareous member in places carrying some limestone but more generally consisting of calcareous sandstones and shales. In Piedra Canyon and its branches the lower La Plata sandstone in many places has nearly its normal character

and above it come dark bituminous limestones, locally thin-bedded and brecciated. The upper La Plata sandstone is presumably present in less than the normal thickness, but owing to its soft and friable character it affords no good exposures. This character renders it possible, however, that these soft beds belong in fact to the McElmo formation and that the La Plata here lacks its upper member.

At the base of the La Plata a basal conglomerate, variably developed, is composed mainly of dense quartzite pebbles from the Algonkian Uncompahgre formation, a great thickness of which is shown in the adjacent Needle Mountains area. Such conglomerate was observed at several places near the mouth of Wiminuche Creek, where the La Plata rests on an irregular surface of Algonkian strata.

The lower La Plata sandstone is variable in thickness and is very thin or wanting in some places, as on the east side of the Wiminuche about a mile above its mouth. A short distance below this point conglomerate and some sandstone occur between the underlying granite and dark limestone breccia. These variations are no doubt due to the uneven surface on which the sandstone was deposited.

The limestone member of the La Plata in the Piedra Valley presents very nearly the same features that it does north of Ouray. Its total thickness is locally more than 30 feet, and usually a gray massive cavernous limestone lies in thin beds above and below it, but in some localities almost the entire member is black breccia of thin limestone cemented by white calcite. In the thin shaly limestone layers below the more massive part scanty fish remains were found. Dr. C. R. Eastman has examined these remains carefully but is unable to make any satisfactory determinations of the forms represented.

Section of La Plata sandstone.—On the northwest side of the Piedra, about midway between Sand and Wiminuche creeks, the section given below was found.

Section of La Plata sandstone on Piedra River between Sand and Wiminuche creeks.

Top.	Feet.
1. Sandstone of the McElmo formation, red, thin-bedded, argillaceous; poor exposures.	
2. No exposures; unexposed interval probably occupied by upper La Plata sandstone with some McElmo beds	70
3. Limestone breccia, dark, made up of fragments like underlying limestone; contains open spaces, as the cementing material does not fill all the interstices; makes good ledge outcrops	15
4. Limestone, dark, in places nearly black; shaly; has a decided bituminous odor; carries fragments of small fish	10
5. Quartzose sandstone, light yellowish gray, fine, even-textured; weathers with rounded, pitted forms	20
6. Quartzose sandstone, white, even-grained, cross-bedded; makes rounded cliffs	55

This is the normal section of the La Plata of this area, but the two limestone members are rather variable and the upper limestone breccia alone reaches a thickness of 30 feet just north of the mouth of Sand Creek, though at some other places it is much thinner. The heavy sandstone bed at the base is also somewhat variable in thickness.

TRIASSIC SYSTEM.

DOLORES FORMATION.

The only known exposures of the Dolores formation are adjacent to the fault in Wiminuche Canyon and in the valley of First Fork. In neither locality were good sections seen, but it is clear that the formation here exhibits no marked change in character from that shown in the Animas Valley, as described in the Engineer Mountain folio. There is the usual alternation of fine limestone conglomerate and thin-bedded sandstones and shales near the base, followed above by intensely red shales and more or less massive sandstones. The original thickness of this sandstone in this region is presumably nowhere preserved, owing to pre-La Plata erosion, and it may have been much greater than at present. Probably 350 to 400 feet is a maximum measure of the Dolores formation now occurring in the Piedra Valley.

Unless small isolated exposures of the Dolores occur in the San Juan, Navajo, or other valleys east of the Piedra, near the volcanic rocks of the mountains, these outcrops of Dolores beds of the Piedra are probably nearer than any others of Colorado to the long-known fossiliferous beds of Rio Chama in New Mexico. No conglomerate like that of the Dolores has been reported from New Mexico, but it is evident that if the worn particles of limestone were a little smaller than they are in the conglomerate of First Fork and were mingled with sand grains the peculiar character of the "saurian conglomerate" would be lost.

CARBONIFEROUS SYSTEM.

PERMIAN (?) SERIES.

CUTLER FORMATION.

The most complete section of the Cutler formation is in Dolores Valley below Rico, Colo.[1]

The only observed outcrops of the Cutler formation in the areas here considered are those in First Fork, already mentioned, where, as noted, some of the sandstones and shales are very bright red, but the strata near the Dolores formation have the character of the partial section given below, which occurs on the northeast side of First Fork about half a mile above the Piedra, where it is crossed by the Forest Service trail leading up First Fork. The top of the section is not more than 200 feet below the Dolores, but the intervening beds are poorly exposed.

