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R. D. GEORGE, State Geologist

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Radium, Uranium, and Vanadium Deposits of Southwestern Colorado

By
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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, November 15, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 16 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

ILLUSTRATIONS

Radium, Uranium, and Vanadium Deposits of Southwestern Colorado

By R. C. Coffin

INTRODUCTION

AREA MAPPED

The area covered by this report includes the exploited carnotite districts of southwestern Colorado, together with certain extended portions of these districts, some of which are believed to be well worth prospecting. This does not mean that this area includes all the ground that should be prospected. The McElmo formation, which carries carnotite, extends into Utah, and for long distances north and east of the districts mapped in Colorado. It is entirely probable that Colorado deposits will be found outside this area.

OBJECTS AND SCOPE OF THE SURVEY

The objects of the survey were: To prepare a general base map of the region; to determine and map the boundaries of the McElmo formation in which all the commercial deposits of carnotite have thus far been found, and to prepare a report on the district to serve as a guide in prospecting and an aid in the development of the mineral resources of the region.

The original plan was to prepare a suitable base map and to show only the boundaries of the McElmo formation. But as the work progressed it soon became apparent that it would be possible to map some of the overlying and underlying formations with very little extra work. Accordingly, the plans were changed to allow the mapping of the "Dakota" and Mancos above, and the La Plata, Dolores, and older formations below the McElmo. This new plan was carried out only in part, for problems appeared with regard to the division of the formations below the La Plata, which could not be settled in the limited time available. It seemed advisable to adopt arbitrarily a boundary which would indicate the upper limit of the carnotite-bearing horizons, and to map some of the formations together. These arbitrary boundaries, with reasons for their adoption, are fully discussed in the chapter on general geology.

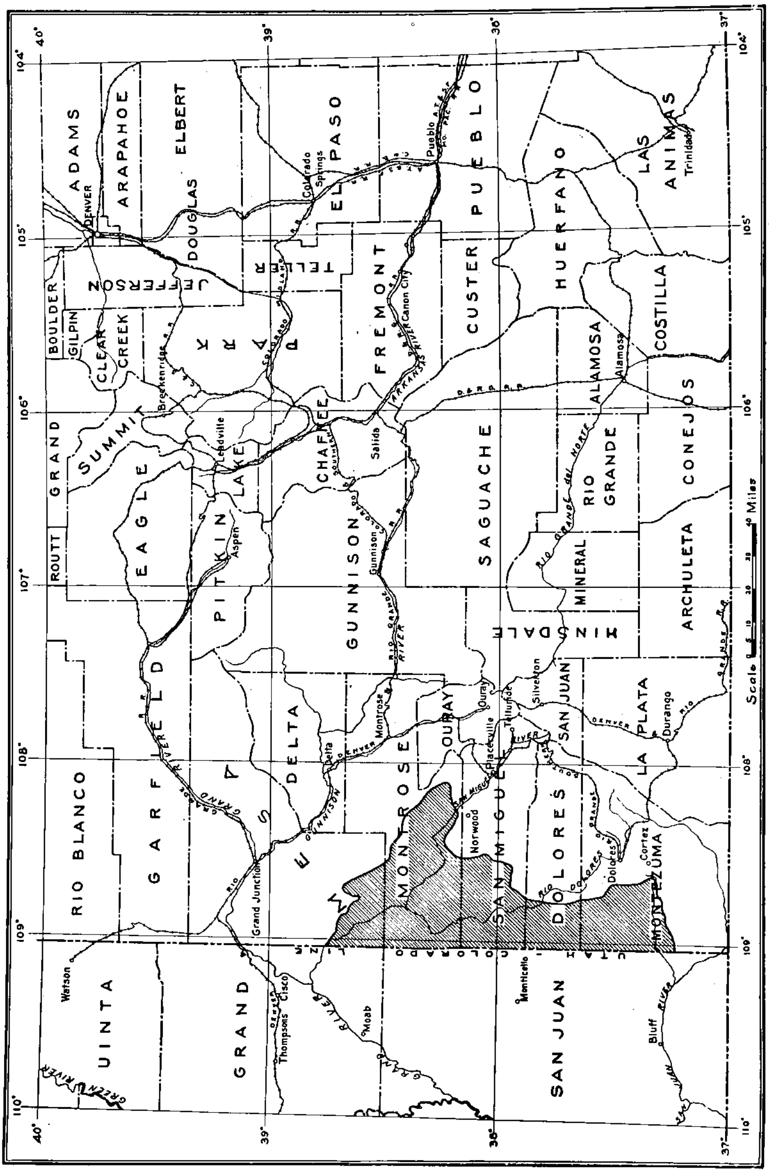


Fig. 1. Index map showing the area discussed in the present report.

METHODS OF MAPPING

A base line about 3 miles long was measured in East Paradox Valley and by triangulation its position was determined with respect to an unnamed secondary triangulation station of the Hayden Survey. This station, which was named by our party Mount Misery, is the highest point on the south side of East Paradox Valley. It is about 3 miles south of the junction of the Paradox and Long Park roads. By means of a three-point method, Mount Misery was tied to Lone Cone in Colorado, to Mount Peale in the La Sal Mountains, and to Abajo Peak in the Blue Mountains of Utah. This base line served, with numerous check sights on the peaks mentioned, to control the northern part of the map and the area as far south as the McIntyre District.

It was impractical to carry the first triangulation beyond the high ground south of Disappointment Valley and a second base line about 4½ miles long was measured north of the Dove Creek post office. The position of this line was determined as before by a three-point method, using Ute Peak with the three already mentioned. A triangulation skeleton was extended from this line to include stations located by the first work. In the same way a third line about 1½ miles in length was laid out along the west side of Hovenweep Canyon and its triangulation system extended to the former systems. A traverse plane-table, with either a Gale or a 10-inch open-sight alidade was used for all triangulation, both primary and secondary.

The four high peaks, Abajo and Peale on the west, Lone Cone on the east, and Ute on the south made very convenient points along the margin of the area examined, and were often used in checking the control. Their geographic and relative positions as determined by the Hayden and other surveys, were accepted and used by the present survey. None of the four peaks was occupied for triangulation purposes.

The main roads, most of the larger streams, and many of the trails were traversed with a plane-table. The same method was applied to prominent ridges and to some minor streams and roads. However, most of the less important features were sketched after critical points had been located by triangulation. The geology was mapped in part by those who used the plane-table for road and stream traverses, but most of this work was done by the more experienced men, who, being supplied with the main triangulation points, used Brunton compasses as a means of location. The mapping was done on a scale of 1 inch to a mile, and, except for two areas showing much detail, was reduced one-half when transferred to the finished map. These two areas are represented by sub-maps on plate I (in pocket).

Much of the region between Disappointment and McElmo creeks is so flat that it was difficult to extend triangulation. Other parts of the area, particularly those near the Dolores and San Miguel rivers are much dissected and offer many obstacles to accurate and rapid mapping. In such places it was often necessary to sketch both the geology and the relief features. Sketching, however, was a last resort and was always controlled by compass sights.

ACCURACY OF THE MAP

The survey of this area of some 2,500 square miles was strictly reconnaissance work. It was made without the assistance of topographic maps and was carried forward rapidly in spite of the numerous obstacles interposed by nature. Obviously, the details shown on the map and presented in the report are governed by the scope and character of the field work. Although it is believed that the major features of the area have been adequately treated, it is acknowledged that the minor details have been omitted or given relatively little attention. To illustrate, the important mining districts are shown on the map, but no attempt was made to locate every prospect hole or mine that ever produced ore. In the first place it would have taken an undue amount of time to hunt out and map all such prospects and mining claims, and in the second place the scale of the map is not such as to allow the details of a thoroughly prospected region to be adequately shown.

The time spent on the present survey extended over a period of such length that in 1918 a re-examination was made of the more intensely mined areas which were covered at the beginning of the work in 1914. In as much as the first work was inadequate to show the present activities in certain mined districts, two areas were remapped showing more detail than was possible by the first surveys.

One of the areas re-examined includes Long Park and vicinity, and lower San Miguel river. In as much as the work of 1914 had already been engraved at the time of the re-examination, the first mapping was not altered to show the changes made by the more recent work. Minor inconsistencies can be found between the large map and the more recent work which appears in a sub-map. The larger map, however, shows correctly the extent of the mining up to 1914. These two representations of the same area serve another purpose; that is to show the progress made from 1914 to 1918.

The area adjacent to the Dolores river below the mouth of Blue Creek was worked hurriedly under a severe handicap of inadequate transportation; the mapping is less detailed than in other areas, and contacts are, for the most part, generalized.

Mining and prospecting in an area adjacent to Maverick and Calamity gulches have been so extensive since the mapping in 1914 that a second sub-map was necessary to show this increased activity. Discrepancies exist between the earlier reconnaissance of this region and the detailed work of 1918. The recent work should, of course, take precedence.

A triangulation party of the U. S. Geological Survey was working in the area during the summer of 1914. This triangulation was preliminary to the topographic mapping of the Naturita quadrangle in progress during the latter part of the present work. The results of the Federal Survey, which covered the most intensely mined area of the region, were not available in time to be of help in the present work. No claim is made that this reconnaissance would equal in accuracy the mapping of such a detailed survey.

Many new roads and trails have been built, and many mines opened between the time of the survey and the publishing of this report. A wagon road has been built from the Joe Dandy camp on the south of Paradox valley and connects with the main road leading from the valley. The recent work in La Sal creek includes the construction of a road from Bedrock, by way of Dolores River and La Sal Creek, to the Cashin mine. Silvey's Pocket, whose outlet was formerly by trail along Dolores River to Bedrock, can now be reached by wagon road through Little Gypsum Valley. And recent settlers in the region north of McElmo Canyon, especially in the vicinity of Dover Creek, have constructed many new roads.

Two camps have been renamed since they were first established. Wilmarth's camp is now Sunny Jim camp, and the site of the National Radium Institute's camp is now occupied by Marvel camp. Numerous other recently added features doubtless exist which do not appear. In judging the completeness of the survey for the cultural features, reference must be made to the index map on Plate I (in pocket), which indicates the areas mapped in the different years.

BOUNDARIES, LAND-LINES, AND STREAMS

Township corners were placed on the map where possible. In some places the corners were located; in others, section lines were used to determine the positions of these boundaries. Results were far from satisfactory, as much of the region has not been sectionized and, in the areas surveyed, few corners could be found. Several townships in the vicinity of Dove Creek were being surveyed at the time of this examination. Later these and other landlines were placed on the map either by direct field observations or from data supplied by the General Land Office. Locations thought to be reasonably correct have been shown.

Only a few monuments were found along the Colorado-Utah boundary, and its position was determined largely by notes of the early surveys. Some inaccuracies doubtless exist in this boundary as represented.

The numerous streams suggest that the area is well watered for at least a part of the year. This impression, unless properly qualified, is misleading. The streams are represented as permanent or intermittent. As most of the intermittent streams carry water less than two months of the year or during infrequent showers, their channels might better be termed dry water courses. The mapping of all stream-courses was desirable, in as much as the topography was not represented, and their positions give the only clew to the location of abrupt changes in the elevation. Only well-defined water courses of one-half mile or more in length are shown.

FIELD WORK AND PERSONNEL OF THE PARTIES

The present survey was conducted under the general direction of R. D. George, who spent about 10 days in the field in 1914, and 3 days in 1916. His field work was largely confined to the economic geology, and was more or less independent of that of the organized parties.

The work was begun June 9, 1914, by two parties, one working south from Paradox Valley, and one working north from this valley. The southern party consisted of R. C. Coffin, in charge, Junius Henderson, R. G. Coffin, N. E. Hinds, and R. L. Heaton. The northern party consisted of P. G. Worcester, in charge, P. B. Whitney, Frank Rohwer and J. A. Pynch. The work of the southern party was continued through September, by R. G. Coffin, assisted by Frank Rohwer and J. A. Pynch. About August 10th, C. E. Smith and Hyrum Schneider replaced P. G. Worcester and J. A. Pynch in the northern party which worked until the last of August.

In 1915 the work in the southern part of the field was completed under the direction of R. C. Coffin, assisted by R. G. Coffin, R. L. Heaton and J. T. Duce. The party worked from June 20th to August 20th.

During the summer of 1916 the work was extended to the top of the Uncompahgre Plateau by a party consisting of R. C. Coffin, assisted by Hyrum Schneider and P. J. McIntyre. P. G. Worcester spent about a month with the party. The field season extended from June 21 to August 22.

R. C. Coffin spent June and July of 1918 examining the more intensely mined areas and remapping two such areas. In 1919 Mr. Coffin made a short trip into the field to determine the extent of operations during that summer.

The index map which is a part of Plate I outlines approximately the areas mapped by different parties.

ACKNOWLEDGMENTS

It is impossible to acknowledge individually all favors received by the different members of the field parties. Anyone familiar with the carnotite country will understand that many parts of the area are sparsely settled and difficult of access. In such places reconnaissance parties were obliged to ask for material assistance of different kinds. To the many people who aided these parties the author is indeed grateful.

Special acknowledgment is made to the superintendents of the operating companies, John I. Mullin, C. P. Willis, C. L. Harrington, and George B. Pickett for a vast amount of information, without which many deductions would have been impossible. The author wishes to thank the different mine foremen who gave much time, often at an inconvenience to themselves, to show members of the survey the mining operations. The author feels he will be pardoned if he does not mention by name all persons who have contributed to this work, whether farmers, miners, prospectors or stockmen. The author is grateful for the help of R. D. George, Director of the Survey, and for the many suggestions of R. D. Crawford and Junius Henderson. To O. C. Lester he is indebted for information on the radioactive materials.

The photographs in this bulletin were taken by R. C. Coffin, Junius Henderson and R. G. Coffin.

CHAPTER I

GEOGRAPHY

By P. G. Worcester

LOCATION

The area described in this report lies east of the La Sal and Blue mountains, south of the Uncompahgre Plateau, west of the San Juan Mountains and north of McElmo Creek. Limiting it more definitely, the area is bounded on the west by the Colorado-Utah line, on the north by a line running from the point where the Dolores River leaves Colorado southwesterly to Blue Creek at the base of the Uncompahgre Plateau, and eastward along this divide to a point some 8 or 10 miles east of Ute. The east boundary is very irregular. Starting on the crest of the Uncompahgre Plateau it extends south to Horsefly Creek, westward to the San Miguel River and southward near Naturita, Cedar, and Lewis to McElmo Creek. McElmo Creek may be considered, somewhat arbitrarily, as the southern boundary of the area.

TOWNS AND ROADS

Five towns, Placerville and Dolores on the Rio Grande Southern, and Whitewater, Delta and Montrose on the Denver and Rio Grande, handle the railroad business of all this region.

Whitewater, 45 miles from Gateway, is the shipping point for the Gateway district and for Sinbad Valley. Delta and Montrose each get a small amount of business from the part of the area which immediately borders the Uncompahgre Plateau, but the roads are poor, grades steep, and the trade is limited. Recently an automobile road has been completed from Nucla by way of Tabequatche Basin to Delta. This route is a direct outlet to a broad-gauge railroad.

Placerville, at the present time, is the most important railroad town. It is on a good automobile road, the "Rainbow Route" to Moab, Utah, which, with its branches, connects all the important mining camps of the central part of the district.

Dolores is far from any known deposits of carnotite, but it is the railroad station sometimes used by the operators in the McIntyre District, and, with Mancos, which is also on the Rio Grande Southern, it shares the trade of the settlements along McElmo

Creek, and the other agricultural and grazing areas south of Disappointment Valley.

Within the boundaries of the area mapped there are two towns, Nucla and Naturita, and four villages, Bedrock, Paradox, Gateway and Dove Creek. All are small but important centers of the mining and agricultural activities. Nucla is somewhat outside the beaten paths to the mining centers and is essentially an agricultural community. Naturita and Bedrock handle most of the mining supplies for the district. Paradox, Dove Creek and Gateway derive their small trade from farming interests.

With the exception of the roads over the Uncompahgre Plateau to Delta, Montrose and Whitewater, the roads of the region are fairly good. The Rainbow road is the best of all. The increasing use of automobiles causes a demand for better roads which can hardly be ignored.

The table of distances given below is probably not entirely correct, but it gives the approximate distances from various railroad towns to local centers and outlying mining districts, and should be of value to anyone interested in the development of the region. Attention is drawn to the fact that some of the places mentioned in the table and others not mentioned, cannot be reached by roads at the present time. In such cases supplies are brought in and ore is taken out on pack animals. All the more important roads and trails within the area mapped are shown with the conventional symbols on the map accompanying this report.

TABLE OF APPROXIMATE DISTANCES

Placerville to Naturita	42 miles
Placerville to Nucla	43 miles
Naturita to Nucla	5 miles
Naturita to Coke Ovens	5 miles
Naturita to Ford Camp	14 miles
Naturita to Long Park	21 miles
Naturita to Bedrock	22 miles
Naturita to Bull Canyon	18 miles
Naturita to Uranium via Mesa Creek	35 miles
Naturita to Uranium via Bedrock	45 miles
Bedrock to Paradox	8 miles
Bedrock to Cashin Mine	8 miles
Bedrock to Silvey's Pocket	12 miles
Whitewater to Gateway	46 miles
Gateway to Sinbad Valley	18 miles
Dolores to McIntyre District	62 miles

RELIEF

Although much of the region is flat, there is a great relief when it is considered as a whole. The lowest places in the area are on McElmo Creek and the Dolores River where they cross the State line. The elevation at both points is slightly less than 5,000 feet. The highest elevations are on the Uncompahgre Plateau, where several points reach 9,500 feet.

Over much of the southern end of the area mapped the country is flat. Many of the canyons are not more than 400 feet deep, and the relief is low compared with that in the central and northern parts of the district, where many canyons are more than 1,000, and some more than 2,000, feet deep.

TOPOGRAPHY

The topography of the region is typical of that of the dissected plateaus of southwestern United States. Although essentially level over great areas, the surface in many places has been thrown into valleys and ridges by synclinal and anticlinal folds. Streams have cut narrow, deep, steep-walled canyons in the massive sandstones; have deepened the synclinal valleys, and have cut great valleys in the crests of the anticlines. Faults, also, have had

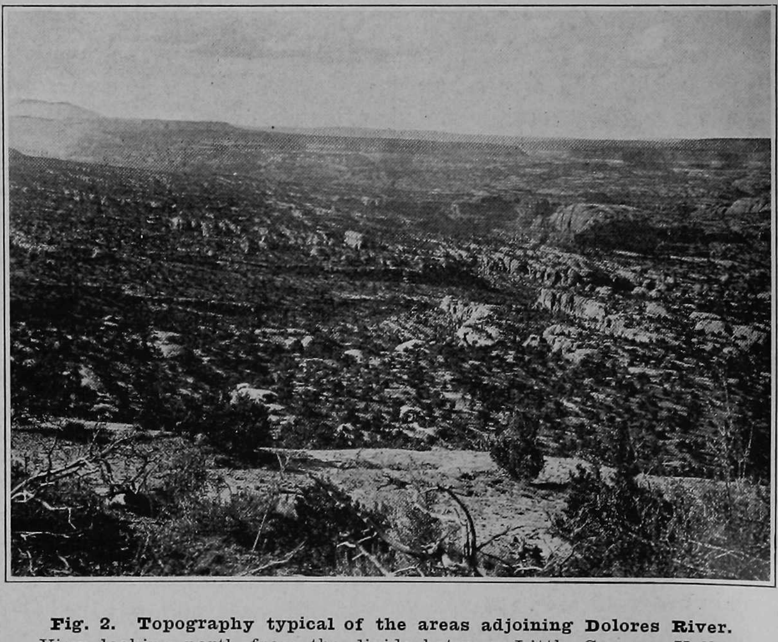


Fig. 2. Topography typical of the areas adjoining Dolores River.
View looking north from the divide between Little Gypsum Valley and Dolores River; the smooth-weathering outcrops are of the Dolores and La Plata sandstones.

a part in modifying the surface of the land. Benches many miles long have been formed on the south side of Paradox Valley by normal faults. Wind has eroded great caves in some of the massive sandstones and has been a minor factor in shaping the topography of the region.

It is difficult to consider in general terms the topography of so large an area. In many respects the northern and the southern portions are unlike. Disappointment Valley may be used as a rough dividing line between these regions of rather unlike topography.

Fig. 3. Topography typical of a portion of the area mapped.
View looking south from the divide between Dolores River and McElmo Creek drainage: Ute Mountains in the distance.

It is necessary to know something of the geology, in order to readily understand the development of the topography. The four formations which have had the most important influence on the topography are the Dolores, La Plata, McElmo, and Post-McElmo. The Dolores consists of 1,000 feet or more of shale and sandstone, with a massive bed near the top. This massive bed, which is evidently the Vermilion Cliff sandstone of Powell[1] is in many places 300 feet thick. In nearly every case where a stream has cut its valley through this horizon it has left a vertical cliff.

The La Plata formation consists of one, and in most places south of Paradox Valley, of two massive, cross-bedded sandstones which are separated by a few feet of shaly sandstone or limestone.

[1] Powell, W., Some remarks on the geologic structure of the district of country lying to the north of the Grand Canyon of the Colorado: Am. Jour. Sci. 3d ser., vol. V, pp. 456-465, 1873.

The thickness of each of these members is 100 to 300 feet. The color of the sandstone is not uniform. In the upper member, particularly, it is variable, and in many local areas, pink, white, or orange colors may be found. Vertical cliffs often occur where streams have cut through this formation which is believed by Cross[2] to be Powell's White Cliff sandstone.

The McElmo formation is from 700 to 1,000 feet thick over most of the area. It contains at least four and in most places five beds of very resistant sandstone, separated by layers of shale or limestone. Many of the beds of resistant rock are 50 or more feet thick. Where this formation has been dissected by streams, cliffs or terraces invariably have been formed.

A thick resistant bed of conglomerate occurs persistently at or near the base of the Post-McElmo formation. The overlying rocks are less resistant sandstones and shales. As in the previous cases, this formation offers opportunities for very unequal erosion.

It is evident that in regions where the streams have cut through the whole section, from the "Dakota" down through the Dolores there may be as many as nine distinct terraces, each limited above and below by vertical or nearly vertical walls. These are the so-called "rim rocks" which, in many places, offer very serious obstacles to the building of roads and trails.

South of Disappointment Creek the chief characteristics of the topography are great flat plains, cut by many narrow, steep-sided valleys.

In the central and northern parts of this area the surface is much rougher, the relief as a whole is greater and the country is much more dissected. The roughest topography of the district is in a belt 8 or 9 miles wide along Dolores River between the mouth of Disappointment Creek and Gateway.

The country around Big and Little Gypsum valleys, Silvey's Pocket, La Sal Creek, Sinbad Valley, Mesa Creek, etc., is very rough and inaccessible. The canyons are deep and steep walled and separated from neighboring valleys by flat-topped divides.

East Paradox and West Paradox valleys have been carved by streams out of a great anticline. Several faults parallel with and near the crest of the fold aided the work of erosion. The sides of the valley are steep, in many places vertical, and near Dolores River are almost 2,000 feet in height. The valley bottoms are 3 or 4 miles across and slope gently toward Dolores River. The whole structure is, in a way, paradoxical, for Dolores River flows across

[2] Cross, Whitman, Stratigraphic results of a reconnaissance in Western Colorado and Eastern Utah; Jour. Geol., vol. 15, pp. 634-679, 1907.

the axis of the fold. It is a good example of an antecedent stream whose direction was not changed by the uplift.

Sinbad Valley is another notable example of an anticlinal valley. The fold here is almost quaquaversal and has been eroded so that a rim is left, which rises abruptly from nearly all directions and surrounds a deep interior valley 5 miles long and 3 miles broad drained by a single creek, Salt Wash.

In contrast to the anticlinal valleys are the lower courses of the Dolores and San Miguel rivers, which are in gentle synclines.

In the extreme northern part of the area the Uncompahgre Plateau dominates the topography of the region. At the top the elevation is between 8,000 and 10,000 feet over most of the plateau. This is nearly a mile higher than the foot of the main uplift. The top of the plateau is broad and in many places nearly flat. The rainfall is heavy and many strong streams derive their waters from this source of supply. Because of their high gradient and large volume of water the streams are powerful eroding agents and have cut deep canyons into the sides of the plateau.

On the west side of Dolores River, between La Sal Creek and Gateway, the topography is controlled by the La Sal Mountains. Within the limits of the area mapped the ground rises to an elevation of nearly 8,000 feet. The land surface is rough, due to folding and erosion, and the canyons are deep and narrow.

Considered as a whole, the topography of the main carnotite region of Colorado is youthful.

DRAINAGE

Three streams, the Dolores and San Miguel rivers, and McElmo Creek, with their many tributaries, drain the whole area. However, this number may be reduced to two, for San Miguel River empties into the Dolores, well within the area mapped.

When the aridity of the climate is considered alone, it seems rather remarkable that there should be so many large streams, but their presence is accounted for when one remembers that most of the westward flowing streams have their source of supply in or on the flanks of the San Juan Mountains. Aside from the McElmo Creek drainage, those streams which flow to the south head on the Uncompahgre Plateau, while the eastward flowing streams come mainly from the La Sal and Blue mountains. This statement refers to the main drainage. There are, of course, many small streams which are fed by springs, or flow intermittently, depending on the seasonal precipitation for their source of water supply. There are many arroyas which are entirely dry, except during a heavy rainfall, when, if the bottoms are narrow, the drainage slopes bare and steep, and the gradients high, they flood very quickly.

Stream erosion has been an important factor in exposing the McElmo formation, and, with few exceptions, all of the carnotite claims and mines are located along the sides of valleys. The volume of water in the streams which flow from the La Sal Mountains and the Uncompahgre Plateau is considerable. In the past, West Paradox Creek has furnished a large amount of water for irrigation along its valley. Recently its flow has been rendered more uniform through the construction of the Buckeye reservoir. Unfortunately, there are only small tracts of land suitable for irrigation and agriculture below the streams which are large enough to water extensive areas. As a consequence, large irrigation projects, based on a local supply of water are not likely to meet with success.

Many schemes have been proposed to irrigate East Paradox Valley and equally desirable tracts of land in other parts of the district. In considering such proposals it should be remembered that the rocks in which the canals and ditches would be built are porous and the ground water table is low. Evaporation is rapid and becomes a serious factor when the long distances through which the water would have to come are considered. The cost of initial construction and the high cost of ditch maintenance, because of silting, breaks, etc., are other extremely unfavorable factors which should be carefully considered before any irrigation scheme is adopted. There is, undoubtedly, a great deal of land in the area covered by this report which would be immensely productive if it could be watered. However, the high cost and the uncertainty connected with such enterprises will probably limit their promotion.

In many places, particularly along the Dolores and San Miguel rivers and the La Sal, Blue, and Mesa creeks, there is plenty of water for reasonably extensive mining and milling operations. Unfortunately, this condition does not prevail in most places, and the scarcity of water is a serious handicap to the development of mining in the region as a whole.

LAKES AND RESERVOIRS

There are no natural lakes in the area, but in favorable situations, reservoirs for irrigating purposes have been built. The Buckeye reservoir on the side of the La Sal Mountains, and several small lakes used to supply water for stock, constitute the only bodies of water in the area.

CLIMATE

Accurate records of precipitation, sunshine, winds, temperature, etc., are not available. As has already been indicated, the rainfall is considerable on the slopes of the La Sal Mountains and the Uncompahgre Plateau. In the winter the snow fall is very heavy in the same regions. Over the less elevated areas the precipitation is undoubtedly below 15 inches a year, and in the south between Disappointment and McElmo creeks, it probably does not average more than 10 inches. The summers are very hot and dry.

In the winter there is likely to be several inches of snow over most of the area, and the temperature stands well below the freezing point for days at a time. On the whole the climate is typical of that of the plateau region of semi-arid southwestern Colorado and southeastern Utah.

SOILS

There are as many residual soils in the area as there are formations, but only those from the La Plata, "Dakota," and Dolores rocks are fertile. The McElmo soils, and those made up in considerable part of gypsum are nonproductive.

Wind-blown dust, in many places several inches thick, is widely distributed over the lower parts of the area. This, and the alluvial soils which more or less completely cover many of the larger valley floors, and occur in narrow strips along some of the larger streams, are fertile. They are capable of great productivity where irrigation is practical.

VEGETATION

Sage brush, salt weed, cactus, and cedar are abundant over all except the highest portions of the area. Pinon pine grows in the middle and low altitudes. Willow and cottonwood, and other trees and shrub which demand considerable water, are found sparingly in some of the larger valleys. In the highlands, small scrub-oak, pine, and aspen are the important varieties of trees. On the Uncompahgre Plateau and in the regions around the Buckeye reservoir are valuable forests of pine, but near the carnotite areas there is little or no timber.

Native grasses, important in the grazing industry, flourish in the highlands. In the lowlands, however, there is too little grass to warrant the introduction of grazing projects on a very large scale. In the irrigated areas almost all of Colorado's fruits, vegetables, grains and grasses can be grown successfully. Corn, wheat, alfalfa, melons, grapes, and peaches are representative crops, and their production is limited only by the amount of irrigated land and the available market.

INDUSTRIES

Grazing, mining, agriculture, and lumbering are the only industries of any importance in this area. There are several large cattle companies operating in the district. The stock runs in the highlands most of the summer, and in the lowlands during the winter; a limited number of cattle can, of course, run on the lower range the year round.

The ore production of the district has fluctuated with the changing market conditions and with the interest shown in the development of the mines. The output of carnotite, which reached a maximum in 1913 and 1914, declined rapidly as soon as the European war began, and is now (1920) becoming stabilized. A few years ago there was a large production of copper from the Cashin mine on La Sal Creek, but the mine was closed in 1906 and has only recently been reopened. Other copper and silver mines have produced considerable ore, but their production has been very irregular.

Agriculture is especially important in West Paradox Valley, in portions of McElmo, Dolores, and San Miguel valleys, on the plateaus near Nucla, and west and south of the town of Dolores. Isolated farms, like the Blue Creek ranch, those in Sinbad Valley, and along La Sal Creek, Roc Creek, Cross Canyon, etc., are of local importance, but on account of their isolation they do not figure prominently in the development of the region as a whole.

Lumbering is important only in the pines near the Buckeye reservoir, and on the Uncompahgre Plateau, where there are several sawmills. At best, the industry is small.

Salt is made from the waters of a well which is situated near the north wall of East Paradox Valley, just east of the Dolores River. No attempt has been made to develop the industry in a large way, but the salt produced is of good quality for stock, and the possibilities of increasing the output of this well and of locating new wells are good. Grazing is extensive enough now to warrant giving more attention to the salt industry, which would mean much to the Paradox cattlemen, who now have to haul salt 65 miles from the railroad.

There is an opportunity for the development of considerable mining in this region. It is probable, however, that the other industries mentioned, while important, are not capable of large increase because of the limitations set by the natural geographic conditions already mentioned. As has already been indicated, more extensive irrigation systems would do much to increase the prosperity of the country, and in so far as successful systems can be developed the country so improved should advance rapidly.

Generalized Section of ***Rocks*** *in the Main Carnotite Area of Southwestern Colorado*

System	Formation	Thickness in feet	Character	Remarks
Cretaceous	Mesaverde	Not measured	Sandstone and shale	Forms high bluffs southeast of Dry Creek Basin.
Cretaceous	Mancos	1,500 ±	Shale and limestone	Occurs in Dry Creek Basin and Disappointment Valley.
Cretaceous	"Dakota"	100-200 ±	Sandstone, conglomerate, and shale; coal locally.	The two units together form the cap-rock to numerous mesas.
Cretaceous	Post-McElmo	100-200 ±	Conglomerate, sandstone, shale, and chert	The two units together form the cap-rock to numerous mesas.
Cretaceous or Jurassic	McElmo Morrison	450-980	Sandstone and shale	Carnotite-bearing.
Jurassic	La Plata Entrada	0-450	Massive sandstone	Crops out as smooth rounded cliffs.
Permo-Triassic	Dolores and Cutler	0-2,000 ±	Sandstone and shale	Comprises the bulk of the red strata of the area.
Carboniferous	In part Hermosa	Unknown	Limestone, gypsum, and shale	Occurs in Sinbad, Paradox, and Gypsum valleys.
Pre-Cambrian		Unknown	Granite, gneiss, and schist	Occurs at base of Uncompahgre Plateau.

CHAPTER II

GENERAL GEOLOGY

GENERAL RELATIONS

The "Plateau province" of many writers includes a considerable area adjacent to the Colorado and Grand rivers. This physiographic division comprises parts of southern Utah, northern Arizona, northwestern New Mexico, and a strip of western Colorado. The area concerned in this report lies within the Colorado portion of this Plateau province.

The geology in this area is that common to the plateau country to the west, being a series of more or less horizontal beds that extend over large areas. The exposed sedimentary rocks range in age from Pennsylvanian Carboniferous to late Cretaceous. Erosional unconformities have interrupted this sequence from time to time and the entire series is not complete. Especially is this true of strata older than Jurassic. Probably the entire series of Upper Cretaceous sediments once covered the area, but only detached remnants of Mancos shale remain to tell the story of the removal of thousands of feet of material belonging to this unit. Quaternary deposits of sand and gravel fringe some of the streams, and parts of mesas are covered with a veneer of coarse gravel and boulders.

One part of the area is occupied by granite, in which are included small areas of metamorphic rocks. Both types are considered pre-Cambrian. Two regions show intruded rock assigned tentatively to the Tertiary system.

The different resistance to weathering offered by the several formations gives to each a topographic expression of its own. These topographic forms linked with the characteristic color possessed by each formation make the larger geologic divisions easily followed. Although the geology is rather simple and easily interpreted, four general regions of folding and faulting bring the usually horizontal beds into abnormal relationships and produce some structural obscurity.

Sedimentary rocks cover more than 98 per cent of the area mapped. The predominant rock of this group is sandstone. Shales rank next in abundance, and, although conglomerates are more conspicuous and more abundant in outcrop, they make up a smaller fraction of the total sedimentation. Calcareous layers are present, but true limestones are not common. All gradations of rock, from conglomerates which carry boulders one foot in diameter to fine, even-grained sandstones, and from sandstones to shales of different degrees of purity are present in the area. Pure clay shales are not abundant.

The igneous rocks include types of granite and gneiss in the northern part; intrusions of breccia and diorite porphyry in the central, and bodies of andesite porphyry in the southern part.

The area covered by this survey is intermediate in position between the Grand Canyon country to the west and the San Juan Mountains to the east. Its closeness to the latter, with their more carefully studied areas, makes it advisable to retain the names of formations used by Whitman Cross in the quadrangle maps of that district. With certain qualifications this has been done.

PREVIOUS GEOLOGIC WORK

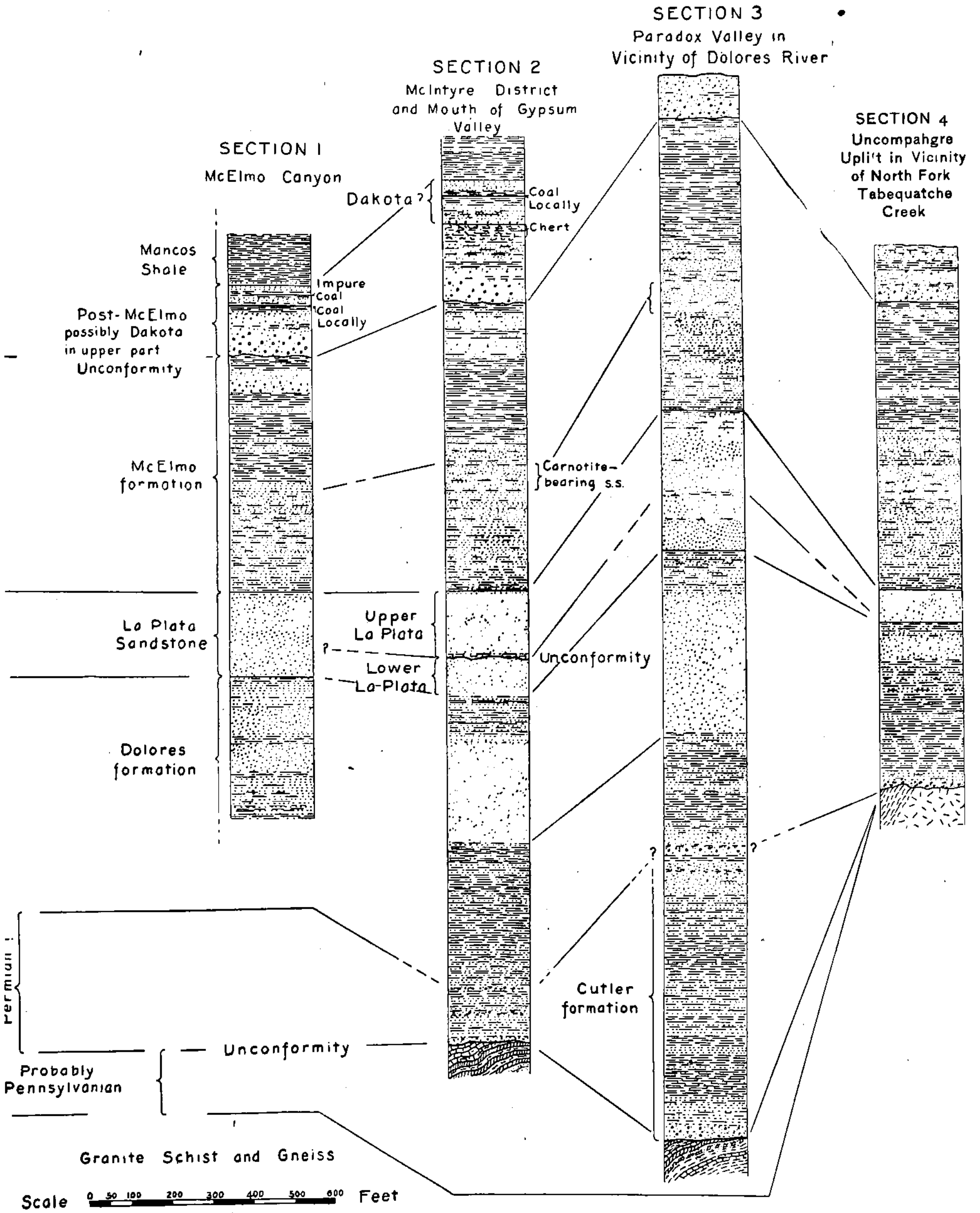
The geologic literature of the Plateau province dates from 1853, when Lieut. A. W. Whipple's expedition passed south of the area covered by this report. Jules Marcon[3] was geologist for this party, whose route was approximately that of the present Santa Fe Railroad. Among other geologists who visited the plateau country previous to 1875 are J. S. Newberry, A. R. Marvine, and E. E. Howell. Their work has little bearing on the present area.

Little has been written dealing directly with the geology of the eastern edge of the Plateau province. Although the geologic and physiographic features of this area are similar to those of the country west and south, the early work has been more generally confined to the Grand Canyon sections, with their larger geologic features and greater thicknesses of exposed sedimentary rocks. Below are given brief outlines of the areas visited by the first geological expeditions that touched the area mapped by the present survey.

During the work of the Hayden Survey in 1875, Peale[4] traversed the Uncompahgre Plateau and the country drained by lower San Miguel River. In the same report Holmes discusses briefly that portion of the area traversed by McElmo Creek and the Dolores River.

In 1876 Peale[5] added to the work of the previous year when he extended his observations south to the high ground beyond Disap-

[3] Marcon, Jules, Reports of explorations and surveys for R. R. routes from the Mississippi to the Pacific Ocean, Vol. 3, Part 7.
[4] Peale, A. C., Ninth Ann. Rept. U. S. Geol. and Geog. Survey of the Territories, pp. 95-98 and 262-269, 1875.
[5] Peale, A. C., Tenth Ann. Rept. U. S. Geol. and Geog. Survey of the Territories, pp. 163-69, 1876.



Vertical section of strata exposed in different parts of the carnotite district.

pointment Valley which marks a part of the northern and eastern limits of the Great Sage Plain. In the same year Holmes[6] again visited the area. This route lay across the headwaters of Yellow Jacket and Montezuma creeks, thence west to the Sierro Abajo, now called the Blue Mountains, in Utah. He returned, crossing the Great Sage Plain in the direction of Lone Cone. His observations appear in the reports of the Hayden Survey.

In connection with the work of Whitman Cross[7] in the San Juan Mountains in 1897, H. S. Gane traversed McElmo Canyon from its head to the San Juan River. In 1899 A. C. Spencer, who assisted Cross in the San Juan work, made a reconnaissance trip to Paradox and Sinbad valleys. A general statement of his observations has been published. The most complete work of the correlation of the sediments of this area with those of the neighboring districts was that carried out by Cross[8] and party in 1905.

Of their route he writes as follows:

"The party proceeded west from Mancos to Cortez, in the Montezuma Valley; thence northwesterly across the head waters 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. 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 twenty miles, and then turned east, passing over the northern slopes of the La Sal Mountains, and thence south through Sinbad and 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. 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."

The work of these first writers is often referred to in this paper. From time to time other articles and reports have been published dealing primarily with the carnotite deposits, or other economic material found in the area. Some of these have discussed more or less the geology of the particular areas considered. Chief among

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[6] Holmes, William H., Ninth Ann. Rept. U. S. Geol. and Geog. Survey of the Territories, pp. 262-265, 1875.

[7] Cross, Whitman and Howe, Ernest, Red Beds of southwestern Colo. and their correlation: Bull. Geol. Soc. of America, vol. 16, pp. 447-497, 1905.

[8] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. of Geol. vol. 15, pp. 634-635, No. 7, Oct.-Nov., 1907.

these are the reports by R. B. Moore[9], K. L. Kithil[11] and associates[10]. These men and others have done much work on the technology of carnotite and related minerals. The literature bearing on this area is listed in the bibliography at the end of this report.

This survey had the use of an unpublished map of McElmo Canyon and adjoining territory made by Max A. Pischel.

Mention has been made of the topographic survey of the Naturita quadrangle which was being made by the U. S. Geological Survey during 1914-15-16.

PRE-CAMBRIAN ROCKS

GRANITES AND GNEISSES

DISTRIBUTION

An abrupt change in elevation of 1,000 to 3,000 feet takes place along the southwest side of the Uncompahgre Plateau within a horizontal distance of 2 to 5 miles. The strip within which this sudden change of elevation occurs and the area affected by the resultant bending of the strata are here referred to as the Uncompahgre uplift.

The exposures of pre-Cambrian rocks are limited to the immediate vicinity of this flexure. Across this uplift many streams have cut their canyons through the sedimentary formations to the underlying granites and associated rocks.

To the east along this edge of the Plateau, Big Red Canyon exposes a small area of granite. A similar cutting has taken place in the canyon of the North Fork of the Tabequatche Creek, where a fault aids erosion. Within 2 miles west of this point a strip of granite and gneiss one-fourth of a mile to a mile wide extends northwest to the head of Atkinson Creek, where the sediments extend over the uplift. Mesa Creek, Blue Creek with its tributaries, and branches of Calamity Gulch expose these rocks in long strips, one of which is, in places, a mile wide. From the most northerly exposure mapped, a more or less continuous strip of granite extends to Unaweep Canyon, where these rocks are exposed along both sides of West Creek and East Creek across the width of the Plateau.

The reference of these rocks to the pre-Cambrian presupposes that they are only a part of an immense body of unknown thickness which is the foundation upon which all sedimentary rocks of the area were deposited, and through which the bodies of later intrusives found their way.

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[9] Moore, Richard B. and Kithil, Karl L., A preliminary report on uranium, radium and vanadium: U. S. Bur. of Mines Bull. 70, 1914.

[10] Parsons, Chas. L. and others, Extraction and recovery of radium, uranium and vanadium from carnotite: U. S. Bur. of Mines Bull. 104, 1916.

[11] Kithil, Karl L. and Davis, John A., Mining and concentration of carnotite ores: U. S. Bur. of Mines Bull. 103, 1917.

PHYSIOGRAPHIC FORMS

These outcrops of granite and gneiss form a more or less continuous strip running north to northwest, increasing in width westward along the edge of the Plateau. This central strip is limited above by 1,000 feet of generally horizontal beds of sandstone and shale. Below, the sediments turned up at different angles, rest upon and against this granite mass.

The erosional features of the granite and gneiss contrast with the monotonous duplication of forms of the bedded rocks above. Erosion has carved from these older rocks rounded hills and knolls that project from the side of the Plateau. Irregularly shaped benches, pinnacles, castles, and spires all speak of the great difference in the character of the materials making up this unit. Tongues of granite and gneiss extend back from the main body into the canyon bottoms from the edge of the Plateau. In such places the exposures take the form of two inner benches which limit the stream courses to narrow gorges.

TYPES

It is not practical in this reconnaissance to discuss separately the different types of rock found in this complex. Most of the material has been metamorphosed, and one kind of rock grades into another without definite contact. Granites with no directional structure grade into those with a distinct lamination which is probably the result of shearing and mashing. Gneisses and gneissoid granites are numerous. Irregular masses of gneisses and schists containing considerable mica and hornblende are often cut by fine- and coarse-grained granites. Pegmatite dikes from a few inches to several feet wide appear to be the youngest rocks in this complex. The most common types of these rocks are described further.

Biotite granite.—This rock, with its different phases, is the most common. In the coarsest varieties red to pink orthoclase phenocrysts reach 1¼ inches in length, and one-half inch in width. These phenocrysts are imbedded in a matrix of grains of quartz and biotite one-tenth of an inch or less in diameter. The rock is commonly a porphyritic granite in which pink feldspar predominates. This rock was not examined microscopically.

Gneisses.—The group includes two general types that possibly have an entirely different origin. A granite gneiss with predominant feldspar or quartz, carrying both biotite and muscovite, makes no distinct contact with the granite described above, and is probably a result of the metamorphism of this rock.

Another type of gneiss contains a high proportion of biotite and hornblende. This rock grades into a schist in which the darker minerals are in excess of the quartz and feldspar. The average hand specimen contains quartz in excess of feldspar and contains hornblende and biotite up to one-third of the material in the rock. Individual seams of light or dark minerals are often three-fourths of an inch thick, but the average is less than one-fifth of an inch thick.

In the finer grained gneisses of the composition of the rocks just described, the quartz and feldspar appear as flattened grains. These rocks are dark colored and locally grade into schists. The exposures at the head of Atkinson Creek show many of these finer grained rocks which have been crumpled and folded. Another phase of this group is a hornblende gneiss which carries a minor quantity of feldspar and quartz, and occasionally a little biotite. These darker gneisses in many places occur in sharp contact with the granites which cut them into irregular masses. The relation of these hornblende gneisses to the other rocks and their extreme folding suggest that they are the oldest rocks of the region.

Other types.—Float was found of a basic rock that resembled hornblendite, but its parent ledge was not located. The pegmatite dikes already noted were not studied to determine their mineral content.

AGE

Direct field evidence proved only that these rocks were pre-Permian. Their attitude, general character, extreme range in composition, and evidences of metamorphism leave little doubt that they are a part of the pre-Cambrian complex as known elsewhere in this part of Colorado. Cross[12] examined similar rocks in Unaweep Canyon and states: "There is every reason to suppose that the rocks in question do belong to the pre-Cambrian complex. * * * * There are many gneisses and schists, the origin of which is not wholly evident." Of these he states as follows: "But there are many very dark hornblendic schists and others containing both hornblende and biotite. These gneisses and schists are probably the oldest rocks of the district and are naturally referable to the Archean."

[12] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. of Geol., vol. 15, No. 7, p. 676, 1907.

CARBONIFEROUS FORMATIONS

PENNSYLVANIAN DIVISION

(HERMOSA IN PART)

DEFINITION

Erosion has cut through the "Red Beds" in three valleys and has exposed an intensely folded and faulted series of rocks which has been mapped "Carboniferous." Fossils found in these rocks place definitely a part of this unit in the Pennsylvanian division of this unit. Equivalents of the Hermosa formation of the San Juan Mountains exist in a few places. Stratigraphic position and character of individual beds are other criteria used to determine the age of these beds.

Beds referred to this unit include all exposed sedimentary rocks stratigraphically below the red shales and sandstones, which are considered Permian(?) and correlated with the Cutler of the San Juan Mountains. Their upper boundary is not everywhere limited by these shales and sandstones, as uncomformities, in one area at least, have thrown all formations below the Post-McElmo, successively in contact with Carboniferous beds.

Although gypsum is not the most abundant it is the characteristic material of the unit. The term gypsum series, as herein used, includes all strata mapped under this division. Limestone, shale, and sandstone, with gypsum, make up the beds of this unit.

DISTRIBUTION

Carboniferous beds with alluvium form the floors of Sinbad, Paradox, and Gypsum valleys. The ease with which these beds are removed and their location in deep, steep-walled valleys, have made it possible for slope wash to cover most of the contacts. The cutting in Paradox and Gypsum valleys has exposed only the top of the series. These limited exposures and observations confined to only a fraction of the upper beds of this series have made the understanding of all relationships impossible.

The thickness of the series is unknown, though the maximum thickness exposed occurs in Sinbad Valley where P. G. Worcester estimated 800 to 1,000 feet of sediment below that part of the section correlated with the Cutler formation. In East Paradox and West Paradox valleys, exposures are badly covered with alluvium and slope wash through which detached areas of gypsum and associated limestone are exposed for the length of the valleys. The largest single area of the gypsum series occurs at the head of Gypsum Valley. This area connects with one in the region known as Klondyke, whose drainage is through Disappointment Creek.

The absence of Pennsylvanian strata adjacent to the granite mass of the Uncompahgre Plateau is explained by an overlap of younger sediments. This point is considered under Permo-Triassic formations.

HISTORIC SKETCH

The Upper Carboniferous, as mapped by Peale in the Geologic Atlas of the Hayden Survey does not include the same beds in the three regions in which the gypsum series is exposed. In most places the Upper Carboniferous of the Hayden Survey includes areas here referred to as Permian(?). Along Dolores River below Paradox Valley a strip of "Upper Carboniferous" occupies the stratigraphic position of beds here correlated with the Cutler. The mapping of this same unit in Paradox Valley has included areas of gypsum, and the area mapped northwest of the mouth of Gypsum Valley includes rocks younger than the gypsum beds. The presence of gypsum in the upper part of Gypsum Valley was noted by Peale[11], but this area and the adjacent fossil-bearing beds of Klondyke and vicinity were mapped as Jurassic or younger. Peale[12] considered the gypsum beds Permian or Permo-Carboniferous.

The area of "Middle Carboniferous" of the Hayden Survey includes in places the Pennsylvanian of the present report. It appears that the intention was to include in the "Upper Carboniferous" the Cutler of the present report and a part of the formation immediately below.

The fossiliferous beds in Sinbad Valley were visited by A. C. Spencer during a reconnaissance made in connection with Cross' work in the San Juan Mountains. As a result of Spencer's observations in this valley, Cross[13] wrote the following:

"Below the Dolores beds, Spencer found coarser Red beds, often conglomeratic with pebbles 3 inches or more in diameter, and several hundred feet of such strata were noted. No opportunity was found to measure a section showing the full thickness of these coarser Red beds, but, as observed by Peale, they are underlain by fossiliferous Pennsylvanian Carboniferous in Sinbad Valley, where there is also much structural complexity obscuring the relations."

The gypsum beds of this area were not mentioned. During a reconnaissance by Cross[14] and party in 1904, fossils were collected from Sinbad Valley, and a detailed study made of the section on West Creek. In discussing this section he says:

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[11] Peale, A. C., Tenth Annual Report of the U. S. Geol. and Geog. Survey, p. 167, 1876.

[12] Peale, A. C., Ninth Annual Report of the U. S. Geol. and Geog. Survey, p. 74, 1875.

[13] Cross, Whitman, Red beds of southwestern Colo. and their correlations: Bull. Geol. Soc. of America, vol. 16, p. 473, 1905.

[14] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. of Geol., vol. 15, No. 7, p. 666, Oct.-Nov., 1907.

"Below the measured section (referred to the Permian) 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 Sinbad 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 gypsiferous beds were not assigned definitely to any age, but were recorded as being older than the reddish grits and shales that came below the Dolores (Triassic) and which has been included in the Permian(?). The beds below those considered Permian(?) were not discussed in detail.

DESCRIPTION

The prevailing light colors of the gypsum beds, with their associated limestones and shales, make a sharp color contrast with the overlying strata. The white to gray valley floor fringed with the intense red of the Dolores and Cutler beds makes a color scheme that is certainly unique.

Gypsum masses form low-rounded hills, fringed and covered with a highly gypsiferous soil. Wherever exposed, the gypsum shows evidence of the solvent action of ground waters. A pitted pulverulent residue that surfaces the solid gypsum contains in places cavities several inches in diameter. To the tramp of a horse these exposures give a distinctly cavernous sound. The fact that beds of soluble gypsum outcrop over such large areas is in part due to the aridity of the climate in which they exist.

Gypsum is found in quantities from tiny seams less than one-half inch thick to beds of uncertain dimensions which probably reach a thickness of 50 to 75 feet. The highly gypsiferous beds are often so badly broken and folded as to lose their identity as beds and become irregular blocks or masses. Granular masses which show no evidence of bedding are often mixed with those that are distinctly foliated. Both light and dark gray varieties make up the massive beds of gypsum, and selenite is abundant in the thinner beds and in the shales of this formation.

The limestones differ considerably in purity; those associated with the gypsum are dark gray to blue black in color and, although they give evidence of having been much broken and mashed, they are very dense and universally bituminous. No fossils were found in these limestones. The less pure varieties are not generally associated with the gypsum, but are commonly granular and grade into shales and sandstones that are more or less calcareous. The sandy varieties carry the fossils found in these beds.

The shales range in color from maroon to green to black; all are more or less arenaceous. The green shales grade into sandstones and the darker colors are closely associated with the gypsum. Black paper shale often underlies the gypsum which has been more or less infiltered into them.

Brown, massive, even-grained sandstones in beds from 1 to 3 feet thick make up a small fraction of the exposures. These beds are separated by seams of arenaceous shale. More detailed descriptions are better applied to individual areas.

Occurrence in Gypsum Valley.—The gypsum series was studied more carefully in Gypsum Valley than elsewhere, and is described in greater detail. Most of the exposures include beds of gypsum and limestone intimately mixed, and gypsiferous shales as intricately folded and faulted masses are common. Complex minor folds and faults are common within the gypsum areas. These folds and faults are due in part to the formation of solution cavities which eventually collapse and necessitate readjustments of the strata involved.

On the north side of the valley, 8 miles from the mouth, a series of beds tilted at angles from 45° to those that are slightly overturned, include sandstones and impure limestones that carry fossils. Professor Henderson collected and identified the following Hermosan fossils from these outcrops.

Hermosan Carboniferous fossils from Gypsum Valley

Edmondia gibbosa (Geinitz)
Myalina subquadrata Shumard?
Aviculopecten sp.
Derbya crassa (M. & H.)
Composita subtilita (Hall)
Productus nebraskensis Owen

These fossiliferous beds do not include gypsiferous material, but occupy a stratigraphic position which is probably above the massive gypsum beds at the head of the valley. Two exposures of gypsum in upper Gypsum Valley include such minor quantities of other material that they have been outlined separately. In these compact granular masses rock gypsum is present which shows signs of bedding in only a few places. Epsomite (magnesium sulphate) in hair-like crystals and black carbonaceous matter resembling impure coal are associated with a few of the beds. Badly brecciated limestone is generally present along the margins of the large areas of gypsum, and occupies a position stratigraphically above this material. No strata below the gypsum are exposed, nor can a prevailing dip be assigned to these beds.

Outcrops of Carboniferous beds extend from the gypsum areas referred to above into Klondyke, where several hundred feet of Carboniferous beds are well exposed. These beds dip away from the gypsum masses and are separted from them by a fault and a

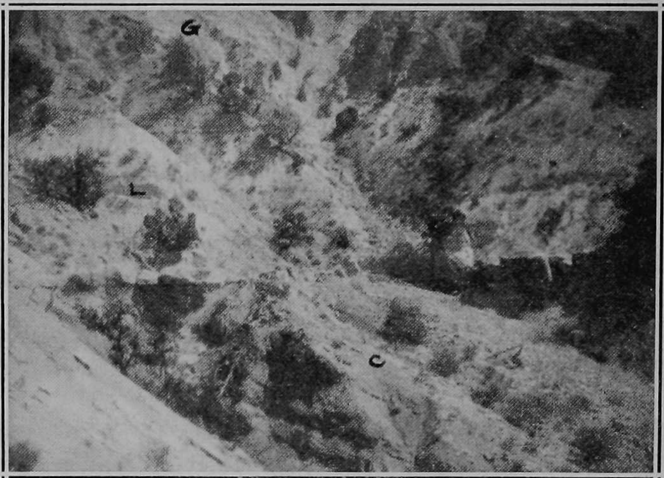

Fig. 4. Angular unconformity in Klondyke between Hermosa (Carboniferous) and La Plata (Jurassic) formations.
C, Hermosa; L, La Plata; G, post-Mancos gravels.

sharp fold. Although there is some doubt as to the relative stratigraphic position of the beds in the two areas, the Klondyke beds are probably younger than the masses of gypsum in Gypsum Valley. From the beds in Klondyke, Prof. Henderson collected and identified the following Hermosan fossils.

Hermosan Carboniferous fossils from Klondyke

Fenestella? sp.
Rhombopora lepidodendroides (Meek)?
Prismopora triangulata (White?)
Zaphrentis? sp.
Crinoid stems
Lingula sp.
Derbya crassa (M. & H.)
Composita subtilita (Hall)
Reticularia perplexa (McCh.)
Chonetes mesolobus (N. & P.)
Spirifer cameratus (Morton)
Spirifer boonensis (Swallow?)
Spirifer rockymontanus (Marcou?)

Productus cora (Orb)
Productus punctatus Martin?
Productus semireticulatus hermosanus Girty
Nucula ventricosa Hall
Aviculopecten providensis (Cox)
Aviculopecten sp.
Myalina perattenuata (M. & H.)
Myalina subquadrata Shumard
Schizodus? sp.
Allerisma terminale Hall
Edmondia gibbosa (Geinitz)
Acanthopecten carbonarius (Stevens)
Conularia sp.
Euphemus nodocarinatus (Hall)
Bellerophon sp.

The youngest Carboniferous beds exposed in Klondyke are calcareous shales and sandstones which lie against and stratigraphically above the fossiliferous beds. These sandstones, which are generally brown, are interbedded with maroon or red shales. Near the bottom of this fossiliferous series gray to green shales are interbedded with shaly sandstones which include several ripple-marked beds, and the top of the series includes red sandstones and shales. Aside from the limestones the materials are all poorly cemented and crumble readily.

Occurrence in Paradox Valley.—Mr. Worcester gives the following sequence of strata in East Paradox Valley near the Dolores River:

Section of Carboniferous strata in Paradox Valley

Top	
1. Gypsum, shale and limestone all folded together	thickness unknown
2. Gray shale	" "
3. Gray limestone	" "
4. Black paper shale	" "
Total thickness probably less than 200 feet.	

There is evidence that a sandstone, and at least one limestone, exist above the gypsum in this valley, but have been removed or are covered at the point of the above section. Nothing which would correspond to the fossiliferous beds of Gypsum Valley was observed.

Occurrence in Sinbad Valley.—C. E. Smith, of this Survey, describes the floor of Sinbad Valley as covered with low, weathered, clay-colored hills composed of limestones of various textures which range from soft arenaceous and friable argillaceous to very hard blue limestones which break with a conchoidal fracture. Somewhere in the upper part of the series he reports a horizon that carries much gypsum.

Mr. Worcester, in a hurried trip to the valley, found it impractical to attempt detailed mapping. Faulting and folding have obscured most of the relationships, but the following sequence of Carboniferous beds was worked out.

Section of Carboniferous strata in Sinbad Valley

MEASURED BY P. G. WORCESTER

Top
1. Gypsum, perhaps 10 to 20 feet, possibly more
2. Limestone and limestone breccia
3. Thin beds of shaly sandstone
4. Gray shale
5. Black paper shale

Thickness undetermined but at least 800 to 1,000 feet

No fossils were collected from this region.

UPPER LIMIT OF THE GYPSUM SERIES

The angular unconformity which separates the gypsum series from overlying beds in the region of Gypsum Valley was apparent wherever this contact was exposed. The discordance in dip of beds above and below the unconformity is 60° in the north wall of Gypsum Valley, and is 30° in Klondyke. Unconformities which exist above the Carboniferous bring the beds of the gypsum series in this region successively in contact with Cutler, Dolores, La Plata, and McElmo formations.

The presence of an unconformity at the upper limit of the gypsum series was not definitely determined outside of Gypsum Valley. However, the general arrangement of beds and the fact that between Sinbad and Paradox valleys, and the Uncompahgre Plateau, the Permian(?) conglomerates completely overlap the gypsum, suggest that such an unconformity is wide spread. The upper limit of gypsum beds in Paradox Valley is not a smooth surface, but differs from point to point in its stratigraphic distance below the La Plata sandstone. The relation of the gypsum series in Sinbad Valley to the overlying beds was not determined.

AGE AND CORRELATIONS

Peale[13], during the Hayden Survey, divided the Carboniferous into (1) Permian or Permo-Carboniferous, (2) Carboniferous (Coal-Measures), and (3) Sub-Carboniferous. On doubtful evidence he referred the gypsiferous beds of this region to the Permian or Permo-Carboniferous, but in his table of Carboniferous strata for Dolores River sections, he includes gypsiferous beds at the top of his Coal-Measures. He was not able to correlate the sections of this region with those farther west.

[13] Peale, A. C., Ninth annual Report of U. S. Geol. and Geog. Survey, pp. 76-77, 1875.

Cross[14] considered the gypsum beds older than beds tentatively referred to the Cutler. Under "Carboniferous formations," he states:

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.

Elsewhere he states[15]:

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 sturian conglomerate, (base of the Triassic), and this does not seem at all unlikely, for gypsiferous beds are known in the Paleozic Red beds of northwestern Colorado, as reported by Peale.

The existence of a gypsum series in widely separated localities in the western part of the United States and its reference to the Permian, suggest that the gypsum of the present area is the same age. Many of the measured sections of the Grand Canyon include in their Permian beds much gypsiferous shale and clay. In these sections red shales and sandstones are associated with the gypsum, but beds of rock gypsum are, however, seldom, if ever, reported. It might be said in this connection that gypsum in the area of this report, is by no means limited to beds below the Cutler, as the red shales of this formation and higher ones include considerable of this material, but not in amounts found in the lower beds where it is not associated with red shales and sandstones.

The closest reported deposits of gypsum in beds of considerable thickness are in the Rico Mountains, where gypsum beds are a part of the Hermosa formation. A. C. Spencer[16] notes along Hermosa Creek, "Green sandstones and shales with bands of gypsiferous shale." He further notes that the gypsum beds extend to the south and were an original deposit.

The occurrence of heavy beds of gypsum associated with black shales and blocky bituminous limestones in the Animas region in the corresponding part of the lower Hermosa formation, together with the massive character of the gypsum rock as observed at Rico, is strong evidence for accepting the deposit as an original part of the formation, rather than as of secondary origin through the action of sulphuric solutions, as proposed by Rickard.

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[14] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. of Geol., vol. 15, No. 7, p. 661, Oct.-Nov., 1907.

[15] Idem., p. 667.

[16] Spencer, A. C., Geol. of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 49-53, 1900.

In the Rico quadrangle, Cross[17] describes a portion of the Hermosa as follows:

> Above these rocks (shales and impure limestones) are green or gray grits, or sandstones, alternating with gray shales and containing several beds of black shale and occasional thin, impure limestones. * * * A bed of rock gypsum, reaching in some places a thickness of 30 feet, occurs locally above the black shales, * * * and was probably more widely distributed originally, since wherever it has been attacked by circulating waters and in part removed by solution.

F. L. Ransome[18], in considering the origin of certain ore deposits of the Rico Mountains, proves that:

> The gypsum once possessed a greater horizontal extent than at present. * * * And that the recognition of the fact that the present gypsum masses are mere wasted remnants of a continuous bed that once occupied the entire space now filled by the Enterprise blanket, is of more importance for an understanding of the genesis of the ore deposits than is the distinct question of the origin of the gypsum itself.

Conditions necessary for the deposition of gypsum existed in the region of the Rico Mountains during Pennsylvanian times, and once extended over a much larger area than that represented by its present outcrop.

Fossils were found in this unit in three points, Sinbad Valley, from which no collections were made, the north side of Gypsum Valley and in Klondyke. The collections from the last two points have already been discussed.

Although faulting exists near the head of Gypsum Valley, there is but little doubt that the beds in Klondyke, which produced the typcial Hermosan fauna, are stratigraphically above the massive gypsum beds which appear in Gypsum Valley. That the greater portion of the beds here mapped Carboniferous are of the Pennsylvanian division cannot be denied. The stratigraphic position of the fossil-bearing beds on the north side of Gypsum Valley is in doubt and is only suggestive of the pre-Cutler age of the gypsum.

The unconformity at the top of the gypsum series, although observed in few places, is thought to be wide spread. The relations of the gypsum series to the overlying beds in Sinbad Valley were not established, neither were beds similar to those carrying the fossils in Gypsum Valley and Klondyke found at other than the two points. If their position above the gypsum is correct, the unconformity has elsewhere cut them off. The beds underlying the

[17] Cross, Whitman, U. S. Geol. Survey Atlas, Rico Folio (No. 130), p. 3, 1905.

[18] Ransome, F. L., Ore deposits of the Rico Mountains, Colo.: U. S. Geol. Survey, Twenty-second Ann. Rept., pt. 2, pp. 277-278, 1900-1901.

gypsum cannot be compared, as exposures of these lower beds are found only in Sinbad Valley and in a small area in Paradox Valley.

The observations of this unit in the area of this report are admittedly not as extensive as they should be to make a complete correlation. The presence of the characteristic gypsum demands special attention. The rocks here mapped Carboniferous do not include beds correlated with the Cutler, which are considered Permian(?) and are mapped with the Dolores above as Permo-Triassic. In considering the correlation and age of these pre-Cutler beds the following points must be considered:

1. The occurrence of gypsum elsewhere in the west and its general reference to the Permian(?).

2. The occurrence of gypsiferous shales and clays in Grand Canyon sections.

3. The occurrence of Permo-Carboniferous fossils in localities of Colorado below gypsum.

Against these points must be considered:

1. The occurrence of rock gypsum in the Rico Mountains associated with beds similar to those found in the present area and their established Hermosan age.

2. The stratigraphic break between beds considered Permian(?) and the gypsum series.

3. The occurrence of Pennsylvanian fossils in limestone below the gypsum in Sinbad Valley, with no apparent unconformity between the two materials.

4. The occurrence at one point of Hermosan fossils which are probably stratigraphically above the gypsum.

Incomplete evidence places the massive beds of gypsum in the Pennsylvanian division of the Carboniferous and suggests that they are a part of the Hermosa formation.

Detailed study would probably determine whether or not the exposures in Sinbad Valley show a break between the gypsum and the Cutler above. And these beds could doubtless be correlated with those farther down Dolores River if the attempt were to be made seriously.

PERMO-TRIASSIC FORMATIONS

HISTORIC SKETCH

The "Red Beds" of the plateau country have been the constant wonder of geologists, as well as tourists, since the earliest expeditions into the Grand Canyon country. This series of red sandstones, red shales, and limestones constituted a geologic unit in the writing of many of the first geologists who visited this wonderland.

The Hayden survey included in their "Red Beds" in parts of Colorado, formations ranging in age from Pennsylvanian to those that are questionably Jurassic. The strata of the San Juan Mountains included within these limits comprise the Rico, Cutler, Dolores, and La Plata formations. All these formations, with the possible exception of the Rico, have equivalents in the area discussed in this paper. In a general way the beds which constitute the La Plata, Dolores, and Cutler formations of the present report were included in the Triassic of the Hayden atlas. However, the mapping of this unit was not consistent, as many exposures of Cutler beds were sometimes mapped Triassic and sometimes Carboniferous; again, McElmo beds were occasionally included within the areas mapped Triassic.

The work of A. C. Spencer in 1899, and of Cross and party in 1905, has already been mentioned. Cross' work included a study of the Utah occurrence of the "Red Beds" and a correlation of these formations with those of the San Juan Mountains. His party examined exposures near the mouth of West Creek and along Dolores River below Gateway. Cross'[19] discussion of the beds below the La Plata in this region is a basis for applying the terms Dolores and Cutler to strata which comprise the bulk of the red rocks of the area. These strata can be traced intermittently along Dolores River across and beyond the limits of the area examined by this survey.

CUTLER AND DOLORES FORMATIONS

INTRODUCTION

A detailed study of strata below the La Plata formation was made in only a few localities. In as much as the problems of correlation and separation of these strata did not seriously involve the object of this report, a systematic study of these lower beds was not made. In fact, it was after the work was well under way that it was considered advisable to map beds lower than the McElmo. The observations here recorded are the result of rather superficial examinations incident to the study of the formations above the La Plata.

DEFINITION

Cross[20] considered a series of grits and conglomerates which he found in the San Juan Mountains at the base of the "Red Beds" to be Permian(?). The age of the series was not determined by fossils, but by its stratigraphic position which was above beds known to be Pennsylvanian and below those thought to be Triassic.

[19] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colo. and Utah: Jour. Geology, vol. 15, No. 7, pp. 649-669, Oct.-Nov. 1907.

[20] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), Rico folio (No. 130), Silverton folio (No. 120), and Engineer Mountain folio (No. 171).

The term Cutler is applied here to somewhat similar strata which come above the gypsum series and are considered equivalent to the Cutler of the San Juan Mountains. These Permian(?) beds are not separated from the Dolores formation in the present mapping; however, the plane of division of these two formations was recognized at several points and it is probable that this division could be mapped throughout the area. Nothing new can be offered to prove conclusively the age of these beds, and the reasons for their questionable reference to the Permian(?) in neighboring territory are still operative in this area.

The Permian(?) strata consist of red to maroon shales and sandstones, arkose conglomerates, and locally, thin beds of gypsum. Their lower limit is marked by an unconformity which separates these beds from the gypsum series in Sinbad, Paradox, and Gypsum valleys, and brings them in contact with pre-Cambrian rocks in the Uncompahgre Plateau.

The Cutler formation is limited above by a bone-bearing conglomerate similar to the "saurian conglomerate"[21] used as the base of the Dolores Triassic elsewhere in this part of Colorado. The normal position of this bed is 400 feet below the massive sandstone which characterizes the upper part of the Dolores formation. This conglomerate is seldom recognized, except by careful search. The character of the Cutler sediments differs so from place to place that individual beds of the formation cannot be recognized in the different outcrops. The limited exposures of these beds make it impossible to work out all their relationships.

An unconformity present in some places at the base of the Dolores formation is in part responsible for a thinning of Cutler beds and their complete removal from places where they normally should appear. A section measured in Paradox Valley shows the Cutler to be 787 feet thick. Estimated sections in the Dolores Canyon near Gateway exceed the Paradox Valley measurement, but estimates made in Gypsum Valley are less than 500 feet.

The common usage of the term Dolores is to apply it to the Triassic portion of the "Red Beds." In this part of Colorado the unit has the "saurian conglomerate" as a lower limit and the La Plata as an upper limit. The basal conglomerate was not recognized in all sections, though its existence was established at several widely separated points, and it is thought to be generally present. In many places a change in color from the brick-red of the Dolores to the maroon of the Cutler marks the division of these two forma-

[21] Cross, Whitman, Jour. Geology, vol. 15, No. 7, pp. 654-655, Oct.-Nov., 1907.

tions. The Dolores formation is limited above by the La Plata sandstone, whose pink to light red colors contrast with the red of the Dolores beds in such a way that the boundary between these two formations is easily recognized.

The Dolores formation measured 852 feet thick in Paradox Valley and was estimated to be over 700 feet thick in several places along Dolores River. In Gypsum Valley this formation becomes thin and wedges out in the vicinity of Klondyke, where the La Plata sandstone rests upon Carboniferous beds.

TOPOGRAPHIC EXPRESSION AND GENERAL APPEARANCE

The Dolores and Cutler formations make up from 1,000 to 2,000 feet of red strata which, aided by the La Plata, give to the region its scenic value. Elaborate sculpturing and uneven weathering have resulted in a maze of canyons and erosion forms not often equaled. These forms contrast with those of younger formations and show such a variety of landscape that no prediction can be made by the expectant traveler as to what the next view will present. Rounded corners contrast with sharp ones, thick beds with thin, narrow benches with wide ones, both of which form the rim of canyons 1,000 feet or more in depth. Resistant beds stand out in

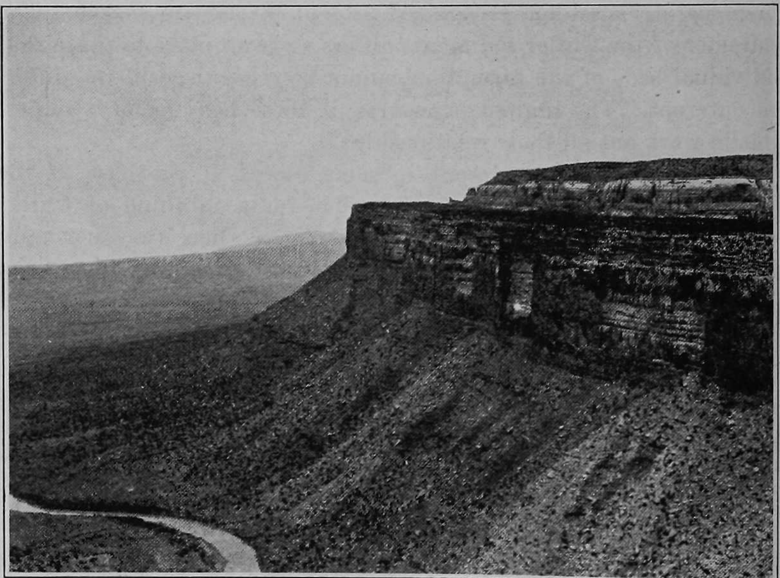

Fig. 5. North wall of West Paradox Valley.

Main cliff formed by sandstones of the Dolores formation; light colored outcrop, La Plata formation; uppermost beds, basal part of the McElmo formation; Cutler formation includes beds exposed near Dolores River: total stratigraphic interval involved over 2,500 feet.

vertical cliffs and overhang or form arched roofs over cavities cut from the softer shales. Shades of red, pink, and maroon contrast with bands of white and yellow which can be traced for miles.

The Dolores formation occupies the commanding position in this complexity of erosion forms. Its distribution is greater than that of the Cutler formation which appears as maroon strips along the edges of valleys or in canyon bottoms. Even where the Cutler formation reaches its maximum thickness, in Sinbad Valley and along the lower part of Dolores River, where it exceeds the Dolores formation in thickness, the upper beds are the more prominent and stand out in bold cliffs which are the most striking feature of the region.

The Dolores-Cutler unit appears on the map as narrow strips which do not suggest the prominence of this unit. The outcrop of these two formations is generally a cliff terminated above by a massive sandstone of the Dolores formation, and below by a red slope whose length reaches to the canyon bottom. The Dolores sandstone often reaches a thickness of 300 feet and, with the La Plata, make up two most striking and constant beds of the region.

The massive Dolores sandstone forms an inner rim which is generally an impassable barrier, taking the form of a sheer wall whose height is the thickness of the bed. This sandstone is the controlling factor of the physiography in all canyons cut to this formation. It forms the largest of a succession of steps which go to make up the profile of the average canyon wall. The main line of this cliff is frequently interrupted and made irregular by recesses, rincons, or circular re-entrants. These circular re-entrants are numerous and of different sizes, up to those three-fourths of a mile across; their outlines represent almost every fractional part of a circle. One adjacent to Dolores River measured over 200 yards across, and its ground plan shows 230° of a circle. The upper part of this amphitheater was walled in by the massive sandstone cliff 200 feet high, and the lower part was carved from deep red shales that formed surfaces sloping centrally at approximately 30-degree angles. The re-entrant presented the form of a huge, stemless funnel with vertical sides encircling all but a small part of its circumference through which the odd basin drained.

A vertical jointing in the massive sandstone, aided by the softer shales below, makes it possible for this bed to retain its vertical wall in all its weathered forms. This massive bed often exhibits vertical, smooth surfaces of several thousand square feet, in which the only markings are the slightest tracery of bedding. Other cliffs show distinct evidence of bedding, but definite planes of division are often absent. Occasionally, the smoothness of the La Plata is duplicated by the massive Dolores sandstone (see fig. 9, p. 63), though angular corners are the general rule in the latter bed and serve with the color differences to contrast it with the La Plata above.

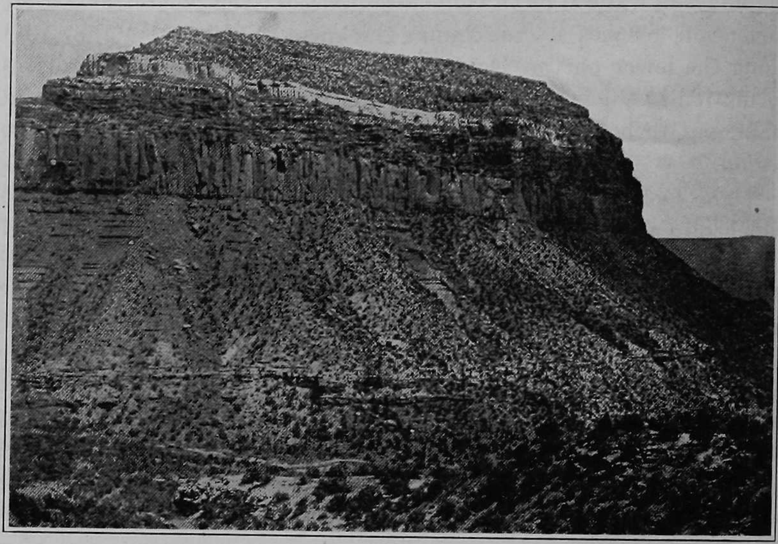

Fig. 6. Formations exposed in the canyon of Dolores River above the mouth of Disappointment Valley.

Lower cliff is formed by the massive sandstone of the Dolores formation; note the columnar jointing of this sandstone: the light colored outcrop is of the La Plata formation, and the beds exposed near the bottom of the canyon are of the Cutler formation.

Another phase of the weathered forms of the massive Dolores sandstone is due to a jointing in this bed at right angles to the bedding (see fig. 6, p. 50). Rude upright columns weather out as irregular spires, slabs, castles, and sentinel rocks that stand detached from or rest against the main cliff. Lower La Sal Creek shows a typical development of these forms.

A series of alternating sandstones and shales above the massive sandstone in the Dolores formation sometimes extend out to, and form a part of the main cliff. Elsewhere they weather back in a continually rising slope which forms a narrow bench between the massive Dolores and La Plata sandstones. Below the Dolores cliff-forming sandstone, red shales and sandstones make an even slope to the bottom of the canyons. Where the total thickness of the Cutler formation is exposed this slope is interrupted near its base by a series of ledges formed by the conglomerates of this formation.

DISTRIBUTION

The Dolores River, from which the formation gets its name, traverses a gorge whose inner walls are cut from the beds of the Dolores-Cutler unit. In the Dolores canyon, south of Disappointment Valley, the exposures of these rocks fringe the river in 1,000-foot cliffs and in decreased thickness they continue up the river and pass beyond the limits of the map. The monoclinal folding which connects Disappointment Valley and the plateau to the south exposes narrow strips of the Dolores formation along Summit and Bishop canyons. Near the mouth of Disappointment Creek dips to the northeast quickly cover the Dolores and lower formations, and from this point to Gypsum Valley they do not appear.

Along the north side of Gypsum Valley a strip of these rocks connects with the exposures which extend along Dolores River to La Sal Creek and to Paradox Valley. The monoclinal folding in Silvey's Pocket exposes a narrow band of the Dolores formation which connects by way of lower Coyote Wash with Dolores River exposures. The Dolores-Cutler unit forms the greater part of the walls of Paradox Valley, but north of this valley the exposures of these beds narrow up along Dolores River until they reach Mesa Creek. Beyond this point they widen into large areas which encircle Sinbad Valley and acquire their greatest prominence near Gateway, where the Cutler beds attain a maximum thickness.

Outcrops of the Dolores and Cutler beds follow West Creek to the top of Uncompahgre Plateau and in diminished thickness fringe

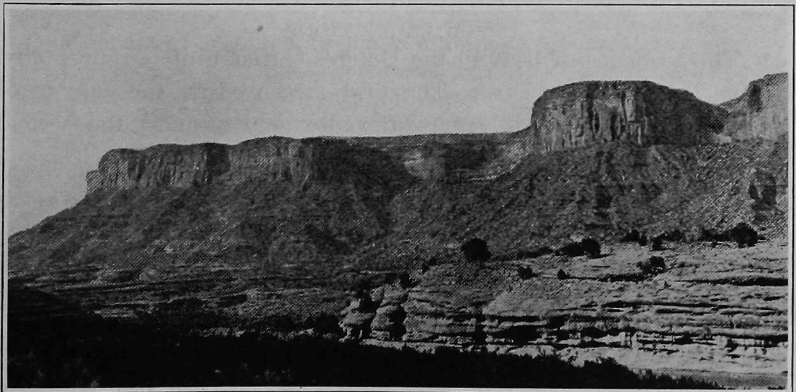

Fig. 7. East wall of Dolores River Canyon above Gateway.

The prominent cliff is formed by the massive bed of the Dolores formation; beds in the foreground are Cutler conglomerates.

the granite area of this upland as far east as North Fork of Tabequatche Creek. They appear again in Little Red and Big Red canyons and along Horse Fly Creek. Cutler beds are not exposed in all the areas mentioned, as pre-Dolores erosion, in places, has entirely removed these beds.

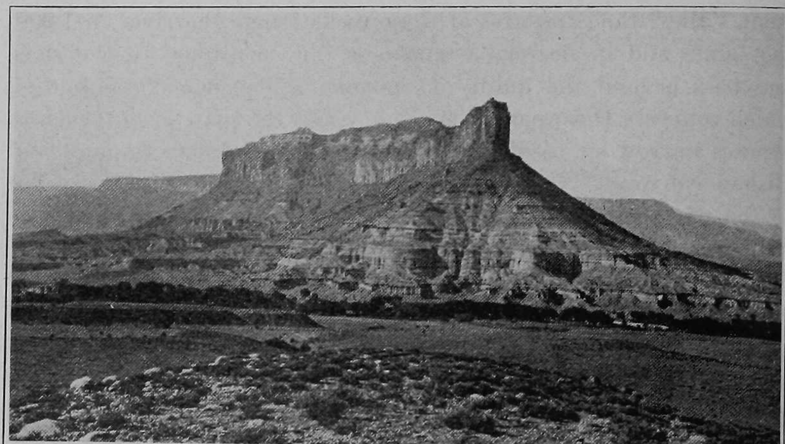

Fig. 8. Palisades near Gateway.

Prominent cliff is formed by the massive bed of the Dolores formation; lower outcropping beds are of the Cutler formation: the boundary between these formations is approximately the boundary between the light colored portion below (light red) and the dark colored portion above (dark red).

The Dolores formation is exposed in McElmo Canyon where a limb of an anticlinal fold is crossed by McElmo Creek. The outcrops at this point are confined to the top 300 feet of the formation, and no strata are present that can be correlated with the Cutler.

TYPICAL SECTIONS

The sequence of beds in the Dolores-Cutler unit is represented by the following sections: The first measured in the canyon of Dolores River where it enters Paradox Valley, and the second measured in the walls of Sinbad Valley.

Section of Dolores and Cutler formations one-fourth mile southwest of the bridge across the Dolores River at Bedrock

MEASURED BY P. G. WORCESTER AND J. A. PYNCH

	Feet
Top	
La Plata sandstone, white, cross bedded.	
1. Dolores sandstone, pink to white, thin bedded	84.2
2. Sandstone, white, more massive than No. 1	143.2
3. Sandstone, red to light red, very massive, cliff making, cross bedded	300.00

4.	Shale and sandstone, alternating, red	306
5.	Conglomerate, coarse, massive, red to pink	19
		852.4
	Cutler	
6.	Shale, green	19
7.	Sandstone, massive, white	86
8.	Sandstone and shale, alternating; sandstone, thin bedded, white to red	136
9.	Shales, red and purple	128
10.	Shales and sandstones, yellow and green	110
11.	Sandstones and shales, red and purple	108
12.	Shale, red, very calcareous	100
13.	Base, approximately 100 feet not exposed; contains at least one conglomerate	100
		787
	Total thickness	1,639.4
	Gypsum series (Carboniferous).	

Generalized section of part of the Dolores-Cutler formations near the point where Salt Wash leaves Sinbad Valley

(THICKNESS DETERMINED BY ANEROID)
MEASURED BY R. C. COFFIN

Top.		Feet
Beds above the Dolores massive sandstone absent.		
1.	Sandstone, red, massive; forms the main cliff of the valley walls	225
2.	Shales and Sandstones, in about equal amounts, sandstone fine grained, in beds 2 to 6 feet thick	300
3.	Conglomerate, pebbles of limestone	12
4.	Shales and sandstones, red and green	280
5.	Sandstones and shales, red, thin bedded; sandstones predominate	40
6.	Sandstone, dark red to black on weathered surfaces, beds 2 in. to 6 ft. thick, separated by red shale partings	50
7.	Shale, brownish red, sandy throughout	100
8.	Gypsum, wedges out along the strike	3
9.	Sandstone and shale, different shades of red, claret red most common; sandstones grade downward into shales; shale and sandstone strata grade one into the other without definite planes of division	200
10.	Shale, chocolate-colored	30
11.	Sandstone, brownish, carrying some undeterminable fossils	30
12.	Interval, not exposed	50
		1,330
	Gypsum, Carboniferous.	

The deep cutting of the Dolores River near Gateway does not show the total thickness of the Cutler formation which is here characterized by many beds of arkose conglomerates. The marked differences and rapid transitions in character of the Permian(?) sediments are evident in the comparison of the Gateway and Sinbad Valley sections. The heavy, coarse conglomerates in the former sections are not duplicated in the walls of Sinbad Valley, but are largely replaced by deep red to maroon shales. North and east from Paradox Valley the Dolores-Cutler unit is greatly decreased in thickness by the thinning and possible disappearance of the Cutler beds. The 1,600 feet of Dolores-Cutler beds in Paradox Valley is reduced to 420 at the head of Shavano Creek. In as much as a hurried examination at this point did not locate the bone (saurian) conglomerate, it is possible the Cutler is not represented. At the head of Mesa Creek the sandstone-shale series at the top of the Dolores formation, is so much diminished in thickness that the La Plata and massive Dolores sandstones are practically in contact, and make it impossible to divide the formations with certainty. In Little Red and Big Red canyons the massive Dolores sandstone was not recognized.

A partial section measured in Gypsum Valley shows the general character of the Permian(?) part of the unit.

Partial section of Cutler formation in the north side of Gypsum Valley 2 miles above its mouth

MEASURED BY JUNIUS HENDERSON

Top.

Conglomerate; bone fragments, "saurian conglomerate," probably the base of the Dolores.

Dip 50° N. 40° W.		Feet
1.	Sandstone, deep red, shaly, soft, friable, fine grained; strata wedges out along the strike	3
2.	Sandstone, coarse	5
3.	Sandstone, like No. 1 partly covered	20
4.	Conglomerate, red	15
5.	Sandstone, like No. 1	37
6.	Conglomerate, white cement below, red to drab above, many limestone pebbles; not well exposed, thickness uncertain	30
7.	Sandstone, similar to No. 1	35
8.	Conglomerate, light red, composed of white quartz grains, with red cement and scattered pebbles up to one inch in diameter, bedding obscure and irreglar	5
9.	Sandstone, like No. 1	40
		190

The conglomerate used as the base of the Dolores transgresses beds No. 1 and No. 2 and rests upon No. 3. The basal part of the Cutler formation was not exposed, but its total thickness does not exceed the amount measured by more than 200 feet. The total Dolores-Cutler unit is approximately 1,000 feet thick near the mouth of Gypsum Valley but decreases in thickness toward the east and wedges out at the head of the valley.

In the Dolores Canyon above the mouth of Disappointment Valley the Dolores-Cutler beds exceed 1,000 feet in thickness without exposing the base of the Permian(?). A bone-bearing conglomerate, probably representing the base of the Dolores, is present near the bottom of the canyon.

The section of Dolores exposed in McElmo Canyon shows the following beds:

Generalized section of Dolores formation along Sand Gulch, McElmo Canyon

(THICKNESS DETERMINED BY ANEROID)
MEASURED BY R. C. COFFIN

Top.	La Plata	Feet
1.	Sandstone, white at top, red at base; shaly layer in upper part; weathered into nodular forms ½ to 1½ feet in diameter	50
2.	Sandstone, massive, yellowish to white in upper 20 feet, red at base, shaly in lower part where nodular masses are formed; small cavities present in middle part; forms cliff 70 to 80 feet high	85
3.	Sandstone, red to yellowish brown, in beds 1 to 3 feet thick	35
4.	Sandstone, massive, cross bedded, cliff forming; color banding prominent, upper 10 feet light red, middle portion deep red	80
	Bottom of Canyon.	

As the exposures involve only the top of the formation the equivalent of the massive Dolores sandstone of the northern sections cannot be determined.

The character of the Dolores beds is so constant in all the sections that correlations can often be made of beds in widely separated areas. The sections given of the Cutler beds illustrate the lack of uniformity in this member both in changes in character of material found along the strike of individual beds and the quick succession vertically of extremely coarse and fine material.

RELATION OF DOLORES AND CUTLER FORMATIONS

The exact boundary of the Dolores and Cutler formations cannot always be placed with confidence. In Gypsum Valley a bone-bearing conglomerate overrides lower beds which are considered Permian(?). Here, at least, an angular unconformity exists between the two formations. The uneven thickness of Cutler beds, and the fact that they are absent in places, suggest that this unconformity is wide spread. The Cutler formation is over 700 feet thick in Paradox Valley, less than 400 feet in Gypsum Valley, and is absent in the region of Klondyke. At the west end of the Uncompahgre Plateau typical Cutler beds make up more than 1,000 feet of sediment, but in the eastern exposures along the south side of this plateau these beds are inconspicuous or absent. In the canyon of the West Creek north of Gateway the Dolores beds truncate the entire Cutler formation within a distance of three miles.

The similarity of the material in the Cutler conglomerates near Gateway, and the materials of the pre-Cambrian complex in the Uncompahgre Plateau, suggest that a land mass not far from the present site of the plateau supplied the materials for the making of these conglomerates. The arrangement and distribution of these conglomerates point to a northeasterly source of these materials. It was Peale's[22] idea that an area including Uncompahgre Plateau remained an island during Upper Carboniferous (Permian) and Triassic times. Such a view cannot be wholly correct, as the overlapping of the Dolores formation on Cutler beds (considered Triassic by Peale) in the vicinity of Gateway points to a once greater extension of these beds than is represented by their present outcrop. The unconformity below the Dolores formation indicates that a period of erosion followed Permian(?) deposition, during which some of the Cutler beds were removed. The somewhat smooth surface of pre-Cambrian rocks upon which the Dolores beds rest in the southern edge of the Uncompahgre Plateau indicates that erosion reached an advanced stage of base-leveling previous to Dolores deposition, and that the time interval represented by this unconformity was of considerable duration.

The land mass which existed during Permian(?) times did not extend to the western edge of the Uncompahgre Plateau, and it is doubtful if the present relation of the high ground of this upland to the lower areas at the south, outlines in any manner the land and sea areas during the deposition of the Cutler beds.

The overlap of the Dolores formation can be seen at the head of Gypsum Valley. Twelve hundred feet of Dolores and Cutler beds are exposed in the Dolores Canyon above the mouth of Disappointment Creek without showing the base of the unit. But in Klondyke, only 10 miles distant, the Dolores is less than 200 feet thick and rests upon Pennsylvanian formations without the presence of intervening beds which can be correlated with the Cutler.

[22]Peale, A. C., Ninth Annual Report of U. S. Geol. Survey: pp. 80-82, 1875.

The limited observations of pre-Dolores beds show that the dividing bed of the Dolores and Cutler formations is generally a peculiar bone-bearing conglomerate; that an unconformity exists at the base of this conglomerate in a part of the area; and that this unconformity has made it possible for the Dolores formation in places to completely overlap the Cutler beds.

It is interesting to note in connection with the unconformity at the base of the Dolores formation, and the one at the top of the gypsum series, that in this area there is evidence of a much greater break in the character of deposition between the gypsum series (Pennsylvanian) and the Cutler (Permian[?]) than there is between the Cutler and the Dolores (Triassic). If, as some suggest, the large areas of gypsum are considered Permian, then the unconformity within the Permian, at the base of the Cutler, is of greater magnitude than the change of conditions from the last of the Paleozoic era, represented by the Cutler, to the first of the Mesozoic era, represented by the Dolores.

GENERAL TEXTURE AND COMPOSITION

The beds that constitute the upper half of the Dolores formation differ little, except in thickness of individual beds. They are uniformly fine grained, few grains being large enough to be easily recognized by the unaided eye. Impure quartz sand with a cement of ferric iron, silica, and a minor quantity of calcium carbonate make up the bulk of the material in these beds. Ferric iron often occurs in excess of the amount necessary to bond individual particles. This excess takes the form of specks and minute spheres of extremely red ochre, which weather readily, leaving tiny cavities. Impure clay shales make up a minor part of the material in the upper half of the Dolores formation.

Shales other than in beds a few feet thick are confined to the series below the massive Dolores sandstone. In fact, the lower half of the Dolores formation is predominantly shale that weathers into a deep red clay which is plastic when wet. Green colors often replace the red tints of both shales and sandstones along fault planes or in fractured zones.

Cross bedding is common in the massive layers of this unit, and the wedging out of beds along the strike is characteristic of parts of the Cutler formation.

Calcium carbonate occurs in minor amounts throughout the formation. Fault planes, seams, and fissures that afford passage to ground waters, almost without exception, show crystalline calcite and limy incrustations. The irregular distribution of lime and local concentration of ferric iron result in a peculiar form of weathering locally possessed by the Dolores beds. Irregular solution cavities, 1 to 3 inches deep, often produce a honeycomb effect over surfaces of more than 20 square feet.

Barite (heavy spar), along with copper minerals, is sometimes associated with the calcite of the fault planes. At least three deposits of copper have been mined along fault planes within the Dolores formation. Impressions of plant fragments in the form of tiny stems were observed in one place in Paradox Valley within the Dolores formation, but the fossil wood, so abundant in the Triassic of the Navajo country, was not observed. Black streaks over many of the red sandstone beds, and numerous black films along planes of minor displacement, give reactions for iron and manganese.