Section of Cutler formation about one-half mile above the Piedra.

Top.	Feet.
1. Arkose grit with subordinate red sandy shale; upper bed of arkose, 6 to 12 feet thick, varies locally inversely with red sandstone	20
2. Arkose, cross-bedded, massive, pink; forms rounded outcrops	12–15
3. Shale, calcareous, and nodular pink limestone	8
4. Sandstone, light gray, somewhat calcareous, weathering into rounded forms; tough fracture	6–7
5. Limestone and shale; red nodular limestone with shaly matrix; crumbling	3
6. Sandstone, gray, fine and even-grained	3
7. Shale, sandy; dark red in upper part, grading below into dark-green sandstone at base	12
8. Sandstone; thin-bedded, greenish gray, dark at top and lighter below; strike N. 12°–18° E., dip 7°–8° W	30
	98

This section is in general characteristic of the Cutler of the southern San Juan region as to the variety of beds and their alternation, though no two sections agree in thickness or similar beds or in details of gradation. No exposures were found in the zone between the Cutler beds and the typical Hermosa, so that it is uncertain whether the Rico formation (Permian ?) is present in the Piedra Valley or not.

PENNSYLVANIAN SERIES.

HERMOSA FORMATION.

The lower part of the Hermosa is exposed south of Sand Creek and near the Piedra, in a diagonal section which is continuous for about 500 feet, the beds dipping 18° to 25° NE. Owing to a fault the actual base of the formation is not shown in relation to this section, but probably there is a gap of less than 200 feet. The section is on the northeast limb of the anticline shown in figure 3.

Partial section of Hermosa formation near Piedra Canyon, south of Sand Creek.

Top.	Feet.
1. Sandstone, yellowish green, argillaceous	4
2. Sandstone, pinkish, with a few thin variegated bands; slightly cross bedded, medium to coarse-grained	16
3. Shale, purplish	3
4. Limestone, dark gray	2
5. Sandy shale, dark red to purplish	20

[1] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, p. 464, 1905.

		Feet.
6.	Grit, light gray	6
7.	Limestone, nodular, with very fossiliferous shale layers	6
8.	Limestone, nodular and fossiliferous, and shale; strike N. 65° W., dip 27° NE.	
9.	Shale, reddish to purplish at base, drab at top	20
10.	Limestone, nodular and fossiliferous, with thin shale	3
11.	Shale, purplish	17
12.	Shaly limestone; fossils	2
13.	Shale, sandy and reddish near base, calcareous and black near top	6
14.	Sandstone, coarse, somewhat variegated, brown or red	8
15.	Sandy shale	2
16.	Sandstone, soft, shaly, greenish, and somewhat variegated	5
17.	Grit and coarse sandstone	19
18.	Limestone, very fossiliferous	1
19.	Grit, light colored	22
20.	Shale, reddish and calcareous at top	23
21.	Grit, light colored	17
22.	Limestone, dark gray; few shells	3
23.	Sandstone, thin-bedded, shaly, gray, and cross-bedded	9
24.	Shale, forming flaky sandy clay, upper part dark gray, lower part reddish	20
25.	Limestone, sparingly fossiliferous; strike N. 35° W., dip 18° NE	4
26.	Shale, very fine-grained, green and gray, or red; soft and poorly exposed (estimated thickness)	40
27.	Sandstone, arkosic, green with prominent red feldspar grains	5
28.	Limestone; upper 5 feet nodular, gray, dense, rich in Productus, Spirifer, Terebratula, and Triticites; lower 7 feet earthy limestone grading downward; alternation of shales and limestone in layer 3 to 4 inches thick; fossiliferous	12
29.	Shale, dark, calcareous	3
30.	Limestone, nodular; rich in *Triticites secalicus*	2½
31.	Shale, soft, gray; poorly exposed	20
32.	Sandstone, yellowish gray	2
33.	Limestone, nodular in upper part, thinner bedded and sandy below; very fossiliferous	23
34.	Shale and shaly sandstone	10
35.	Grit, arkosic, pink, gray, and mottled; cross-bedded, massive; much quartz	14
36.	Shale, red and gray	8
37.	Limestone, part laminated, part nodular; fossiliferous	22
38.	Shale, red, with irregular nodules of limestone	12
39.	Limestone, massive, gray	5
40.	Shale, red	4
41.	Limestone and red shale of irregular development; rich Triticites-bearing limestone layer	20
42.	Grit, gray, massive	25
43.	Sandstone, dense, with dark-red shale partings to beds; pink and gray spots in sandstone	18
		490