With the exception of one thin limestone conglomerate above the massive Dolores sandstone in Saucer Basin, the coarse beds are confined to the lower third of the Dolores formation and may occur in any part of the Cutler formation. The Dolores conglomerates, of which there are two or more, often carry limestone fragments mixed with well-rounded quartz and feldspar pebbles. One conglomerate in Paradox Valley near the base of this formation contained pebbles derived from a quartzitic sandstone, and occasional pieces of limestone which appeared to be fragments of coral. A calcareous cement is frequently mixed with the ferric cement which, with fine sand, forms the bonding materials of these conglomerates.

The materials in the Permian(?) fraction of the section range from the finest of maroon shales in the Paradox and Gypsum Valley sections to the coarse arkose conglomerates of lower Dolores River, where the beds contain boulders up to 1½ feet in diameter. These conglomeratic beds are comprised of almost every material found in the pre-Cambrian complex of the Uncompahgre Plateau. The most common type of boulder is derived from a granite characterized by large phenocrysts of pink to red feldspar. These materials, with types of schists and gneisses in almost every stage of decay, make up the bulk of these beds.

Quick lateral and vertical changes in the character of beds is typical of this formation. Sandstones and shales are intermingled with and follow quickly above the coarsest of conglomerates. Laterally these beds often grade into sandstone of a blood red color in which mica is a characterizing material. One half the specimens collected from the Cutler conglomerates react for calcium carbonates when treated with hydrochloric acid.

Gypsum beds occur locally interbedded with the arkose conglomerates of the Cutler, and appear singularly out of place in such a formation.

CONDITIONS OF DEPOSITION

The question of the conditions that surrounded the deposition of the "Red Beds" has been a topic of considerable discussion. In the main there seems to be agreement that much of their bulk is made of materials deposited on land rather than in the sea.

W. T. Lee[23] suggests that the following order of events prevailed during the deposition of the Permian(?) and Triassic beds of the southern Rocky Mountain Province: Permian sedimentation followed the uplift of the southern Rocky Mountains at the close of Pennsylvanian times. "In many places it (Permian[?] sediment) gathered as upland deposits on the plains which sloped away from the mountains. * * * * There followed a time not well recorded in the mountain region, during which many events of importance occurred farther west. An arm of the Pacific extending eastward into Colorado and New Mexico, in later Permian or early Triassic time, was expelled, and rocks which formed in it exposed to erosion." Again a change in the elevation of highlands and lowlands favored land deposition and Triassic beds were formed.

After reviewing the literature on the subject C. W. Tomlinson[24] concluded: "The types of sediment probably most important in the Red Beds group are stream deposits, submarine fluviatile deposits and playa deposits. * * * Of these types the first is by all odds the most important."

H. E. Gregory[25] considered the physiography of the Navajo country to be in Permian times, "Probably a region of low relief bordering the sea and having an arid climate. * * * Over the long slopes and into flat-floored depressions sediments were carried from surrounding lands and deposited on flood plains, piedmont slopes, and the floors of fresh and alkaline lakes."

The Permian (?) and Triassic beds within the area of this report are similar to corresponding beds in other areas. The extreme coarseness of the Cutler beds in the region of the Uncompahgre Plateau indicates that they had a near-by source. The abundance of unweathered feldspar suggests an arid climate. The general arrangement of beds, their quick transitions, the intermingling of

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[23] Lee, W. T., Early Mesozoic Physiography of the southern Rocky Mountains: Smithsonian miscellaneous collections, vol. 69, No. 4, pp. 9-10, July, 1918.

[24] Tomlinson, C. W., The origin of the "Red Beds." A study of the conditions of the origin of the Permo-Carboniferous and Triassic Red beds of the western U. S.: Jour. of Geol., vol. 24, No. 3, p. 253, 1916.

[25] Gregory, H. E., Geol. Survey Prof. Paper 93, p. 34, 1917.

the fine shale or clay with the coarse conglomerates, and the absence of fossils are all consistent with their probable continental origin. The sudden transition from conglomerates to beds of gypsum is best understood as representing concentrations in alkaline lakes or playas.

The Triassic beds also show evidence of fluviatile origin, but not in the manner of the Cutler formation. The Dolores beds show a lack of complete sorting; their sandstones are shaly, their shales are sandy, and their conglomerates gritty. Interformational unconformities of local extent and the wedging out of individual beds suggest that some beds were deposited by streams. However, their even bedding and an occasional ripple-marked surface indicate that many of these beds were deposited in bodies of water. The conditions which caused the deposition of coarse material in the lower half of the Dolores-Cutler unit ceased to exist during the deposition of the upper Dolores which is uniformly fine grained and for the most part even bedded. Aridity to the extent of the formation of sand dunes is suggested by the degree of cross bedding sometimes present in the massive beds in the Dolores formation.

Much is yet to be determined as to this great series of unfossiliferous beds. The site of the land masses from which these beds derived their sediments cannot be placed definitely. In the case of the Permian(?) beds a land mass appears to have existed at no great distance north and east of their present outcrops. The Triassic beds of the Plateau region may have derived their materials both from the present site of the Rocky Mountains and land areas farther west. The present outcrops of the several formations that go to make up the "Red Beds" do not represent their maximum extent as erosion previous to Dolores, La Plata and McElmo deposition has removed portions of these beds.

AGE AND CORRELATION

No determinative fossils were collected from the Triassic or Permian(?) beds during this reconnaissance. Fragments of unio sp. were found on the north side of East Paradox Valley, and teeth, presumably of a belodant crocodile, were collected from the base of the Dolores in Gypsum Valley. However, lithologic character and stratigraphic position leave no doubt as to their proper correlation with similarly named strata of the San Juan Mountains.

Cross[26] considered that the Dolores of Colorado included diminished equivalents of Powell's Shinarump group of the Plateau

[26] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, No. 7, p. 660, Oct.-Nov., 1907

country. Later he abandoned this tentative correlation and suggested that the massive Dolores sandstone was equivalent to the Vermilion Cliff sandstone of the Grand Canyon country. Lee[27] considered Gilbert's Vermilion Cliff of the Henry Mountain in Utah equivalent to the La Plata, and Gregory[28] correlated the upper half of the Chinile of the Navajo country* with the Dolores and suggested that his Moenkopi was equivalent to the Cutler of the San Juan Mountains. H. S. Gale,[29] on superficial examination, was not able to separate the Vermilion Cliff from the Shinarump group in northwestern Colorado.

JURASSIC FORMATIONS

Strata assigned to the Jurassic period make up the La Plata formation and questionably include those of the McElmo formation. The basis of separation of these beds is stratigraphic position and lithologic character; no determinative fossils were found. The very striking outcrop and general appearance of these units, especially the La Plata, serve to make the placing of the broader planes of division a simple task.

The La Plata formation in a general way consists of an upper, massive, cliff-forming sandstone, and a lower member of highly cross-bedded sandstone. Both beds are remarkably uniform in their general characteristics. Their combined thickness ranges from 70 to 450 feet.

LA PLATA FORMATION

DEFINITION

The term, La Plata, was first applied by Cross[30] to strata found in the San Juan and neighboring mountains, and later he recognized equivalent beds in a part of the area here mapped.

It was possible in certain regions to divide the La Plata formation into an Upper La Plata and a Lower La Plata, but both subdivisions and the areas of undivided La Plata are given a single color pattern on the map. Where subdivided the two parts of the formation are outlined by the usual contact lines and are given separate symbols.

The upper limit of the La Plata is marked by thin-bedded sandstones and shales of the McElmo formation. The exact plane of separation is the base of a series of red and maroon shales which

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[27] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains, Smithsonian Miscellaneous Collections: vol. 69, No. 4, p. 13, July, 1919.

[28] Gregory, H. E., Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, p. 48, 1917.

*op. cit., p. 31.

[29] Gale, H. S., Coal fields of northwestern Colo. and northeastern Utah, U. S. Geol. Survey Bull. 415, pp. 50-52, 1910.

[30] Cross, Whitman, U. S. Geol. Survey, Geol. Atlas, Ouray folio (No. 153), Rico folio (No. ~~130), Engineer Mountain fo~~lio (No. 57).

makes an abrupt contact with the massive bed of the Upper La Plata sandstone. This boundary is easily recognized.

The lower limit of this formation is generally marked by a color change from the brick-red of the Dolores below to the salmon-red of the La Plata above. Locally the color tints grade one into the other, or faulting causes either formation to lose its characteristic color. The Upper La Plata sandstone is remarkably uniform over a large area and with the massive sandstone of the Dolores formation constitutes two planes of reference which have been frequently used. Because of the range in thickness of the Lower La Plata and the shaly sandstone series at the top of the Dolores, the base of the La Plata formation does not come the same distance below the McElmo nor equally high above the Dolores sandstones.

The lower limit of the La Plata is easily located with respect to the massive Dolores sandstone, which is capped by a series of red, thin-bedded sandstones, and dark red to maroon shales. The upper limit of this series, which ranges in thickness from 50 to 200 feet, is considered the base of the La Plata.

In places where erosion has exposed only a small part of the Dolores formation or in places where the Lower La Plata is inconspicuous, the lower limit of the La Plata formation is placed with some uncertainty.

TOPOGRAPHIC EXPRESSION AND GENERAL APPEARANCE

Several factors make the La Plata formation the most striking single unit of the plateau country. It contributes the master architectural features of canyon walls throughout the area. It reaches a greater thickness west and south of the area mapped and becomes of even greater scenic interest in those parts.

The cliff-forming tendency of the formation, especially of the Upper La Plata sandstone, causes it to stand out as a unit which would not require a knowledge of geology to recognize. Where the beds are horizontal, round, overhanging cliffs or almost vertical walls from 100 to 300 feet high, extend unbroken for miles. This cliff constitutes a barrier that presents a problem to travel along other than the beaten paths. For great distances faulted regions or masses of slide rock afford the only means of crossing the outcrop, and then passage is seldom possible to a saddle horse. This problem is made more difficult in the deeper canyons by the appearance of the massive Dolores sandstone.

The softer character of the lower part of the Upper La Plata sandstone allows its outcrop to retain its vertical or overhanging cliff for great distances. Planes of division are often suggested but are almost never developed into definite cracks, and jointing is limited to disturbed areas. Everywhere in canyons which reach this formation the characteristic smoothness of the La Plata is in evi-

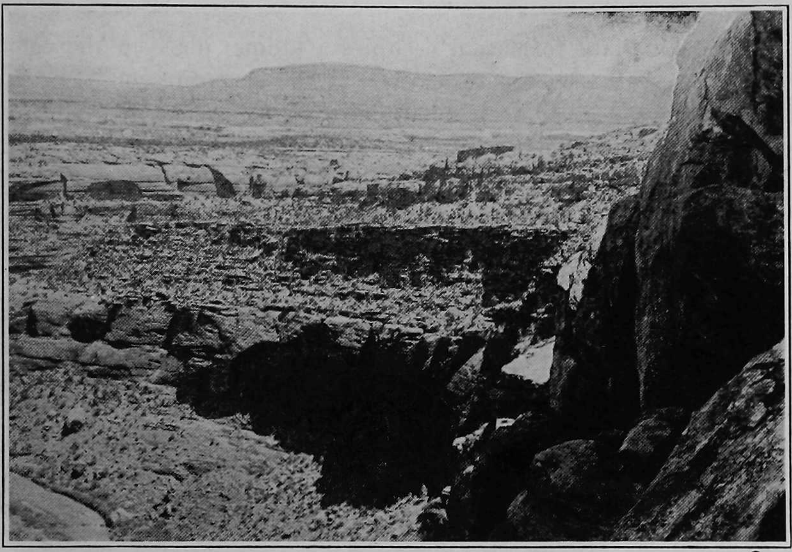

Fig. 9. Canyon of the Dolores River between Gypsum Valley and the mouth of Bull Canyon.

The lowest smooth-weathering bed is the massive sandstone of the Dolores formation; upper smooth-weathering beds, Upper and Lower La Plata sandstones.

dence. Its tendency to weather into rounded outcrops brings it in contrast with all other formations and it is well described as ''the slick rock'' or ''the slick rim,'' by which terms the formation is known to miners and prospectors.

Numerous water courses cross the La Plata outcrop forming re-entrants that retreat in places a half mile from the main line of the cliff. Parallel gulches often form serrated edges of smooth, rounded sandstone which nose out from the otherwise straight outcrop. Again, parallel streams cutting headward leave between their courses bare, elongated remnants of white La Plata sandstone on bases of red sandstone. Such remnants form the so-called ''ship rocks'' in different localities.

The precipitous outcrop of Upper La Plata sandstone stands on a base of Lower La Plata which shows several distinct phases. In regions where this lower member reaches considerable thickness it forms an outcrop whose cross-section is that of the half of an inverted bowl; or it forms a second cliff separated from the upper one by a bench whose width may reach one-fourth of a mile. In regions where the Lower La Plata becomes relatively thin, its beds bench out only short distances from the cliff of the upper sandstone and serve only to obscure the proper placing of the lower limit of this formation.

The La Plata formation occupies a unique place in the color scheme presented by the formations of the carnotite country. In broad valleys, seas of deep red Dolores are encircled with ribbons of La Plata sandstone beautifully tinted. In canyon walls this unit marks the upper limit of a red wall on which an occasional shelf covered with green pines and cedars serves only to intensify the prevailing red. From the deeper canyons cut by Dolores River a network of canyon sculpturing extends in all directions. This immense picture is framed above by the white and pink walls of the La Plata, within which bands of white, and narrow strips of pale pink in the upper part grade downward into bands of pink or light shades of red. Single color units extend unbroken for miles. These color changes are seldom limited by distinct bedding, but smooth surfaces are often marked by several sharply outlined color bands. This color banding extends through great differences in the thickness of the formation, and each band generally occupies a propor-

Fig. 10. Erosion forms in the La Plata formation in Yellow Jacket Canyon.

tional part of the outcrop whether it is 200 feet high or only 60 feet high.

The Lower La Plata does not show the color phases possessed by the upper member. Its light red outcrop is marked by an occasional band of red shale or of thin-bedded sandstone. In faulted or highly folded regions this sandstone, like the upper one, loses many of its characteristics. It becomes crumbly and its red colors are replaced by yellow or lighter shades.

The markings constitute another unusual feature of this formation. The combination of a superior resistance in the upper portion

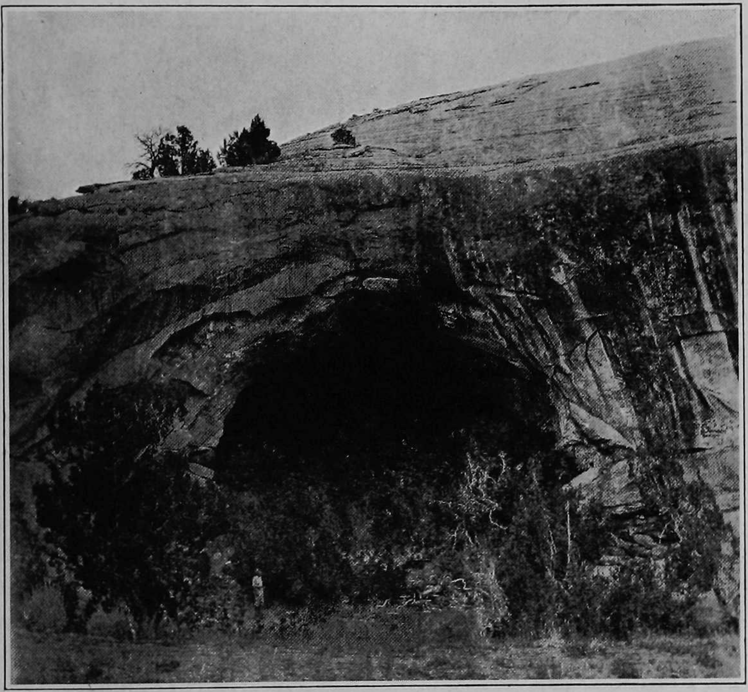

Fig.11. Grotto in the Upper La Plata sandstone in Summit Canyon, McIntyre District.

of the Upper La Plata sandstone and the more easily eroded beds below result in the formation of overhanging cliffs. From the lower beds cavities ranging from those a fraction of a foot in diameter, to alcoves and recesses that would accommodate an ordinary house, are carved from solid rock.

Jointing, although generally absent in this unit, is in two places remarkably developed. The parallel jointing of Saucer Basin and a peculiar jointing found in Yellow Jacket Canyon are peculiar to these localities.

The cross bedding of the La Plata formation is hard to exaggerate. Cliffs 200 feet high often show only the slightest tracery of bedding, but along the strike from such localities it is often only a short distance to outcrops showing the other extreme. In places layers 40 feet thick are composed entirely of laminae making 30 degree angles with the true bedding, and are truncated both above and below by sandstones which show no evidence of stratification.

The Lower La Plata shows the greatest development of this false bedding where it reaches its maximum thickness. Beds making 20- to 30-degree angles with underlying strata often show parallelism in their outcropping edges over areas of several acres. Isolated exposures in such localities are useless in working out problems of structure; in fact, observations in a single locality can never be trusted to establish the direction of true bedding. Individual laminae of cross-bedded material are over 100 feet long in many places and show little if any curvature in that distance. Again beds curved by different radii often measure only a few feet in length. The more or less straight laminae make up the greater volume of the cross-bedded materials. Aside from local areas the direction of this false bedding appears to be lawless.

DISTRIBUTION

The La Plata outcrops, except for one small area in Gypsum Valley, are underlain by Dolores sediments, and presumably once extended over all the area now covered by the Dolores formation.

Because of the vertical faces of the La Plata outcrop, its distribution is that of a ribbon which occupies only a small fraction of the total area mapped. It appears in the walls of Paradox and Sinbad valleys and extends down either side of the Dolores Canyon to and beyond the boundary of Colorado. Along Dolores River the La Plata outcrop parallels the massive Dolores sandstone and together they make great detours around the heads of the many canyons tributary to Dolores River. In the vicinity of West Creek the La Plata outcrop swings back to the base of the Uncompahgre uplift and connects with its exposures along Maverick and Calamity gulches.

Along the face of the Uncompahgre Plateau the La Plata fringes the Dolores formation. Here its decreased thickness and a heavy mantle of vegetation make it less conspicuous than elsewhere. Along the base of the plateau its upturned edges appear at intervals as white or red spots; in other places faulting prevents it from

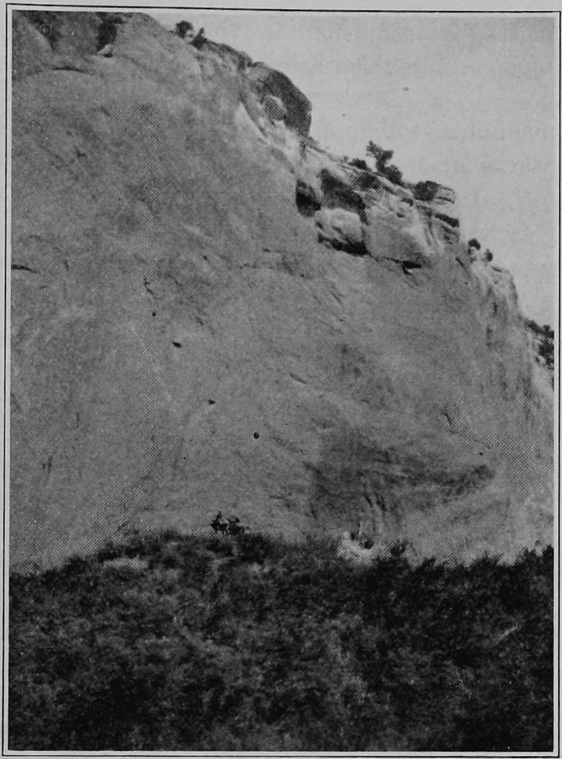

Fig. 12. Sandstone of the La Plata formation in Yellow Jacket Canyon.

outcropping. La Plata sandstone can be traced eastward to Tabequatche Basin and it occurs as isolated exposures in Horse Fly Creek and its tributaries.

From Paradox Valley the La Plata can be traced south in continuous outcrop up La Sal Creek and to Coyote Wash. It encircles Silvey's Pocket and becomes conspicuous in Bull Canyon; from here it swings back to its Paradox exposures. It follows up the north side of Gypsum Valley at the head of which an unconformity cuts it off. The downwarp of Disappointment Valley causes its disappearance for a short distance along the Dolores River near the mouth of Disappointment Creek. Above this creek La Plata appears in the canyon walls to the limit of the map. Its exposures in Bush Canyon are isolated, but its outcrops in Summit and Bishop canyons connect by way of Dolores River with those that reach well up McIntyre Canyon.

The large area of the Dolores formation which occurs in McElmo Canyon is walled in by cliffs of La Plata sandstone 200 feet high. And La Plata sandstone is exposed in the bottom of Yellow Jacket Canyon and its tributaries as long narrow outcrops.

SELECTED SECTIONS

The maximum section of La Plata strata measured occurs near Bedrock, where Messrs. Worcester and Pynch record the following:

Section of La Plata Formation in Paradox Valley Three-fourths of a Mile Southwest of Bedrock

MEASURED BY P. G. WORCESTER AND J. A. PYNCH

Top.		Feet.
	McElmo.	
1.	Sandstone, white, fine grained; a few thin beds of red shale	110
2.	Sandstone, white, cross bedded, yellowish, fine grained, friable	100
3.	Sandstone, reddish to pink, fine grained, very uniform in composition	98
4.	Sandstone, white, highly cross bedded	93
		401

In Bull Canyon the section is typical of the three-phase character of this formation; that is, two massive sandstones separated by thin beds of shaly sandstone.

Approximate Section of La Plata Formation in Bull Canyon

MEASURED BY R. C. COFFIN

Top.		Feet.
	McElmo.	
1.	Sandstone; white at top; pink or red in lower portion; very massive, even grained, weathers with rounded, smooth surfaces with almost no planes of division	130
2.	Sandstone and shaly sandstone, fine grained, red	30
3.	Sandstone, highly cross bedded, even grained, pink to light red	155
		310

No. 1 and No. 2 of the Bull Canyon section constitute the Upper La Plata and No. 3 the Lower La Plata, as mapped in this region.

Section of La Plata Formation in the Dry Creek Anticline, Two Miles Southwest of Coke Ovens.

MEASURED BY R. G. COFFIN AND J. A. PYNCH

Top.		Feet.
	McElmo.	
1.	Sandstone, poorly indurated, grades upward into red shale; calcareous at the base	56
2.	Sandstone, light red to white, calcareous, free from joints or bedding; weathers rough and cavernous	5

3. Sandstone, salmon colored, massive, even grained, well indurated, cross bedded in places; decidedly free from jointing	77
	138

Probable unconformity.
Dolores formation.

FEATURES OF OTHER SECTIONS

The medial limestone in the sections of La Plata strata of the San Juan Mountains was seen in the carnotite country in only one locality. A cherty limestone found on the bench that extends between Bull Canyon and Gypsum Valley comes in that part of the section occupied by bed No. 2 of the Bull Canyon section. It is worthy of note that strata in similar positions in La Plata sections elsewhere contain calcite concretions or include highly calcareous shales. These calcareous beds exist in the Dry Creek anticline, in Summit Canyon, and have been noted at other points.

The general characteristics of the La Plata formation remain constant over areas so wide that sections at different points differ only in thickness. On La Sal Creek and in Coyote Wash the La Plata formation exceeds its Bedrock measurement as a result of a thickening of its lower members. This increase is to be expected

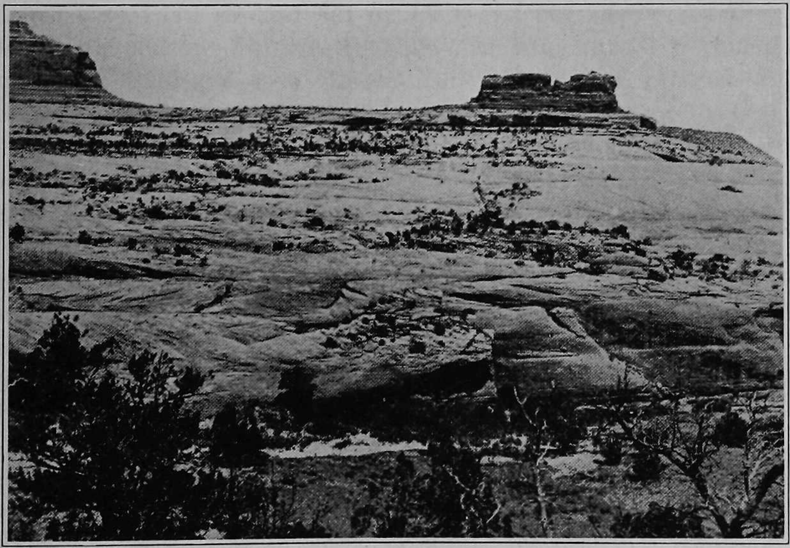

Fig. 13. Sandstones of the La Plata group in the west edge of Silvey's Pocket.

The remnant at the top of the cliff is of the Upper La Plata formation, and the lower beds are of the Lower La Plata formation: the base of the cliff includes beds of the Dolores formation; stratigraphic interval represented, over 500 feet.

in this region as the exposures are contiguous with those of Dry Valley, Utah, where the La Plata is reported to be 700 feet thick.

North and east of Bedrock the thickness of the La Plata formation decreases rapidly. At the mouth of San Miguel River the upper member is 140 feet thick but the lower member is less than 40 feet. Both members decrease further in thickness up the San Miguel, and the total section measures only 120 feet at the Ford Camp of the Standard Chemical Company. La Plata outcrops along the Dolores River from the mouth of the San Miguel to the Utah-Colorado line measure approximately 175 feet at many points. Less than 50 feet is considered Lower La Plata.

Aneroid measurements of La Plata outcrops along the upper Tabequatche and Horse Fly creeks indicate a thickness of 40 to 60 feet. Strata corresponding to the Lower La Plata of the Bull Canyon section, if present in these outcrops, are limited to less than 10 feet.

The La Plata exposures in Klondyke form a wedge which measures 50 feet thick in the southeastern part of the exposures, but decrease in thickness toward Gypsum Valley and do not appear in places along the ridge which divides east Gypsum Valley from the drainage of Disappointment Valley. The Upper La Plata is estimated to be 100 feet thick in the Dolores Canyon above the mouth of Disappointment Valley. Below this the Lower La Plata thickens to over 50 feet, then rapidly decreases in thickness and probably disappears. A similar thinning and apparent disappearance of this unit is observed in Summit Canyon.

The La Plata formation adjacent to McElmo Canyon is about 200 feet thick. However, there is a slight decrease in its thickness in the eastern exposures along this canyon. The lower part of the 200 feet is highly cross bedded and makes no sharp contact with the massive but less cross-bedded upper part. The formation does not show in this region the general subdivisions of the Bull Canyon section and it is impossible to apply here the terms Upper La Plata and Lower La Plata. No unconformity has been reported within the La Plata formation of this region.

The conditions under which the La Plata sandstones were deposited must include those of generally shallow water and possibly wind deposition. In large areas of shallow-water deposits local unconformities may be present in any part of the formation. Two places within the area of the present survey point to this possibility.

Prof. Henderson found Lower La Plata beds in little Gypsum Valley cut off by Upper La Plata sandstones, and on the bench between Gypsum Valley and Bull Canyon he found that the medial limestone appeared and disappeared under the Upper La Plata in a manner best explained by the presence of an unconformity. At one point fragments of this limestone were inclosed in the overlying sandstones. R. G. Coffin observed in Summit Canyon "beds of Lower La Plata truncated by the Upper La Plata."

The presence of an unconformity at the base of the Upper La Plata would presuppose a much wider extension of Lower La Plata sediment than that represented by its present outcrops. The limits of the supposed greater extension of the Lower La Plata cannot now be determined.

THE LOWER CONTACT OF THE LA PLATA GROUP AND THE RELATION OF ITS TWO MEMBERS

The surfaces upon which the La Plata formation rests possess many undulations aside from those given it by faulting and folding. In some places this surface becomes a plane which extends without irregularities over large areas, and no evidence of an unconformity exists. However, the same strata do not represent the basal beds of the La Plata group at all points. As already noted the Upper La Plata occasionally overlaps the Lower La Plata. The series of red sandstones and shales that cap the Dolores formation in this region and separate the massive Dolores and La Plata sandstones ranges greatly in thickness. In Paradox Valley the series is 300 feet thick and in Sinbad Valley not more than 50 feet. Such differences could be due to unequal erosion previous to La Plata deposition. However, no positive evidence was found that an unconformity existed at the base of the La Plata formation in any area north of Paradox Valley. But south of Paradox Valley direct evidence of such an unconformity was found at the north side of Little Gypsum Valley. Prof. Henderson notes at this point an unconformity at the base of the La Plata which "cuts off at least 100 feet of Dolores strata within a distance of 200 yards." He states further, that "the total thickness of the La Plata group does not exceed 150 feet," which includes "the diminished thickness of the Lower La Plata."

This unconformity is also apparent in Gypsum Valley. The Dolores formation decreases in thickness continually from the mouth of Gypsum Valley to its head where La Plata strata overlap all Triassic sediments and rests upon Pennsylvanian beds. (See fig. 49, p. 210). Again, a slight discordance of dip between beds of the

Dolores formation and the La Plata formation in the Dry Creek anticline suggests an unconformity at that point. Incomplete observations in the canyons south and west of Disappointment Valley show that the rapid thickening of the Lower La Plata is due either to a Dolores-La Plata unconformity, or to an unconformity within the La Plata itself. No evidence of an unconformity between the La Plata and the Dolores formations was found in McElmo Canyon.

The observed relations of the Upper La Plata and the Lower La Plata would admit of any one of the following interpretations:

(1) An unconformity at the base of the Lower La Plata;

(2) An unconformity between the Upper La Plata and the Lower La Plata;

(3) Or, an unconformity both above and below the Lower La Plata.

The conditions implied by any one of the assumptions could have produced an undulating surface of Dolores upon which younger beds would accumulate in unequal thickness. The lower La Plata sandstone being the first deposited would acquire its maximum thickness in depressions due either to erosion or to warping. Sediment would accumulate less rapidly on the elevated parts of this uneven surface and would appear in their present outcrop as beds of lesser thickness. It must be noted further that deposition becomes less as distance from the source of material increases.

In such an arrangement as the one postulated, beds of the Lower La Plata would disappear successively from the base; upper beds continually overlapping the lower and reaching further up the sides of the depressions. In this way the upper beds would cover greater areas than the lower ones, and, in lesser thickness, might cover the areas of greatest elevation. Such a condition would explain the thinning of individual parts of the Lower La Plata north and east from Paradox Valley.

The unconformity which is established at points south of Paradox Valley at the base of the Upper La Plata and the one suggested as being present at the base of the Lower La Plata are probably general, although single outcrops which show these conditions are not plentiful.

LITHOLOGIC CHARACTER

The material in both the Upper and Lower La Plata sandstones is remarkably uniform throughout the area. Slight differences of color and bedding are apparent in large cliffs which cannot be recognized in small exposures. Hand specimens collected from La Plata outcrops 75 miles apart appear to have come from the same ledge. The bulk of the material is subangular to well-rounded quartz grains, with a cement of ferric iron, some calcite, and occasionally quartz. Poorly cemented grains make up a large fraction of the exposed rock, the original cement having been largely removed. Few grains exceed a twentieth of an inch in diameter and others are too small to be recognized by the unaided eye. Occasional minute grains of clay appear to be altered feldspar. Some specimens examined under a lens were made up of almost perfect spheres of translucent quartz which had the appearance of fish roe. Occasionally grains of quartz the size of peas occur in seams or distributed singly.

The occurrence of secondary color changes in this formation is common in faulted or highly folded regions. Fractures sometimes abruptly terminate the generally red to pink colors on one side and white to yellowish ones on the other.

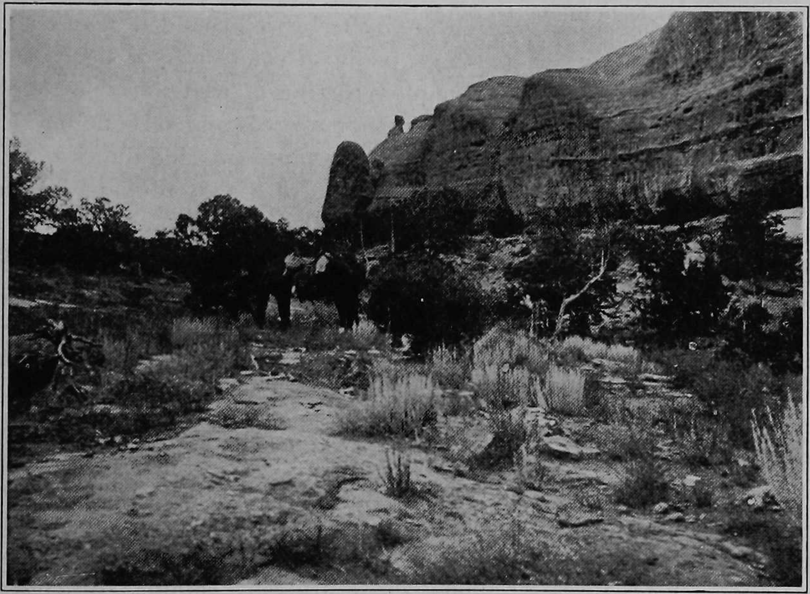

Fig. 14. Detail of the Upper La Plata in the north wall of Gypsum Valley. The medial limestone of the La Plata group, where present, is located at the foot of this cliff.

Shaly seams form partings and thin beds in the top 10 feet of the Upper La Plata formation, again near the base of this unit, and indiscriminately in the Lower La Plata. These beds are often two feet thick and are generally made up of deep red sandy shale.

These shaly beds, especially those in the base of the Upper La Plata, carry calcite concretions at many points.

Beds of La Plata limestone were observed only on the bench between Gypsum Valley and Bull Canyon. These exposures consist of a 4-foot bed of dense blue limestone which breaks with a conchoidal fracture. Chert was present in seams up to those two inches in thickness.

CONDITIONS OF DEPOSITION

The generally red color of the La Plata and lower formations has long been held as evidence of the aridity of the climate of the lands from which they were derived. The suggestion of the dune origin of some of these deposits fits well with this idea. H. E. Gregory,[31] in describing the Navajo sandstone (equivalent of the Upper La Plata) in Arizona and New Mexico, states that the Navajo outcrops differ in no way from the present sand dunes of the region except in color and consolidation.

The predominance of clean quartz in well-rounded grains and the absence of coarse particles point to conditions of deposition which involved an almost complete sorting of well worn particles. Wind-blown sand could supply these materials and account for the elaborate scheme of cross bedding. The supposed sand dunes would be modified more or less by the invasion of a body of water under which they were largely consolidated in their present form. Waters advancing over these wind-shifted sands would rework the deposits, obliterating the original markings on all elevated parts and filling in depressions. Such an order of events would explain the areas of intricately cross-bedded sandstone terminated above by material which indicates the true bedding.

The beginning of this water invasion would necessarily result in irregularly distributed ponds in which may have been formed the isolated beds of limestones below the Upper La Plata. Cross bedding is present in the upper member of this formation, but is not as abundant or as intricate in design as the cross bedding of the Lower La Plata. Shallow water probably obtained through a part of Upper La Plata deposition but not necessarily at the close of this period.

The lack of animal fossils in these beds has been used as evidence of its probable fresh-water origin. A rapid advance of water over an arid region could explain the apparent absence of plant remains. West of the area mapped, beds of gypsum between the

[31] Gregory, H. E., Geol. of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, p. 59, 1917.

equivalents of the La Plata and McElmo formations point to the existence of salt-forming conditions for at least a short time at the close of La Plata deposition. No strata in the La Plata sections of the area surveyed appear to be equivalent to these probable oceanic beds.

PREVIOUS DESCRIPTIONS AND CORRELATIONS

Different Hayden geologists included the La Plata in their "Triassic," and G. H. Eldridge[32] included strata in his Jurassic formation (Gunnison) of the Anthracite and Crested Butte quadrangles which were later correlated with Cross's[33] McElmo and La Plata of the San Juan Mountains.

Cross[34] correlated the La Plata with Powell's[35] White Cliff of the Grand Canyon section, and recently W. T. Lee[36] suggested the inclusion of the Vermilion Cliff of the same locality as a part of the Lower La Plata. If the massive Dolores sandstone in the area of this report is to be considered the equivalent of the Vermilion Cliff, as Cross[37] seems to think it should be, some doubt exists as to Lee's correlations of the Dolores sandstone, as the observations of the present survey clearly show its position below the La Plata.

The descriptions by Cross of the Upper La Plata and the Lower La Plata of Dry Valley, Utah, would indicate that these beds differ only in thickness from similarly named units of the present report.

Farther south H. E. Gregory[38] recognized the equivalents of the La Plata group in his Navajo, Todilto, and Wingate formations which he correlated respectively with the upper, middle, and lower La Plata of the San Juan Mountains.

A. C. Spencer, during his traverse down the San Miguel River and into neighboring territory, assigned 1,000 feet of strata in Paradox Valley to the La Plata.[39]

No such measurements were made of this formation by the present survey and some doubt exists as to his supposed limits of the La Plata formation. It is possible that Spencer here included

[32] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite and Crested Butte folio (No. 9).
[33] Cross, Whitman and Howe, Ernest, Red Beds of southwestern Colo. and their correlation: Bull. Geol. Soc. of America, vol. 16. p. 469, 1905.
[34] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colo. and Utah: Jour. Geology, vol. 15, No. 7, pp. 641-642, Oct.-Nov., 1907.
[35] Powell, J. W., Report on the Geology of the eastern portion of the Uinta Mountains: U. S. Geol. Survey Terr., pp. 51-54, 1876.
[36] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Miscellaneous Collections, vol. 69, No. 4, pp. 26 and 39, 1918.
[37] Cross, Whitman, Idem. pp. 659, 661 and 664.
[38] Gregory, H. E., Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, pp. 16 and 52, 1917.
[39] Cross, Whitman and Howe, Ernest, Red Beds of southwestern Colo. and their correlation: Bull. Geol. Soc. America, vol. 16, pp. 472-473, 1905.

in his La Plata the massive Dolores sandstone which, in places, is separated by a stratigraphic break from typical Lower La Plata sandstone.

A. C. Peale[40] cited "the upper portion of the Triassic beds (equivalent of La Plata), as being directly superimposed on Archean Rocks," at the head of Atkinson Creek. La Plata beds are locally in contact with the granite in this region but their position is due to faulting, as they are not in original contact but are separated stratigraphically from them by 400 feet of Dolores and Cutler beds.

W. T. Lee[41] has recently made elaborate correlations of Jurassic strata for a large part of the Southern Rocky Mountain province and shows that the La Plata formation probably has equivalents in the "Red Beds" far beyond the limits represented by the correlations given.

The subdivisions of the La Plata as used in this report are, in a general way, equivalent to the main divisions of the La Plata of the San Juan Mountains. The Upper La Plata, where mapped, probably includes at its base strata equivalent to the middle or calcareous part of the mountain sections which have here become inconspicuous and hard to separate from the overlying sandstone.

The descriptions of the members of this formation in other regions differ from the observations in the present area only in the relative thickness and extent of its upper and lower members. In the area of this report the Upper La Plata is more conspicuous and does not show the extreme range of thickness of the lower member. This condition does not appear to be the normal relation elsewhere. Cross[42] in generalizing the relations in the La Plata, says: "Of the two sandstone members (Upper and Lower La Plata) 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." Lee comments on the general distribution of the La Plata group as follows:

> These accumulations constitute the upper part of the La Plata group, which seems to form a wedge entering from the west and thinning eastward. * * * The rocks of this wedge are not as regular in thickness as those of the lower La Plata. They thin out to the south and east and also in some places in the midst of the area where the upper La Plata is typically developed.

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[40] Peale, A. C., U. S. Geol. and Geog. Survey of the Territories, Ninth Ann. Rept., p. 55, 1875.

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

[42] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colo. and Utah: Jour. Geology, vol. 15, No. 7, p. 641, Oct.-Nov., 1907.
Lee, W. T.: Idem. p. 40.

These observations are not necessarily at variance with each other, as the area of this survey may represent a local phase and not an average section of these rocks. In this connection it can be stated that west from the central area mapped a very rapid thickening of the Lower La Plata appears to be the beginning of a rather increased prominence of this bed, which, in Utah, equals and then surpasses the Upper La Plata in thickness and regularity.

JURASSIC OR CRETACEOUS FORMATIONS

The beds which immediately overlie the La Plata formation and come below the conglomerate which caps numerous mesas, constitute a geologic unit whose age has never been conclusively determined. No determinative fossils have been found in these beds which geologists agree comprise the McElmo formation, or the equivalent of the Morrison formation of the front range. The question as to the Jurassic or Cretaceous age of the McElmo formation is not made a part of this paper.

McELMO FORMATION

INTRODUCTION

The McElmo formation consists of an upper part predominantly shale and a lower part predominantly sandstone. These two parts are about equally prominent and constitute a thickness of sediment which ranges from 500 to 900 feet. In as much as the sandstone part of the formation includes the carnotite-bearing beds the formation is the most important one of the series.

DEFINITION AND BOUNDARIES

The area covered by this report includes that part of McElmo Canyon which Cross used as the type locality of the McElmo formation. H. S. Gane, under the direction of Cross, studied these beds in this canyon and applied the term McElmo to a series of sandstones and shales which he found above the La Plata sandstone and below the mesa-forming conglomerate of the "Dakota."

The lower limit of this formation presents no problem of separation, as the boundary is well marked by the abrupt change from the massive, white to pink La Plata sandstone to a series of dark maroon shales and thin-bedded sandstones of the basal McElmo. The plane dividing these two formations can be placed within an error of 20 feet. In one small area near the head of Gypsum Valley the La Plata sandstone has been removed by pre-McElmo erosion; in this area the McElmo formation rests upon Pennsylvanian (Carboniferous) beds.

The upper limit of this formation is a massive sandstone conglomerate which, for reasons to be stated presently, is referred to as

Post-McElmo. This massive bed so consistently forms the highest of several benches that prospectors term it "the rim rock." In the southern areas a conglomerate near the top of the McElmo formation is so much like the conglomerate in the next higher formation, and their positions stratigraphically so close, that their division is sometimes difficult. The plane which divides the McElmo from the Post-McElmo formation is an undulating surface which brings different beds in contact with the overlying conglomerate. It is nowhere difficult to limit approximately the McElmo formation, and it is only in places where its upper part includes conglomerates that this boundary needs careful study.

GENERAL CHARACTERISTICS

The McElmo formation reaches its minimum thickness of 500 feet in McElmo Canyon and its maximum thickness of 900 feet at points within the northern half of the area examined.

The lower half of the formation is made up of vari-colored shales interspersed with thin beds of sandstone, an occasional limestone or calcareous bed, and locally one or more conglomerates near the top. Although individual beds play out along the strike, the general characteristics of the formation, the succession of beds, and the ratio of shale to sandstone prevail over the entire area. It is probable the 500 feet of sediment in the southern area and the 900 feet in the northern area represent practically the same interval of time.

PREVIOUS DESCRIPTIONS

The descriptions of the geologic units recognized by the Hayden geologists who studied this region are necessarily generalized in such a way that their application to any single area is a difficult, if not a questionable, procedure.

It is interesting to note that the mapping of W. H. Holmes[43] during this early survey does not include in McElmo Canyon any Jurassic division.[44] The mapping of the Lower Dakota in this region includes in a general way the McElmo of the present report. In fact, in the section of strata of the San Juan Valley the Lower Dakota corresponds very well with the section of the McElmo formation in McElmo Canyon.

The exact division of the several geologic units used by A. C. Peale[45] in the region of Paradox Valley is not entirely clear. His section for the region includes the following:

[43] Holmes, W. H., Hayden Geol. and Geog. Atlas of Colo., sheet XV.
[44] Holmes, W. H., Geol. and Geog. Survey of the Territories, Ninth Ann. Rept., p. 244, 1875.
[45] Peale, A. C., U. S. Geol. and Geog. Survey of the Territories, Tenth Ann. Rept., p. 180, 1876.

The Dakota group for the most part is horizontal, and the conditions of the strata are uniform. It forms the tops of the bluffs on all the canyons. It is a moderately compact, yellowish, siliceous sandstone. Beneath are greenish shales and bands of sandstone. The latter have been referred to the Lower Dakota. The total thickness is about 600 to 700 feet, about 200 feet being referable to the upper Dakota.

In his description of the Jura-Trias,[46] he states:

Its (the Trias) thickness is from 500 to 1,000 feet. * * *. The variegated sandstone shales that lie above have been colored on the map to represent the Jurassic. The general character is the same as previously described—soft greenish and gray argillaceous and arenaceous shales and marls near the top, passing into the Lower Dakota sandstone, and dull, reddish laminated sandstones and shales at the base. * * * The Rio San Miguel has an outcrop of Jurassic at the bottom of its canyon walls almost its entire length.

Peale's Lower Dakota corresponds in general to the variegated shales of the McElmo and his upper division of the Jura-Trias includes the sandstones of the lower McElmo. His mapping in places includes areas of La Plata within the "Jura."

The McElmo formation of the San Juan Mountains[47] is somewhat thinner and contains a larger proportion of shale than it does within the areas covered by this report. A conglomerate is described as being present near the top of the formation in only the Telluride quadrangle, in which particular the area resembles the McElmo Canyon district. However, it must be remembered that conglomerates may be locally present within any part of the upper half of this formation.

H. E. Gregory[48] found beds in the Navajo country occupying the stratigraphic position of the McElmo of Colorado, and he extended the name to include this geologic unit in his mapping of the region. This formation, as described by Gregory, is somewhat thinner and includes more sandstone beds in its upper half than does the McElmo of the present report.

TOPOGRAPHIC EXPRESSION

The relation of the shale part of the McElmo formation to its sandstone part has resulted in a topographic form of great help to prospectors in recognizing the important carnotite-bearing sandstones. The important productive beds are included within a 50-foot zone which offers more resistance to weathering than any similar combination of beds within the lower two-thirds of the formation. Inasmuch as this carnotite-bearing zone comes at the base of the easily eroded shales and at the top of the sandstone

[46] Op. cit., p. 179.
[47] Cross, Whitman, and others, U. S. Geol. Atlas: Telluride folio (No. 57), Engineer Mt. folio (No. 171).
[48] Gregory, H. E., Geology of the Navajo Country, U. S. Geol. Survey, Prof. Paper 93, pp. 59-65, 1917.

fraction of the formation, this zone forms a bench when in horizontal outcrop, and a ridge when in tilted outcrop.

Where the McElmo and the overlying and underlying formations are exposed in horizontal position their cross section becomes so nearly constant as to make a generalized profile represent con-

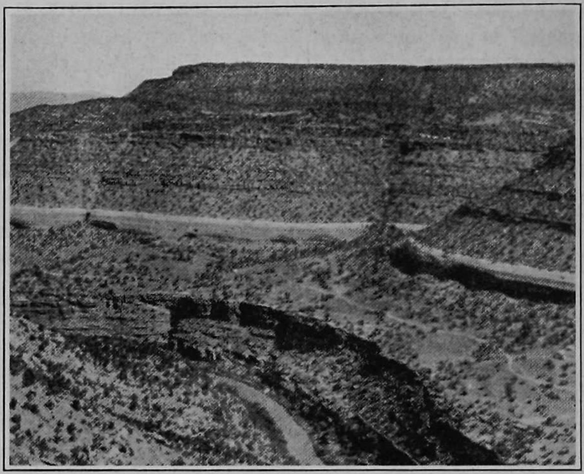

Fig. 15. Typical outcrop of the McElmo and adjoining formations along San Miguel River 2 miles above its mouth.

The beds exposed from the bottom up are: Dolores, forming the inner gorge; La Plata, smooth-weathering formation; carnotite-bearing sandstones first bench-forming beds above the La Plata; topmost beds, Post-McElmo and "Dakota." Dolores Camp is situated on the bench formed by the carnotite-bearing sandstone near the right hand margin of the picture.

ditions at many points. The sandstones in the lower part of the formation form a steep slope consisting of about 300 feet of sediment, terminated at the base by the smooth La Plata outcrop and above by the carnotite-bearing sandstone bench. Within this slope from 3 to 6 ledges represent as many sandstones separated by less massive beds. Above these strata the shales weather back in a continually rising slope, within which an occasional sandstone layer shows disconnected outcrops. The protection afforded by the sandstone-conglomerate above the McElmo causes the upper part of the formation to retain a rather steep slope which often includes the conglomerate locally present near the top of this formation. The bench carved from the McElmo shales is so continuous that it, with the bench below the La Plata, affords two parallel routes differing in elevation by approximately 500 feet, and by means of which the carnotite-bearing sandstones can be followed along both their upper and lower limits.

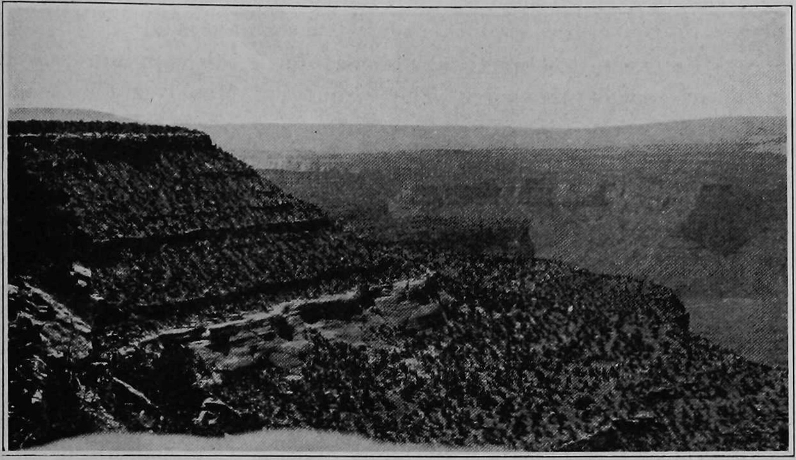

Fig. 16. Normal outcrop of the lower half of the McElmo formation and the La Plata (light colored) sandstone.

The uppermost bed is the main carnotite-bearing sandstone: Dolores River Canyon to the right.

Within disturbed or highly folded areas the outcrop of the McElmo sandstones rises from the La Plata in a series of steps, each sandstone furnishing the cap rock for a bench which parallels the La Plata outcrop and which is separated from the next lower or higher one by a distance that ranges from a few yards to a half mile.

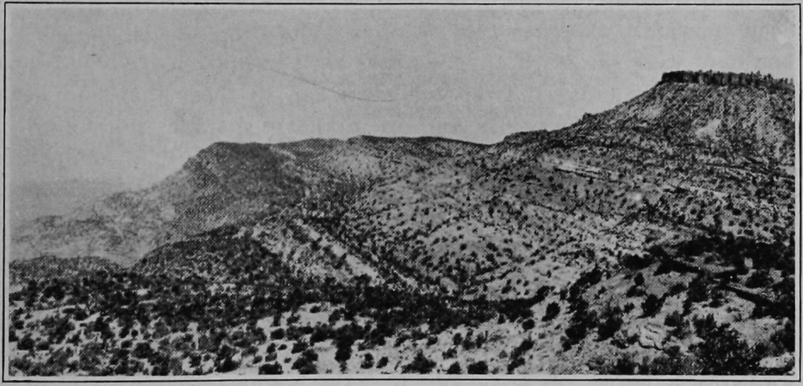

Fig. 17. Outcrop of the McElmo and adjoining formations in the north wall of East Paradox Valley.

Uppermost bed is the Post-McElmo conglomerate; light colored beds in the left central part are La Plata sandstones: the main carnotite-bearing sandstones are the light colored beds outcropping midway between these two formations.

The absence of the Post-McElmo conglomerate has resulted in places in the entire removal of the variegated shales. In such areas the carnotite-bearing sandstones form the capping rock of mesas of considerable size. The vicinity of Maverick Gulch and the divide between West Paradox Valley and Roc Creek offer good examples of such removal.

The southern part of the area mapped includes examples of bad-lands topography developed in the McElmo shales. A large area is composed of irregular buttes, rounded hills and cones. Bands of green, blue, brown, black, and occasionally red, which traverse the sides of these remnants, justify the term "variegated shales," and suggest the reason for Ward's "Painted Desert formation" of the Plateau Country.

The plastic character of the McElmo shales when wet, has developed slump togopraphy in many places. This slumping proceeds as movements of individual boulders or in large masses. In Tabequatche Basin the latter type of movement prevails and the results can be described as mud flows. These movements are characteristic of the upper half of the McElmo formation, and generally involve the overlying conglomerate. Debris from these beds covers the upper carnotite-bearing sandstone in places, and their nature should be understood by the carnotite prospector.

The area between the Post-McElmo "rim rock" and the bench marking the outer limit of the shale exposures often presents a jumble of boulders derived from the overlying formation. These boulders are turned at every possible angle and are of all sizes; some measure over 25 feet in their shortest dimension. Many boulders were observed representing all stages of movement from those scarcely cracked from the mesa cap to those that had been lowered 900 feet vertically and an unknown distance horizontally. Many of these boulders move by the creeping of the shales on which they rest, and probably at no time in their travel is their motion visible. One isolated boulder along Maverick Gulch had been lowered 30 feet from its parent bed; on top of this boulder a smaller one rested upon a shaly sandstone which separated the two. The two boulders and remnant of dividing shaly sandstone represented the arrangement and order of deposition as found above in the undisturbed cliff. It is evident that the boulder remained oriented in approximately its original position throughout its movement. Many cases exist, however, where huge blocks of sandstone or conglomerate have broken from ledges and rolled great distances.

Depressions of rudely circular outline and without visible outlets occur in places within the shale areas. Several measured more than 30 feet across and 15 feet in depth. Such depressions represent removal of shale, when wet, through subterranean outlets to near-by gulches. Their formation is due to the movement of shale as a very plastic or semi-fluid material rather than the direct result of solution. No limestone beds or other soluble material exist in these strata in sufficient thickness to make possible the formation of these depressions by the collapse of solution cavities.

Areas one-fourth to one mile across exist in Tabequatche Basin and vicinity, which show no regular bedding but consist of an erratic mixture of McElmo shales and sandstone from the overlying formation. Distinct features of these areas are the numerous lakelets, swamps, and marshy patches surrounded by low hills of different sizes and shapes. Outwardly, the area resembles a glaciated district. The arrangement of the lakelets and relation of disturbed to undisturbed beds and the absence of materials other than those of the McElmo and immediately overlying formation, would not admit of their glacial origin. The basin owes its peculiar topography to the ability of the McElmo shales to flow when wet, and the presence of similar slumping along the Uncompahgre Plateau is due to the greater rainfall of this region.

Slumping is characteristic of the upper part of the McElmo formation and there are many areas of the sort just described besides those mapped. The only ones shown are those of considerable size or those wherein doubt exists as to the character of the underlying formation.

In view of the fact that a complete understanding of the habits and relations of outcrop of several members of the McElmo formation, especially of its sandstone members, is absolutely necessary for the most efficient prospecting for carnotite, the nature of the McElmo outcrop will again be referred to under the suggestions to prospectors.

DISTRIBUTION

The McElmo formation once extended over the entire area covered by the present report, and is now exposed in practically all canyon walls. Aside from the exposures along Dolores and San Miguel rivers, the areas showing McElmo as the surface formation can be placed in five general regions: The Uncompahgre uplift and vicinity, Paradox and Sinbad valleys with adjoining territory, Gypsum Valley and Silvey's Pocket, McIntyre District and vicinity, and McElmo Canyon and the area drained by its tributaries.

The McElmo formation is exposed along the edge of the Uncompahgre Plateau for over 30 miles. The width of the McElmo exposure increases in the western part of the plateau and north and east of Uncompahgre Butte, McElmo shale extends beyond the area mapped. Narrow strips of this formation are exposed along the numerous streams which cross the basin between the Uncompahgre Plateau and Dolores and San Miguel rivers. Near the plateau these strips widen into a more or less continuous outcrop which follows the foot of the uplift. Exposures of this formation are of considerable size along Tabequatche Creek and in Spradlin Park. And east of this park the exposures follow the abrupt changes in elevation which result from the Uncompahgre uplift.

Many remnants of McElmo exist adjacent to Dolores River. Maverich Gulch, West Creek, and Dolores River bound a huge block of the Dolores and La Plata beds capped by McElmo sandstone. The exposures of this formation along the east side of Maverich Gulch are only a part of a large area which includes the Calamity Gulch and Blue Creek exposures and extends back to the Uncompahgre uplift.

The canyon of San Miguel River exposes McElmo beds throughout the part of its course which comes within the area mapped. The divide between this stream and East Paradox Valley is entrenched by numerous gulches which have left a surface of the McElmo formation dotted with irregularly shaped remnants of Post-McElmo conglomerate. The divide between West Paradox Valley and Roc Creek includes areas of McElmo beds from which the shales have been largely removed. These same beds circle the west side of Sinbad Valley and from here their outcrop parallels the La Plata outcrop to the Utah-Colorado line.

The south wall of Paradox Valley contains McElmo beds which extend east into the Dry Creek anticline and thence up Dry Creek into the edge of Dry Creek Basin. Broad exposures of these beds extend south from Paradox Valley along either side of Dolores River. On the west side they extend west along La Sal Creek, appear in Coyote Wash, and extend from here through Silvey's Pocket into Little Gypsum Valley. On the east side of Dolores River re-entrants of this formation border Spring and Bull canyons and connect with exposures which outline Gypsum Valley.

The syncline of Disappointment Valley confines the McElmo outcrops to an area adjacent to the Dolores River. From Little

Gypsum Valley its exposures can be traced into McIntyre Canyon and into the east end of Lisbon Valley, Utah, thence by circuitous routes they can be followed to the areas along Summit and Bishop canyons. From the head of Summit Creek the high ground running in an easterly direction marks the south, and Dolores River the north boundaries of a large area of McElmo which wedges out toward the Dolores Canyon where the exposures are limited to two narrow strips along the river.

The exposures of the McElmo formation in McElmo Canyon show a very irregular pattern of strips and patches along and between streams which extend back from the main canyon. Among the important canyons which expose these beds are: Cross, Hovenweep, Nigger, and Yellow Jacket with its tributary, Sandstone Canyon.

Numerous shorter canyons and gulches leave remnants and head-lands of Post-McElmo formation extending out from the main plateau. More than 75 per cent of the area mapped McElmo in this region, shows only the shale beds of the formation. Along the Colorado-Utah boundary the drainage through Montezuma Creek of Utah, shows small areas of McElmo which are the beginning of large exposures that extend beyond the Colorado line.

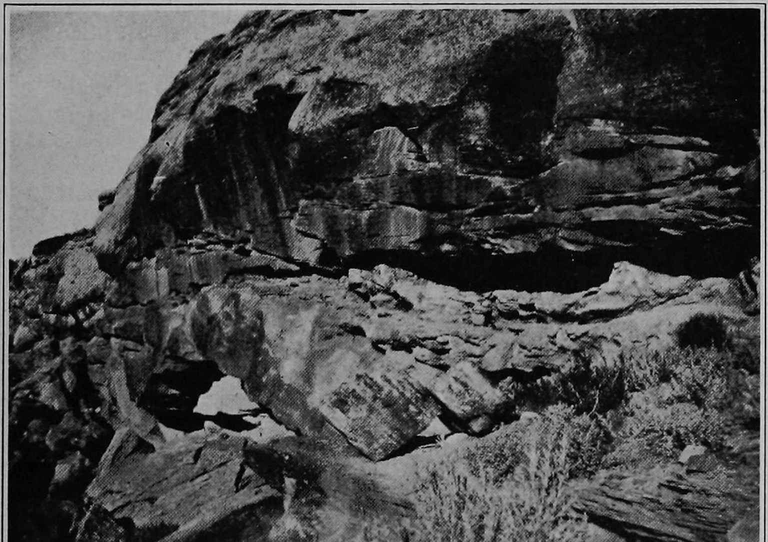

Fig. 18. Detail of the main carnotite-bearing sandstones.

The cavernous parts of the beds are due to the weathering out of shale lenses which are characteristic of these sandstones.

The distribution of the McElmo formation outlined is not a complete guide for the direction of prospectors of carnotite ores. Much of the area mapped McElmo can be excluded as being unworthy of the prospector's attention. This point is given further attention in discussing geology of individual areas.

TYPICAL SECTIONS

Detailed sections of the McElmo formation are of little value in correlating beds at any great distance. Although the general sequence of beds and the relation of sandstone and shale content remain remarkably uniform for the lower two-thirds of the formation, single strata cannot often be traced great distances. Sections 100 feet apart often show differences in the thickness of corresponding beds. In spite of these differences the total shale and sandstone content of either section is often the same.

The four sections that follow give the main features as found in representative regions.

Section of McElmo strata in the north wall of McElmo Canyon, east of Sand Gulch.

(THICKNESS OF LARGER UNITS DETERMINED BY ANEROID)
MEASURED BY R. C. COFFIN

Top.			Feet.
	Post-McElmo conglomerate.		
1.	Shale, greenish, with an occasional thin bed of sandstone		32
2.	Conglomerate and coarse sandstone, green pebbles in conglomerate; forms cliff subordinate to the Post-McElmo conglomerate above		60
3.	Shale, with an occasional thin impure sandstone bed; shale predominantly green with chocolate-colored bands interspersed		150
4.	Sandstone and shale alternating; shale generally green, predominates in upper half and sandstone in the lower half		100
5.	Sandstone, in beds from 2 to 12 feet thick, with dividing lenses of red to chocolate-colored shale		190
6.	Sandstone and shale; shale red to chocolate-colored—		
Detail of No. 6—			
	a. Sandstone, massive white	14	
	b. Shale, green and chocolate-colored	1	
	c. Sandstone, with thin seams of clay	7	
	d. Shale, with sandstone lenses	3	
	e. Sandstone	6.5	
	f. Sandstone, in beds from 4 in. to one foot thick, separated by seams of red shale	5	
	g. Shale, chocolate colored	2	
	h. Sandstone, massive	5	
	i. Sandstone and shale, thin bedded; shale red to chocolate colored	25	68.5
	La Plata Sandstone		600.5

This section, which is in the type locality, shows the presence of a cliff-forming conglomerate near the top of the formation. This conglomerate is a distinctive feature of the formation in this region but is seldom recognized in the northern areas.

A detailed section of the lower part of the McElmo formation taken one-fourth of a mile south from the mouth of Bush Canyon in the McIntyre District, shows the character of this part of the formation. The main features of the section apply to the bulk of the productive areas.

Section of lower part of the McElmo formation in the McIntyre District, one-quarter mile south from the mouth of Bush Canyon

MEASURED BY R. C. COFFIN

Top.		Feet.
1.	Sandstone, white, shades of pale pink on weathered surfaces, coarse to even grained, sugary grains of quartz easily recognized, occasionally pebbles of impure chert the size of marbles occur; blocks 20 feet thick often show no evidence of bedding; a bench former	27
2.	Sandstone, similar to No. 1 but finer and more even grained, carries concretions of calcite and, locally, bone fragments	10
3.	Sandstone, like No. 2, bench former, not uniform in thickness; weathered surfaces covered with tiny spheres of sandstone carrying "iron stained" spheres ½ inch or less in diameter	8
4.	Sandstone, in beds 1 foot or less in thickness with maroon shale partings; carnotite bearing	11
5.	Sandstone, white sugary grains of quartz, massive, in beds 10 to 20 feet thick; cross bedded in places; laterally the massive beds give way to less massive ones with greenish shale lenses; bench former; carnotite bearing near top and in center. This bed is the important carnotite bearing sandstone of the productive areas	26
6.	Sandstone, thin bedded; laterally the beds are replaced by shale	4
7.	Sandstone, massive like No. 5	5
8.	Sandstone, and shale in alternating beds from 2 inches to 1 foot thick; laterally the shale grades into sandstone or sandstone into shale; shale green or maroon	9
9.	Sandstone, light to pale pink, poorly cemented, shaly layers in lower half	38
10.	Sandstone, even grained, massive; upper part of member carries beds 10 feet thick which grade downward into beds 1 foot thick; entire member has a distinct pink tint. Weathered material includes, in places, spheres of sandstone ¼-inch in diameter	55
11.	Sandstone, similar to No. 10	32
12.	Sandstone, pale pink, fine, even grained, some beds well cemented; in beds 8 inches to 1 foot thick with thin sandy shale partings; a bench former	63

13.	Sandstone, similar to No. 12 with maroon shale partings up to 1 foot thick	35
14.	Sandstone, white to pink, in uniform beds 2 to 8 feet thick with maroon shale partings; ripple-marked in lower part	12
15.	Sandstone and shale, alternating; shale predominates near base	33
16.	Shale with some sandstone, shale maroon to chocolate-brown,; sandstone thin bedded, lenslike	5
17.	Shale and shaly sandstone	20
	La Plata sandstone	393

A section measured in the Dry Creek anticline shows the maximum thickness observed of the McElmo formation.

Section of the McElmo formation along Dry Creek, two miles south of Coke Ovens.

MEASURED BY R. G. COFFIN AND J. A. PYNCH

Top.		Feet.
	Post-Elmo Conglomerate.	
1.	Sandstone, white, loosely cemented, some parts carry greenish cast shale, calcareous in places	37
2.	Shales and sandstone, shale green and red; sandstone in places conglomeratic and interspersed with shale; member not well exposed	380
3.	Limestone, compact, weathers brown, light gray on fresh surface	4
4.	Sandstone, shaly, light in color	12
5.	Sandstone, dense, almost a quartzite, carrying some calcite, weathers gray to black	3
6.	Shale and sandstone, badly covered	235
7.	Sandstone, mottled, hard, compact, shows little jointing, cliff forming	28
8.	Sandstone and shale, red and green	62
9.	Sandstone, white, somewhat mottled	30
10.	Shale and sandstone, thin bedded	105
11.	Sandstone, massive, cross bedded, weathers pink, poorly cemented in places, cliff forming	55
12.	Sandstones, massive in upper and central part; weathered surfaces show many concretion-like spheres of sandstone; lower part of member thinner bedded than upper part	25
13.	Sandstone, white to light brown, cross bedded, cliff forming; 16 feet down in the member a 2-foot stratum of soft light-gray sandstone separates the lower part, which is distinctly cross bedded, from a more thinly bedded upper part which carries green clay spots	51
14.	Limestone, compact, dark colored	2
15.	Shale and sandstone; sandstones thin bedded, shales maroon with some green colors in lower part	51
	La Plata sandstone	980

The top of the section just given differs from sections in many areas in that the sandstone may exceed the shale content. A section measured near the mouth of Mesa Creek is representative of the type wherein shales characterize the upper part. A distinct bluish green cast in shales of the Mesa Creek section is characteristic of this region and of the area further north.

Section of the McElmo formation one mile northeast of the mouth of Mesa Creek.

(THICKNESS OF LARGER UNITS DETERMINED BY ANEROID)
MEASURED BY R. C. COFFIN

Top.		Feet
	Post-McElmo conglomerate capping the mesa in cliff 80 to 100 feet high.	
1.	Sandstone, shaly, many grains of green sand the size of sweet pea seed; very loosely cemented; along the strike the bed grades into a conglomerate	16
1.	Shale, very green, grades downward into sandstone with greenish cement	67
3.	Shale, bluish green, carrying lime concretions up to 1 foot in thickness	11
4.	Shale, bluish green, calcareous near top	76
5.	Shale, green, some shaly sandstones carrying specks of iron oxide	22
6.	Shale and sandstone, shale greenish, sandstone in beds 1 foot or less in thickness, calcareous in lower part	110
7.	Sandstone like No. 5	7
8.	Shale, green, a 2-foot bed of dense quartzitic sandstone near the center of the member	33
9.	Shale, green, two bands of dense brown-weathering sandstone near the top	78
10.	Shale, green and maroon. Above this point green to bluish green is the characteristic color of the entire series, below this point green colors are inconspicuous or absent	12
11.	Sandstone, fine to even grained, reddish brown, massive, bench former; laterally this bed grades into a conglomerate or coarse sandstone. This horizon commonly includes a conglomeratic sandstone	36
12.	Shale, maroon to red	10
13.	Sandstone, white, massive, cross bedded, thin sandstone partings	33
14.	Sandstone, very much like No. 13 but in thinner beds	22
15.	Sandstone, white, massive, similar to No. 14; some seams of shale 2 inches thick	32
16.	Shale and sandstone, in beds 2 to 6 inches thick with maroon shale partings	22
17.	Sandstone, similar to No. 13, beds of sandstone 4 feet thick with maroon shale or thin sandstone partings; individual beds uniform in thickness	65
18.	Sandstone, massive like No. 13	25

19.	Sandstone, in beds of 6 inches to 1 foot thick with shale partings	24
20.	Sandstone, in beds like No. 13, beds, some of which are 4 feet thick, wedge out along the strike. Locally this member carries stains of carnotite and another vanadium mineral	10
21.	Shale and sandstone in beds 2 inches to 1½ feet thick separated by maroon and green shale beds; shale makes up the greater part of the volume of the unit	73
	La Plata Sandstone	784

Beds number 13, 14, and 15 constitute the important carnotite horizon. These three units often combine to make one continuous cliff.

SPECIAL FEATURES OF SECTIONS

The most striking feature of the McElmo formation is the variety of colors of its shale beds. Shades of green, blue, red, maroon, pink, brown, and black, exist in the upper half of the McElmo formation. Shades of green, which are the most common, exist in every section of the McElmo formation and their prominence is determined largely by the ability of the shale members to outcrop. These green shales, however, are more abundant north and east of Paradox Valley, and south of the Dolores-Montezuma county boundary line, than in other parts of the area.

In Klondyke and in parts of McElmo Canyon light red to pink bands of shales and marls are mixed with the prevailing green ones. Similar bands exist west of Ute Mountain, where they contrast with the black stains of "desert varnish" (manganese stains), which are abundant in the region.

The conglomerate which exists near the top of the McElmo formation in McElmo Canyon sections is characterized by dense green pebbles. This McElmo conglomerate is normally separated from one in the overlying formation by a series of sandstones and green shales which range in thickness from a few inches to 100 feet.

Although the normal outcrop of these two beds forms two separate cliffs in most of this area, at a few points, particularly in Yellow Jacket Canyon, the dividing shale is absent and these conglomerates appear in the same cliff. The upper one of these two beds was so consistently light colored and the lower one so consistently brown, that, for purposes of field work, they were termed "white conglomerate" and the "brown conglomerate."

A second McElmo conglomerate exists below the first and within the upper 200 feet of the formation. These two beds are similar in composition and, like the first, the second is found in many parts of the McElmo Canyon country but is inconspicuous or absent in the northern parts of the area. The occurrence of the lower conglomerate near the mouth of Yellow Jacket Canyon needs special mention.

Section measured at point one-half mile east of the junction of Hovenweep and Yellow Jacket Canyons.

(THICKNESS OF LARGER UNITS DETERMINED BY ANEROID)
MEASURED BY R. C. COFFIN

		Feet
	Top of mesa.	
1.	Sandstone, coarse to fine, thick bedded, breaking off in blocks 20 feet thick	75
2.	Sandstone, thin bedded	5
3.	Sandstone and conglomerate, fine to even grained at top, grading into coarse conglomerate at the base, weathers light. Base of Post-McElmo	75
	McElmo formation.	
4.	Shale, maroon	4
5.	Sandstone and conglomerate; bed very uneven in thickness. Laterally this bed increases or decreases in thickness with a corresponding decrease or increase in underlying shale. This bed has wide-spread occurrence in McElmo Canyon	40
6.	Shales and sandy shales, green	25
7.	Conglomerate, very coarse, black to dark brown on weathered surface. This bed is replaced by green shale along the strike	40
8.	Shale, green and maroon	40
	Bottom of Canyon.	

The conglomerate in bed No. 7 decreases in thickness from 40 feet to 5 feet within a horizontal distance of 80 feet and changes in character from a coarse conglomerate to an even-grained sandstone. The exact contact of the conglomerate and the replacing shale was not visible.

A sudden thinning and disappearance of this same bed is even more striking in Bridge Canyon 1½ miles above its mouth. The section at this point is similar to the one just given. A black-weathering conglomerate in the position of bed No. 7 forms the so-called "bridge" from which the canyon gets its name. This conglomerate forms a flat-topped ridge 50 to 150 feet wide and four tenths of a mile long. The ridge crosses the canyon at right angles to its length and reaches from one wall of the canyon to the other. The broad, flat canyon bottom, which is not more than 75 feet below the bridging conglomerate drains from above the "bridge" through a dry stream course which cuts a slice from the center of this unusual outcrop. The character of this conglomerate is such that the pieces which break from the main bed are huge blocks many of which measure over 20 feet in their shortest dimension. Inasmuch as the low gradient of the canyon makes it possible for the intermittent stream to remove only the finer sediment, and the fact that debris from the conglomerate is confined to the immediate vicinity of the "bridge," it follows that this conglomerate was never of much greater extent than that represented by the present "bridge." On either side of the canyon the conglomerate suddenly disappears along the strike and is replaced by green and maroon shales in the same manner as in Yellow Jacket Canyon.

These irregular masses of conglomerate represent stream channels cut in the shales during the period of their deposition. Coarse sediment eventually filled these depressions and now appears as isolated patches of conglomerate singularly out of place in such a formation. Abrupt changes in the character of sediment in individual beds and ancient channels occur in many parts of the formation and give direct evidence of the manner in which these beds were laid down.

Other features of the McElmo formation include an irregular occurrence of limestone beds. The upper half of the formation includes calcareous beds carrying numerous lime concretions rather than distinct limestones, but the lower half contains beds of dense, blocky limestone. These beds are never thick, the maximum recorded being 2½ feet. Limestone beds are not present in all sections, but come at different horizons in the formation and never extend far along the outcrop. One mile below the junction of Horse Fly Creek and San Miguel River, a limestone bed 1 foot thick was found within 30 feet of the La Plata formation. Opposite the mouth of Atkinson Creek, a 2-foot bed outcropped 100 feet above the La Plata, and in the vicinity of Long Park a limestone bed occurred 200 feet above the base of the formation. At no place were fossils found in these limestones.

COMPOSITION AND LITHOLOGIC CHARACTER

Sandstone and shale make up approximately equal portions of the McElmo formation. The sandstones show considerable difference as to the size of grains and character of the cement. Clean, white quartz sand in sub-angular to well-rounded grains from those a twentieth of an inch in diameter to those of microscopic dimension make up the massive sandstones of this formation. All grades of argillaceous sandstones and arenaceous shales exist in the thinner beds. Silica, lime (calcium carbonate), and iron minerals are the common cementing materials. The resistance which the different sandstones offer to weathering differs considerably. Some of the massive beds crumble readily, their cement having been largely removed. But several beds of extremely fine-grained sandstone in the upper part of the formation are so dense they resemble quartzites.

The sandstones in the lower part of the formation are white to gray, or shades of pink, but above the main carnotite-bearing zone they are green to gray. Cross bedding is common in the massive beds and ripple marks were observed in the thinner beds of the lower half of the formation.

A persistent feature of the massive sandstones, particularly those in the carnotite-bearing zone, is the presence of fragments and pellets of green clay or shale irregularly distributed or grouped in lenses. The material which goes to make up these fragments is similar to the clay material in other parts of the formation.

Another peculiar feature of many sandstones is the manner in which they weather. Little spheres of sand from those the size of peas to those 1½ inches in diameter occur in many places along the outcrop of at least three beds in the lower half of the formation. These little spheres are concretionary in character and are often stained slightly with limonite. Internally their general appearance does not differ from the unweathered sandstone. However, careful tests of several of these spheres showed iron carbonate and calcium carbonate as a cement slightly in excess of the amount found in the parent ledge. The conglomerates in the upper part of the formation contain pebbles of dense green sandstone, red chert and translucent quartz. The green pebbles are similar to the material in the quartzitic sandstones of the upper McElmo. Fine, greenish sand or pure quartz sand, and silica, are the bonding materials of these conglomerates. In some places black or brown manganese stains have disguised the true color of these beds. At such points ledges and boulders possess dark colored surfaces which offer more resistance to weathering than the interior of the beds. These materials are thus inclosed in a resistant shell and are, in a sense, "case-hardened." When once the coating of these case-hardened ledges is broken at any point, the interior weathers more readily than the face of the ledge and the exposure becomes cavernous.

The shales of this formation represent all degrees of purity. Pure clay shales are not plentiful, but occur with those whose sand content ranges from the slight trace to those that are distinctly arenaceous. Many of these shales are so plastic that travel in some areas is difficult, if not impossible, immediately following a rain.

And the ease with which these wet shales flow under pressure is the cause of much trouble in the slumping of newly-constructed roads and ditches. The variety of colors possessed by the McElmo shales has already been mentioned. Those in the upper half of the formation are generally green and those in the lower half are maroon or chocolate brown.

The limestones are dark to drab in color, are very compact, and occasionally contain seams of chert. Calcite as a part of the cementing material occurs in several beds, and concretionary masses which contain considerable calcite are present in the upper half of the formation.

Gypsum is common in the McElmo shales and spring water from any part of the formation attests to the general distribution of this mineral. Gypsum in different forms is often associated with the carnotite ores.

Silicified wood occurs in the upper McElmo beds, but wood fragments which were held in the sandstone lower down were seldom silicified. Many of the latter appear now as cylindrical mass roughly outlined by brownish colored sandstone, and it is not unusual to find parts of tree-shaped masses outlined by calcite, gypsum and, in some horizons, by carnotite-bearing sandstone. Some high-grade carnotite ore has resulted from the replacement of wood.

Evidences of plant life were recorded from at least one point in pratically all the beds of the formation except the lowest. The lowest observed was in a sandstone approximately 100 feet above the La Plata and the highest was in the very top of the formation. In the north wall of Yellow Jacket Canyon, 2½ miles above the mouth of Sandstone Creek, the surface which divides the McElmo and Post-McElmo conglomerates is strewn with fragments of silicified wood. This same surface is similarly marked at other points. Pieces of petrified tree trunks one-half a foot in diameter were among the smallest found, and the largest recorded was 8 feet in diameter. This unusual tree, which occurs within 50 feet of the top of the McElmo formation, is located in the north wall of McElmo Canyon one mile below the mouth of Finley Canyon.

Ill-preserved twigs and plant fragments were collected from beds both above and below the main carnotite zone, and imprints of reeds were found in the upper McElmo of McClain Basin, a tributary of Cross Canyon. In several horizons carbonaceous material was held in sandstones as black blotches and flakes of a coal-like material.

Fossil bone was found in a sandstone within 100 feet of the La Plata formation and in practically all beds above this one to the topmost conglomerate. One single bone found in Yellow Jacket Canyon measured 5 feet in length and 1 foot in diameter at its largest point.

CONDITIONS OF DEPOSITION

Inasmuch as the conditions under which the McElmo beds were deposited are intimately associated with the question of the origin of carnotite, these conditions are briefly stated at this point.

The outstanding features of the McElmo formation are the quick vertical successions of sandstones and shales, and the erratic thickening and thinning of its beds. The absence of fossils other than plant remains, the character of cross bedding, and channeling are other important factors which suggest the conditions under which the beds were deposited.

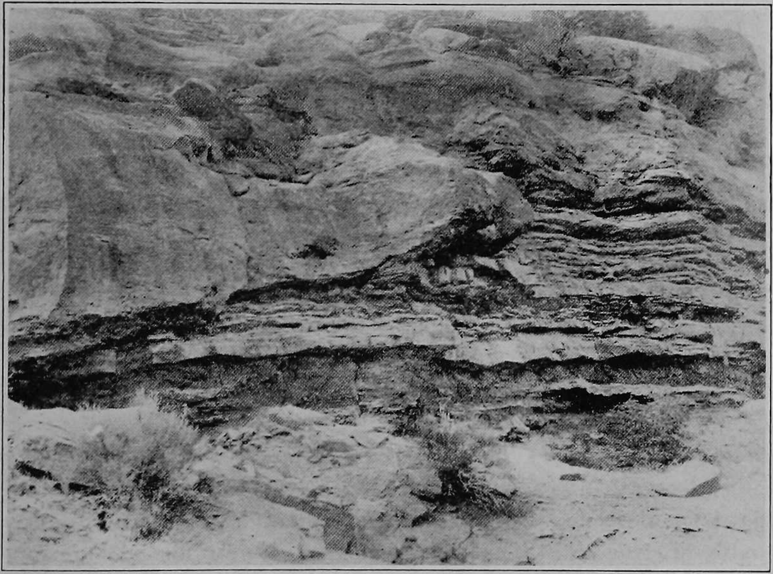

Fig. 19. Local unconformity in the McElmo formation on the west side of Hieroglyphic Canyon.

The massive sandstone fits into an ancient stream channel cut into thinner bedded sandstones and shales: the beds involved are of the lower McElmo formation.

These and other features indicate that the McElmo formation was deposited in lakes and on flood plains across which streams were continually altering their courses. The surface upon which the sediments were deposited was a smooth plain which was so near base-level that it was the site of deposition rather than erosion.

Deposition did not take place evenly over this plain but beds were formed in many places only to be destroyed by shifting streams and deposited elsewhere. Fragments and lumps of shale inclosed in sandstone are evidence of such destruction.

The flood-plain phase of deposition is emphasized further by the presence of ancient stream channels, the thinning and wedging out of individual beds, and the inclusion of lenses of fine material by coarse material. The type and extent of cross bedding, and the undulating and scoured surfaces which generally separate beds of shale from beds of sandstone, are further evidence that many of these beds are the result of stream deposition.

Conditions favoring the deposition of sand and of shale were constantly changing. Although the streams supplying the materials from which the beds were made were generally sluggish, occasional bands of coarse sand or conglomerate indicate periods of stream activity.

Inland lakes doubtless existed at different times over large areas of this plain and were the scene of the deposition of the even-bedded and the finely-banded sandstones. Streams supplied materials of different sorts to different parts of this McElmo plain. These assumptions would account for conglomerates within a certain horizon at one point and their absence in the same horizon elsewhere.

The climate during a part of McElmo deposition was favorable to the growth of trees and plants. The presence of petrified wood, impressions of trees, and of plants has already been mentioned. Although it is probable that many of the pieces of wood were carried to their present positions, the arrangement and abundance of plant fragments in several localities would not suggest such transportation. The partial evaporation of isolated lakes wherein gypsiferous soil may have accumulated is not inconsistent with the conditions postulated. The remains of dinosaurs, presumably of semi-aquatic habits, are suggestive of climatic conditions and the flood-plain idea of the formation of these beds.

During the latter part of the McElmo deposition, streams decreased in activity and sand made up a minor part of their load. But near the close of the period they increased in activity and shales grade upward into sandstones and from sandstones into conglomerates. This upward transition from fine to coarser material is characteristic of the McElmo conglomerates at several points.

The sources of material from which the McElmo beds were derived were west of the area of their present outcrop. This westerly source is emphasized by the east-west course of streams indicated by the channeling.

CORRELATIONS

The McElmo formation or its equivalent, the Morrison formation, was described by Hayden Geologists as Jurassic beds, Lower Dakota, and "variegated beds." The limits of this geologic unit are so evident that the term Morrison was easily extended from its use in the Denver Basin to many parts of Colorado and neighboring states.

The McElmo formation has been correlated with the upper part of the Gunnison formation of the Anthracite and Crested-Butte quadrangles and with the fresh-water portion of the Flaming Gorge formation of Northwestern Colorado.[49]

In making correlations between the McElmo of Colorado and strata between the La Plata and "Dakota" in Utah, it must be noted that this interval in Utah includes marine beds above the La Plata and below the fresh-water McElmo, which have no equivalents in Colorado sections.

CRETACEOUS FORMATIONS

The remaining part of the sedimentary series is referred, with certain qualifications, to the Cretaceous. The basal beds of this unit include conglomerate, sandstone, shale and locally, coal, impure limestone and chert. For reasons to be stated presently a portion of this section is referred to in the present report as Post-McElmo. Above these beds of questionable age a possible true Dakota is recognized. Some fossil evidence found in these beds is discussed later and reasons are given for the qualified usage of the two terms applied to this part of the series.

That portion of the section whose age is in doubt seldom exceeds 300 feet in thickness and above it Mancos shales occur with their characteristic fossils. Measurements of the Mancos shales were not made but they probably exceed 1,000 feet in thickness. In one locality strata of the Mesaverde formation occur within the area mapped.

The Cretaceous sediments of the area are included within the Post-McElmo, "Dakota," Mancos, and Mesaverde formations.

POST-McELMO AND "DAKOTA" FORMATIONS

TERMS

The use of the terms Post-McElmo and "Dakota" to designate strata generally referred to as Dakota is not without its objections

[49] Gale, H. S., Coal fields of northwestern Colo. and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 58-59, 1910.

Inasmuch as the term Post-McElmo is applied to definite beds, it is used as a formation name and is therefore capitalized.

and is apt to meet with criticism. The nature of the work demanding the attention of the present parties did not admit of extensive study of this portion of the section. Wherever practical, contacts were studied. It is hoped that this work is only preliminary to the more thorough study of this portion of the sedimentary series in this section of Colorado.

The amount of study given these formations hardly seems to justify the coining of a new name for strata below supposed "Dakota" and above established McElmo. This is especially true since the boundaries of these strata can not now be extended throughout the area, and the particular beds involved come within that portion of the geologic column which, in the past, has needed revision and about which there is still some question.

Certainly the massive sandstone conglomerate and the unconformity used as the upper limit of the McElmo mark a definite change of conditions of sedimentation. Above this massive stratum are beds of more or less pure limestone, massive beds of chert, and much green shale—strata the like of which have never been included in the Dakota. As there are no fossils to aid in the proper placing of these beds, lithologic character and stratigraphic position alone remain as usable evidence of their age.

The character of these beds would not admit of their inclusion in the "Dakota" even with the qualified application of this term. Further, to place them in the McElmo formation would require the use of this term in a sense different from that in which it was first applied—to strata in McElmo Canyon. Further justification of the temporary use of these two terms is offered in the discussion of their age and correlations where the "Dakota" problem is considered generally.

DEFINITION AND BOUNDARIES

The two units, Post-McElmo and "Dakota," include strata between two easily recognized limits—the bottom of a massive sand stone-conglomerate as a base, and the dark Mancos shales as an upper limit. The strata so included reach a thickness of 300 to 350 feet in the region of Third Park and near the mouth of Disappointment Creek, and less than 100 feet in places along the north foot of the Ute Mountains.

In regions where the "Dakota" is separated from the Post-McElmo the division is made at the base of the first sandstone or conglomerate which underlies the lowest carbonaceous shale or coal horizon. In such places the "Dakota" shows the usual three-phase character, conglomerate or sandstone at the base, and shale, capped with sandstone above. There are in places two distinct black shale beds separated and capped by sandstone beds. Where the "Dakota" is mapped separate from the underlying beds, the basal conglomerate or sandstone of the "Dakota" ranges in thickness from 2 feet to 30 feet. In such places it differs from the basal member of the Post-McElmo in being much thinner and in its darker color.

It is impracticable to attempt the placing of the upper limit of the "Dakota" within 20 feet. In the northern areas beds of limestone up to 1 foot in thickness come within 20 feet of the base of the Mancos shales. Below this bed dark shales grade downward into impure sandstone within this 20-foot limit. These sandy layers are regarded as the top of the "Dakota." Thus limited, this unit measures, in places, a little more than 150 feet.

The term Post-McElmo is here applied to approximately 150 feet of sediments whose age is in doubt. They are younger than McElmo and older than the "Dakota," as already defined. The two terms, Pre-"Dakota" and Post-McElmo, are used to place this unit on the geologic map of the area. For the sake of brevity it is convenient to refer to them as Post-McElmo, bearing in mind that they are limited to from 100 to 200 feet of beds whose upper boundary can be carefully drawn only over parts of the area mapped.

The basal beds of this Post-McElmo unit are characterized by a sandstone conglomerate which outcrops in a cliff. The lower limit of this massive bed forms an undulating contact with the underlying McElmo shales and sandstones. This contact marks the upper limit of the McElmo and the lower limit of the Post-McElmo formations.

Two miles below the mouth of Disappoinment Creek the Post-McElmo unit reaches a maximum thickness of 222 feet. Laterally this unit diminishes in thickness and the chert, limestone, and green shale that characterize these beds in some localities are not everywhere present. The beds used as the base of the Post-McElmo and the base of the "Dakota" are stratigraphically not far apart, and in horizontal outcrops their boundaries are close together. But in inclined outcrops the upper member weathers down the dip and the two boundaries are separated by a considerable distance. These contacts are typically exposed in tilted outcrop in the vicinity of Dry Creek Basin and Disappointment Valley, where the two units have been mapped separately with different color patterns. Southward in the Dolores Plateau and beyond, the chert and limestone beds are not continuous and the separation of the two formations was not made. One color pattern here serves to represent their undivided outcrops. Chert and cherty limestone beds of the Post-McElmo were observed north of the San Miguel but the division of these strata from overlying ones was not made, and here also a single color is used to represent the distribution of Post-McElmo and "Dakota" beds.

In the areas adjacent to Dolores River below Paradox Valley, where strata occur above the McElmo, the lowest members of the Post-McElmo are the only remaining beds. Here large areas marked Kd include only the basal conglomerate. To the south the reverse is true as the upper "Dakota" covers the greater area represented by this single color unit. Where the two units are separated the upper or "Dakota" has been given the symbol Kd′, and the lower or Post-McElmo, Kd″. The areas of the undivided sediments of these units are marked Kd, and the outcrops may be represented by either or both groups. It is often convenient to refer to these two units collectively as the Kd unit.

PHYSIOGRAPHIC FEATURES

The presence of the resistant beds of the Post-McElmo and "Dakota" formations below the easily removed Mancos shales would explain the singular fact that these undivided formations, the thin-

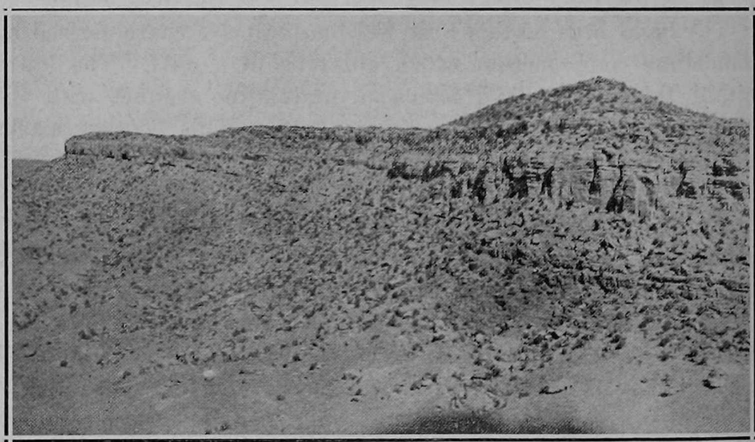

Fig. 20. Post-McElmo beds making unconformable contact with the McElmo formation in the McIntyre District.

nest unit of the region, show a greater area on the map than any other single formation. Its beds form the floor of numerous plateaus and cap most of the mesas throughout the area.

Aside from tilted and highly folded areas the mesas are monotonously the same, being flat-topped mountains or hills of different sizes, with pedestals of McElmo shale capped with sandstones or conglomerates of the younger formations. The edges of these mesas are in many places perpendicular walls 100 to 150 feet high, which determine the upper limit of many canyons.

The tops of the plateaus are horizontal or slightly warped surfaces showing some undulation due to the erosion of the upper beds of the unit. Travel is never difficult across these uplands except where the streams have succeeded in cutting through the basal sandstone-conglomerate. In such places canyons whose depths are at least equal to the thickness of the McElmo shales often make travel across their line of direction impossible.

In regions where the strata are highly inclined these massive sandstones stand out as serrated ridges and the several beds weather down the dip in a succession of tilted outcrops. Such an arrangement of saw-tooth peaks overlooks East Paradox and Gypsum valleys. At places along the foot of the Uncompaghre Plateau the massive beds of these formations dip at an angle of 80° and weather out as huge flat-irons.

DISTRIBUTION

Along the southern edge of the Uncompahgre Plateau the outcrops of Post-McElmo and "Dakota" sandstones overlook the lower country to the south, and from here these formations extend northward beyond the limits of the map. At the western end of this plateau these formations weather down the dip, which is northeasterly, and the capping rocks are beds of lower formations.

The synclinal basin at the base of the Uncompahgre uplift is floored with "Dakota" and Post-McElmo sediments which are terminated by San Miguel River on the south and Dolores River on the west. Across this basin several streams cut narrow strips through these capping beds. The eastern end of this structural basin includes First, Second and Third parks which are floored with these same sediments. These more or less continuous areas are interrupted on the east by San Miguel River and its tributaries. The south side of Tabequatche Basin is outlined by a timbered bench of these rocks, and tributaries of Horse Fly Creek and the San Miguel River flow in canyons bounding irregular blocks capped by the Kd unit. Many of these areas show warped surfaces, which indicates that these beds once connected the exposures of this unit on the San Miguel Plateau with those of the Uncompahgre Plateau to the north. Near the head of Hank's Creek the Kd strata extend unbroken up over the Uncompahgre uplift.

Numerous remnants of the Post-McElmo conglomerate cover much of the ground between San Miguel River and East Paradox Valley. From San Miguel River in the region of Naturita, strata of the Kd unit extend southward without interruption up over the two lines of folding represented by the eastward extension of the two edges of Paradox Valley, and bend down into Dry Creek Basin, to appear again along the northeastern side of Gypsum Valley. These strata cap the high ground that encircles Bull Canyon and from which their outcrop reaches up to the edge of East Paradox Valley. From the exposures along this valley a dip slope of these sediments extends south into Dry Creek Basin. This slope is traversed by minor dry stream courses, some of which cut through the cap rock and expose small areas of the uppermost beds of the McElmo. But these small areas of McElmo are not shown on the map of this region.

From the south side of Gypsum Valley, "Dakota" and Post-McElmo beds dip under Disappointment Valley and emerge on the southwest side to be cut off in the western part by Dolores River. From the eastern portion of Disappointment Valley, which appears on the map, these strata reach unbroken from the valley floor to the high plateau to the south, where they fringe Dolores River Canyon to and beyond the limits of the map.

The high ground south of Disappointment Valley and west of Dolores River Canyon is capped for great distances by Post-McElmo and "Dakota" sandstones and conglomerates. They extend west around the head of Bishop and Summit canyons and are bounded on the north by McIntyre Canyon and its drainage.

Several isolated areas of these mesa-capping rocks occur north of Silvey's Pocket, along the margin of the map. They occur in Wray Mesa and between Coyote Wash and La Sal Creek, and north of La Sal Creek a strip connects with the Paradox Valley fold. These beds occur on the divide north of West Paradox Valley, and north of Sinbad Valley they cap a mesa whose edges are serrated by the headward cutting of several streams that enter Dolores River from this area.