Below this section is a zone, about 200 feet wide, in which the rocks are not exposed, and below that the Ouray limestone appears. On the south side of the fault which interrupts the continuity of the section the two lowest beds of the Hermosa are exposed. At the base is a gritty sandstone about 20 feet thick, and overlying it is a more or less sandy fossiliferous limestone of wavy bedding, exhibiting an irregular alternation of pure dark-gray material with streaks of yellowish earthy limestone. This constitution is characteristic of the lowest limestone of the Hermosa in the Animas Valley.

MOLAS FORMATION.

The descriptions of the Molas formation in the Silverton, Needle Mountains, and Ouray folios show the persistent character of this thin and peculiar formation throughout the San Juan region.

The Ouray limestone south of and adjacent to the fault that interrupts the Hermosa section lies below reddish clay, shale, and calcareous beds that are typical of the Molas formation. The full thickness of the Molas formation was not seen, but near the fault there are unusually good though not continuous exposures, making it clear that the formation is at least 100 feet thick. It has the usual character, consisting mainly of red calcareous shale. Much of it is almost a red clay, but where the calcareous element is prominent the mass becomes irregularly

nodular or lumpy. Layers or lenses of mottled limestone are rare. The largest extend several yards laterally. Some layers of calcareous mud are twisted and are held by ordinary shale or clay. Near the top is a calcareous sandstone, apparently quartz-free, 1 to 2 feet thick. The upper 20 feet is not well enough exposed to show the character of the rock.

CARBONIFEROUS AND DEVONIAN SYSTEMS.

OURAY LIMESTONE.

A massive light-gray crystalline limestone about 30 feet thick occurs below the Molas formation in the section on the northeast limb of the anticline below Sand Creek. The upper surface of the limestone contains deep solution crevices filled by the reddish mud of the Molas, a condition common throughout the San Juan region. In the limestone were found cup coral and fragments of crinoid stems such as are common in the Carboniferous part of the Ouray limestones elsewhere. Chert nodules occur in the upper part of the limestone. No Devonian fossils were found, and it may be that no part of the limestone here should be referred to that period.

DEVONIAN SYSTEM (?).

ELBERT FORMATION(?).[1]

Below the Ouray limestone there are several quartzite beds, 4 to 5 feet thick in all, and some reddish or mottled crumbling sandstone. Green or reddish shale occurs below these sandstones but is poorly exposed. No place for a section was found. It is estimated that there are 40 to 50 feet of sandy and shaly beds between the Ouray limestone and pre-Cambrian formations, and the reference of these to the Elbert rather than to the Upper Cambrian (Ignacio quartzite) is based simply on probabilities. The Ignacio is absent on Pine River about 12 to 15 miles west of the Piedra Canyon.

ALGONKIAN SYSTEM.

UNCOMPAHGRE FORMATION.

As shown in the profile section, there are in the Piedra Canyon two distinct exposures of quartzite and schist or shale belonging to the Uncompahgre formation. In the one at and near the mouth of Wiminuche Creek the strata have nearly the same character that they exhibit in the Needle Mountains. The quartzites are dense and hard and are bluish-gray in color. They are in part coarse and in part fine grained. The shales have been somewhat metamorphosed and some beds are schistose through abundant mica, but in many places they are soft and crumbling. Much of the decomposed appearance of these strata is probably due to weathering in a long period of exposure before the decomposition of the earliest Paleozoic sediments.

In the area of these Uncompahgre beds in the Piedra Canyon between Sand Creek and First Fork quartzite, accompanied by pronounced schists, is the principal rock, occurring in a band about 100 feet wide, adjoining the granite body. Brown tourmaline and rudely developed chiastolite or andalusite characterize the schists near the granite and indicate that the granite is intrusive. The Piedra Canyon, cut for a depth of 200 to 300 feet in these beds, is very rugged and has somber gray walls.

The Uncompahgre strata beneath the La Plata sandstone of Plate VIII are locally contorted and crushed. Those of the canyon below Sand Creek strike nearly east and dip 60° or more to the north.

[1] The Elbert formation was first described in 1904 (Cross, Whitman, A new Devonian formation in Colorado: Am. Jour. Sci., 4th ser., vol. 18, p. 245). For further descriptions and map of type locality see U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), p. 5, 1910.