The largest single area of "Dakota" and Post-McElmo in the region caps a plateau, part of which is covered by the southern mapping of this survey. The high ground south of Disappointment Valley is only a portion of the northern edge of a generally smooth plain that has been termed the Dolores Plateau or Great Sage Plain. On this upland the conglomerates and sandstones of the Kd unit extend without interruption for great distances into Utah and south to McElmo Canyon.

McElmo Canyon and its tributaries, Cross Canyon, Sandstone Creek, and Yellow Jacket Creek, cut a portion of the plateau into northeast and southwest strips of irregular outline. As these dividing strips approach McElmo Canyon they are broken up into remnants of conglomerate-capped mesas. On the south side of McElmo Canyon a similar arrangement of buttes and headlands extends outward from the slopes of the Ute Mountains. Folding in this region has determined largely the extent of the removal of this plateau. Eastward the capping strata extend around the head of McElmo Canyon and several of its short tributaries to and beyond the town of Cortez, where these strata dip south and are soon covered by Mancos shales.

SELECTED SECTIONS

The sections of "Dakota" and Post-McElmo strata are of two types. Those from the central areas include impure limestones and chert, whereas in corresponding sections of the southern areas these materials are inconspicuous or absent. Those of the first type are represented by the following:

Section of Post-McElmo and "Dakota" strata in McIntyre District along Dolores River, three-quarters of a mile east of the mill of the American Rare Metals Company.

(THICKNESS LARGER UNITS DETERMINED BY MEANS OF ANEROID)
MEASURED BY R. C. COFFIN

Top		Feet
	Uppermost beds of the "Dakota", which probably include less than 50 feet of strata, are not given.	
1.	Sandstone, yellowish, sugary, carrying many limonite concretions; beds 2 to 5 feet thick	24
2.	Shale, carbonaceous, some small seams of impure coal	30
3.	Sandstone, like No. 1	2
4.	Shale and sandstone; shales of a greenish cast interbedded with thin sandstones; unit includes at least one 2-foot bed of dense green sandstone	25
5.	Conglomerate and sandstone, massive, white to gray; many pebbles of quartz, white to gray chert and red jasper; lenses of dense white quarzitic sandstone occur in upper part	20
	"Dakota"	
	Post-McElmo.	
6.	Chert and cherty limestone; includes bands of chalcedony 2 inches thick	5
7.	Shale and chert; shale highly calcareous; chert in beds 2 feet thick	23

8.	Shale and limestone, all more or less greenish; some dark shale at the base; in places calcareous layers grade into distinct limestones; at other points grains and flakes of green shale are included within the calcareous portions; at least one band of cherty phyllite is present in this unit	24
9.	Sandstone, sugary, light colored, coarse to even grained; conglomeratic at the base; in beds 3 to 10 feet thick; iron concretions in the top beds; cliff forming	35
10.	Shale, green and chocolate colored, some impure sandstones carrying flakes and irregular pieces of green shale; cementing material largely calcareous	22
11.	Sandstone-conglomerate, massive, white; cliff faces 40 feet high sometimes show no planes of division; weathers readily into a crumbly mass; similar to No. 9 but more conglomeratic at the base; cliff forming	33
12.	Sandstone and shale; shaly sandstone partings; shale greenish; sandstone in beds 3 feet or less in thickness, and similar to those of the upper part of No. 11; along the strike the shale and shaly sandstone members grade into sandstones and these beds grade upward into No. 11 and downward into No. 13 without definite contact	30
13.	Conglomerate and sandstone, white to gray; locally poorly cemented and weathers cavernous; pebbles of dark or light chert along with jasper and quartzite make up the coarser material; pebbles the size of eggs not uncommon. The base is a coarse sandstone that grades upward into a conglomerate; along the strike the conglomerate becomes the basal member. Conglomerate streaks very irregularly distributed. Laterally Nos. 11, 12 and 13 appear in the same cliff where they make a single unit containing inconspicuous seams of shale which play out along the strike	30
		303
	Unconformity.	
	McElmo.	
14.	Shale, chocolate colored and green; arenaceous in places	30
15.	Conglomerate and sandstone, massive, brown; contains green pebbles	27
16.	Shale and sandstone; typical McElmo; interval includes one sandy stratum which locally grades into black-coated conglomerate	....

Section of "Dakota", Post-McElmo, and upper McElmo strata on the north side of the San Miguel River, seven miles below Naturita.

MEASURED BY R. C. COFFIN AND H. S. SCHNEIDER

Top		Feet
	Approximately upper 75 feet of "Dakota" not included in Section.	
1.	Sandstone, thin bedded, yellowish	3
2.	Shale, black, some thin sandy layers	32
3.	Sandstone, thin bedded, quartzose	3

4.	Shale, black to drab	1.5
5.	Sandstone, thick and thin bedded, even grained, brownish; carries plant remains	5
6.	Shale, black, carbonaceous, thin seams of coal	4
7.	Sandstone, quartzose, coarse to conglomeratic; carries many specks of limonite	2
	"Dakota"	
	Post-McElmo	
8.	Shale and clay, greenish, calcareous; includes seams of chert	1.5
9.	Sandstone and limestone, argillaceous, calcareous sandstone grading into arenaceous, argillaceous limestone; weathers brownish; pieces of chert in float from this horizon	25
10.	Sandstone, massive, conglomerate, quartzose, greenish; carries "iron" concretions	19
11.	Shale and sandstone, friable argillaceous sandstones with greenish shale predominating at the top	24
12.	Sandstone, conglomeratic, white to brown to gray, cross bedded; base a quartz sandstone that makes wavy contact with underlying shale; grades upward into conglomerate which carries pebbles of chert and quartzite 2 inches in diameter. At a point 39 feet from the base, a bed of shaly sandstone 1 foot thick carries much fossil wood; along the strike this member disappears and the lower 39 feet could not be separated from what came above; the upper 53 feet less conglomeratic than the lower part. The entire member is more or less cross bedded and very erratic as to occurrence and distribution of conglomeratic streaks, suggesting stream deposit. So called rim former of the region	92
		212
	Post-McElmo	
	McElmo	
13.	Shale, greenish to drab, some thin sandstone beds	35–40
14.	Conglomerate, carrying green pebbles and lumps of green clay, poorly exposed	10–15
15.	Shales, typical, variegated McElmo shales with some sandstone bands	190
16.	Sandstone, coarse to fine, inclosing green shale lenses, iron stained; one bed near the base includes a massive, cross-bedded, conglomeratic sandstone	165

Sections wherein the limestone and chert are not present are represented by the following:

Section of Kd strata on the south side of McElmo Canyon along Pine Creek, two and one-half miles from its mouth.

MEASURED BY R. C. COFFIN

Top	Feet
Sandstone, yellowish, many cavities due to weathering out of plant casts, top of unit contains fossils (Gryphae newberryi).	

	Mancos	
	"Dakota" and Post-McElmo (?)	
1.	Sandstone, yellowish brown, many cavities due to weathering out of plant casts	4.5
2.	Sandstone, similar to No. 1 but loosely cemented and containing many clay partings, thin bedded	20
3.	Sandstone, light yellow, clay partings, laminae ¼ to 3 inches thick	4
4.	Shale, black, paper like, impure coal in center	2.8
5.	Sandstone, yellowish, like No. 3, poorly cemented; some beds a foot thick; cross bedded at base	7
6.	Shale, gray to black, coal in thin seams	11
7.	Sandstone, light to gray, even grained, cross bedded, beds ½ to 4 feet thick; this member increases in thickness along the strike to 20 feet	10
8.	Shale, black to gray, some green and chocolate colored; includes some thin seams of sandstone	30
9.	Sandstone-conglomerate, light to gray, quartzose, base conglomerate carrying chert and quartzite pebbles ½ inch in diameter; member increases rapidly in thickness along the strike	12
		102.3
	McElmo shales.	

The above section contains more shale and less sandstone than the average for the region.

Section of Kd strata north of McElmo Canyon on divide between Cut-throat Gulch and Hovenweep Canyon.

(THICKNESS OF MEMBERS APPROXIMATE)
MEASURED BY R. C. COFFIN

Top		Feet
1.	Sandstone, hard quartzose, variable in thickness; caps the mesa; carries fossil plant remains. (See p. 115)	10–20
2.	Shale and sandstone, shales carbonaceous, sandstones in thin beds	20
3.	Sandstone, massive	10–20
4.	Shale and sandstone, like No. 2	20
5.	Conglomerate, white, massive, many pebbles of chert and jasper	20
6.	Shale, green to gray; beds occur in a lens which does not extend far along the strike and which may have only local significance	1–3
7.	Conglomerate, white, cross bedded, like No. 5. No. 5 and No. 7 come together along the strike	6
		87–109
	Probable unconformity.	
	McElmo	
8.	Shale, greenish	10

9. Sandstone and conglomerate, brown, carrying green pebbles. This is the so-called McElmo conglomerate of this region 10

FEATURES OF OTHER SECTIONS

The Post-McElmo and "Dakota" beds obtain their maximum thickness in the central part of the area mapped. The chert so characteristic of the Post-McElmo near the mouth of Disappointment Creek is not present in all sections, but exists in lenses whose distribution is co-extensive with the areas within which the formation has its maximum thickness. The fact that erosion has left only the basal conglomerates of the Post-McElmo in many areas adjacent to Dolores River below Paradox Valley makes it impossible to determine whether or not chert was once a part of the formation in these areas. Massive beds of chert and calcareous cherty material occur as a cap-rock to parts of the mesa southwest of Silvey's Pocket and in lesser amounts in the remnants of Post-McElmo northeast of Long Park. Lenses of impure chert up to those 2 feet thick occur in the sections north of San Miguel River, but they were not found in the outcrops along the Uncompahgre Plateau. South of Disappointment Valley a massive bed of chert 8 feet thick occurs at one point in Cross Canyon immediately overlying the basal conglomerate of this formation, but chert in distinct beds was not observed in other parts of the McElmo Canyon country.

Coal beds of good quality and of such thickness that they can be profitably mined occur in the "Dakota" formation at several points between Nucla and the mouth of Tabequatche Creek. The seams are lens-like and come within the upper 75 feet of the formation. Beds of coal occupying a similar stratigraphic position have been opened up in the west end of West Paradox Valley, near Coke Ovens, along the edge of Dry Creek Basin, and at points along the south side of Disappointment Valley. But at no place visited was the coal of as good a grade or as thick as in the region of Nucla. Coaly shales and thin coal seams have been prospected along McElmo Creek east of the boundary of the present map, and good coal has been reported west of Ute Mountain, presumably in the "Dakota" formation.

CORRELATION OF SECTIONS AND DISTRIBUTION OF INDIVIDUAL BEDS

The rather unlike sections of the Post-McElmo and "Dakota" beds in the southern and central parts of the area examined are not connected by continuous outcrops, and some doubt exists as to the correct correlation of beds in these two areas. Three possible ways of correlation suggest themselves.

One correlation places the massive white conglomeratic sandstone, which is used as the base of the Post-McElmo in the Disappointment Valley section, equivalent to the so-called McElmo conglomerate which comes near the top of that formation in McElmo Canyon. This correlation implies that the sandstone at the base of the "Dakota" in Disappointment Valley is equivalent to the conglomeratic sandstone which overlies the McElmo formation as mapped in McElmo Canyon.

A second scheme of correlating these sections considers as equivalent the massive white conglomeratic sandstone which is the basal bed of the Kd unit in either area. It follows that the conglomerate, so characteristic of the upper part of the McElmo in the southern areas, is absent or inconspicuous in the central and northern areas, due to its diminished thickness and its inability to outcrop except in favored localities. This correlation would further assume that the chert, calcareous layers, and green shale of the Disappointment Valley section have only local representatives in the southern sections, and that the basal bed of the "Dakota" to the north, if present at all to the south, is included in the basal members of the Kd unit as mapped.

A third scheme of correlation would suggest that beds between the McElmo and "Dakota" in Disappointment Valley have no equivalents in McElmo Canyon, but the bed which immediately overlies the McElmo formation in the southern areas is equivalent to the basal "Dakota" farther north.

The second scheme of correlation fits the observed relations and is considered correct for the following reasons:

(1) The general appearance and the nature of outcrop of the basal bed of the Kd unit as mapped in both regions are identical.

(2) The materials included in this bed are alike in the two areas but differ from the materials in the McElmo conglomerate in that the latter carries an abundance of green pebbles.

(3) Carboniferous fossils were found in the pebbles of this conglomerate in both areas but were not observed in conglomerates either above or below.

(4) The basal bed of the Kd unit is in disconformable contact with underlying beds in both northern and southern areas.

(5) Massive beds of chert exist in Cross Canyon above the massive conglomerate, used as the base of the Kd unit, in the same stratigraphic position as the chert in the Disappointment Valley section.

Such a correlation would indicate that the 303 feet of Post-McElmo and "Dakota" beds in Disappointment Valley have diminished to 212 feet along San Miguel River and to slightly more than 100 feet south of McElmo Creek. This thinning is accomplished by a wedging out of the calcareous and cherty layer and the green shales, both to the north and to the south from Disappointment Valley. The section measured along the edge of Third Park (p. 104) shows that these beds extend at least as far north as San Miguel River. In as much as erosion has removed the upper beds of the Kd unit from most of the areas north of Paradox Valley, it is impossible to determine the northern limit of deposition of these materials.

This thinning of beds could be due to either non-deposition or deposition and subsequent erosion. It is probable that the surface upon which Post-McElmo sediment was deposited possessed a shallow depression of considerable extent in the central part of the area mapped. This depression could have resulted from erosion previous to the deposition of these beds or warping before or during that time. Into this depression the sediments which formed the different beds, especially the lower ones, accumulated in greater thickness than elsewhere. The deposition of the calcareous layers and the green shale of these formations may not have occurred beyond the limits of this shallow basin. Although no widespread unconformity exists above the massive Kd unit, the nature of the deposit and apparent scouring of streams make possible local unconformities within the formation.

The filling of the supposed depression would be accomplished by an increase in the thickness of individual beds in the region of the basin and possibly the appearance of some in the depression which do not appear elsewhere. It is probably no mere coincidence that the present distribution of chert and the good showing of coal are co-extensive with the areas within which the thickness of these formations is abnormal. It is possible these shallow basins survived the period of Post-McElmo deposition into "Dakota" time and were the basins in which swamp conditions prevailed during the deposition of the present coal beds of this formation. Observations point to the conclusion that the depressions in the surface upon which these formations were deposited determined the maximum limits of the calcareous cherts and the associated beds of green shale, and that after deposition the boundaries of these beds were altered slightly by local unconformities.

CONTACT OF POST-McELMO AND McELMO FORMATIONS

The surface of McElmo shale upon which the Post-McElmo formation rests possesses many depressions in which the conglomerate and sandstone of the upper formation rest without discordance in the dip of beds in either formation. Knolls of McElmo shale occasionally extend up into the overlying sandstone and cause a rapid thinning of the basal bed of the Post-McElmo formation. A shale knoll of this sort at the upper end of Cross Canyon causes the overlying conglomerate to decrease in thickness from 40 to 10 feet within a horizontal distance of 50 yards. No discordance of dip was observed between the shale in the knoll and the conglomerate above.

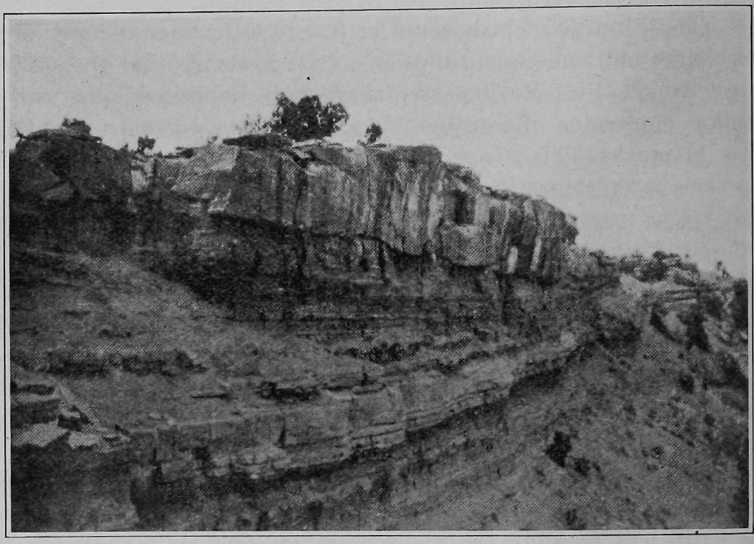

Fig. 21. Normal contacts of the Post-McElmo and McElmo formations.
The contact plane is at the base of the massive sandstone.

Other irregularities in this contact surface are evident in the McElmo Canyon country by the range in thickness of the series of shales and thin sandstones which separate the McElmo conglomerate from the Post-McElmo conglomerate. These two beds are 75 feet apart in the angle between McElmo Creek and Sand Gulch, and they are in contact in Yellow Jacket Canyon 3 miles away. These elevations and depressions in the McElmo shales are less apparent in the northern areas because no conspicuous bed is consistently present in the upper McElmo to act as a common plane of reference from which these irregularities can be measured.

In as much as the conditions under which the Post-McElmo beds were laid down are only a step removed from those operating during McElmo deposition, the scouring and channeling so common in the McElmo formation could account for the irregular surface which limits the McElmo formation above. Streams which became active at the close of McElmo time could have produced such a surface even without a long period of base leveling of beds which were above water for a considerable time.

LITHOLOGIC CHARACTER AND CONDITIONS OF DEPOSITIONS

The Post-McElmo and "Dakota" formations resemble the underlying McElmo in that they are largely of fluviatile origin. The two formations are the result of a set of conditions which produced a general sequence of material rather than a series of specific beds. Although the larger lithologic units can be recognized in nearly all sections, the subdivision of these larger units can be traced only short distances. Beds are everywhere lenticular, and shale lenses appear and disappear in all parts of the formation. Massive beds, 20 feet thick, often grade into thin-bedded sandstones within a quarter of a mile. The material in these two phases of the same bed is often such that hand specimens from two places cannot be distinguished.

The basal conglomerate is the most persistent bed of the unit. This "Dakota rim" is made up of well-rounded and subangular grains of quartz, chert, and particles of clay, inclosing irregularly distributed pebbles of quartz, quartzite, chert, and jasper. The individual grains or pebbles range in size from those of microscopic dimension to pebbles 3 inches in diameter. Ninety per cent of the sand, however, is more than a twentieth of an inch and less than a fifth of an inch in diameter. In the north wall of the canyon of Tabequatche Creek huge rounded masses of sand 1 foot in diameter and similarly shaped lumps of clay were held in this massive sandstone and indicated the remaking of a bed during Post-McElmo deposition at the site of the present sandstone. Carboniferous fossils which were found in the pebbles of this bed at many points prove the age of beds contributing material to the making of these formations. A common feature of this sandstone-conglomerate is the transition upward from sand of medium grain at the base into coarse conglomerate in the upper parts of the bed. This reversal of the normal sequence of materials in a conglomerate-sandstone bed is very noticeable and indicates a gradual increase in stream activity which reached a maximum and then subsided. In areas where the Post-McElmo approaches its maximum thickness the sequence noted in the above sandstone is sometimes repeated in higher beds.

The greenish shales in these formations differ from those in the McElmo formation only in amount. Chemical analysis shows them to be sandy shales whose green color is due largely to a magnesian iron silicate, probably glauconite. The shales in the upper part of these formations are gray to black, depending upon the amount of carbonaceous material. These shales invariably make a wavy contact with their overlying sandstones which suggest the scouring action of stream and the possibilities of local unconformities within these beds.

The massive chert probably resulted from the replacement of calcareous portions of the formation by silica. This is to be expected as conditions favoring the solution and deposition of silica must have been general in these beds not long after the deposition of the sediments. Silicified wood in a perfect state of preservation was found in several localities, and beds both above and below the chert contain in local areas sandstone which resembles quartzite. The chert beds weather into gray nodular masses and, because of their resistance, stand out in conspicuous outcrop.

The "Dakota" sandstones differ from the lower sandstones in their general brown color and more uniform grain. Their color is due to an abundance of rusty-brown limonite. "Iron" concretions are abundant in one bed and weather out either as tiny cavities, once filled with limonite, or they appear as small spheres. Marcasite concretions were found at several points.

Cross bedding of the stream type with laminae diverging at angles of 30° is common in the massive sandstones of this formation. The supposed fluviatile origin of these beds and the absence of fossils in the lower beds suggest that they are of fresh-water origin. However, marine or brackish water is suggested at one point by the presence of a fossil alga-*Halymenites* sp. This alga was collected from the top of the basal sandstone of the Post-McElmo unit on the north side of McClain Basin (tributary to Cross Canyon). Prof. Henderson comments as follows on this specimen.

This indicates that the stratum is marine, or possibly of brackish-water origin. The specimens are smaller than those of *Halymenites major* in the Fox Hills of Eastern Colorado, and are about the same size as those from the Huerfano sandstone (upper Benton) of Huerfano Park. It is doubtless whether plants of this character in a fossil state have their specific characters sufficiently preserved for specific identification. I see no way of distinguishing these specimens from true *Halymenites major*, unless it be the size, and mere size in such an organism is not a good specific character, in addition to the fact that the size so often depends upon the portion of the stem that is found.

The cementing materials in the sandstones of these beds include in their order of abundance, silica, iron minerals (largely limonite), calcium carbonate, and manganese oxide.

Swamp conditions which prevailed in "Dakota" times and made possible the formation of coal seams were of greater extent and longer duration in the central part of the area mapped than they were in other regions.

THE "DAKOTA PROBLEM"

Prof. Henderson, whose work on this survey had to do with the stratigraphy, contributes the following discussion on the "Dakota problem" as it is found in Colorado and particularly as it occurs in southwestern Colorado.

"In many portions of Colorado and adjacent states certain successions of strata have been referred to the Dakota formation, largely because of their stratigraphic position immediately underlying the marine Fort Benton formation or its equivalents. In a general way the strata so referred consist of an upper sandstone member, a medial shale and sandstone member, and a massive lower sandstone and conglomerate member, the three together usually measuring from 100 to 300 feet in thickness. Where the strata are flat the lower member usually forms the "rim rock" of the canyons, the middle and upper members sloping upward away from the rim, and the upper member often forming a secondary rim above. This is the condition found in much of southwestern Colorado. Where the strata are upturned to a high angle, as along the eastern Colorado foothills, the Dakota formation forms the outer "hogback," often divided into two low ridges by the erosion of the weaker middle member. The remarkable persistence of such a succession of strata over so large an area is very striking, at once attracting the attention of thoughtful observers. In all Colorado localities where it has been studied, in addition to its tripartite character and the uniformity of its general lithological character, it immediately underlies the Benton (lower Mancos of western Colorado) and is itself underlaid by the sandstones and variegated shales of the Morrison, or its equivalent, the McElmo. This naturally leads to the supposition that it is everywhere the same formation representing the same time interval. It may be said, however, that it is doubtful (1) whether much of it is really the time equivalent of the typical Dakota; (2) whether the so-called Dakota in various parts of Colorado and the adjacent region everywhere represents the same time interval; (3) whether it is to be considered everywhere in this region a single formation. In some portions of the state it should be divided into two formations at least, one possibly referable to lower Cretaceous and the other to upper Cretaceous.

"Perhaps it would be better to adopt local names and to avoid the use of the name "Dakota" in this region, but it has been so extensively and definitely used to designate this tripartite succession, limited above by the Benton-Mancos and below by the Morrison-McElmo, that it seems very convenient to retain the name in most localities, using it in the sense in which it is generally used, at least until the problem can be more thoroughly worked out over the whole southern Rocky Mountain region. However, its use is consistent and justifiable only if it be limited to the three members hereinbefore specified. If any of the underlying shales, sandstones or conglomerates be added, then we change the sense in which the term generally is used, and use it to designate a different lithological succession. Such a course is contrary to the practice of scientists for the very sound reason that it would soon destroy the value of scientific names. It is possible that the subdivision of the strata should be quite different from that generally accepted, in any particular region. If so, new names should be established, rather than using old names to designate new local combinations. Thus if we shift the dividing line between formations to a lower horizon, taking in some more shales and another conglomerate, then the name Dakota should by all means be abandoned and a new name adopted. The typical Dakota has been considered upper Cretaceous, characterized by the first appearance in members of broad net-veined leaves of Angiosperms. Meek and Hayden,[50] in describing it, mentioned numerous fossil leaves, fossil wood and several species of fossil mollusks, some of which would be considered marine under ordinary circumstances. Whether the marine shells actually occurred in the same layers with the leaves may be doubted.

"In southern Colorado, east of the mountains, Stanton,[51] Lee, and Darton have found a definite Washita Comanche marine fauna in the medial member of what had been theretofore designated the Dakota, with a Dakota flora in the upper member. In northern Colorado[52] the upper portion of the medial member at many locali-

[50] Meek and Hayden, Proc. Acad. Nat. Sci. Phila., vol. 13, 1861, pp. 419-420. Hayden, U. S. Geol. Surv. Wyo., 1870 (1871), p. 87. Lesquereux, Monog. U. S. Geol. Surv. Terr. (Hayden Surv.), vol. 6, 1874, p. 14.

[51] Stanton, Jour. Geol., vol. 13, 1905, p. 662. Lee, Jour. Geol., vol. 9, 1901, p. 343. Darton, Science, n. s., vol. 22, 1905, p. 120.

[52] Henderson, Colo. Geol. Survey, First Report, 1909, p. 175.

ties has yielded a marine fauna strongly, though not conclusively, suggestive of the Benton fauna. The material is too poorly preserved for definite specific identification, and the general types to which the fossils belong might occur in the lower Cretaceous as well as in the upper Cretaceous. However, the numerous specimens of *Inoceramus* are not distinguishable from *I. labiatus* Schl., which is abundant in some portions of the overlying Benton shales. The specimens of *Avicula* appear to be closely related to, if not identical with, *A. linguiformis* E. and S., which is found at a much higher horizon in the region, particularly in the Hygiene sandstone member of the Pierre between Loveland and Fort Collins. *Ostrea* is abundant, but specifically not even approximately determinable. Though suggestive of the Benton formation, they throw no light upon the lower two-thirds of the formation, which may quite possibly be Comanche, thus corresponding with the section farther south.

"In western Colorado we have very little evidence of the age of the so-called Dakota. It apparently occupies the same stratigraphic position as in eastern Colorado, lying immediately beneath the marine Lower Mancos (Benton horizon), and resting upon the McElmo variegated shales and sandstones which appear to be equivalent to the Morrison. No marine fossils have been found in the Dakota of western Colorado, or in the underlying McElmo, La Plata or Dolores, except Carboniferous fossils found in pebbles of the "Dakota" conglomerate, and these of course have no stratigraphic significance. It seems probable that these four formations are of fluviatile origin, as is usual with the western non-marine formations, with perhaps some lacustrine beds of more limited area. Thin, but workable, beds of coal in the middle and upper Dakota suggest the likelihood of many fossil leaves, though very few good specimens have yet been found, and no fossil verterbrates.

"This survey obtained quite a number of leaves from a white sandstone on the high point between Cutthroat Gulch and Hovenweep Canyon (see section on page 106).

"Professor T. D. A. Cockerell[53] published a report upon this material, in which he identified the best-preserved of the leaves "with confidence" as *Matonidium althausii* (Dunker) Ward. Some poorer material he referred to the genera *Sapindopsis* (differing slightly from *S. variabilis* Fontaine), *Equisetum* (compared with *E. burchardti* Dunker), and *Cycadospadix?* sp. Some leaves not

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[53] Cockerell, Jour. Wash. Acad. Sci., vol. 6, pp. 109-112, 1916.

published were labeled by him *Todites* and *Weichselia*. He assigned all these leaves to the Lower Cretaceous.

"The assignment of this horizon to the Lower Cretaceous is unsatisfactory, because it is well above the horizon hereinafter mentioned, containing broad-leafed plants, and including among others the well-known *Sassafras mudgii* Lea. Dr. E. W. Berry has examined the same material upon which Professor Cockerell's publication was based, and reports as follows:

The upper or sandstone horizon contains scarcely anything except *Matonidium*. This is not *Matonidium althausii*, however, as Prof. Cockerall thought, but a new species and not necessarily indicative of Lower Cretaceous age, since very fine *Matonidiums* occur in the European Cenomanian. In my judgment Prof. Cockerell's *Cycadospadix*, *Todites*, *Weichselia* and *Equisetum* all represent different parts of the *Matonidium* frond, frond-base and stipe. The forms which Professor Cockerell identified as *Sapindopsis* from this horizon are not *Sapindopsis*, as the venation is distinctly not that of *Sapindopsis*. What it is I am not prepared to say, as there are a great many unallied genera that have very similar lanceolate leaves, and the venation of the Colorado material is not complete enough except to show that it is not *Sapindopsis*. There are other fern fragments in the collection which probably represent the genus *Onychiopsis*. These are probably identical with some of the things that have been called *Asplenium dicksonianum* Heer. They differ from the species of *Onychiopsis* known to me from the Potomac formations and appear to approach closest to a described species from the Cenomanian of Bohemia.

"We have found in a shale lens, in the basal conglomerate of the so-called Dakota, near the top of Norwood Hill, where the wagon road from Placerville to Norwood leaves the San Miguel Canyon, some leaves which were also submitted to Dr. Berry, upon which he comments thus:

The lower or black shale horizon contains the following identifiable forms:

Pinus susquaensis Dawson, known previously from the Kootenai, Lakota and Fuson.

Cissites sp.

Sassafras mudgii Lesq., known previously from the Dakota, the supposed Dakota of the Black Hills, and the Cheyenne sandstone of Belvidere Co., Kansas.

Sphenolepis kurriana (Dunker) Schenk, a probably composite species ranging from the Wealden to the Cenomanian and recorded from the Fuson.

Brachyphyllum sp. This is either *B. Crassicaule* Font., or *B. obesum* Heer. It is not in my opinion *B. macrocarpum* Newberry of the Dakota and Raritan, but one cannot be too certain with *Brachyphyllum*, as all the species are variable.

"Commenting upon both collections, Dr. Berry says:

Regarding the age of the material, it is not extensive or good enough for one to be dogmatic about, but I see nothing to indicate that either the older shale or the younger sandstone represent the true Dakota. There are no typical Dakota species in either and the general facies appears to me to be slightly older. Neither would I place either in the Lower Cretaceous, but would be inclined to consider that both floras represent the same general horizon, and I am strongly of the opinion that this horizon is to be correlated with what has been called the Purgatoire formation in southeastern Colorado and described by Stose, Finlay and Richardson (folios 186, 198, 203). It is also to be correlated with the Belvidere section of southern Kansas at the top of the Washita division of the Texas Comanchean. The Washita is commonly considered to represent the top of the Lower Cretaceous, but I am confident that it is Cenomanian in age and represents the lower part of the Upper Cretaceous, as I stated in my Upper Cretaceous Floras of the World, and in this I am corroborated by European paleontologists from the faunal evidence.

"Stanton places the Washita in Lower Cretaceous. Inasmuch as the Purgatoire is the base of the so-called Dakota of southeastern Colorado in which Washita marine fossils have been found, referring both leaf horizons of southwestern Colorado to the Purgatoire raises the question of whether in eastern Colorado there is any true Dakota. Stanton does not mention the species of leaves from southeastern Colorado referred by him to the Dakota.

"Richardson, in Castle Rock Folio (No. 198), reports *Salix proteaefolia* LX. and *Sapindus morrisoni* LX., from the upper sandstone of the formation usually designated as Dakota, neither of which has been reported from the type locality of the Dakota. It seems clear that the whole problem of the Dakota is yet to be solved. So far as is known there is no unconformity between the upper sandstone assigned to that formation by general usage in southwestern Colorado, and the overlying Benton. The same is true of the Dakota-Benton boundary in eastern Colorado. On the other hand, nearly everywhere an unconformity is suspected between the lower "Dakota" or Purgatoire and the underlying Morrison-McElmo beds, and in some places such an unconformity is actually observed. That appears to be true on Norwood Hill. The occurrence of a continuous, strong, coarse sandstone and conglomerate over such large areas itself strongly suggests an unconformity.

"South and southwest of the area under discussion, in New Mexico and Arizona, Gregory[54] has reported a Dakota flora, chiefly from the upper part of the formation, consisting of *Phyllocladus*

[54] Gregory, U. S. Geol. Survey Prof. Paper No. 93, pp. 71-72, 1917.

subintegrifolius LX., *Ficus inaequalis* LX., *Ilex* sp., *Salix* sp., *Andromeda pfaffiana* Herr? and *Juglans* cf. J. *crassipes* Herr. With them he reports at one locality *Ostrea* sp. and *Corbula* sp., indicating an invasion of brackish water and possibly marine water shortly prior to the ushering in of the marine conditions of the Benton epoch, just as in northeastern Colorado.''

The natural inference from these correlations and the character of the beds involved is that the basal portion of the section which comes between the McElmo as mapped and the Mancos above may contain beds equivalent to the Purgatoire of southeastern Colorado. Cross,[55] however, states that: ''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 Dakota in the San Juan folios to the Comanche series.''

MANCOS FORMATION

The Mancos formation consists of a mass of slate-colored to drab clay shales with minor amounts of limestones and impure sandstone. These shales were not carefully examined and observations of this unit were confined to their lower contact.

The shales lie conformably on the ''Dakota'' and inasmuch as the Mancos formation carries abundant fossils of *Graphaea newberryi* near its base the division of the two formations can be made with certainty. These fossils were found within 20 feet of typical ''Dakota'' sandstone at many points. *Gryphae* sp. were found at the foot of the Ute Mountain in a sandstone in contact with a ''Dakota'' bed which carried abundant plant fragments.

The thickness of the Mancos shale was not determined, but it probably exceeds 1,500 feet in the upper part of Disappointment Valley. Elsewhere the areas covered by this formation include less than 1,000 feet of these sediments. The ease with which these shales are eroded is illustrated by the almost constant discharge of mud from Disappointment Creek into Dolores River. A shower in the shale areas of Disappointment Valley is evidenced for several days by the muddy water in Dolores River.

The present distribution of the Mancos formation is determined by the structural features of the area. Mancos shale covers the bottom of the Disappointment syncline (see Pl. 2 in pocket) and the synclinal trough of Dry Creek Basin. It occurs in smaller amounts in the San Miguel syncline north of Naturita and in the

[55] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colo. and Utah: Jour. Geol., vol. 15, No. 7, p. 637, Oct.-Nov. 1907.

structural basin south of Coke Ovens. Downward movement of a block in Gypsum Valley has protected some of these shales, and a sharp syncline has retained a remnant of them in Little Gypsum Valley. Isolated areas of Mancos shale exist along the foot of the Uncompahgre uplift east of Cottonwood Creek and recent diamond drilling near the Copper King prospect east of North Fork of Tabequatche Creek shows that Mancos shale is present on this bench, although no outcrop of these shales was found in the vicinity.

Small areas of Mancos shale exist at the upper end of the numerous headlands which extend out from the base of Ute Mountain and probably exist at many points on the Dolores Plateau. Scattered fossils of *graphaea* suggest remnants at several points in the vicinity of Dove Creek. However, isolated fossils are not conclusive evidence of the presence of the shales. The fossils are so much more resistant than the shale in which they generally occur that they are sometimes found out of their parent formation. In many places along the headwaters of Squaw and Monument creeks the surface of "Dakota" beds is strewn with these fossils and at one point near Bug Spring 30 more or less perfect specimens of *graphaea newberri* were counted on the surface of a massive "Dakota" sandstone within an area of 4 square feet.

The Mancos shales include thin-bedded, papery, and blocky varieties, and sandy shales that locally grade into sandstone lenses. Beds of limestone 1 foot or less in thickness come within the lower 200 feet of the formation at many points. Seams of calcite are common in the limy horizons and selenite crystals occur in almost every part of the formation.

Prof. Henderson collected and identified the following marine fossils from this formation.

Lower Mancos Cretaceous Fossils from the Mancos Formation

Dry Creek southeast of Coke Oven:

Gryphaea newberryi Stanton.
Ostrea sp.
Shark teeth.

Dry Creek Basin, 2 to 3 miles southwest of Stone Cabin:

Ostrea lugubris Conrad.
Gryphaea newberryi Stanton.
Inoceramus dimidius White.
Inoceramus fragilis H. & M.
Cardium pauperculum Meek?
Prionotropis woolgari (Mantell)?

Head of Gypsum Valley:

Ostrea sp.
Inoceramus sp.

Head of Little Gypsum Valley:

Ostrea lugubris Conrad.
Gryphaea newberryi Stanton.
Inoceramus dimidius White.
Inoceramus fragilis H. & M.
Prionotropis woolgari (Mantell).
Prionocyclus wyomingensis Meek.
Scaphites warreni M. & H.
Baculites gracilis Shumard?

North side Disappointment Valley, northeast of Cedar P. O.:

Ostrea congesta Conrad.
Ostrea lugubris Conrad.
Gryphaea newberryi Stanton.
Inoceramus fragilis H. & M.
Inoceramus sp.
Prionotropis woolgari (Mantell).
Prionocyclus wyomingensis Meek.
Baculites gracilis Shumard?

North side of creek, Disappointment Valley, west end:

Ostrea sp.
Inoceramus dimidius White.
Gryphaea newberryi Stanton.

Lower Mancos Cretaceous Fossils from the Mancos Formation

Cliff southeast of Stone Cabin, Dry Creek Basin:

Baculites ovatus Say.

Cliff about 10 miles east of Cedar P. O., Disappointment Valley:

Inoceramus cripsi barabini Morton.
Baculites compressus Say.

MESAVERDE FORMATION

Beds of the Mesaverde formation cap the high bluff which stands near the head of Gypsum Valley. Only the lower part of the formation is represented by these cliffs. These beds were not examined in detail, but appear to consist of sandy shales and brown sandstones in about equal amounts. The sandstones occur in thin beds alternating with shales and as massive beds 10 to 30 feet thick which weather out in huge blocks that slump into all sorts of positions along the foot of the cliff. The contact as drawn between the Mesaverde and Mancos formations follows the contour of the bluff and comes at the base of the predominantly sandy part of the section.

INTRUSIVE ROCKS

(PROBABLY OF TERTIARY AGE)

The intrusive rocks of the area are confined to two regions—the Ute Mountains and the north side of Disappointment Valley. The maximum extent of these intrusions is not shown by the mapping in either region.

UTE MOUNTAIN INTRUSIVES.

The Ute or El Late Mountains as they were known to the Hayden geologist, rise out of an otherwise smooth plain to an elevation exceeding 9,000 feet; 3,000 feet above the general level of the surrounding country. Hayden geologists considered them a laccolithic mass whose capping rocks had been removed. The rather vertical walls along which these rocks make contact with Mancos shales in Pine Creek and streams further east suggest the possibility of their being stock-like in outline. The idea is further emphasized by the fact that no outlying remnants of this resistant rock exist to outline the thinned edge of a laccolith, but the walls of the igneous mass rise very abruptly out of the plain and suggest that the present mountain represents practically the maximum limits of these rocks. However, these rocks probably do not exist in as large a mass as that suggested by the cross section of McElmo Canyon (see Pl. I in pocket).

All the rocks examined from this intrusion were of the same general composition but different in texture. Specimens and petrographic sections representing both the coarse and fine textured materials were submitted to Prof. R. D. Crawford for examination. He describes the rock as an andesite porphyry and comments as follows:

> Though the specimens of this rock that were collected are fairly uniform in mineral composition, they differ greatly in texture. One variety carries many white feldspar phenocrysts 2 to 5 mm. in diameter and many smaller hornblende phenocrysts in a greenish-gray groundmass. Another variety carries many black hornblende crystals 2 to 5 mm. long and a few feldspar phenocrysts in a bluish-gray groundmass.
>
> The rock is so much weathered that it is impossible to identify with certainty all the constituents, but the microscope shows that the phenocrystic feldspar in both varieties is a soda-lime plagioclase. The groundmass carries many minute lath-shaped microlites of feldspar that are probably plagioclase, and also hornblende and numerous minute grains of magnetite or ilmenite. Orthoclase may be present in the groundmass.

Mancos shale was baked into a porcelainite near the contact of the intruded rocks, and effects of metamorphism were observed in shale along Finley Canyon over a half mile from any known intrusive. The "Dakota" sandstones where observed in contact with these intruded rocks were practically unaffected. Showings of copper minerals near the border of the igneous rocks have caused considerable prospecting. Materials collected from two prospects contained copper, silver, and traces of gold and the material from one contained arsenic with small quantities of silver.

INTRUSIVE ROCKS OF DISAPPOINTMENT VALLEY

The intruded rocks in Disappointment Valley occur as sheets between beds of the "Dakota" formation and, in one place, between beds of the Mancos shale. These sheets follow closely the bedding of the formations in which they occur and at a distance appear to be only the normal outcrop of a resistant bed. One isolated outcrop forms the cap to a small butte of Mancos shale. These intrusions exceed 30 feet in thickness at several points.

The age of these sheets can be fixed as younger than the Mancos shale, and an offset in one due to a fault proves them to be older than the faulting. It is probable these sheets are connected, at least indirectly, with the general period of igneous activity which affected this part of Colorado and which is considered Tertiary.

Prof. Crawford has examined hand specimens and thin sections of these rocks, which he terms diorite porphyry and describes them as follows:

> This fine-grained rock is composed almost entirely of white or gray feldspar and black hornblende. The hornblende makes up about one-fourth to one-third of the rock, by volume. Small phenocrysts of both hornblende and feldspar are abundant in a subordinate grayish groundmass.
>
> The microscope shows the feldspar phenocrysts to be soda-lime feldspar, probably andesine. The groundmass is composed mainly of a microcrystalline aggregate of feldspar. Both phenocrysts and groundmass are considerably weathered.

An intruded sheet of rock, unlike those near Klondyke, occurs along the ridge which divides Disappointment and Gypsum valleys and west of the gap through which the road to Cedar crosses this divide. The sheet followed the bedding of the McElmo shale into which it had been intruded.

Prof. Crawford describes this rock as follows:

> This [eruptive breccia] is a dense, dark-gray rock that carries numerous small fragments of black, green, and light gray sediments. Both inclusions and matrix contain enough calcium carbonate to give ready effervescence with dilute acid.
>
> In thin section the matrix is seen to be about one-half glass through which are uniformly scattered many microscopic grains of quartz and feldspar. These grains show almost no crystal outline and have irregular and sharply angular forms. Their apparently clastic

character may have been brought about by movement of the magma after quartz and feldspar phenocrysts have crystallized, thus fracturing the crystals.

The float from a rock similar to this breccia was found along this same divide east of the gap mentioned above. The parent ledge was not located but the position of the float was such as to suggest a sheet in the same stratigraphic position as the one west of the gap. The present mapping of this divide probably does not include all areas of these intruded rocks.

The age of this intruded breccia cannot be determined nor was a relation established between it and the sheets of diorite porphyry farther east.

QUATERNARY DEPOSITS

Mesa and Terrace Gravels—Coarse gravel and boulders 1 foot or less in diameter exist as thin deposits at several points, particularly within the drainage of San Miguel River. These deposits contain boulders of practically every rock found in the San Juan Mountains.

A remnant of Mancos shale north of Naturita, protected by a veneer of these gravels, forms a flat-topped mesa 200 feet above the general level of the area. This elevated surface is known locally as High Mesa. Other patches of these gravels exist within the area but their distribution is confined generally to the region adjoining San Miguel River.

Numerous terraces covered with these gravels exist along San Miguel River and some along Dolores River. It is of interest to note that these terrace gravels sometimes carry gold in such quantities as to cause their exploitation as placer deposits.

The area mapped as "eruptive debris" at the foot of the Ute Mountains differs in no way from the mesa gravels just described except that the Ute Mountain deposits are made of water-worn boulders of igneous rock from which the mountain is made. These boulders are mixed with soil derived largely from the Mancos formation upon which the gravels generally rest.

At the head of Gypsum Valley a mass of water-worn eruptive boulders stands out in cliffs 100 feet high. These boulders are not distributed as in a normal, flat-topped mesa cap but appear to be a more or less jumbled mass of considerable thickness. Topography cannot explain their present position, nor could a near-by source of such materials be found. The degree to which these boulders have been rounded suggests that they traveled a considerable distance. Similar boulders along streams that drain north from Lone Cone point to this region as the origin of these materials.

Landslide Material.—Regions affected by slumping are common in the upper McElmo formation, particularly along the Uncompahgre Plateau. The slumping in Tabequatche Basin already described (p. 83) is typical of this formation. The edges of most valleys contain local areas of landslide material, but their size does not warrant their separate mapping.

Slope Wash.—In Gypsum and Paradox valleys angular debris from the valley walls has accumulated over large areas and in places has reached considerable thickness. At one point in Paradox Valley a ravine has cut over 70 feet into this slope wash without exposing the underlying beds. Typical stream sand and gravel make up a minor part of these deposits.

Alluvium.—Typical stream-laid gravels and sands are confined to narrow strips along the main streams and cover only a minor part of the total area represented as "alluvium."

Wind-blown Deposits.—Isolated patches of wind-blown material exist in the areas south of Disappointment Valley. Patches of reddish colored soil occur along Monument Creek, which must have been derived from beds other than the "Dakota" upon which they rested. After witnessing one of the dust storms which sometimes crosses this area from the west it is not difficult to understand that such soils may contain an appreciable amount of wind-blown material from Dry Valley and other areas in this part of Utah.

Wind-blown material of local origin exists in areas where the lower formations are exposed. The material in the La Plata sandstones, and the character of their outcrop, is particularly favorable to wind erosion. Many of the rounded forms of this formation are due to the scouring and the removal of weathered material by winds. McElmo and tributary canyons contain many deposits of these sands. Even in narrow canyons such as Yellow Jacket Canyon where the La Plata sandstones are exposed, mounds and tiny dunes are formed from the sand resulting from the weathering of these beds. It is a singular fact that these beds presumably formed from wind-blown sand in Jurassic times should again be subjected to the same means of transportation as effected their original deposition.

CHAPTER III

STRUCTURAL GEOLOGY

GENERAL RELATIONS

The bulk of the carnotite area of Colorado is structurally a series of parallel folds whose axes trend northwest and southeast. A line drawn southwest from the Uncompahgre Plateau to the high ground south of Disappointment Valley, commonly referred to as the Dolores Plateau, passes over in quick succession a series of monoclines, synclines, and anticlines. Eight regions of folding lie north of the Dolores Plateau. One prominent anticline adjacent to McElmo Canyon is the only structural feature of importance within the southern 50 miles of the area examined.

The master folds occurred along lines of weakness, some of which were established before the bulk of the rocks in the area were laid down. In certain zones of folding the nature of the deformation differs from place to place. The present position of beds along Gypsum Valley is due in some places to folding, and in others to faulting. Paradox Valley is carved from an anticline which is modified at either end by faulting and synclinal folding. Although the folding in individual regions cannot be described correctly by a single term, these regions of deformations are discussed under the following heads: Uncompahgre uplift, San Miguel syncline, Paradox Valley deformation, Sinbad anticline, Basin syncline, Gypsum Valley deformation, Disappointment syncline, Dolores anticline, and McElmo anticline. The axes of these folds are shown on a structural sheet (Pl. II in pocket).

NATURE AND EXTENT OF FOLDING

The exposures of Carboniferous rocks in Paradox and Gypsum valleys show that folding in these regions took place before the deposition of Triassic and younger formations. These ancient folds are not considered in the present discussion which has to do with deformations which took place after the deposition of the Mancos shale.

North of the Dolores anticline downwarps follow upwarps in a regular order at approximately equal intervals like huge waves on an ocean. The regularity of this folding would be apparent by restoring the material removed by erosion and by adjusting strata to the position they occupied before the faulting.

The energy expended in producing the different movements is progressively less for each fold south from the Uncompahgre uplift. The stresses which operated to produce the bending in the smaller of these eight regions of deformation, affected less material than in the larger folds and, therefore, produced more intense upwarps or downwarps. In no case, however, has the movement been extreme.

The structural units are from 3 to 12 miles wide, and the length of some exceed the width of the area mapped. The 25 miles of the Uncompahgre uplift which comes within the area examined, is less than half its total length. The Paradox fold continues into Utah to the foot of the La Sal Mountains. Indeed, a fold which extends beyond these mountains is possibly a part of this same flexure. The Colorado portion of this fold is 30 miles long. Sinbad Valley is carved from an anticline which is part of a flexure extending into Utah. Other zones of folding can be traced across and beyond the limits of the present mapping.

Folding is extreme at only a few points. Dips of 30° are not common, and those of more than 45° are rare. At a few points ''dragging'' incident to faulting has tilted beds locally to vertical positions. The difference in elevation of individual beds in adjoining folds often exceeds 2,000 feet and is more than 3,000 in two folds. The ''Dakota'' is 3,500 feet higher on the Uncompahgre Plateau than it is in the San Miguel syncline, and the same beds are depressed 3,000 feet from the Dolores anticline to the Disappointment syncline. In as much as erosion has removed the central part of several anticlines, and slope wash has covered the floors of the resulting valley, the total amount of upwarping is often difficult to estimate. Paradox Valley is a typical example of such an anticline.

The synclines, which involve greater areas than do the other folds, are structurally simple, whereas, the anticlines are so modified by faulting and cut by erosion that details of structure are often obscured.

NATURE AND EXTENT OF FAULTING

The large faults of the region are displacements along almost vertical planes which dip toward the down-throw side. The surfaces along which the faulting occurred are, in some places, smooth planes with movement confined to a simple fracture; in other places, faulting occurred along warped surfaces and was often distributed along several more or less parallel fractures. Step faults are not uncommon.

Although the large faults are of the gravity type, one small displacement north of Silvey's Pocket was the result of a thrust. Other small displacements in Gypsum Valley suggest thrusts which are secondary to the main faulting of the region. The direction of dip of several fault planes could not be determined.

The maximum vertical displacement due to faulting exists in Gypsum Valley, where a stratigraphic throw of approximately 2,700 feet brings Mancos shale in contact with Carboniferous limestone. Displacements in other regions seldom exceed 400 feet, and most of them are less than 200 feet. In as much as the faults are related to the folds, they are described with the individual regions in which they occur.

Several faults known to exist in Sinbad Valley and vicinity are not shown by the present mapping. Nor does the mapping in West Paradox Valley include all the faults of that region.

FAULT BLOCKS

Intersecting faults have made possible the vertical movement of blocks of sediments, some of which are over a mile across. Most of these blocks moved downward with respect to the unfaulted ground. In a few places, however, individual beds stand higher in the blocks than they do in the adjoining ground. Blocks of the last sort exist in the west end of Paradox Valley and along the Uncompahgre Plateau.

The carnotite mined on Roc Creek is from a fault-block which has been tilted during the process of settling. The Cliff Dweller and Cashin mines are on either side of a fault-block of Dolores sandstone. The relation of outcrops of formations in the east end of Paradox Valley is easily explained by assuming the presence of fault-blocks whose edges cannot be definitely outlined. Blocks bounded on two sides by faults exist in Silvey's Pocket and Klondyke. The region where McIntyre Canyon crosses into Utah includes several tilted blocks which have settled unequal distances below the rim of the canyon. This region is the end of a much faulted zone which extends eastward from Lisbon Valley, Utah.

JOINTING

Systems of joints have, in places, affected large areas. They are well developed in some areas adjoining the main folds and obtain their greatest expression when they traverse the massive beds of the Dolores and La Plata formations.

On either side of Paradox Valley a system of joint planes parallels the lines of folding of the valley and traverses the strata at right angles to their bedding (see fig. 22, p. 128). The faults of this region are essentially dislocations along joint planes. At one point south of Saucer Basin seven parallel faults traverse a strip of ground less than half a mile wide. The blocks bounded by these planes are better described as fault slices, one of which is only 300 feet wide but is more than 2 miles long.

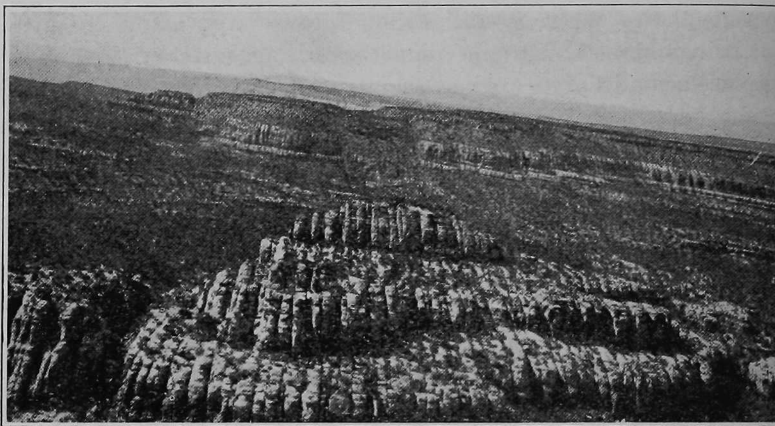

Fig. 22. Jointing in the La Plata formation south of Saucer Basin.

A rude columnar jointing possessed by the massive Dolores sandstone (see fig. 6, p. 50) is not related to the recent folding of the region but is present in practically all exposures of this bed.

In many places, notably in Yellow Jacket Canyon and vicinity, the La Plata sandstone is patterned by a network of joints, forming polygons from 1 to 6 feet across (see fig. 53, p. 218). These joints, which cause development of ''turtle backs'' in this sandstone, are probably the result of daily temperature changes which are extreme in this arid climate.

UNCOMPAHGRE UPLIFT

The master structural feature developed by the Uncompahgre uplift is a fold-fault along the edge of a gigantic block which constitutes the Uncompahgre Plateau. The fold is technically an asymmetrical anticline, but dips on one side are so gentle that it resembles a monocline more than an anticline.

The axis of folding follows near the southwestern edge of the plateau. Dips to the northeast from this axis measure from one-half to 2°, but beyond the limits of the map they increase toward the Gunnison River. Southwest from the top of the folding beds are occasionally tilted 45°, and in local areas, ''dragging,'' incident to faulting, has brought them to vertical positions. The change in elevation of individual beds, due to this faulting and folding, is 2,500 feet between the head of Tabequatche Basin and the mouth of Horse Fly Creek, 3,000 feet between Uncompahgre Butte and the mouth of Calamity Creek, and 3,500 feet between Spruce Mountain and Third Park.

The part of the uplift which lies east of Spruce Mountain includes two lines of deformation. One line passes 2 miles south of Spruce Mountain and follows the north edge of Tabequatche Basin. The other line begins 5 miles south of Spruce Mountain at the western edge of Pinto Mesa and continues southeast to Patterson Mountain.

South of Spruce Mountain, the northern line of deformation consists of beds dipping south on either side of a fault which extends east from this point. Where this fault crosses North Fork of Tabequatche Creek there is little folding, as sedimentary rocks abut against the granite mass in the creek bottom with only slight southern dips. The vertical displacement is about 800 feet at this point. East of this stream beds are tilted on either side of the fault, but the displacement is progressively less toward the head of Tabequatche Basin, where the fault passes into a gentle fold, which is absorbed by the main uplift. East of Tabequatche Basin the main line of folding trends southeast, crossing Little Red and Big Red canyons, 3½ miles from Horse Fly Creek.

The second line of displacement begins with block faulting on Tabequatche Creek 4 miles south of Spruce Mountain. The main line of faulting, which in this region trends northwest and southeast, intersects a cross fault which trends S. 15° W. The block included in this angle shows on its northeast side a downward movement of 500 feet and upward movement of 350 feet on its west side. The faulting, which continues southeast from this block, follows the abrupt rise from Pinto Mesa to the west end of the ridge constituting the southern limit of Tabequatche Creek drainage. Beds adjacent to the faulting show little, if any, tilting at this point, but east of Little Bucktail Creek, Post-McElmo and "Dakota" beds stand adjacent to the fault in an almost vertical position. The faulting becomes less prominent eastward from North Fork of Cottonwood Creek and passes into a low anticline which forms Patterson Mountain. East of Horse Fly Creek this anticline is indistinct.

A fault branches from the one just described at a point 2 miles west of Little Cottonwood Creek and trends east to meet the monoclinal folding of the main uplift at the head of Sheep Creek. This line of movement is accompanied by tilting of beds throughout its course.

East of Spruce Mountain the elevation of beds from the San Miguel to the Dolores Plateau is thus accomplished in two steps, whose edges are marked by the lines of faulting and folding just described. A north-south section from the mouth of Cottonwood Creek to the Uncompahgre Plateau shows the relations of the blocks involved. By restoring the parts of the ''Dakota'' formation which have been removed by erosion, the deformation is easily recognized as two faulted monoclines. The ''Dakota'' beds are tilted gently upward from Cottonwood Creek toward the north for 1½ miles. From this point the dips increase until adjacent to the fault they stand almost vertically. North of the fault the ''Dakota'' has been removed from the edge of what would otherwise be an elevated bench. This folding and faulting result in an abrupt rise of 1,200 feet.

North from this flexure the ''Dakota'' beds are tilted slightly upward toward the plateau. They cap the timbered bench on which Kenshol's saw mill is situated, and, formerly, continued with small undulations across what is now the Tabequatche Basin. Two miles north of Tabequatche Creek a second step, similar to the first, makes a rise of 1,000 feet to the top of the Uncompahgre Plateau. The block included between these two steps is horizontal at its western end but becomes warped in its eastern part where its beds once connected with those of the plateau.

West of Spruce Mountain the distortion of formations along the uplift is limited to a single zone, whose vertical displacement of beds equals the combined effect of the two zones east of this point. From Winter's Camp, which lies south of Spruce Mountain, to the point where Atkinson Creek crosses the uplift, folding and faulting are more extreme than in any other part of the uplift. In this distance dips exceeding 60° were recorded in three places. At the head of Cambell's Creek, McElmo sandstones abut against granite in almost horizontal position. The fault at this point exceeds 1,600 feet in displacement. Northwest from Atkinson Creek faulting plays out and beds of the Dolores formation pass unbroken across the uplift. In the vicinity of Mesa and Blue creeks the base of the uplift is outlined by a fault of small displacement from which the beds reach up to the top of the plateau in long, bold sweeps. The deformation along the plateau increases northwest from the limits of this map.

SAN MIGUEL SYNCLINE

San Miguel syncline is the name applied to the broad, shallow structural basin which extends from the foot of the Uncompahgre uplift to the upwarping of the Paradox anticline.

The axis of this fold crosses San Miguel River 3 miles above Naturita, and passes through the low ground in First, Second, and Third parks. It crosses Calamity Creek near its mouth and Dolores River 3 miles from Gateway. At one end the fold becomes lost in the flat-lying sediments of Mailbox Park, and at the other end the folding becomes indistinct, and beds along the Dolores below Gateway cross the river to the Uncompahgre uplift with only gentle downwarping. This syncline is 35 miles long, but at no place is the folding sufficiently pronounced but what there was always doubt as to the proper placing of its axis. No bed is depressed in this basin as much as 300 feet below the position it occupies along San Miguel River. Dips seldom exceed 2° within a mile of the axis, and dips of 6° probably do not occur in this fold until it comes within the area affected by the Uncompahgre uplift.

The trough of this syncline is covered with Post-McElmo and "Dakota" beds as warped and tilted blocks which are so disconnected in places that the complete folding is evident only by projecting dips from one block to another. San Miguel River below Naturita runs parallel to the axis of the fold but follows well up on its southwest limb. Streams that cross from the Uncompahgre Plateau to the San Miguel River have been unaffected by this fold.

PARADOX VALLEY DEFORMATION

FOLDING

The Paradox anticline is the main feature of a zone of deformation which affects an area 8 to 12 miles wide and 40 miles long. The center line of this zone extends southeast from the La Sal Mountains in Utah through Paradox Valley to a point 5 miles south and 3 miles east of Naturita. At either end of the Paradox anticline there is a downwarping of beds where the anticline grades into a syncline.

Paradox Valley is gouged from the anticlinal part of this deformation. Beds in the valley walls dip away from an axis whose position is in doubt, due to the fact that few beds outcrop in the center of the valley. With the exception of recent faulting along the southwest side of this anticline and block faulting in the southeast end of the valley, the structure is a simple anticline whose central part has been eroded down to and into Carboniferous beds. The two sections of this valley which appear on plate I (in pocket) are not typical in that they show more than the average amount of faulting.

Two miles west of Paradox post office strata occupying the center of the valley dip west and, by means of cross fault, sag across what would otherwise be the northwestward extension of the Paradox anticline. The deformation at this point passes from an anticline to a syncline bounded by two anticlinal ridges whose axes

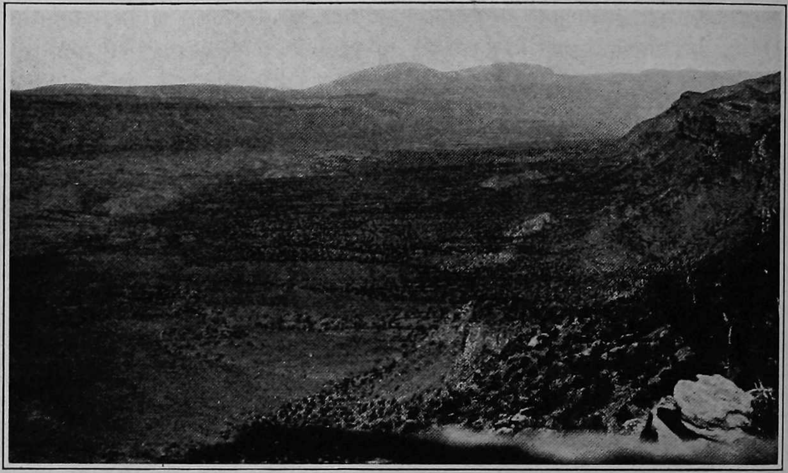

Fig. 23. Looking west into East Paradox Valley.
Even slopes in the valley bottom formed by Quaternary slope wash, and light colored hills on the south side of the valley formed of gypsum (Carboniferous): La Sal Mountain in the distance.

coincide with the extension of the edges of Paradox Valley. The downwarping of the Post-McElmo and "Dakota" beds is so apparent that the careless observer, without a knowledge of the westward dips of these central beds, gains the impression that the entire valley is a depression resulting from the settling of a huge block. The anticlinal and syclinal phases of this deformation are shown by fig. 24, p. 133.

The southeast end of the Paradox Valley zone of deformation is structurally similar to the northwest end. A fold with some obscure faulting crosses the axes of Paradox Valley 3 miles west of Coke Ovens and terminates the valley at this point by a low ridge capped by the "Dakota" formation. Beds dip east from this dividing ridge into a synclinal basin whose axis is in line with the main Paradox fold. The limbs of this syncline connect with two anticlinal ridges whose axes are the southeastward extension of the edges of Paradox Valley.

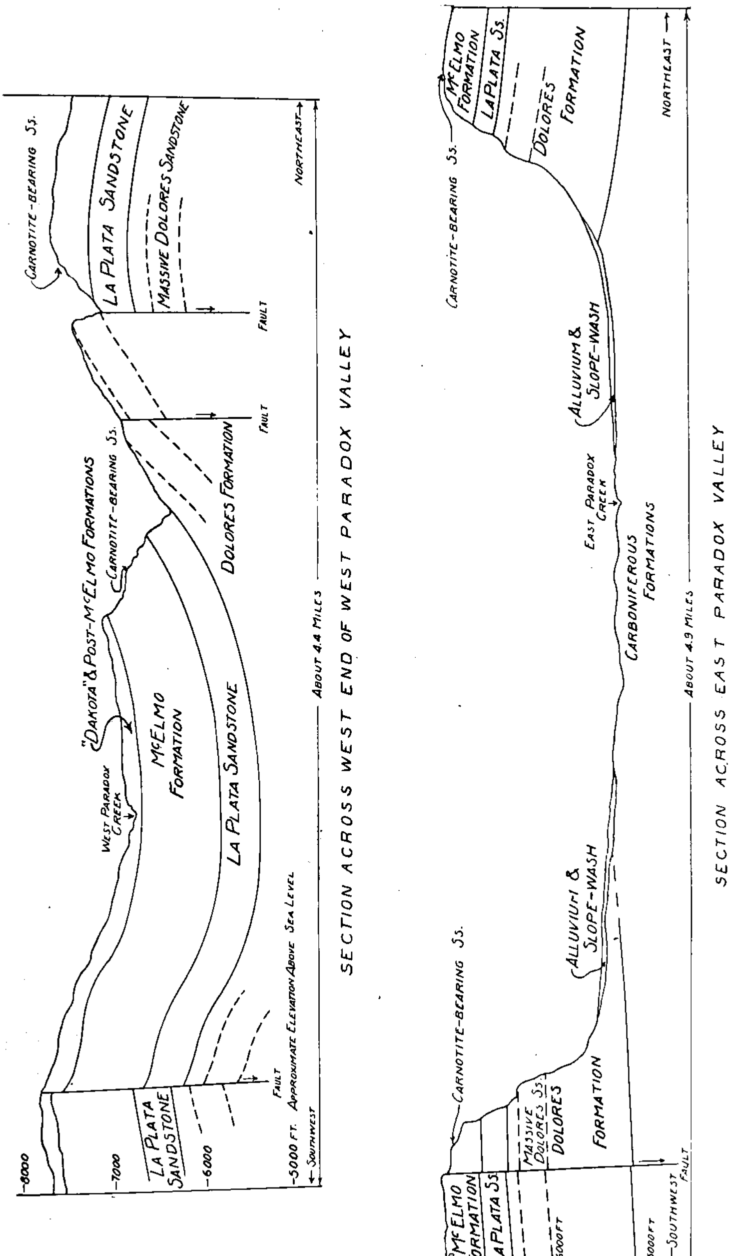

Fig. 24. Sections showing the anticlinal and synclinal phases of the Paradox Valley deformation.

The axis of the folding on the northeast side of the syncline just mentioned crosses Dry Creek 1½ miles above its mouth. East of the creek the anticline grades into a monocline which plays out in the flat-lying beds south of Naturita.

The fold on the southwest side of the synclinal basin is prominent, the crest of the anticline being the highest ground in the vicinity. This fold, called Dry Creek anticline, is cut by Dry Creek at approximately the point of maximum flexing. It is a part of the Paradox deformation and results from the eastward extension of the southern limb of the Paradox anticline and the downwarping

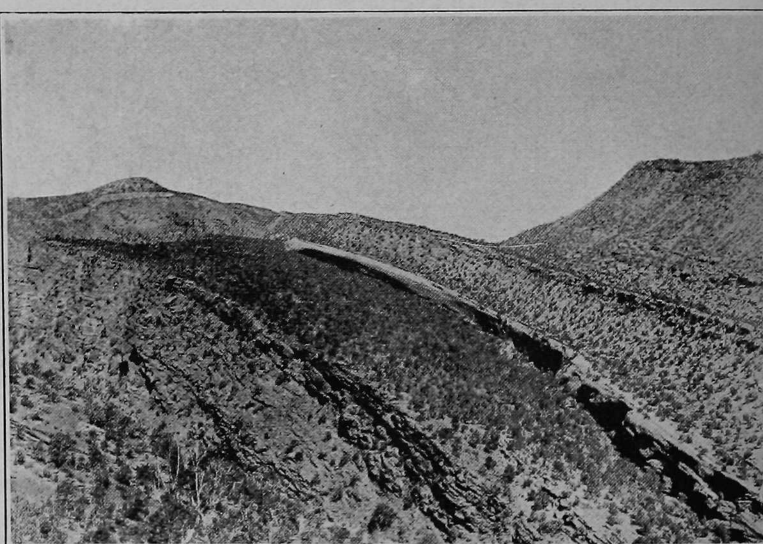

Fig. 25. Dry Creek anticline from the east side of Dry Creek.
The smooth-weathering bed is the La Plata formation.

immediately south of Coke Ovens. Practically the thickness of the Dolores formation is exposed where Dry Creek crosses this fold (see fig. 25, p. 134). The outcrop of the La Plata, which fringes the exposures of Dolores, reflects the nature of the folding. Dips of 15° to 20° toward the northeast from the crest of the anticline quickly submerge the La Plata in the northeast limb, and dips of 2° to 4° toward the southeast allow the La Plata to outcrop more than 2 miles up Dry Creek from the axis of folding. Aside from the erosion adjacent to Dry Creek, that part of the fold lying east of the creek appears as a "Dakota" ridge which extends approximately 10 miles southeast. A plunging of the axis in this direction causes the fold to decrease in prominence and to become lost in the horizontal beds northeast of Dry Creek Basin. A small fault follows the crest of the fold in the region where Dry Creek crosses its axis.

Three miles southeast of Coke Ovens the limbs of the Dry Creek anticline and the fold between Coke Ovens and the San Miguel are connected by westward dipping beds of the "Dakota" formation. The synclinal basin thus outlined on three sides is completed by the north-south ridge which marks the eastern limit of Paradox Valley. In general, beds in this basin, which is 5 miles long and 3 miles wide, dip centrally toward a point one-half mile southwest of Coke Ovens. The combined effect of the upwarping of the anticlines and downwarping of the syncline is to place the "Dakota" 2,000 feet higher in the Dry Creek anticline than in the bottom of the basin and only 250 feet higher northeast of Coke Ovens than in the basin. Mancos shale is the surface material in the center of this syncline.

FAULTING

A fault extends along the southwest side of Paradox Valley for a distance of 21 miles. East of Thunderbolt camp this fault gives way to the folding of the Dry Creek anticline. Beds on the valley side of this displacement have settled 200 feet near Joe Dandy Camp and 150 feet in Wild Steer Canyon, and at points along the southwest edge of West Paradox Valley the displacement is less than 50 feet.

Along the axis of Paradox Valley near its southeast end McElmo sandstone dips toward beds of gypsum which are only one-tenth of a mile away. In as much as the two formations involved are stratigraphically 1,500 feet apart a fault must pass between the two exposures. Similar arrangement of these beds indicates that this fault extends down the center of the valley to a point north of Joe Dandy Camp, where it probably connects with cross faulting from the southwest side of the valley. This huge block, which includes the Thunderbolt and Joe Dandy camps, is tilted toward the valley at its west end and is warped into a limb of Dry Creek anticline at the other end. The presence of alluvium and slope wash makes it impossible to limit carefully this huge block.

The Dry Creek anticline and the anticline between Coke Ovens and San Miguel River are both faulted along their axes. In either case the vertical displacement is less than 200 feet, with the downthrow side in either fault toward the synclinal basin which is bounded by these anticlines.

A zone of flexing follows the northern edge of West Paradox Valley and passes on the north side of the Buckeye reservoir. North of the village of Paradox minor faulting exists further east along the edge of the valley than is shown by the present mapping. North of the Buckeye reservoir the folding becomes a sharp anticline, with dips of 70° existing locally. However, the flexing becomes less intense as the fold approaches the Colorado-Utah boundary line. This zone of folding can be traced from the Colorado boundary to the foot of the La Sal Mountains, a distance of 10 miles.

SINBAD ANTICLINE

Sinbad Valley is an elliptical-shaped depression carved from a short anticline or quaquaversal fold whose long dimension extends northwest and southeast. The main line of folding, if extended, passes through the fault blocks on Roc Creek, and there is probably some genetic relation between the disturbances of the two districts.

In as much as this survey did little mapping in Sinbad Valley, the geology shown for this district is not complete. Several faults are known to exist in connection with this fold, but none have been mapped. Faulting exists in the west end of the valley and along the northeast side of the fold. Two faults with displacements between 100 and 300 feet parallel Salt Wash on either side of the point where it leaves the valley. The discovery work of the Copper Rivet prospect was done along the fault lying west of the creek.

The maximum tilting of beds in the Sinbad anticline occurs in the north wall of the valley east of the point where Salt Wash cuts the edge of the fold; at this point Permian(?) beds dip 35° N. 60° E. East of Salt Wash the rim of Sinbad Valley stands out in a bold cliff capped by the massive Dolores sandstone. Dips along this rim exceed 15° in a northeasterly direction. The tilting decreases rapidly along Salt Wash to Dolores River, where dips are less than 3°. Beds of the Dolores formation in the south wall of the valley dip southwest at angles exceeding 9°, but a synclinal trough which follows approximately the course of Roc Creek terminates these southwesterly dips within a mile of the edge of the valley.

The tilting of beds is, in general, away from the area mapped Carboniferous and roughly at right angles to the line bounding this area from the Dolores-Cutler unit. This line, in fact, represents fairly well the shape of the fold. The intense folding of Carboniferous beds in the center of the valley is probably due to pre-Triassic movements and does not infer that similar folds existed in beds which once filled the valley. The present knowledge of this anticline does not include the exact amount of uplift. However, the restoration of the Dolores beds would probably show a domical upwarping exceeding 1,000 feet.

BASIN SYNCLINE

Dry Creek Basin is structurally a broad syncline, with dips of less than 6° in its northeast limb and dips of more than 20° in its southeast limb. South of Young's ranch faulting along the edge of the basin allows beds which would otherwise be warped into a limb of this syncline to retain a horizontal position. North of Young's ranch beds rise gently to the northeast.

A section across the syncline through Rock Cabin shows a maximum depression of the beds involved. The "Dakota" along such a line is 1,500 feet lower in the syncline than in the Dry Creek anticline and about 1,200 feet below the rim of Gypsum Valley. A restoration of the "Dakota" beds eroded from Gypsum Valley would show a difference in elevation between this syncline and the Gypsum Valley anticline of considerably more than 1,200 feet.

Mancos shale covers this synclinal basin for 10 miles west of Young's ranch. As the axis of the syncline rises westward the shale thins out and "Dakota" beds become the surface material as far west as the edge of Bull Canyon. The uneven removal of formations below the "Dakota" in Bull Canyon and territory to the northwest has made the syncline less apparent. This fold continues in reduced amount northwest of Bull Canyon to Dolores River. Beds in this part of the folding are nearly horizontal across a 5-mile strip between the Paradox anticline and the upwarping along the edge of Little Gypsum Valley and Silvey's Pocket.

GYPSUM VALLEY DEFORMATION

GENERAL RELATIONS

Gypsum Valley, Little Gypsum Valley, and Silvey's Pocket are included in the same zone of deformation which involves an area 6 miles wide and 30 miles long. The three valleys involve different phases of the same deformation which results in a maximum dislocation of the beds involved at a point midway between the ends of this zone. In either direction from this central region displacements of beds within this zone become less pronounced, but the nature of the folding more complex.

GYPSUM VALLEY

Gypsum Valley, on superficial examination, appears to be a simple anticline whose core has been removed by erosion. Along the northeast rim of this valley the Post-McElmo is tipped up in a saw-tooth ridge from Radium Hill to the head of the valley. On the other side these same beds dip southwest from a ridge extending from Dolores River to Klondyke. These two ridges appear at first glance to be the limbs of a large anticline. However, faults of over 1,500 feet displacement and beds dipping toward the valley from either side show the fold to be no simple anticline. The covering of a part of the valley floor by alluvium and slope wash has resulted in much structural obscurity. An understanding of the details of the folding is further complicated by angular unconformities be-

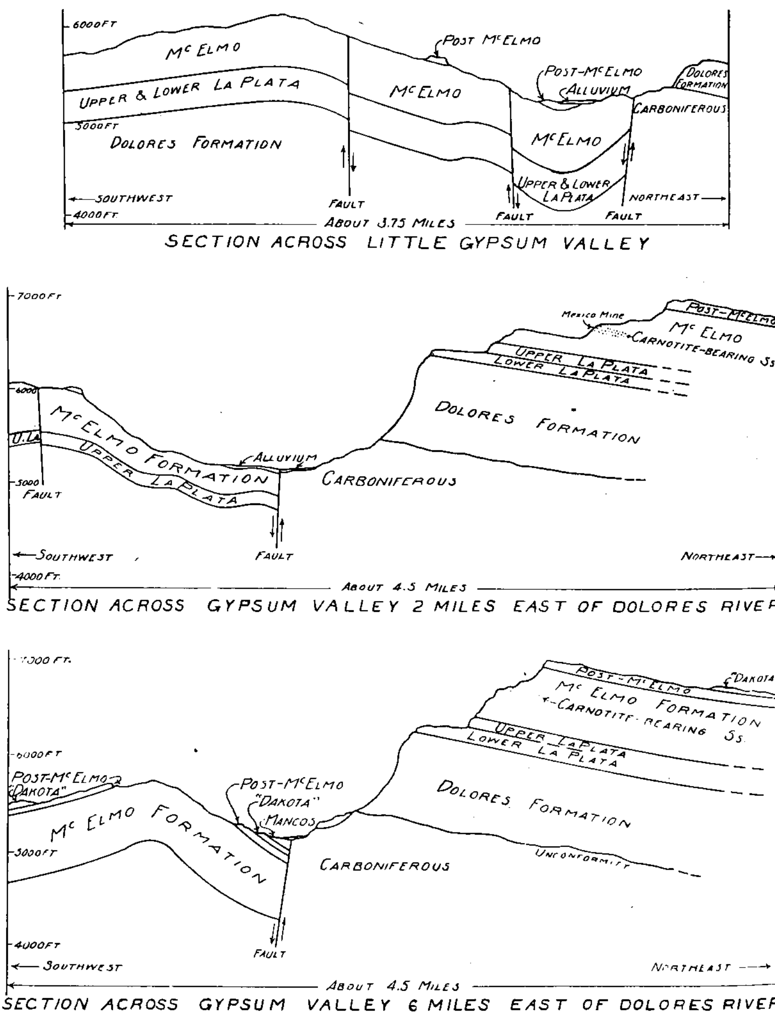

Fig. 26. Sections showing different phases of the Gypsum Valley deformation.

tween formations below the McElmo. Much folding and faulting exist in this region, which cannot be determined by reconnaissance methods.

The predominant structural feature of the region is a faulted anticline whose axis lies southwest of the valley bottom. The anticline is shown in cross section by the cutting of the Dolores .

The main fault in the lower end of Gypsum Valley follows near the base of the northeast wall. Between the points where the Dolores enters and leaves the valley McElmo beds abut against Carboniferous limestone. The displacement along this fault at this point is 1,800 feet. Patches of McElmo sandstone surrounded by Carboniferous beds along the northeast side of the valley probably came to their present position by dragging during the process of faulting; and some peculiar relations of Dolores and La Plata sandstones farther east suggest small thrusts, and it is possible that similar relations of McElmo and Carboniferous beds are brought about by such movements.

The axis of the anticlinal fold follows the ridge dividing Gypsum Valley from Disappointment Valley. The crest of the folding is practically the highest ground along this ridge. Four miles above the mouth of Gypsum Valley beds dipping northeast from the anticlinal axis include Mancos shale which is brought in contact with Carboniferous beds. Faulting at this point produces a displacement of approximately 2,000 feet. The anticlinal axis on the south side of the valley can be traced southeast to the so-called "gap," which is a low place in the ridge due to the headward cutting of a branch of Disappointment Creek. Opposite this point in the northeast wall of Gypsum Valley McElmo beds dip both ways from a ridge which divides Dry Creek from Gypsum Valley drainage. Gypsum Valley at this point is a depression between two anticlinal ridges. East of this point the Dolores and Cutler formations have been so reduced in thickness that they are inconspicuous or absent in all outcrops. The mass of gypsum and limestone at the head of Gypsum Valley was once covered by McElmo and younger beds in a low arch across what is now the center of the valley. Faulting and sharp, narrow synclinal folding along either side of the gypsum and limestone mass are indicated by the attitude of small detached masses of the McElmo formation. The inner limbs of these narrow synclines once extended over the area now exposing Carboniferous gypsum and limestone. Beds dip away from the exposures of Carboniferous rock on three sides.

Folding along the southwest side of the valley passes into a fault which continues to Klondyke, where it divides into two lines of displacement that trend south into Disappointment Valley and play out. Folding along the northeast side extends to the gap through which the road from Redvale enters the valley. Eastward from this point the fold is a pitching anticline whose axis dips southeast 25°. The sudden plunging of the axis abruptly terminates the valley wall and forms the gap. The outcrops of "Dakota" and Post-McElmo beds swing around from the end of this ridge in semicircular outcrops one-fourth of a mile across. The southeastward extension of the synclinal folding along this side of the valley passes into a fault which cuts the southwest limb of the plunging anticline. The folding east of the gap becomes progressively less until the beds on either side of the fault plane are nearly horizontal. The south side of this line of displacement is the upthrow side.

The general effect of the folding in Gypsum Valley has been to produce an anticlinal upwarping which has been greatly modified by faulting. This faulting has produced a downward movement of beds on the southwest side of the valley near its mouth and an upward movement of beds on this same side at the head of the valley. In effect, the displacement is rotary in that McElmo beds are in contact with Carboniferous beds at one end and with the Mesaverde at the other. A neutral point for this rotary movement is in the north wall of the valley opposite the "gap." The plane of the main fault at the northwest end of the valley is nearly vertical, but the attitude of the plane at the head of the valley was not determined. The rather pronounced folding in the latter place suggests strong lateral stresses which may have resulted from thrusting.

LITTLE GYPSUM VALLEY

The structural conditions which exist near the mouth of Gypsum Valley prevail for the most part through Little Gypsum Valley. Erosion has so modified results in either place that the two regions are outwardly different. The anticline along the southwest edge of Little Gypsum Valley is a continuation of similar folding east of Dolores River. Beds dip steeply from one side of this anticline into Little Gypsum Valley and gently from the other side toward McIntyre Canyon. At the point where Dolores River leaves Little Gypsum Valley, beds of the McElmo formation dip steeply northeast against Cutler and Carboniferous beds from which they are separated by the main Gypsum Valley fault. The displacement along this fault is progressively less toward the head of Little Gypsum Valley where it passes gradually into monoclinal bending, or an asymmetrical anticline whose crest is the northeast edge of Little Gypsum Valley and Silvey's Pocket. The dip of beds from this line of folding toward the valley increases westward. These dips combine with northeastern ones from the ridge on the other side of the valley to make the predominant structural feature a syncline whose axis follows approximately the lowest ground in the valley. The physiography does not suggest such a fold, as its northeast limb has been cut down to a plain covered largely by the Lower La Plata sandstone. This plain, which extends north and east from the limit of the fold, is but little higher than the bottom of the valley.

A remnant of the McElmo formation (see fig. 27) showing the synclinal warping stands near the head of Little Gypsum Valley where the axis of the fold rises to a low divide between this valley and Silvey's Pocket. A short distance east of this divide Mancos shale is retained in the valley by the protection afforded by this downwarp.

The folding and faulting in this valley take on two phases. In the eastern part a cross section shows an anticline which has one

Fig. 27. Syncline in west end of Little Gypsum Valley.
The beds showing the synclinal warping are of the McElmo formation.

limb dropped down by a fault. In the western part the folding has produced two asymmetrical anticlines on either side of a syncline. The depression of beds in places in this syncline is over 1,000 feet. The two phases of the folding are represented by section B-B' of Plate I (in pocket) and by figure 26.

SILVEY'S POCKET

Silvey's Pocket is formed by a downwarping at the northwest end of the Gypsum Valley zone of deformation. Upwarping around the edges of the pocket has increased the depth of this synclinal depression.

The axes of the anticlinal folds on either side of Little Gypsum Valley extend northwest along the edges of Silvey's Pocket and converge slightly where the pocket drains into Coyote Wash. Neither of these folds was traced north of this stream. The crests of these anticlines have been eroded until the Dolores formation is exposed as a narrow strip which outlines the pocket on the west, north, and east sides. Adjacent to this strip are two similar bands of the Lower and Upper La Plata sandstones which dip centrally toward the synclinal basin at angles ranging from 7° to 30°. On the outer side of the Dolores strip these same sandstones dip away from the pocket at angles which range from 3° to 10°.

A system of radiating faults breaks up the west edge of Silvey's Pocket into several blocks. Much jumbling of beds and faulting exists in the center of the basin which cannot be shown by the scale used in mapping this area. The distortion due to the Silvey's Pocket folding brings the McElmo beds 1,200 feet lower in the basin than in the adjoining anticlines.

DISAPPOINTMENT SYNCLINE

Disappointment Valley is a broad synclinal basin 3 to 6 miles wide and over 20 miles long. The downwarping, which is greater in this fold than in any similar one in the area, places the "Dakota" 3,000 feet lower in this syncline than on the top of the Dolores anticline and over 1,000 feet lower than its computed position in the Gypsum anticline.

Beds dip 20° toward this syncline from the edge of Gypsum Valley but quickly flatten under the Mancos shale which covers the bulk of the area in Disappointment Valley. South of Disappointment Creek the beds rise in long unbroken dip slopes to the top of the Dolores Plateau. Dips of 15° exist locally on this side of the syncline.

The axis of folding lies north of Disappointment Creek throughout the part of valley included in the present mapping. This axis rises at the west end of the valley, but folding continues in less degree to McIntyre Canyon and plays out in the high mesas southwest of Silvey's Pocket. Where the axis of this syncline rises out of Disappointment Valley the outcrop of the Post-McElmo and "Dakota" beds connects the edge of the Gypsum Valley anticline and the southwest limb of the Disappointment syncline by a huge semicircular ridge which overlooks Dolores River. The beds dip centrally from this ridge toward a point 2 miles north of the mouth of Disappointment Creek and form the half of a huge saucer. Hayden geologists termed this depression "Saucer Valley." Sections B-B' and C-C' of Plate I (in pocket) show respectively the extent of the folding in the northwestern and southeastern parts of this syncline.

DOLORES ANTICLINE

The folding by which the strata from Disappointment Valley connects with the plateau to the south is in effect a monocline. However, gentle dips southwest from the edge of this plateau complete an asymmetrical anticline which is structurally a mirror image of the Uncompahgre folding.

East of the canyon, which is cut across this fold by Dolores River, dips toward Disappointment Valley often exceed 15°. The "Dakota" on top of the fold in this region and southeast beyond the limits of the map is horizontal. The folding in this direction becomes a huge monocline by which beds change their elevation 3,000 feet. The warping becomes a distinct anticline as it is traced northwest from the Dolores River by an increase in the southwesterly dips and a decrease in the ones toward the Disappointment syncline. The difference of elevation of beds on either side of the fold becomes less in its western part by a rising of the Disappointment syncline and a lowering of the plateau in this direction. The extension of this fold into Utah crosses Lisbon Valley where beds on either side of the depression are of equal elevation. Faulting is negligible in the Dolores anticline and strata pass down across the fold in dip slopes, some of which are 3 miles long.

Faulting in McIntyre Canyon is not in line with the Disappointment syncline or the Dolores anticline, but is a zone of fracturing which extends east from the junction of the Dolores anticline and the folding of Lisbon Valley, Utah. This zone of fracturing which affects McIntyre Canyon has produced entirely different results than those of the folding just described. Between a line which outlines the southern limit of McIntyre Canyon drainage and the mesa-like divide between this drainage and Coyote Wash, an area of depression extends west into Utah and connects with Lisbon Valley. The floor of this depressed area is traversed by several more or less parallel faults which bound a series of blocks warped and tipped into different angles.

McELMO ANTICLINE

The McElmo anticline is a domical upwarping which has affected an area lying adjacent to McElmo Canyon of approximately 100 square miles. The main axis of upwarping extends north from the eastern edge of the Ute Mountain igneous mass and turns west, crossing Sand Gulch at approximately the highest point of the dome. West of the gulch the axis extends N. 60° W. as far as Yellow Jacket Canyon. An axis of secondary folding extends east from the top of the dome to a point 2 miles beyond Cortez. This axis is not well defined west of Trail Canyon but becomes a distinct anticlinal ridge in the region of Cortez.

McElmo Creek and its tributaries have removed beds from the southwest side of this fold down to and including the ones of the Dolores formation. The "Dakota" formation covers the bulk of the area which lies north of McElmo Creek and east of Sand Gulch.

South of McElmo Creek the upturning of strata along the igneous mass of the Ute Mountains forms the southern limit of a synclinal trough which begins 1 mile south of the mouth of Sand Gulch and extends parallel to McElmo Creek as far west as Bowdish Canyon. Section D-D' of Plate I (in pocket) shows the relation of this syncline to the main anticline.

AGE OF THE FOLDING

Folding which affected the carnotite country before the deposition of the "Dakota" formation is not considered in the present topic which is limited to post-Mancos deformations.

The parallelism of all major structural features and their mutual relations indicate that they are the result of forces acting from the same direction and probably date from the same general period. It does not follow that all phases of a zone of movement are of equal age, as a deformation may begin as a fold and end as a fault. Either or both mean the release of the active force and operate at the same time or at different times.

All major folds involve Mancos shale, and at the head of Gypsum Valley beds of the Mesaverde formation are warped into one limb of a syncline. This direct evidence places the age of the folding as post-Mancos. The fact that no Mancos shale occurs in the synclinal warping near Dove Creek where it would be expected to exist is somewhat contradictory to the general rule and suggests that the shale was largely removed from this area before the folding began.

The peculiar relations of present stream courses to existing folds give evidence of the manner of folding and, indirectly, its age. The larger streams established their courses before the main deformations took place and maintained them by a process of downcutting equal in rapidity to the upwarping of the different folds. Paradox Valley gets its name from the fact that Dolores River does not follow the valley but, aside from local meanders, crosses its axis in the shortest possible path. Dolores River flows between the Dolores anticline and Gypsum Valley in a winding course which carries it first along the limb of the Disappointment syncline and then across its axis. San Miguel River crosses the San Miguel syncline near its eastern end and cuts the lower 30 miles of its canyon along the limb of this fold where beds dip 2° to 6° across the course of the river. The fact that Dry Creek cuts the Dry Creek anticline near the point of maximum flexing is further evidence that some stream courses were established prior to the folding.

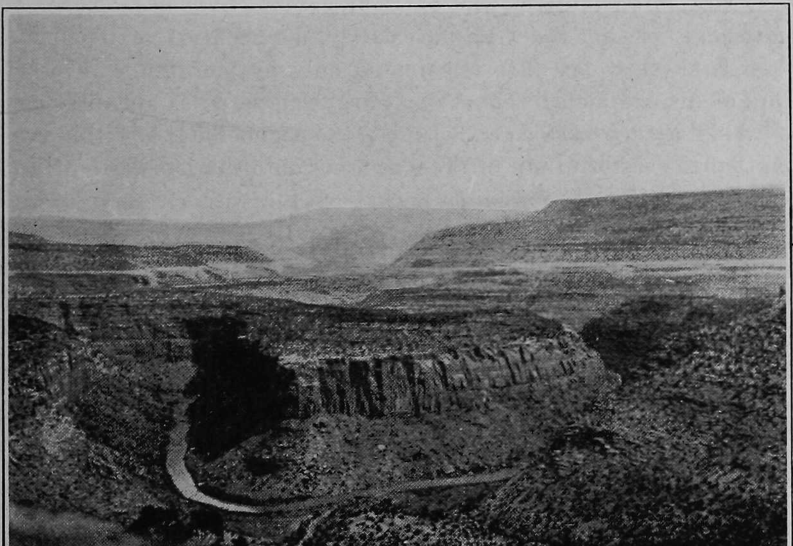

Fig. 28. Entrenched meander of Dolores River northwest of Saucer Basin. Cliff formed by the massive Dolores sandstone.

It is very evident that the folding has taken place slowly and, at some points, has proceeded continuously since its inception. Dolores River follows, in places, a winding course whose meanders have almost vertical walls 900 feet high. One such loop has been carved below Paradox Valley (see fig. 28, p. 145) and several between Bedrock and Gypsum Valley. Meanders in all stages of intrenchment are outlined by this river near the mouth of Disappointment Creek and in the Dolores Canyon above this point. It is evident that when Dolores River outlined its present course it flowed through a region, parts of which were temporarily base leveled. The meanders outlined in these base-leveled areas have been preserved by a process of intrenchment incident to an upwarping of the areas involved. That most of this upwarping occurred after the formation of the San Juan Mountains is evidenced by the fact that igneous boulders were found along an intrenched meander near the mouth of Bull Canyon, 1,000 feet above the present level of the Dolores. Inasmuch as the Rico and La Plata mountains[56] include the only exposures of these rocks reached by Dolores River drainage above this point, the upwarping was largely accomplished after the Rico uplift which is considered Eocene (Tertiary) or later.

Further evidence of the Tertiary beginning of these folds is suggested in an indirect way by their extent. All major zones of movement, except the Gypsum Valley deformation, extend into Utah, and many are then terminated only by merging with other lines of displacement. These zones are terminated so abruptly and so evenly at their eastern ends as to cause comment. It is within reason that the eastern limit of these zones of deformation was outlined during a part of the folding period by the western limit of the Mancos and the Mesaverde formations. By observing these two formations east of Gypsum Valley it is readily understood that the Mancos shale is easily removed after the protection of the Mesaverde is lost. In other words, during the process of erosion the edges of these two formations retreat in the same cliff. It is not difficult to imagine that during the greater part of the folding such a cliff marked the eastern limits of these folds and that the added weight of these several thousand feet of sediment did not allow the folds to extend in this direction. It follows that the folding period probably began after a part of these Cretaceous formations had been removed from areas adjoining Dolores River. This notion is in

[56] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60) 1899.

keeping with the idea already mentioned that parts of the area were at one time temporarily near base level.

These entrenched meanders show further that the entire process of folding cannot be of extremely recent date. The meanders of Dolores River in the canyon above the mouth of Disappointment Creek have been entrenched 2,500 feet below the "Dakota" which is the capping rock of one of these loops. Here, at least, the meander was first outlined in "Dakota" or younger formations, and sufficient time has elapsed to account for the slow upwarping and truncating of 2,500 feet of beds.

The meandering course of Dolores River across Paradox Valley and the low river gradient above Bedrock suggest that upwarping is still in progress at this point and so rapidly that the downcutting of the river is scarcely able to keep pace with it. The introduction of material by East Paradox and West Paradox creeks is possibly a contributing factor to the slow running of the stream at this point. The river gradient increases rapidly below Paradox Valley.

The formation of the McElmo anticline probably began with the introduction of material forming the Ute and El Late mountains. Direct field evidence shows that these mountains are post-Mancos in age, and that they were probably formed during the Tertiary period. In as much as McElmo crosses the fold near the point of maximum flexing, the formation of this anticline must have continued into the Quaternary period, possibly up to and including the present time.

RELATION OF FAULTING TO FOLDING

The faulting of the carnotite country represents at least two periods of movement: (1) displacements incident to and contemporaneous with the folding, and (2) displacements which occurred after the folding period. The latter class can be divided into two groups; the first group including faults which occurred not long after the folds were completed, and a second group including faults of very recent date.

The displacement of beds along the edge of the Uncompahgre Plateau is a result of a too severe bending and stretching incident to the uplift. The faulting and folding of this region extended through the same general period. Although fracturing and minor dislocation of beds occurred at the time of folding in other places, few deformations reached the faulting stage.

Most of the faults are displacements of the second class, which have resulted in a downward movement of huge blocks under the influence of gravity after the forces producing the folding ceased to operate or became relatively inactive. The Gypsum Valley deformation is typical of the faulted anticlines of the region. A restoration of the "Dakota" and older beds would show an arching whose southern limb had been faulted down (see fig. 26, p. 138). The folding up to the edge of the valley is that of a normal anticline, but within the valley the distortion incident to the collapse of the arch has twisted and crumpled beds into numerous minor folds.

Faulting, which occurred after the folding period, has continued up to the present time; indeed, faulting may yet be taking place, but so slowly as to escape detection. That the main fault in Gypsum Valley is among the oldest of these displacements is evidenced by the fact that erosion has had time to modify the results of the deformation to a greater extent than in any similar area. The fault along the southwest side of Paradox Valley is of recent date. In the vicinity of Wild Steer Canyon the displacement has formed a fault-scarp on the upthrow (southwest) side which is capped by the McElmo sandstones. Although these sandstones are not resistant, sufficient time has not elapsed since the faulting for this scarp to be seriously modified. The fault which crosses Tabequatche Creek south of Spruce Mountain and extends to Cottonwood Creek is even more recent than the one just described. The upthrow (northeast) side of this displacement is outlined by a fault-scarp of McElmo and post-McElmo sandstones. This scarp is practically untouched, and, occasionally, pieces of slickensided sandstone were found in place along the plane of movement.

Faults which trend north and south in the vicinity of the Cashin Mine on La Sal Creek are probably related to similar faults in the region of Sinbad Valley. The relation of these displacements to the faulting just described was not determined.

In general the faulting of the carnotite country is more recent than the folding, and in as much as the movement of fractured blocks has been downward, the effect of the folding has been undone in a measure by the faulting process.

CAUSES OF FOLDING AND FAULTING

The intrusion of igneous rocks within the area examined can be definitely assigned as the cause of the folding in only one place.

The formation of the McElmo anticline is probably not directly connected with the movements in the northern part of the area, but undoubtedly resulted from the introduction of the Ute Mountain igneous mass, which is of the same general age as the main disturbances of the region. The syncline near the base of the mountain was formed by the removal of material from great depths to the present site of the mountains and the consequent sagging of the overlying strata. The shortening of beds to accommodate this igneous mass was accomplished by upwarping of the main anticline and small reversed faults which are direct evidence of these lateral stresses.

The small patches of igneous rock near Klondyke are probably not connected to laccolithic masses in the immediate vicinity. If they are so connected, nearby faults of 2,000 feet displacement have failed to reveal them. Although evidence suggests that these igneous rocks are older than the main faulting of the region, their age relative to the folding was not determined.

Mineralized water of such a sort as to suggest the possible occurrence of neighboring igneous rock occurs in Silvey's Pocket and in Sinbad Valley. The extent of the mineralization is, however, no more than could be explained by circulation through sedimentary rocks. Aside from regions adjoining the mapped intrusive rocks, no direct evidence of hydrothermal action was observed. The folding and faulting of the region, aside from the McElmo anticline, show no evidence of having been caused by laccolithic masses of intruded rock which fail to outcrop in the present stage of erosion.

The active forces which caused the main deformations came from the northeast and were connected with the tilting of the block which now forms the Uncompahgre Plateau. These forces belong to the general orogenic movements of this part of Colorado, and a thorough understanding of their origin would be possible only by a study of a much larger area than is covered by the present report.

The main faults of the region were probably due to the sheer weight of arched masses which settled along lines of weakness established by the folding process and occurred after the compressional forces became inoperative.

CHAPTER IV

ECONOMIC GEOLOGY OF CARNOTITE AND ITS RELATED ORES

INTRODUCTION

The carnotite country of Colorado includes several materials of economic value in addition to carnotite and its related ores. A brief discussion of these several materials is given in Chapter VI, p. 219.

The present discussion is applicable to the Colorado occurrence of carnotite ores, but may not apply in all detail to the Utah deposits. An examination of several deposits in the vicinity of Dry Valley, Utah, and some immediately west of the La Sal Mountains shows them to be of the same general sort as those of Colorado. However, the McElmo formation thickens westward, and marine strata wedge in from the north and west near the top of the La Plata group in Utah. It follows that beds equivalent to the productive beds in Colorado probably do not occupy the same position with respect to the different La Plata sandstones in Utah as suggested by the Colorado areas.

HISTORY OF CARNOTITE MINING.

The existence of a yellow substance in the sandstone of the Paradox country was known to the settlers of the region before 1880. Fleck[56] and Haldane suggest that the Ute and Navajo Indians probably used this yellow powder as a pigment even before white people came to the region.

In 1898, through the agency of Gordon Kimball, of Ouray, some of this yellow mineral was placed in the hands of Charles Poulot, a French chemist, who determined that it contained uranium and in sufficient quantity to make it commercially valuable. The mining of carnotite dates from this time and received impetus from the discovery that other elements were an integral part of its make up. In 1899, M. M. C. Friedel and E. Cumenge determined the approximate analysis of this mineral and named it carnotite, after the French scientist, Adolphe Carnot.

The real incentive, however, to mine these ores came through a chain of events which began with the discovery of radium by M.

[56] Fleck, Herman and Haldane, W. G., A study of the uranium and vanadium belts of southern Colorado: Colorado State Bur. Mines Twelfth Bienn. Rept., p. 47, 1907.

and Mme. Curie in 1898, and led to the discovery that all uranium ores contained this new element. Experiments with radium soon astonished the medical profession by revealing its action on certain cancerous growths, and the search which followed for uranium ores was the beginning of an industry which has become a more or less permanent fixture in the mining scheme of Colorado.

The pioneers of the present methods of mining carnotite entered the field in 1910. Activity in mining these ores increased each year from 1910 until 1914, when the war stopped their sale. Up to that time they had been largely sold to foreign buyers. After the slump of the carnotite market at the beginning of the war, demand for this ore increased, although not uniformly, until in 1919 the quantity of ore mined exceeded that of any previous year.

Three factors have contributed to the demand for carnotite since the discovery that radium could be used in treatment of certain cancers. These factors are: First, the making of a luminous paint based upon the peculiar properties of radium; second, the establishment in the United States of concerns which extract the radium from its ores and put it in marketable form; and third, the recent demands for vanadium in manufacturing vanadium steel.

The first mining of carnotite centered around an area on Roc Creek near what is now the post office of Uranium. Gordon Kimball, of Ouray, Talbert brothers, of Paradox, Ike Hallet, of Norwood, and others have contributed information concerning the first work of the region.

In 1881 Tom Talbert sunk a shaft within the boundaries of what is now a claim on Roc Creek and sent some of the "yellow mineral" to an assayer in Leadville, who reported that the material contained gold and traces of silver. Several other attempts were made to determine the elements present in the mineral, but without success. The Roc Creek claim was staked by other prospectors during the next few years, but each in turn found nothing of value in the material and let the claim lapse. In 1887 the ground was relocated and named the Copper Prince on the supposition that the minerals present included "chrome-copper." However, the "chrome-copper" was not marketable and the property was soon abandoned and remained idle for several years. About 1896 a prospector by the name of Tom Dullan relocated and held the Roc Creek claims until 1898, when Mr. Kimball and associates acquired a bond and lease on the properties and made the first shipment of carnotite ore. This shipment consisted of 10 tons of ore which averaged over 20 per cent uranium oxide (U_3O_8) and 15 per cent vanadium oxide

(V_2O_5). It is doubtful if the initial shipment from any other claim has ever equaled the one made by Mr. Kimball. The details of this first mining of carnotite have been written by Mr. Kimball[57].

Soon after the first shipment of carnotite it became generally known that the "yellow mineral" was of value and claims were staked at many places. Among the first claims staked outside of the Roc Creek area were those located in 1899 by Ike Hallet on ground now partially covered by the Salt Lick claim near the Shamrock camp of the Standard Chemical Company. Other claims were located this same year near Hydraulic and on La Sal Creek. The claims on La Sal Creek included the Yellow Bird which became noted for its production of high-grade ore.

In 1900 M. Poulot became associated with a M. Voilleque and together they did experimental work at the Cashin mine, by which they attempted to extract uranium and vanadium oxides from carnotite. The ore upon which they experimented was mined on Roc Creek, near Hydraulic, and on La Sal Creek. This experimental work led to the formation of a company which included, beside the two experimentors, James McBride, who was interested in the early development of the Cashin mine. In 1901 this company built a mill in the McIntyre District at the mouth of Summit Creek and shifted the center of operations to this region. Mining and milling of carnotite ore were carried on intermittently in this region from 1901 to 1904. Details of the operations of this company and other early activity have already been written by Fleck[58] and Haldane. Carnotite mining before 1904 was practically limited to this one area, and had the recovery of uranium as its primary object and vanadium as a secondary one.

Aside from some experimental work, nothing of importance happened in the carnotite country after 1904, until about 1910, when individuals who eventually represented the interests of the General Vanadium Company acquired property in Paradox Valley. The Crucible Steel Company became interested in Long Park claims about this time, and in 1910 the Standard Chemical Company purchased from one of the Talbert brothers claims that are now included in their Thunderbolt group. From this date the mining of carnotite has expanded to its present proportions. This growth has been irregular and fraught with many difficulties; districts had to be opened in an unsettled and semi-arid country, processes of ore treatment had to be worked out and perfected, and markets estab-

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[57] Kimball, Gordon, Discovery of carnotite: Eng. and Min. Jour., vol. 77, p. 956, 1904.

[58] Op. cit., pp. 47-117; 1905-1906.

lished for the refined products. Transportation still remains one of the biggest problems of carnotite mining. Although progress has been made in methods of milling low-grade ore, much remains to be done in this phase of the work.

OCCURRENCE OF THE ORE-BEARING SANDSTONES

The fact that carnotite was first mined on Roc Creek in a tilted block of McElmo sandstone which had been faulted down in contact with Dolores and Cutler formations, caused the first prospectors to look for carnotite in the "Red Beds." They were further misled by a resemblance of the tilted beds to fissure veins with which most of the prospectors were familiar. Early reports incorrectly associated the deposits with the La Plata formation.

The exploited carnotite deposits occur in the sandstones of the lower half of the McElmo formation as lenses, seams, and irregular pockets whose long dimensions follow in general the bedding of the sandstones. The larger ore bodies are associated with the massive beds generally near or at their base, but sometimes in the center or even at the top of these beds. Seams or lenses of greenish shale less than 2 feet thick underlie the ore and appear in places to have influenced its deposition. Shale, however, is not a constant factor in the occurrence of this ore, and in so far as it may have influenced the circulation of ground water its position is related to the present site of the ore deposits.

GENERAL POSITION OF PRODUCTIVE BEDS

With two exceptions, all observed occurrences of uranium-bearing ores were limited to the McElmo formation. In McElmo Canyon a vanadium-bearing sandstone containing small amounts of uranium was found near the top of the Dolores formation, and carnotite stains were observed in faulted regions in Carboniferous and Dolores beds in Gypsum Valley, though never in such quantity or position but that their presence could be explained by processes of leaching and transfer from McElmo beds. Search for carnotite and its related minerals should be in the McElmo formation, and for the most part, in two zones: an upper one from 275 to 325 feet above the base, and a lower one from 60 to 125 feet above the base of the formation. The outcrop of these beds is so constant wherever they are horizontal that a generalized section represents conditions in many places (see fig. 29, p. 154).

Some operators and prospectors speak of the three strata of the "carnotite formation" and consider the "main carnotite bed" the upper or third "rim" above the La Plata sandstone. This notion is misleading.

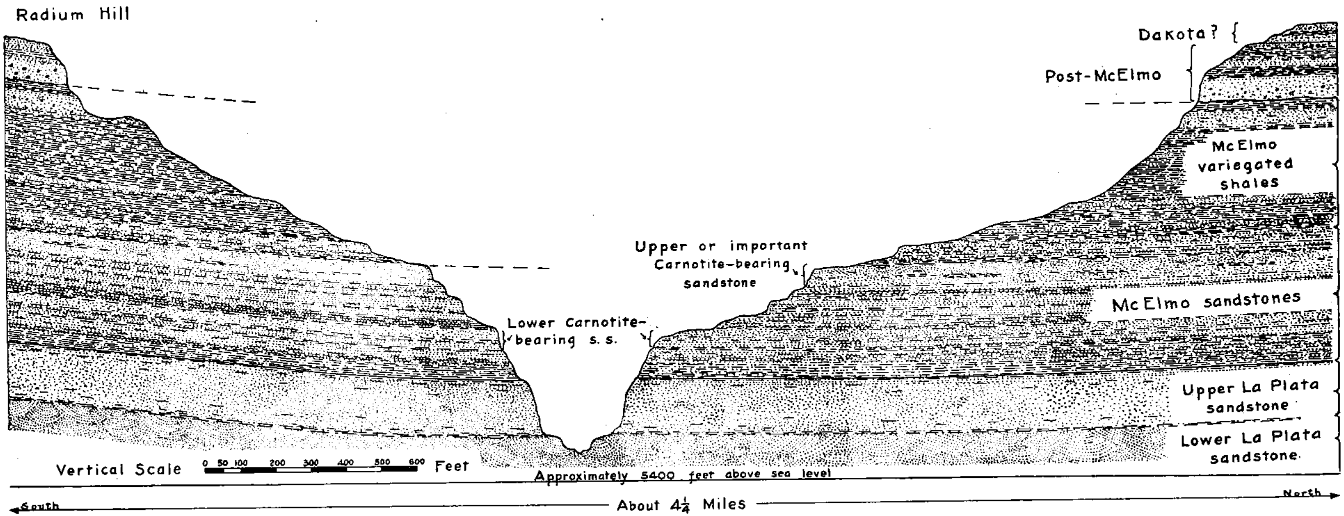

Fig. 29. Section across Bull Canyon showing the relation of the two carnotite-bearing zones.

The outcrop of the different beds as shown by that part of the section south of the canyon is typical.

Owing to the peculiar conditions under which the McElmo formation was deposited, individual beds often continue only short distances along the outcrop before they split up, coalesce, or even disappear. Outcrops of the lower 300 feet or sandstone portion of the formation show, in places, seven distinct massive beds, each forming an individual cliff or rim; again, the same interval may include only two. Though the general sequence of sandstone and shale remains fairly constant, single beds thicken and thin, appear and disappear in a very erratic manner. Obviously, counting the number of beds from the La Plata sandstone upward cannot be a reliable means of locating any particular horizon.

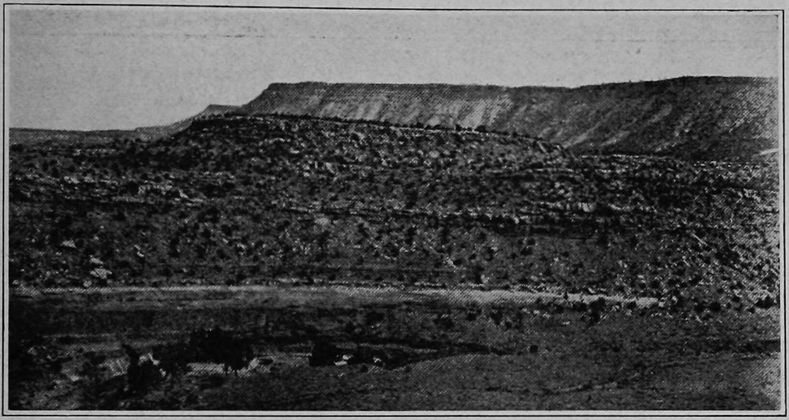

Fig. 30. McElmo sandstones near the mouth of Mesa Creek.

Uranium- and vanadium-bearing ores have been found in three different beds in these outcrops; the lowest was found in the first prominent bed above the La Plata (smooth-weathering bed) and the highest was in the uppermost bed shown in the foreground: the capping beds on the distant hill are of the Post-McElmo and "Dakota" formations.

In many localities ore is not confined to one horizon and is often found at two or more levels within the same bed. At the Club Camp flat ore occurs in two massive sandstones about 40 feet apart; the upper one by far the more productive. At one place in the McIntyre District ore occurs at three levels; the distance from the upper to the lower occurrence is approximately 40 feet. At the head of Calamity Gulch ore was mined at several places from both the bottom and the top of a massive sandstone which was approximately 30 feet thick. All these occurrences were within the limits of the upper or important carnotite zone. The units referred to as zones often include more than one massive bed, in fact, the intervals are often made up entirely of massive sandstone beds separated by only a few inches of shale. The unique position of these zones

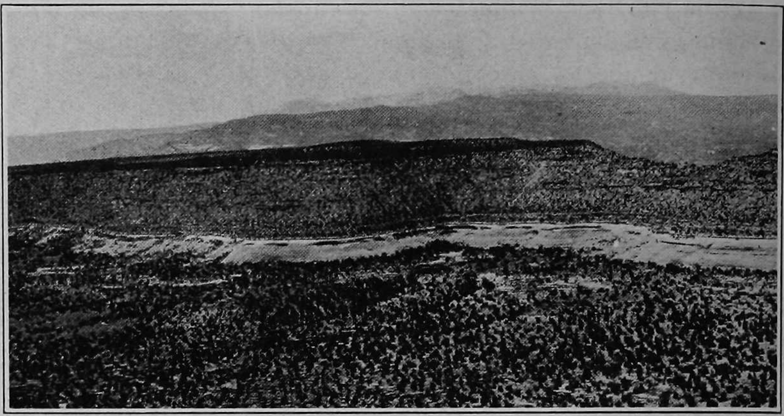

Fig. 31. Flattop from the east side of Maverick Gulch.
The topmost beds are the main carnotite-bearing sandstones.

within the cross section of the McElmo formation, their light color, and the outcropping of their beds render them generally conspicuous.

The upper limit of the important productive zone approximates the dividing line between the easily eroded shale portion of the formation above and the resistant sandstone portion below. This arrangement brings many ore bodies near or at the top of the bench which results from the uneven weathering of this formation. Much

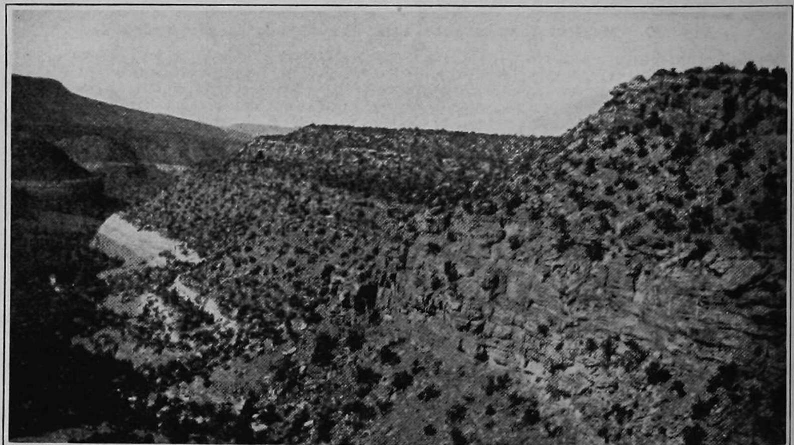

Fig. 32. Outcrop of the two productive zones in Bull Canyon.
Lower zone is the first prominent group of beds above the La Plata (smooth-weathering sandstone) and the upper zone includes the uppermost bed shown.

ore has been found on this bench so near the surface that it has been mined from open pits. More often the ore bodies are near the base of the massive sandstone forming the cap to the bench and are mined from the rim or through inclines.

The position of the lower productive zone is easily followed, as its location with respect to the base of the McElmo is nearly constant. This zone, which is made up of massive beds of sandstone separated by lenses and seams of shale, includes the first prominent bed above the La Plata formation. The cliff or ledge formed by this bed comes within the limits assigned to this productive zone—from 60 to 125 feet from the base of the formation. Ore has been mined from this lower zone in Bull Canyon, Saucer Basin, and near the mouth of Mesa Creek on both sides of Dolores River. Prospects contain ore elsewhere in this horizon, but the deposits found thus far are smaller and more pocket-like than those in the upper zone.

LIMITS OF COMMERCIAL DEPOSITS

STRATIGRAPHIC LIMITS

Many rumors of carnotite in the variegated shales of the upper part of the McElmo formation came to members of the survey, and much time was spent in trying to verify such rumors. Material reported to be carnotite was collected from upper McElmo beds north of San Miguel River near Naturita, on the north side of East Paradox Valley, in Silvey's Pocket, Gypsum Valley, and McElmo Canyon. In each place the material mistaken for carnotite proved to be a rusty yellow clay colored with limonite or other iron minerals. No carnotite was found by the present survey more than 400 feet stratigraphically above the base of the McElmo formation.

It would be unwise to state that carnotite does not exist above the sandstones of the McElmo formation or even to assume that it does not exist in formations above the McElmo. So far as practical in a reconnaissance of this kind all formations were examined to determine the limits of carnotite occurrence. Repeated tests for uranium and vanadium were made of materials from the upper part of the McElmo formation. The materials came from many different beds and from many parts of the area, but all tests for these elements were negative, and nothing was found which would suggest that commercial deposits of these ores occur above the limits mentioned.

The occurrence of a vanadium-bearing sandstone in McElmo Canyon at the top of the Dolores formation is not in itself sufficient reason for assuming that the formation is generally productive.

But the vanadium-bearing mineral found in the Chinile formation (Triassic) of the Navajo country,[59] the vanadium ore in the La Plata formation at Placerville, and the uranium-vanadium deposits[60] in the Triassic shales of the San Rafael Swell suggest that formations below the McElmo, particularly the Triassic, might be productive. Such examinations as were possible of these lower beds lend little encouragement to prospecting for carnotite below the McElmo formation in the area covered by this report.

GEOGRAPHIC LIMITS

The Colorado production of carnotite and related ores has thus far been limited to an area much smaller than that represented by the present map. The exploited deposits have been confined to the McElmo formation within the following limits: The northern boundary begins at the point where Dolores River crosses the Utah-Colorado boundary and continues up the river to Gateway. From this point the boundary is drawn east to the foot of the Uncompahgre Plateau and then southeast to include the Grub Stake camp on Mesa Creek. The line then runs a little east of south to the mouth of Tabequatche Creek and thence south into East Paradox Valley, passing east of Thunderbolt Camp. From this camp the boundary runs southeast around the head of Gypsum Valley and Klondyke, and then southwest to the canyon of Dolores River, from which point it runs west to the edge of the state. The western boundary of this area is the Colorado-Utah line.

To include the exploited deposits of Utah this boundary is extended from the southernmost point of the area just outlined toward Monticello, Utah, to include the deposits along the edge of Dry Valley, and thence west toward the junction of Grand and Green rivers, and thence southwest to include the Henry Mountains. The northern boundary begins at the point where Dolores River crosses into Utah and continues west and slightly north to include Cisco, Thompsons and Greenriver. It is then extended west and south around the San Rafael Swell to join the one already outlined. The area thus outlined is a huge ellipse whose major axis extends 95 miles west and 30 miles east from the La Sal Mountains. Although by far the greater part of this area lies in Utah the exploited deposits in Colorado are not so scattered as those in Utah where erosion has left only disconnected areas of the McElmo formation.

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[59] Gregory, H. E., Geology of the Navajo Country: U. S. Geol. Survey, Prof. Paper 93, p. 148, 1917.

[60] Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 608, 1920.

Carnotite and its related ores are by no means limited to the area outlined. Within Colorado they have been reported in the Dry Creek anticline south of Coke Ovens and in the canyon of Dolores River south of the area outlined. There appears to be no reason why these minerals do not exist, at least in minor quantities, elsewhere outside of the limits of present production.

In Utah carnotite is known to occur in Coal Beds Creek southeast of Monticello, and it has been reported in the Indian reservation of New Mexico. Carnotite occurs near Meeker, Colorado, in beds equivalent to the McElmo formation and in the Blue Mountains of Moffat County, Colorado.

It is impossible with present knowledge to place geographical limits on the distribution of these ores. However, the deposits thus far discovered show that an area including an east-west strip contiguous to the La Sal Mountains should be thoroughly prospected. It should be noted that no definite relation has been established between the position of the La Sal Mountains and the abundance or size of these deposits.

ORE DEPOSITS

The author believes that deposits of carnotite and its related ores are due to chemical changes and the transfer of material deposited originally with the rock. This material was introduced with the beds at the time of their deposition and probably at no great distance stratigraphically from the ones in which the ore is now found. Even assuming that some of the "trees" of ore were laid down at the time of the deposition of the sandstones in which they occur, most of the deposits are clearly younger than the inclosing sandstone and are therefore classed as epigenetic.

FORM OF ORE DEPOSITS

On the basis of form the workable ore deposits are divided into three classes:

1. Rather continuous deposits—in plate-like masses and lenses, but of irregular outline.

2. Discontinuous deposits — consisting of seams, crusts, bunches, and irregular pockets of many sizes and shapes.

3. Cylindrical masses—commonly called "trees" or "logs"; ore frequently of very high grade.

Few deposits can be placed in any one class, as most of them possess characteristics of all three groups. The largest ore bodies are deposits of the first type, but the ore in most of the claims is so pockety and irregular that the deposits characterize the second group. The plate-like masses often have crusts and irregular bunches at their edges and the deposits possess characteristics of two groups. Again, "trees" of ore extend from the limits of other ore masses or occur as bodies of high-grade ore inclosed in the main deposit. Most carnotite claims that have been extensively prospected contain all three types of deposits.

Rather Continuous Deposits.—The plate-like ore bodies have their longer dimensions parallel to the bedding of the sandstones with which they are associated. Projections often extend from the margin of these large bodies as seams, so-called "bug holes," irregular pockets, and bunches which, in some places, lead to other bodies. Patches of barren sandstone often occur within the ore body and give to the workable ground an irregular outline. Many continuous ore bodies have been worked out, which paralleled the bedding of the sandstone for a distance of 20 feet or more and were from 1 to 4 feet thick. The length of such bodies is often four or five times their width. Figure 37 (p. 172) shows the outline of several ore bodies of this class.

A continuous ore body of unusual dimension was mined at the Club Camp of the Standard Chemical Company. The deposit was more than 450 feet long, about 60 feet wide, and from 1 to 4 feet thick. Throughout these limits the ore was continuous and rested on an undulating surface whose depressions were not more than 4 feet deep. This body produced approximately 50,000 sacks, or 2,000 tons of ore.

Discontinuous Deposits.—Normally the ore on any one claim is not continuous but thickens, thins, and plays out in short distances. In places beds of ore 3 feet thick are terminated within a horizontal distance of 4 feet. Nor does the ore streak hold the same position with respect to the top or the bottom of any bed used as a plane of reference, but may rise or fall 5 to 10 feet within the same distance horizontally. Again, the body may split and contain ore at two levels with barren rock intervening. The irregularities and the erratic changes in level of the ore bodies are but little greater than the irregularities of bedding, size of grains, and distribution of shaly seams as exhibited by the massive sandstone with which the ore bodies are associated. Indeed, it is probable that the present position of the ore has been determined by these factors. It follows that the ore bodies will show less irregularity when associated with beds wherein cross bedding and inequalities of grain are reduced to a minimum.

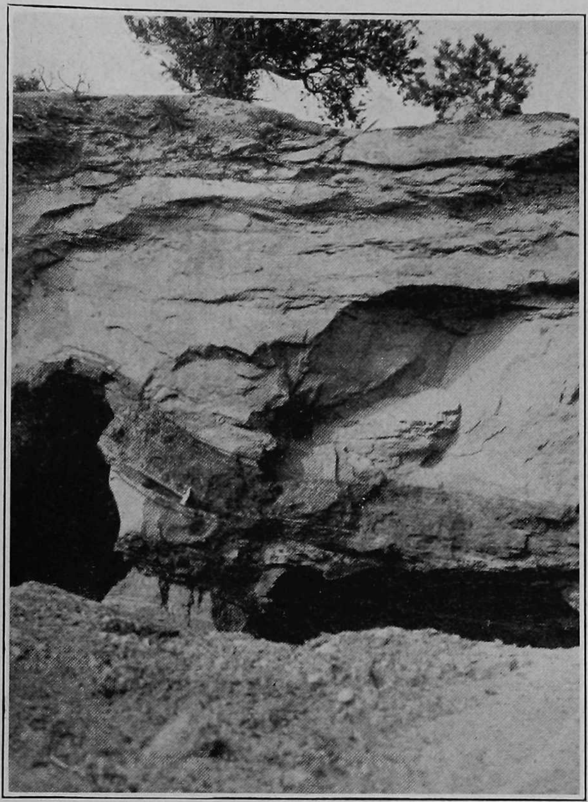


Fig. 33. Outcrop of an ore body on the Calamity group of claims, Upper Calamity Creek.

Several phases of irregular ore bodies are illustrated by the Cripple Creek claim in Long Park. The guiding principle in the development of this claim was production of ore carrying 2 per cent or more uranium oxide (U_3O_8), with the result that considerable ore carrying less than 2 per cent U_3O_8 is left in the mine, and its removal would extend the limits of the ore, as suggested by figure 35. Ore has been mined from a series of lenses and plate-like bodies some of which were more than 30 feet in diameter and were 4 feet thick. These larger bodies were connectd by irregular pockets and thin ore seams which inclose occasional masses of barren sandstone. Characteristics of the first two types of ore bodies were equally common. The third type was represented by several log-shaped masses of rich ore which have been mined within and on the border of the main deposit. At one point the main ore

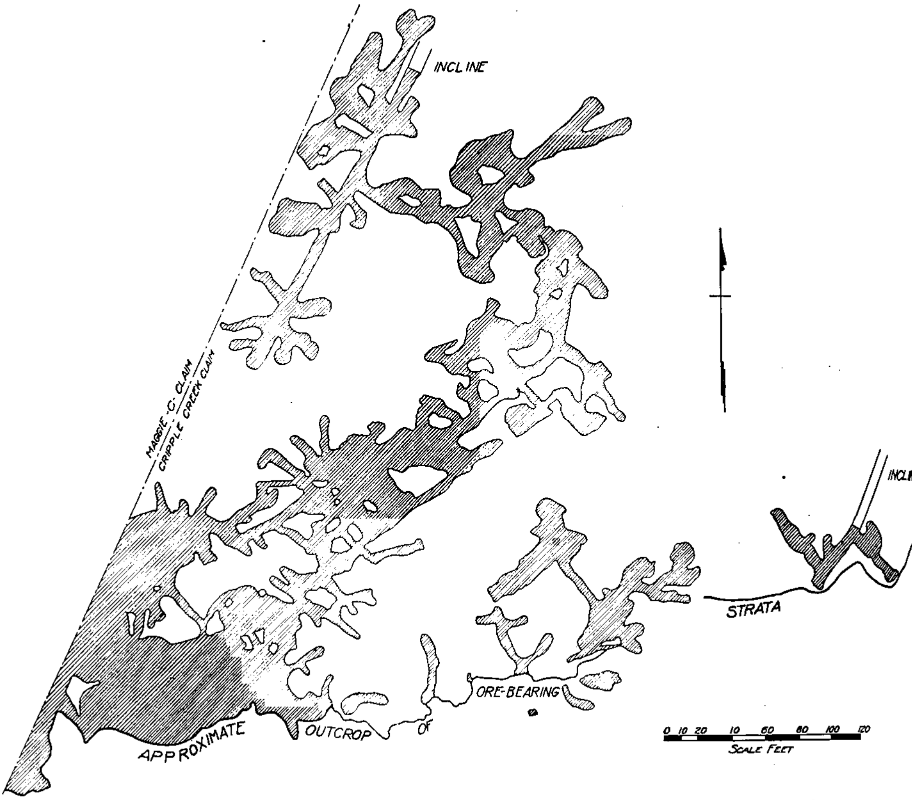


Fig. 34. Exploited ore body of the Cripple Creek claim in Long Park.

streak dropped across the bedding 11 feet within a horizontal distance of 26 feet. Although many such irregularities were encountered within the several hundred feet of development work, production has been confined to a stratigraphic interval of approximately 20 feet. Strike joints, which traverse the formation at right angles to the bedding, occasionally result in abrupt changes in the thickness of the ore seams. In one place the ore streak was 2½ feet thicker on one side of a joint than it was on the other, the joint-plane forming, in a part of its course, a sharp boundary between ore and barren sandstone.

Operations on the Cripple Creek claim previous to January 1, 1920, proved that the ore body extended down the dip of the beds for more than 450 feet and along their strike, in one place, for 150 feet. Although masses of barren sandstone existed within the worked ground the ore was continuous from one limit of the mining to the other. In all stoped ground the ore averaged 2

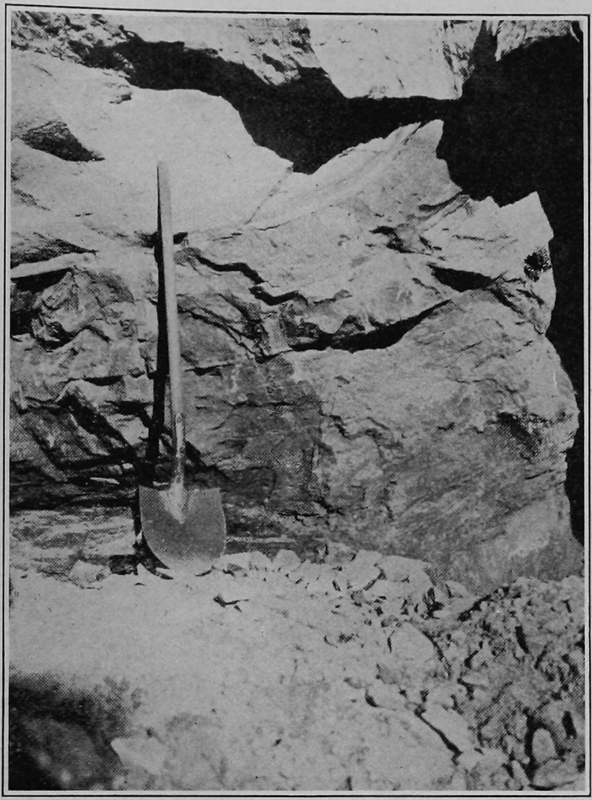


Fig. 35. Uranium and vanadium-bearing sandstone (dark colored) in Cripple Creek claim.

A sample taken across the streak at the point of the shovel assayed more than 0.50 per cent U_3O_8

feet in thickness and at one point reached a maximum of 10 feet. The ore bodies of this claim join those of the Maggie C claim and together they constitute one of the two largest deposits thus far exploited.

Cylindrical Masses.—The cylindrical deposits, or so-called "trees" and "logs," are generally associated with those of other types, either as masses of rich ore in, or projections from, other deposits. In a few places these log-shaped bodies were surrounded by barren sandstone. Most of these bodies contain rich ore as impregnated sandstone and more or less pure carnotite in cavities. Some consist of mineralized sandstone without pockets of high-grade ore. These deposits are of different sizes, from those a few inches in diameter and 10 feet long, to those 4 feet in diameter

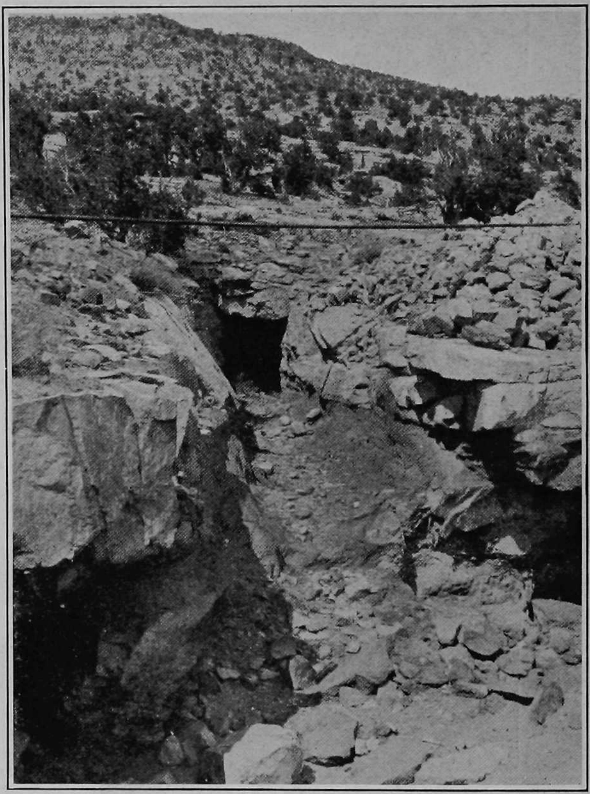


Fig. 36. "Tree" of ore mined from the Dolores group of claims along lower San Miguel River.

and 30 feet long. Their length parallels the bedding of the sandstones in which they occur and they often taper toward one or both ends. Many of the so-called "trees" or "logs" are probably not related to any process of wood replacement.

CHARACTER OF THE ORE

The term "carnotite ore" has been applied to ores of different sorts, often including any uranium-bearing material in the district. Although the average ore contains carnotite its value may depend upon one or more of several uranium and vanadium minerals. The character of these minerals, as they occur in the average "carnotite" deposit, differ greatly in different parts of the deposit.

A classification of "carnotite" ores is of little value for other than descriptive purposes as no exposure of ore exists which does not show two or more of the phases given below; indeed, hand specimens generally show more than one phase. A classification of the common ores made somewhat independent of their mineral content includes the following types:

1. Impregnated sandstones—the uranium and vanadium minerals cementing the sand grains.
2. "Spotted ore" or "rattlesnake ore"—the uranium and vanadium minerals occurring in sandstone or shaly sandstone as dark blotches wherein vanadium-bearing minerals predominate, and as almond-shaped pieces and small fragments of shale or carbonaceous material speckled with carnotite.
3. Nearly pure carnotite or other minerals in seams, crusts, irregular vugs, and elongated masses called "bug holes."
4. Replacements of wood by carnotite or other minerals—ore often of extremely high grade.
5. Unusual ores—including bluish-black vanadium-bearing material and coal-black material carrying both uranium and vanadium.

Impregnated Sandstones.—In this type of ore the cement which bonds the sand grains is one or more of the minerals common to the district. The color of the ore, which is determined by the predominant mineral and the extent to which the original cement has been replaced, ranges from the canary-yellow carnotite through shades of orange and brown to black or red ores wherein vanadium-bearing minerals predominate. This ore commonly occurs in seams or beds in which carnotite is the characteristic mineral bordered by streaks or bunches of "spotted ore." In sandstones which have their cement entirely replaced by the usual carnotite, or less often by a calcium vanadate, the resulting material is a crumbly mass. Vanadium minerals, unless present in excess of the pore space of the sandstone, form harder ores. These impregnated sandstones, wherein carnotite is the characteristic mineral, make up the greater volume and probably the greater value of shipped ore.

A class of ore related to the impregnated sandstones results from the impregnation of shaly sandstone or sandy shales. Such ores are generally dark due to the presence of vanadium minerals. Inasmuch as the shaly parts contain few pore spaces into which the minerals are capable of penetrating, the minerals are for the most part confined to surface coatings. Such ores are deceptive, as these coatings make them appear of better grade than assays show them to be.

"Spotted Ore."—This is only a phase of the type just described, but the distribution of the vanadium and uranium min-

erals is very different, being confined to the less dense parts of the sandstone. The erratic distribution of these minerals gives the ore a distinctly mottled appearance. The spots consist of dark-colored patches which have yellowish borders or lie adjacent to spots colored yellow by disseminated particles of carnotite, either replacing the cement or filling open spaces between the grains of sand. Again the dark spots are sometimes fragments of shale or bits of carbonaceous material included in the sandstone. Spotted ore is present in all deposits, but its position within the ore mass appears to follow no general rule. To the uninitiated this class of ore is deceptive as it is generally low grade.

Nearly pure carnotite and other minerals.—In places, seams of nearly pure carnotite have healed cracks in the main ore mass or have formed crusts in open cracks in sandstone. These occurrences are secondary to the deposition of the main ore body. The irregular vugs and "bug holes" of carnotite appear to have filled open cavities, or to have replaced masses of soluble minerals such as gypsum and calcite. A black material, rich in vanadium, is sometimes associated with the carnotite in these high-grade pockets. Calcium vanadates occur as seams of pure mineral in sandstones which have been impregnated with these minerals.

Replacements of wood by carnotite or other minerals.—The purest carnotite found in other than small quantities is in the replacement of wood. These masses are frequently brilliant yellow and of such a character that pieces can be made to retain a polish; others are mottled brown and yellow by small quantities of iron minerals mixed with carnotite. Many of the small pockets and a few of the "bug holes" of more or less pure carnotite possibly occupy spaces once filled by pieces of wood, but replacement has occurred in such a way that the wood structure is not preserved. The true wood replacements, in which wood structure is commonly outlined, are not to be confused with the so-called "trees" or "logs" which may contain actual wood replacements as a fraction of their make-up, but which are more often log-shaped sandstone masses impregnated with carnotite and other minerals.

These so-called "logs" show many phases of mineralization, each resulting in an ore of a different sort. A common phase shows a central core 3 to 10 inches in diameter of more or less pure carnotite around which concentric layers grade outwardly into sandstone showing no mineralization. Again the reverse is true and the central part is barren sandstone and the outer shell is the only part that contains carnotite. Gypsum and calcite are associated with carnotite in many of these deposits. These different phases of mineralization probably represent different stages of transformation to which the wood had advanced previous to the replacement process.

Unusual ores.—A bluish-black or dull-black vanadium ore often occurs as seams or bunches with the red calcium vanadate which is generally found as the cementing material of a sandstone. Another vanadium ore occurs at the Joe Dandy claims in Paradox Valley, which is composed of a brecciated mass of black or greenish black material resembling mineralized coal. This ore, which is seamed with tiny veins of calcite, is consistently high in its vanadium content, but its uranium content ranges from negligible amounts to over 3 per cent U_3O_8. In many of these ores the uranium content cannot be estimated sufficiently close to make hand sorting always reliable.

Other unusual varieties include an ore carrying seams less than one-half inch thick of a coal-like material which is identical with the vanadium streaks already mentioned, but which differs from them in its high uranium content. Some of these seams have been known to assay 9 per cent uranium oxide (U_3O_8). Small quantities of a sandstone have been found which resemble a quartzite and which outwardly give no clew to their high uranium content. One such sample consisting of dark and light colored sand grains, showing none of the yellow carnotite, assayed 3 per cent U_3O_8. A sufficient quantity of this material was not available for further study.

MINERALS CONTAINED IN THE ORES

A detailed study of the minerals present in the different ores was impossible during the preparation of this report. Such a study would require considerable time, as material suitable for microscopic determination of many of these minerals is difficult to get. Carnotite and its related minerals rarely crystallize but occur in the ore as mixtures of powder-like materials which are by no means chemically simple. A single pocket often contains the yellow carnotite, the miner's "red oxide" of vanadium, a coal black vanadium-bearing material, and a brownish material, probably a mixture of two or more minerals. Doubtless, minerals exist in these ores which have never been described. Only the common minerals or mineral-bearing materials are described.

Carnotite.—Composition approximately K_2O, $2UO_3$, V_2O_5, X H_2O. Analysis gives approximately uranium oxide (U_3O_8) 59 per cent, and vanadium oxide (V_2O_5) 20.5 per cent. This mineral characterizes the average ore in which it occurs as a canary yellow powder, rarely showing minute crystals under the microscope. It occurs in cavities, in seams, and disseminated through the sandstone. The quantity in sandstone ranges from mere traces to material wherein sand grains are completely surrounded, and this mineral constitutes the only bonding material in the rock. It occurs in different mixtures of calcite and gypsum in cavities and often forms coatings on crusts of tiny calcite crystals. Carnotite never occurs without other vanadium minerals being present in the same ore body.

Vanadium-bearing materials.—The common vanadium-bearing material is dark to pale green. The minerals occur in sandstone associated with carnotite as a finely divided material which resembles a decomposed roscoelite. A small percentage of the material in some samples is a micaceous mineral which reacts chemically as a vanadium-bearing silicate. Sandstones charged with these minerals differ in color due to the amount of vanadium-bearing material present. The minerals in the coal-black and blue-black vanadium-bearing materials have not been determined. It is probable that these materials include several vanadium minerals.

Hewettite.—A hydrous vanadate of calcium, CaO, $3V_2O_5$, $9H_2O$, containing V_2O_5 68.2 per cent, and V_2O_4 1.2 per cent. The mineral occurs as a red powder filling the pore space in sandstones. Its occurrence is similar to that of the sandstones highly charged with carnotite, with which it is associated. This mineral is present in small quantities in ore from several localities.

In the Dolores group of claims along lower San Miguel River and in the Joe Dandy claims of East Paradox Valley this mineral occurs as aggregates of silky hair-like fibers which are present as seams in sandstone heavily charged with this mineral. These hair-like crystals are generally associated with gypsum and are possibly a pseudomorph after the fibrous satin spar (gypsum). Hewettite is probably the mineral present in most of the ore which miners call "red oxide" of vanadium.

Metahewettite[61].—Composition and general occurrence the same as hewettite. This mineral occurs as a dark maroon powder at Morrison camp in the McIntyre district. All the fibrous calcium

[61] For a comparison of hewettite and metahewettite, see, Hillebrand, W. F., and others, Hewettite, metahewettite, and pascoite, hydrous vanadate: Proc. of the American Philosophical Society, vol. 53, No. 213, p. 36, Jan.-May 1914.

vanadate minerals which were examined fit the description of hewettite rather than that of metahewettite.

Unusual minerals.—A green-colored mineral found in several places mixed with carnotite analyzed qualitatively for torbernite, a hydrous copper phosphate of uranium, $Cu\ (UO_2)_2\ P_2O_8+8H_2O$. Other copper-bearing minerals include a copper vanadate which occurs in the Roc Creek claims as olive green tablets formed by radiating crystals. Azurite is present as a minor constituent of some ores, and selenium probably as the uncombined element was found in some of the coal-black seams in the ore bodies of Dolores Camp and in those of Kunkle's claims near Gateway.

An orange-colored mineral which formed coatings on some black ores, reacted qualitatively for a uranium sulphate.

Minerals reported from this district which were not identified include a calcium carnotite, tyuyamunite, and volborthite, a hydrous vanadate of copper, barium, and calcium. Chromium-bearing minerals have also been reported.

Gangue minerals.—Calcite and gypsum are often associated with the tree-like deposits in brecciated ore bodies and are present in minor amounts in most ores. Limonite is present in many of the richer pockets.

THE URANIUM AND VANADIUM CONTENT OF THE ORE

Deposits of uranium and vanadium differ greatly in their mineral make-up and in the uranium and vanadium content of their ores. Under present conditions the minimum requirement of a commercial ore other than that concentrated by a milling process is approximately 2 per cent U_3O_8 and 3 per cent V_2O_5.

The higher limit of uranium content in an ore is that of pure carnotite or 59 per cent U_3O_8, and the lower limit is determined by the ability of the operator to handle low-grade material, which is in general that given above. It is doubtful if the higher limit has ever been approached by these ores in ton lots, though several sacks have been mined from different places which averaged more than 35 per cent U_3O_8. The average uranium content of the ore shipped in 1919 without concentrating was slightly more than 2 per cent U_3O_8, and the vanadium content was approximately 4 per cent $V_2\ O_5$.

The analysis of the mineral carnotite gives approximately 59.14 per cent U_3O_8 and 20.5 per cent V_2O_5, which places the ratio of uranium oxide to vanadium oxide in about 3 to 1. In most uranium ores this ratio is reversed. Analysis of 33 samples of ores, not mineral specimens, during the preparation of this report indicated that the vanadium oxide exceeded the uranium oxide in all but six samples which were picked especially for their uranium content. The ratio of these oxides approached that required by carnotite in only one sample, where the ratio was 2.5 to 1.

No assay of ore from this district has come to the attention of the writer wherein uranium was present without the vanadium, and never in less amount than that required by the 3 to 1 ratio of carnotite. Vanadium ore, however, exists wherein the uranium is absent or negligible, and several claims have been operated for their vanadium ores alone.

In as much as carnotite contains uranium oxide (U_3O_8) and vanadium oxide (V_2O_5) in the ratio of 3 to 1, and the average ore shows the U_3O_8 content to be only half the V_2O_5 content, it follows that only one sixth of the vanadium can be present as carnotite in the average ore, and that other vanadium minerals include the greater per cent of the vanadium present.

RELATION OF ORE DEPOSITS TO FAULTING

The faulting of the region occurred during two general periods, one of which is very recent. Ore deposition occurred before one, and probably before both of these general periods. Secondary changes have taken place since or during the periods of faulting, but results have been generally confined to changes within the ore bodies.

Many transfers of ore within the McElmo formation are of later date than most of the faulting. Evidence of such changes exists in the Sharkey claim of the Standard Chemical Company near their Hieroglyphic Camp. Joints incident to the folding were healed by the deposition of carnotite mixed with iron minerals. The boundary between barren sandstone and ore, marked by a joint plane in the Cripple Creek claim of Long Park, has been already noted (see p. 162). On the other hand carnotite ore was observed in upper Gypsum Valley within 6 inches of a fault, with no evidence of ore in or beyond the plane of the dislocation. Several such occurrences were noted in this valley and in Paradox Valley. Whether or not the tilting of beds incident to their folding has caused a concentration of ore at places favored by the dipping beds is considered at another point (p. 175).

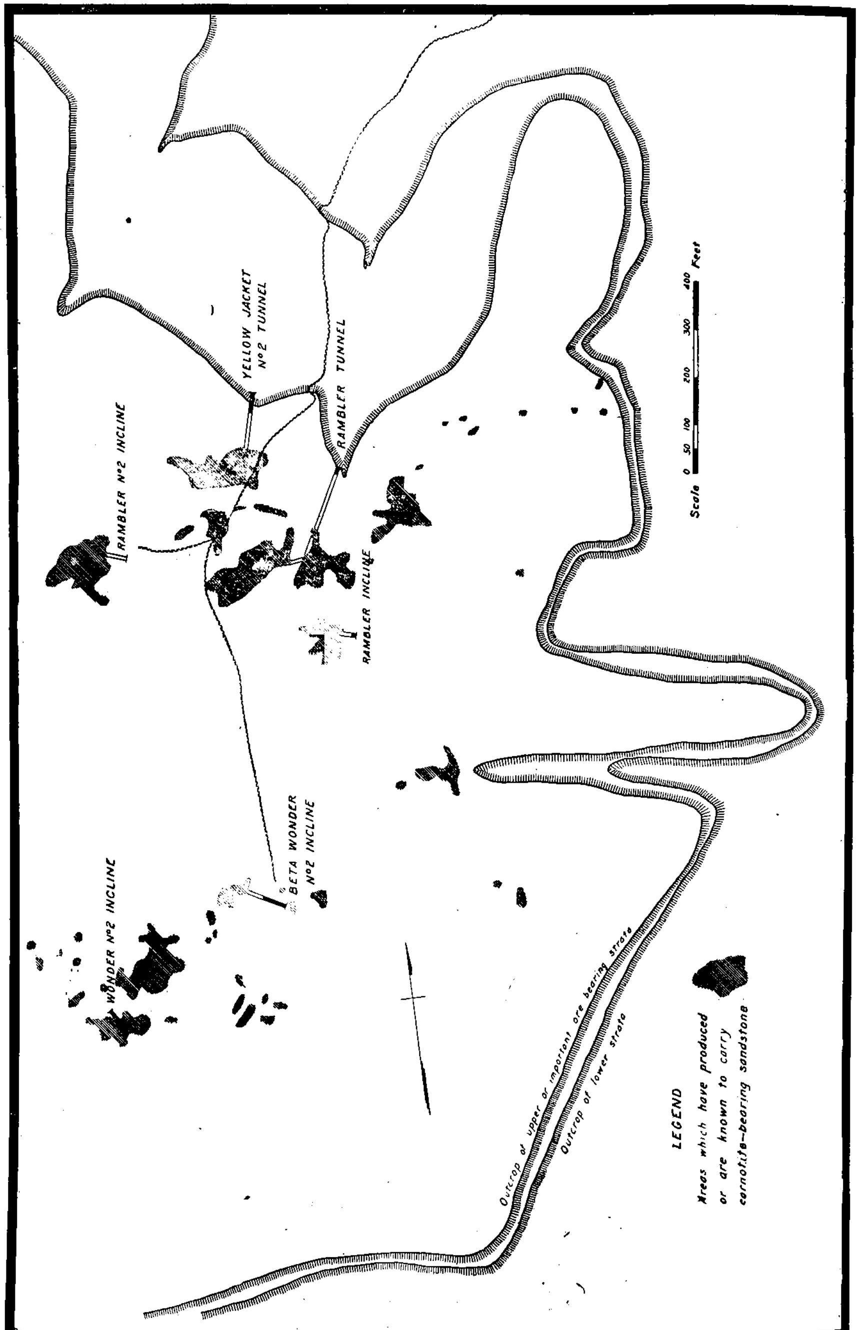
In as much as the folding and faulting determine the position of the McElmo sandstones and have not seriously modified the ore bodies, it is important that the faulting of the region be understood in order to intelligently prospect ground in many places. Many peculiar positions of the ore-bearing beds are brought about by these faults which range in displacement from a few inches to 2,500 feet. Ore exists near the top of the north wall of Gypsum Valley and again 2,000 feet lower in the bottom of the valley. At Monogram Camp ore occurs on three benches formed by a system of step faults (see fig. 48, p. 208). In the vicinity of Hieroglyphic Camp two parallel faults bring a narrow block of the ore-bearing sandstone in contact with unproductive beds. In places in Long Park, slight displacements along a series of strike joints cause the floor of the ore body to make several steps downward toward Paradox Valley. The ore on Roc Creek occurs in a tilted block of the McElmo formation brought into contact with beds of the Dolores sandstone. Other unusual positions of these beds exist, but each requires a separate explanation.

THE RELATION OF ORE DEPOSITS TO DEPTH

(THE "RIM ROCK THEORY")

The question of the horizontal limit of carnotite ores and the probable depth under the surface to which deposits would be found has been raised by operators since the mining of the first carnotite. These ores were first mined from pockets exposed in canyons where the ore-bearing sandstones outcrop. In as much as the ore bodies are never continuous for great distances the working of these pockets soon carried operations into barren ground and the claims were supposed to be worked out. These restricted operations led to the "rim rock theory," according to which the ore would never be found at any great distance from the outcrop of the main ore zone or the "rim." In some way ore deposition was supposed to be restricted to a narrow strip which parallels the outcrop of the ore-bearing sandstone.

The operations near the Club Camp of the Standard Chemical Company furnish some interesting data on the occurrence of these deposits and their relation to the "rim." Prospecting on this flat has been done so thoroughly that the areas represented by figure 37 probably indicate the extent of the commercial deposits. It is noted that all the deposits are within the upper ore-bearing strata and within 50 feet of the surface. The lower strata shown on this plat contained ore along its outcrop, but operations thus far have not included the prospecting of this bed at other points. This lower stratum, which is separated from the upper one by 10 to 20 feet of shale, is not to be confused with a lower productive zone already outlined (p. 157). It is of further interest to note that none of the larger deposits were found by the usual means of prospecting, and the area was supposed to be "worked out" by the removal of


YELLOW JACKET
N°2 TUNNEL
RAMBLER TUNNEL
RAMBLER N°2 INCLINE
RAMBLER INCLINE
BETA WONDER
N°2 INCLINE
WONDER N°2 INCLINE
Outcrop of upper or important ore bearing strata
Outcrop of lower strata
Scale 0 50 100 200 300 400 Feet
LEGEND
Areas which have produced
or are known to carry
carnotite-bearing sandstone

ore along the "rim." Later a more or less systematic scheme of drill holes located the ore as shown. The distribution of the ore bodies on this flat has no apparent relation to the outcrop of the sandstone within which they occur, except to indicate that the "rim" is less productive than other parts of the area.

Operations in other areas provide convincing evidence on this same question. The Cripple Creek claim in Long Park has produced ore 500 feet from the outcrop of the ore-bearing sandstone and was mined at one point from a depth of 50 feet. Ore occurred in the Joe Dandy claims of Paradox Valley at a depth of 100 feet. In a claim on the edge of Dry Valley, Utah, it was demonstrated that an ore body continued back from its outcrop for 300 feet and apparently without a decrease in its thickness or in its mineral content as shown at the surface. And on the bench east of Maverick Gulch ore was found in a claim one-fourth of a mile from the outcrop of the productive bed.

These facts and others demonstrate clearly that carnotite deposits occur on the benches formed by the productive sandstones at least to the depth of present mining, or approximately 100 feet. These developments indicate further that within this depth the location of these deposits is apparently independent of the distance from the outcrop of the productive bed. The question then naturally arises as to whether or not deposits of these ores are co-extensive with the sandstone in which they occur near the surface, and are commercial deposits to be expected at great depths? These questions bear upon the question of "the origin of carnotite," and cannot be satisfactorily answered with present knowledge. Although the occurrence in some mines of dark-colored uranium ores which were not found at the surface suggests a change in the character of the ore with its increased depth, data on this point are not sufficient to form any conclusions.

The inward extension of ore bodies does not preclude the possibility that other uranium and vanadium minerals exist in deep deposits to the partial exclusion of carnotite. Nor does it follow that deposits, if present at considerable depth, are similar in form to those found near the surface. It is probable that the form of the ore bodies and their mineral content as determined thus far are related to their position near the surface, and, possibly, to the aridity of the climate in which they exist.

If, as supposed, deposits of carnotite and its related minerals have been formed by the transfer in favorable localities of minerals in the sandstone, then these minerals, either carnotite or other uranium and vanadium minerals, exist at greater depths than have been reached by present mining.

The suggestion that all these minerals have by some process of circulating water reached a position near the surface seems unfounded. Such a notion would imply that the total uranium and vanadium content of the beds is represented by the present deposits near the surface. It is difficult to understand why such a process should result in a concentration under present conditions and apparently not take place during past ages. A concentration in the outcrop as it existed in former stages of erosion would have resulted in the entire removal of these materials.

Assuming that uranium and vanadium minerals exist in the deeply buried parts of the McElmo sandstones, it is possible these minerals may be concentrated only by processes which obtain through closeness to the surface. In this event the exploitation of these deeper deposits would be impossible even if their location were known. Whether a concentration of uranium and vanadium minerals is peculiar to surface conditions of direct oxidation and to the circulation of meteoric waters cannot be answered until the chemistry of carnotite ores is better understood. The other and more plausible assumption is that ore bodies occur in deeply buried portions of the McElmo sandstone similar in form to the ones already exploited but possibly differing from them in their mineral content. Granting that such ore bodies are present at greater distance from the surface, it is doubtful if they are present in greater abundance or of greater size than those already located. In as much as the expense of prospecting at great depth for ore so pockety is prohibitive under present prices of the refined products, the mining of these ores must be confined to areas wherein these beds are relatively near the surface. And it is probable that a limit will be reached, beyond which prospecting cannot be economically carried on before a depth is reached beyond which ore bodies do not occur in essentially the form of those already exploited.

The inferences then follow that:

1. There are reasons for believing that uranium and vanadium minerals exist in the deeply buried portions of the McElmo sandstones which are ore-bearing near the surface.

2. The conditions of concentration and the nature of these minerals is problematical.

3. Within the depth of present mining no relation is apparent between the location of ore bodies and the outcrop of the ore-bearing sandstones.

4. Present knowledge of these deposits will not permit the assigning of a limiting depth beyond which these ores do not occur. Certainly the facts revealed by operations up to 1920 do not suggest that such a limit had been reached.

RELATION OF ORE DEPOSITS TO STRUCTURE

Butler[62] has suggested that the metalliferous deposits in the sedimentary rocks of Utah may have been influenced by the circulation of ground waters under artesian conditions. In other words, their position is related to structure. He suggests:

That in a series of anticlines and synclines the beds are tapped by erosion in the anticlines before they are in the syncline. In such a region the tapping of these beds might start an artesian flow along the anticline toward the outlet, and from the syncline toward the anticline. If, in particular areas along these zones of flowage, conditions were especially favorable to the precipitation of metallic constituents, metals in considerable amounts might be deposited. Although the study of the Colorado deposits of carnotite and its related minerals, as they are related to structure, arrives at no definite conclusions, the point should not be overlooked in the intensive study of any region.

The axis of the San Miguel syncline (see Pl. 2 in pocket) crosses areas wherein the productive beds are exposed north and west of Blue Creek. Within this area carnotite has been mined from claims in Flattop west of Maverick Gulch. The south limb of this syncline contains the largest deposits thus far exploited. Along either side of the Paradox anticline scattered deposits occur in all areas exposing the productive bed, with the exception of the Dry Creek anticline. The Basin syncline crosses the productive area of Bull Canyon, but, in general, deposits are more numerous on either limb of the fold than in its trough. No commercial deposits have been reported in Wray Mesa except on the north side which is affected by the Paradox anticline. The Gypsum Valley deformation contains deposits intermittently throughout its length. The valley proper represents a special condition in that the faulting has lowered one side of what would otherwise be a more or less symmetrical anticline. The axis of the Disappointment syncline passes through what has thus far proven to be barren ground. Again, better deposits have been found in limbs of this fold than near the top of the Dolores anticline.

Although there appears to be no relation between the distance from the axes of the anticlines or synclines to the larger deposits,

[62]Butler, B. S., and others, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 157, 1920.

the position of the more productive areas as determined thus far is along outcrops which are, in general, parallel to the axes of folding, rather than along outcrops which follow the dip of the beds and extend at right angles to these axes. This relation is suggested by the deposits in Long Park and lower San Miguel River and the less productive outcrops which join these regions running southwest and northeast. The same relation is suggested by the mining along the south side of East Paradox Valley and in Bull Canyon, and again by the relation of known deposits in the McIntyre District. If such a relation is more than accidental, then the deposits would appear to have been influenced by solutions whose movements were determined largely by the present folds. The notion needs some consideration.

It would appear, in general, that regions of at least gentle folding were more advantageous areas in which to prospect than beds which were horizontal, either because of some relation of deposits to structure or because the regions of folding possess more outcrops of the productive beds.

At the outset it must be understood that such an analysis as given cannot be conclusive because of the fact that all the deposits have not been located. Even assuming the locations of all undiscovered deposits were known, their relation as determined by an artesian flow cannot be established until the direction of the flow has been determined, which might be toward the syncline in one place and away from it in another.

AGE OF THE DEPOSITS AND RECENT TRANSFERS OF ORE

The age of the ore cannot be determined except within wide limits. Clearly, most of it came to its present site after the beds were deposited, but the time of its final deposition can be fixed in only a few cases. In fact, it is probable that certain phases of ore deposition, as seen in the present ore bodies, include materials deposited in several different periods.

The bulk of the ore bodies was in essentially its present form before the main faulting process. Some evidence on this point has already been given (p. 147). A slice of an ore body in one of the Badger claims near the Hieroglyphic Camp was let down from its normal position by the settling of a block bounded by two joint planes. The irregularities of the floor upon which ore rests in some Long Park claims are in part due to step faults. And numerous blocks of the McElmo sandstones containing ore have been isolated from their parent bed by faulting, but the ore has retained its normal position in the inclosing bed.

Minor transfers of certain minerals from the main ore bodies have occurred since the faulting. The bones of a woodchuck[63], not unlike the species that now inhabit that area, were found in the Friday Claim in Long Park. These bones were coated with crusts of calcium carbonate, upon which small quantities of carnotite were deposited. A coating of orange-colored uranium mineral was removed from a surface in the Opera Box Claim in East Paradox Valley in the summer of 1916; in 1918 the coating was again present. Seams and fractures in the ore are sometimes healed by a secondary deposition, chiefly of uranium minerals. But in this particular there is no uniformity shown by different deposits. A filling of minor fractures by carnotite was noted in the Sharkey claims near Hieroglyphic Canyon, but no such filling was found in claims west of the canyon, where numerous fractures offered opportunities for such secondary deposition. In as much as the fractures of the two places were undoubtedly of the same age, the difference in the secondary changes must be due to a difference in the ground water conditions.

It is suggested by the many small pockets of rich ore in the Sharkey claims, those on Roc Creek near the post office of Uranium, and those of the Joe Dandy group in Paradox Valley that many secondary changes may be due to the fractured condition of the rock incident to the folding and faulting which are characteristic of these regions. This fracturing would have resulted in the freer circulation of ground water which at one time was probably abundant.

A possible relation between the present ground water circulation and ore bodies is suggested by a group of claims known as the Kearn's properties along the edge of Dry Valley. It may be more than accidental that the known seeps at the base of the productive bed are near or under deposits of ore.

In as much as recent transfers of ore are at present taking place in certain favored spots, it is not impossible that the several known seeps which occur near ore deposits are not accidental. But these seeps may represent the paths of what were zones of greater flowage when ground water was more abundant and, therefore, of greater ability as an ore carrier.

Although it is clear that the faulting took place after the deposition of most of the ore, the relation of ore deposition to the time of the folding is not definitely determined. It is certain that changes in ground water circulation were initiated by the folding

[63] Identified by the National Museum.

processes, which were of considerable proportion. If these changes were of importance in causing the redistribution of ore, then the paths along which these waters traveled should be prospected with care. In as much as the present seeps suggest these paths, wherever they appear along an outcrop which is productive, the areas adjoining these seeps should be prospected with special care.

Different phases of the ore deposits are doubtless of different ages. It is difficult to understand the formation of many "trees" of "high-grade" without assuming their deposition soon after the deposition of the McElmo beds which are Jurassic or lower Cretaceous. On the other hand, it is certain that many parts of ore bodies were formed from minerals transferred since the faulting which is recent

ORIGIN OF THE ORES

INTRODUCTION

Attempts to establish a satisfactory hypothesis for the origin of carnotite and it related ores have to do with insufficient data. New facts which are continually being added answer some questions, and progress has been made toward an understanding of these deposits, but few satisfactory working principles have been established. At the outset it must be understood that many of the notions are only speculative. The solution of some, however, is possible. The possible chemical reactions involved in the formation of the minerals, some of which have never been described, must be better understood before any theory can be tested rigorously.

The following discussion is an attempt to correlate certain facts with suggestions already made and to offer others which are to be used or discarded according as the points are substantiated or replaced by newer data.

OTHER THEORIES

Moore[64] and Kithil were of the opinion that:

> The uranium came from sandstone overlying or underlying the ore bodies, having been leached from these sandstones and concentrated with the vanadium. * * * On the south side of Paradox Valley the thickness and richness of the ore deposits seem to vary directly with the thickness of the overburden, which appears to lend some weight to the theory of downward enrichment.

Ransome[65] concludes:

> That the bodies of carnotite and roscoelite were formed subsequently to the deposition of the sandstones is evident from the facts presented in the preceding pages. It is equally plain that the minerals

[64] Moore, Richard B., and Kithil. Karl L., A preliminary report on uranium, radium and vanadium: U. S. Bur. Mines Bull. 70, p. 30-31, 1913.

[65] Hillebrand, W. F., and Ransome, F. L., U. S. Geol. Survey Bull. No. 262, p. 17, 1905.

could not have resulted from the alteration, in place, of other compounds of vanadium and uranium, originally contained in the sands. The shape and position of the deposits indicate clearly that the ores have been brought to their present position by transportation.

In commenting on the La Sal Creek deposits he[66] says:

The most remarkable and interesting fact in regard to the La Sal Creek deposits is their very superficial character. * * * It is doubtful whether any appreciable quantity of carnotite occurs as much as 20 feet from the surface, on any of the locations. * * * In one case it was observed that a portion of the overlying sandstone had moved upon the underlying shales, the disturbance being apparently a superficial one. * * * The carnotite was here deposited subsequent to the movement and had filled the small openings and dislocations in the shale caused by this very recent disturbance.

Although the very recent phases of ore deposition noted by Ransome are often present, recent prospecting on these claims found ore more than 50 feet from the outcrop.

Hess[67] contends that:

1. Carnotite deposits always contain fossil vegetation.

2. Spaces in the rocks, which were formerly occupied by vegetation, including large trees, are now occupied by carnotite and associated minerals.

3. The fossil wood was floated to its resting place and was not petrified until it had been buried rather deeply.

4. Neither carbonized nor silicified wood has been replaced by metallic minerals.

5. Carnotite is an oxidized mineral which may have migrated some distance from its original position.

He[68] thinks it possible these deposits resulted from the breaking down of veins carrying these metals, and that:

The sulphuric acid formed through the oxidation of pyrite and other sulphides combined with uranium, vanadium, copper, silver, iron, and possibly chromium minerals of the veins to form soluble sulphates which were carried into the shallow sea which existed during La Plata and McElmo time and were there diffused and brought into contact with the decaying organic matter by which the sulphates were reduced, the uranium possibly to an oxide or to a combined sulphide with vanadium or copper or both, and the vanadium, copper, silver and iron to sulphides. Upon the lifting, draining, and aerating of the rocks the minerals were oxidized and part of the vanadium formed vanadic acid, which combined with uranium and potassium or calcium to form carnotite.

In discussing as a whole the deposits in the sedimentary rocks of the plateau country, Lindgren[69] contends that:

The ores are assuredly epigenetic, and their universal appearance in land or shallow-water beds is significant. In all probability

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[66] Op. cit. p. 15.

[67] Hess, Frank L., A hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geol., vol. 9, p. 682, 1914.

[68] Op. cit., pp. 686-687.

[69] Lindgren, Waldemar, Mineral Deposits: p. 368, 1913.

these ores have been concentrated by atmospheric waters which leached the small quantities of metals disseminated in the strata.

Although the different theories agree that certain phases of ore deposition took place after the deposition of the sandstones in which the deposits occur, they differ in their supposed locations at which these materials were originally introduced and the character of the material—either solution or solid—at the time of its deposition.

SIGNIFICANCE OF THE POSITION OF COMMERCIAL DEPOSITS

The stratigraphic limits within which the commercial deposits occur are suggestive of the original position of the materials which formed the deposits. These limits, which have been given (p. 157), apply not only to the Colorado deposits but to those visited by the author in Utah, including deposits as far west as the edge of Dry Valley. Of the other Utah deposits[70], those in the Henry Mountains and some along the San Rafael Swell are in the McElmo formation. The deposits which occur in the latter place in the Triassic beds have no equivalent in the Colorado area, unless it be the vanadium-bearing sandstone in McElmo Canyon.

The limits within which carnotite has been found in the McElmo formation can be extended as far north as the deposits of Meeker, Colorado. Some of these deposits were visited by the writer and were found to be in beds equivalent to the McElmo formation. The ore-bearing strata occupied the same general part of the section as the important ore-bearing sandstone farther south. Gale[71] has correlated the beds containing the carnotite at Meeker with a carnotite-bearing sandstone in the Blue Mountains, Colorado. In as much as these deposits are 100 miles from the nearest known deposits to the south, their presence in the McElmo (Flaming Gorge of the Blue Mountains) is significant. And recently a deposit of these ores has been found in the Carrizo Mountains of Arizona. J. A. Sickler[72], who has studied the geology of the region, describes the deposits as being in a white massive sandstone about 400 feet below the Dakota. Such a description fits the Colorado occurrence and it is presumably in the same stratigraphic position.

Within the above limits, 250 miles north and south, and 150 miles east and west, the McElmo sandstones show all sorts of structural relationships; they occur at different distances from bodies of intruded rocks and are affected by folds and faults of different

[70] Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 630 and 608, 1920.

[71] Gale, H. S., U. S. Geol. Survey Bull. 340-D, p. 31, 1908. Gale originally considered these beds equivalent to the La Plata but later considered them equivalent to the McElmo.

[72] Oral communication.

sorts, but, in general, the commercial deposits are confined to rather narrow stratigraphic limits. Such a distribution would hardly admit of any other explanation than that the materials which ultimately resulted in the present ore bodies found in the McElmo sandstones were introduced into this formation at the time of its deposition.

Observations not only show that the uranium and vanadium minerals were originally deposited in the McElmo formation, but tend to show that these minerals were introduced in the sandstone portion of the formation. Repeated tests for uranium and vanadium made of material from many different beds above the important carnotite-bearing zone gave negative results. Nor did tests made of radioactivity of spring waters issuing from the upper McElmo beds suggest the presence of radioactive substances in these beds in excess of that found in ordinary rocks. On the other hand, waters which issued from the important productive beds, or lower ones, were from 30 to 200 times more active than the ones higher up. Although the radioactivity possessed by spring waters is not necessarily proportional to the amount of the radioactive substances in the beds which the waters pass through, the results are suggestive.

If uranium and vanadium minerals were ever present in appreciable quantities in the upper McElmo beds their removal has been more thorough than is to be expected in a formation of this kind. The upper part of the formation consists largely of dense shales in which it would be difficult for waters to establish free circulation and accomplish such a removal. The upward movement of solutions through the lower part of the formation meets with the same difficulty but to a less degree.

Again, if the uranium and vanadium minerals moved downward from the shale portion of the formation, they should have a wider distribution than is suggested by present mining. The shales are apparently of the same general sort and of about the same thickness in the productive areas as they are elsewhere. On the other hand, it will be shown presently that the sandstones show some differences in productive and unproductive areas.

It seems probable that the uranium and vanadium minerals which eventually formed the deposits were introduced into the McElmo sandstones at the time of their formation and were probably deposited in greater abundance in the upper part of the sandstone portion of the formation than in other beds.

If, as supposed, the uranium and vanadium minerals were deposited in the sandstones of the formation either from solutions or as particles, it is important to review the conditions under which the beds were laid down. The criteria which suggest these conditions have been noted (p. 95). They indicate that the beds were fresh water deposits, the bulk of which was laid down in shallow water by streams. Briefly, the beds are what might be deposited on low-lying flood-plains over which more or less sluggish streams would flow in their shifting courses. Lakes, playas, and marshes were scattered over this plain, into which deltas were built, and which received the finer sediments. Such conditions would not preclude the possibility of some beds being wind-blown deposits as suggested by Burwell[73] and others.

CHARACTER OF THE MINERALS AT THE TIME OF DEPOSITION

Evidence as to the form in which the uranium and vanadium minerals existed at the time of their introduction into the beds is conflicting. Hess[74] has suggested that the replacement of many of the wood forms by carnotite took place during the process of decay of the wood and before it was carbonized. He concludes that the materials were introduced in solution and were deposited by coming in contact with decaying organic matter.

SIGNIFICANCE OF THE TREE-LIKE DEPOSITS

In connection with the possible replacement of wood forms by carnotite, it is important to note the character of some of the so-called "trees" whose general form has already been outlined. Granting that the uranium and vanadium minerals were deposited from solution through the agency of decaying vegetable matter, it is doubtful if many of the so-called trees containing relatively pure carnotite are simple replacements, as the notion might imply. Many "trees" are found whose centers are cylindrically shaped cavities partially filled with a crumbly mass of carnotite and calcite. It is difficult to see how such a cavity could survive the pressure of several thousand feet of strata which must have at one time covered the McElmo formation. A cavity filled with carnotite would hardly provide the necessary resistance. It is possible these cavities were filled with more resistant minerals which have subsequently altered to carnotite.

Although evidence presented by Hess would tend to show that carnotite does not replace carbonized wood, other uranium minerals

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[73] Burwell, Blair, Eng. and Min. Jour., vol. 110, p. 755, 1920.
[74] Hess, Frank L., A hypothesis for the origin of the carnotite of Colorado and Utah; Econ. Geol. vol. 9, p. 686, 1914.

are known to exist in such materials. A specimen collected from the Joe Dandy claim on the south side of East Paradox Valley consisted of a black carbonaceous material showing woody structure. The material contained none of the yellow carnotite, but analysis proved that it contained 4 per cent uranium oxide and an abundance of carbon. It is possible the apparent movement away from centers of carbonization, as noted by Hess, and as suggested by the yellow border of the black spots in certain types of ore, is a property peculiar to carnotite and does not take place in other uranium minerals. It is suggested further that many of these "tree" cores were originally occupied by calcite which has since been replaced by carnotite. Masses have been found in these cores which contained different proportions of calcite, carbonized wood, and carnotite. In many the calcite incloses the carbonized wood, and carnotite occurs distributed as commonly in the calcite as in the wood. In as much as wood is almost never replaced by calcite in such a way that the minute structure is preserved, the woody structure as presented by many specimens is no more intricate than that which might result from calcite or crusts of lime filling cavities in decayed tree trunks. An order of replacement similar to the above, but involving different materials, is suggested by Butler[74] for certain copper deposits of Utah. Carnotite specimens which showed the outline of wood, and which were suitable for a microscopic study of minute structure, were not collected.

Some "trees" of ore exist which consist of a central core of nearly pure carnotite surrounded by concentric rings of ore of different grades. Such deposits are evidence that the deposition of carnotite has been accomplished by chemical reactions which involved the presence of organic matter. W. F. Bleeker[75], of the Tungsten Products Company, volunteers the information that he has found no carnotite ore which he has examined for organic matter, which does not contain an appreciable amount of humus. If humus has been necessary in the formation of the deposits, carnotite or other uranium minerals must have been formed soon after the deposition of the McElmo sandstone. Decaying organic matter could supply the necessary humus which might not be supplied by carbonized wood. It must be understood that the formation of carnotite or other uranium minerals at centers of decaying organic matter does not preclude their movement and subsequent deposition at points a considerable distance from the site of their formation.

[74] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 156, 1920.

[75] Oral communication.

RELATION OF PRODUCTIVE AREAS TO CHARACTER OF McELMO SANDSTONES

It is strikingly brought out over the area examined that the ores are found in those regions where the sandstones are massive and show more cross bedding generally than do other beds. Such a relation appears to be more than accidental. A section of the McElmo formation in McElmo Canyon shows less than 500 feet of sediments, with sandstones less prominent than they are farther north. In the productive area the formation is approximately 850 feet thick, and its ore-bearing sandstones are massive and cross bedded. Near Grand Junction the formation is essentially shale and is not as thick as in Paradox Valley.

In an east-west line through the productive areas the sections show in Dry Valley sandstones that are generally massive, similar ones in Paradox Valley, but less massive ones in Telluride quadrangle.

In general, the productive regions are those wherein the beds, including the important ore bodies, possess their maximum thickness. The areas wherein these beds have a minimum thickness or wherein they have graded into shaly sandstone and shale, are apparently less productive than in other regions, or barren. Although such a relation is noted by comparison of areas many miles apart, a suggestion of such a relation is found in local areas and deserves attention. The massive beds which are so productive in Long Park and vicinity are less prominent in the ridge running east along the edge of East Paradox Valley where no large deposits have been found. The same relation is suggested by the general massiveness of the productive sandstone near the mouth of Summit Canyon, where several good deposits were exploited, and the apparent less productive areas at the head of this canyon. Again, it may be significant that out of a group of claims along the edge of Dry Valley, Utah, one of the richest known deposits is in the most massive part of the outcrop.

In connection with the possibility of the minerals being deposited as solids, it can be said that if more or less shifting streams were carrying a load which included sand, silt, and some heavy mineral grains, the place at which the heavy grains would come to rest would be in general the regions of maximum sand deposition, which are now the areas of the known commercial deposits of these ores. The exact point at which a grain would be deposited is determined by its specific gravity, its size, and the strength of the current. It is important to note further that the uppermost bed of the important carnotite-bearing zone, as outlined, is in many places a conglomeratic sand, and occasionally it is a distinct conglomerate containing pebbles one-half an inch in diameter. This conglomeratic sandstone is typically represented in the outcrops in Long Park, where it occurs about 50 feet above the sandstone in which most of the ore is found. It occurs in a similar position on Mesa Creek, in Gypsum Valley, in Silvey's Pocket, and along Maverick Gulch, where it is ore-bearing. It is perhaps significant that this bed, the coarsest grained one of the lower half of the McElmo formation, should be the bed which contains the highest observed deposits of carnotite.

This apparent relation between the massive sandstones and the ore deposits suggests a deposition of the materials as solid grains. But the concentration of minerals resulting from the disintegration of primary uranium or vanadium minerals to form the present deposits does not easily explain all the points involved. Such a disintegration would have to take place soon after its deposition in order to provide the minerals which may have been deposited by the decaying organic matter. Another point which needs consideration is the relative solubility of radium and uranium compounds. This point is considered in a separate topic.

SIGNIFICANCE OF THE RADIUM CONTENT OF THE ORE

A consideration of the radium-uranium ratio of carnotite ores becomes involved in any explanation of the origin of the deposits. Lind[75] shows that in a carnotite ore the radium is not distributed uniformly with the uranium, but he concluded the total radium content[76] of an ore body is proportional to its uranium content.

In as much as radium and uranium salts are separable by ordinary chemical processes, it is easier to explain the normal ratio of these elements in carnotite by assuming that they were transported as solids whose radium content would be less apt to be removed from its parent uranium than it would if transported in solutions. But, again, it is hard to understand how a particle of a uranium-bearing mineral could break down producing both radium salts and secondary uranium minerals which would be equally soluble in the ordinary solutions which must have circulated through these rocks. In as much as the common salts of uranium and radium are chemically unlike, it is probable that the distribution of radium and ura-

[75] Lind, S. C. and Whittemore, C. F., The radium-uranium ratio in carnotites: U. S. Bur. Mines, Tech. Paper 88, p. 28, 1915.

[76] Radium is supposed to be present in all uranium minerals that are sufficiently old, in the ratio of 1 part to 33,280,000. This ratio is not established in uranium minerals which have been deprived of their radium only by accumulating for a period which is variously estimated from 500,000,000 to 800,000,000 years. To those interested in further facts pertaining to these materials the author suggests study of Rutherford's Radioactive Substances and their Radiations.

nium, which would result from the movement of these compounds under the influence of a common solvent would be less uniform than that which is supposed to exist in the present deposits. The notion is apparently confronted by one of two possibilities; either the materials have been in essentially their present form a sufficiently long time for the radium to reach its equilibrium amount (over 500,000,000) years; or the materials which formed carnotite were so introduced into the beds that their uranium-radium ratio was not seriously disturbed.

SUMMARY OF POINTS

The above facts and others suggest the following as probabilities:

1. The minerals which eventually formed the exploited carnotite deposits in Colorado were introduced into the sandstones of the McElmo formation at the time of their deposition.

2. The evidence which has been presented as to the character of the material at the time of introduction is not conclusive.

3. Since the original deposition the minerals have been redeposited by waters which traveled laterally along the beds rather than across them.

4. Although the movement of uranium minerals is being brought about at the present time at certain favored localities, the relation, if any, of the present folds to known ore bodies is not apparent.

Numerous questions arise from such an order of events as suggested, which cannot be answered. C. C. Mook[77] has outlined the general boundaries of the Morrison formation and its equivalent, the McElmo. These boundaries indicate a western source of the material which supplied the sediment from which the McElmo beds were deposited. Although the older rocks within the area of this supposed land mass do not appear to contain a sufficient quantity of uranium minerals to look to them as a source, they are not unknown in these rocks. Hess[78] has reported a uranium mineral in pre-Cambrian(?) quartzites of Utah, and suggests that the occurrence of uranium and vanadium ores within narrow stratigraphic limits may be explained by the narrow vertical limits of such materials in their parent veins. In considering a source of these materials it must not be overlooked that the Triassic beds of Utah are known to contain such materials. If these minerals are an original deposit with this formation the destruction of similar deposits of these

[77] Mook, Charles C., Origin and distribution of the Morrison formation: Geol. Soc. of Amer. Bull., vol. 26, pp. 315-322, Aug. 1915.
[78] Op. cit., p. 686.

lower beds in other localities may have contributed to the making of those in the McElmo formation.

The source of vanadium is not so difficult to account for in that many rocks carry minor quantities of such minerals, but the method by which it was concentrated in the present ore bodies and its relation to the uranium minerals have not been determined.

SUGGESTIONS TO PROSPECTORS

Interpretation of map.—When using the map as a guide to prospecting, it must be remembered that the upper part of the McElmo formation is largely shale which has not thus far proved productive. It follows that there is a strip of the area mapped McElmo that lies next to the boundary of this formation and the Post-McElmo above, which, in light of present knowledge, is not worthy of the prospector's attention. The McElmo sandstones, or the productive portion of the formation, are confined in general to those areas which border the La Plata formation. Such a division of these beds would exclude from the ground which should be prospected many narrow exposures of this formation, which occur along streams crossing the San Miguel syncline (see Pl. 2 in pocket), and many that adjoin streams which drain into McElmo Creek.

Beds in which to prospect.—In unexplored territory the prospector's attention should be directed first to the so-called "carnotite stratum" of the upper zone and to beds immediately above and below this stratum. Although the two zones already outlined (p. 153) should receive the most attention, no district is completely prospected until the entire section of McElmo sandstones is examined.

The position of the important zones can be located where the La Plata sandstones are exposed from data already given (p. 157). In canyons which are not cut to the La Plata sandstone the important zone can be located from the cliff formed by the Post-McElmo and "Dakota" beds. It is approximately 450 feet stratigraphically below this cliff. Within the limits of this zone one or more white, cross-bedded sandstone strata occupy the prominent place along the edge of what is generally the highest and widest bench formed by the McElmo sandstones. Carnotite and related ores occur in the massive beds, frequently near the top, but more often near or at their base. Green shale often underlies, and in a few places overlies, the ore. Those parts of the massive sandstones wherein ore is generally found are the miners' "loose ground" or "slips" which are the more open parts of the formation. Commonly, the so-called "vein matter" consists of thinner-bedded seams within the massive beds, or of less dense streaks from which the cementing material has been partly removed. Flakes and masses of green shale and bits of carbonaceous material are often present in these seams.

The lower productive zone is characterized by a massive white sandstone similar to that of the upper zone. The ore bodies thus far mined in these lower beds are more pocketlike and smaller than those in the upper beds, and in general, results of mining in this zone have been discouraging. Ore has been produced from these lower beds in Bull Canyon, Saucer Basin, near the mouth of Mesa Creek on both sides of Dolores River, and along Beaver Creek, Utah, near the Colorado line below Gateway. These lower beds are well exposed as benches on the divide between Roc Creek and West Paradox Valley, in Saucer Basin, Bull Creek, and in parts of the McIntyre District.

Surface indications.—Deposits whose edges are exposed are easily recognized by the stains of yellow carnotite and black vanadium material. The black vanadium-bearing material forms irregular patches of dark-colored sandstone often showing no yellow minerals. Many masses of dark-colored sandstone stained by manganese and iron minerals occur within the main carnotite zone, and are often mistaken for vanadium-bearing material. The simple chemicals and apparatus with which to test vanadium should be included in the prospector's equipment.

Ore streaks are very often leached to such an extent at their outcrops that they might be passed over. The surface weathering of the "spotted ore" often removes bits of shale and carbonaceous matter forming small pits or cavities. The margins of these cavities, if the rock is in any way associated with an ore streak, generally show at least a slight stain of black vanadium-bearing material.

New types of ore.—As development proceeds on some claims, new types of ore are encountered whose uranium contents cannot be closely estimated by even the most experienced miners. This uncertainty arises in the black ores, some of which indicate their uranium content upon exposure at the surface by the appearance of yellowish or greenish yellow coatings. However, some black ore containing more than 3 per cent U_3O_8 from the Joe Dandy and Dolores camps was exposed to weathering, and even to moderate heating, without showing any change in color. Clearly, materials which possess unusual characteristics should be tested by the electroscope.

Uncertainties of electroscope determinations.—Although the use of an electroscope will give roughly an idea of the radium, and thus the uranium content of ores, it must be emphasized that even in the hands of an expert such determinations are often untrustworthy[79]. Lind[80] shows that the uranium content of ore as determined by the ordinary methods by the electroscope may be in error as much as 45 per cent. Some of these errors he shows cannot be overcome by care in procedure but are due to the differences in their "emanating power" or their ability to give off their emanation[81]. It must be emphasized that the electroscope should be used to obtain qualitative rather than quantitative results. These sources of error are the result of the almost constant friction between ore buyers and prospectors.

Waste in low-grade ores.—Prospectors are not inclined to give proper consideration to low-grade ores. On the assumption that present prices of the refined products of these ores continue, much material that has been thrown in the discard would be of value had it been saved. Certainly the lower limit of uranium and vanadium content of a milling ore has not been reached by present concentrating methods. In the exploitation of one group of claims it was found that three times as much material carrying approximately 0.85 per cent U_3O_8 was discarded as there was saved of ore carrying 2 per cent U_3O_8. Even in outlying districts the possibilities of better transportation should be kept in mind, and all material which may ultimately become of milling grade should be saved. Where the separation or partial separation of low-grade ore entails only little expense, material assaying as low as 0.25 per cent U_3O_8 should be piled separate from the waste, and similar material not mined should be so left that it could eventually be recovered. With better transportation facilities and a continued demand for radium and vanadium, the history of the mining and milling of gold and silver ores will be paralleled in the future development of carnotite ores.

Other waste occurs in some places because of the improper mining of ore. Because of the fact that the ore bodies are less resistant than the inclosing sandstone, there is a tendency to mine the ore with waste. Much of the fine material which results from the mining of the ore is such that its separation from other material is difficult[82].

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[79] For detailed discussion of the precautions in the use of the electroscope the reader is referred to: Moore, Richard B., and Kithil, Karl L., A preliminary report on uranium, radium, and vanadium: U. S. Bur. Mines Bull. 70, 1913.

[80] Lind, S. C., and Whittemore, S. F., The radium-uranium ratio in carnotites: U. S. Bur. Mines, Technical Paper 88, 1915.

[81] Emanation is a product of the decay of radium which is involved in the ordinary determination made by an electroscope.

[82] For details of mining methods the reader is referred to: Kithil, Karl L., and Davis, John A., Mining and concentration of carnotite ores: U. S. Bur. Mines Bull. 103, 1917.

METHODS OF PROSPECTING

Pockets of carnotite and its related ores are generally small, and mining these ores becomes essentially a process of prospecting. Obviously, drifting is too expensive a means by which to locate ore so pockety and discontinuous. Power drilling has been the means of locating ore where it is within 50 feet of the surface. This manner of prospecting makes feasible search for ore on the benches formed by the important ore zones.

Little prospecting by drilling has been done beyond a depth of 60 feet, and most of it has been done by drilling less than 40 feet. The methods that have been used include the following:

1. Churn drill (man power).
2. Churn drill (gasoline power).
3. Ajax shot drill (gasoline power).
4. Jackhammer (compressed air).
5. Diamond drill (gasoline power).

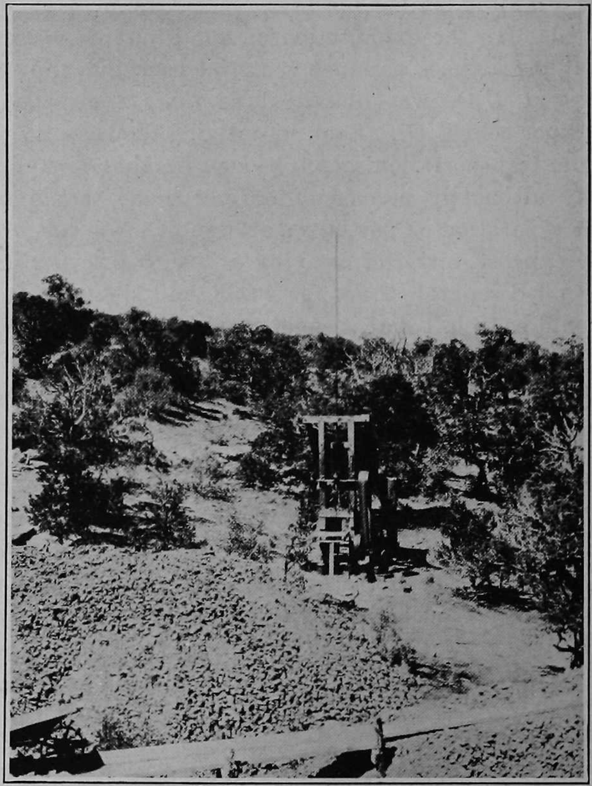

Fig. 38. Prospecting for ore by means of a churn drill (gasoline power) on the Honeymoon claim in Long Park.

Churn drill (man power).—Prospecting has been done in isolated places by "churning" without the use of machinery. The depths reached were less than 15 feet, and for ordinary prospecting, as now carried on, the method is not practical.

Churn drill (gasoline power).—Devices have been used by which a churn drill is actuated by a small gasoline engine and cam, after the fashion of a stamp in the ordinary stamp-mill. Depths of 25 feet have been reached by this sort of drill. It has the advantage in that it represents small investment and can be operated by one man (see fig. 38).

Diamond and shot drills.—The operation of these two drills requires water which is difficult to provide in many localities and only at considerable expense. These drills can operate at any reasonable depth and are adapted to any kind of ground which is not so fractured as to allow the water to escape. Because of the more or less open ground near the outcrop, many attempts to pros-

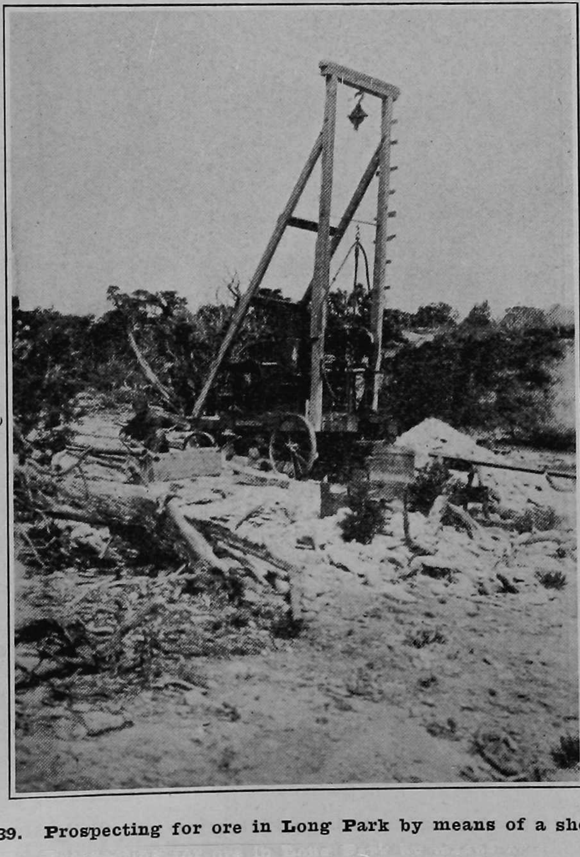

Fig. 39. Prospecting for ore in Long Park by means of a shot drill.

pect in such places have been unsuccessful. The present practice is to operate within the 60-foot limit. Operators consider the cost of such drilling as ranging from $1.00 to $1.75 per foot for the shot drill, and from $0.90 to $1.50 per foot for the diamond drill.

Jackhammer.—The jackhammer (see fig. 40 and 41) has an advantage over other methods in that it requires no water, but does require the installation of a compressor unit, and can be used only for shallow drilling. In a few places prospecting has been done with a jackhammer to a depth of 32 feet; however, operators consider 24 feet to 26 feet the limit beyond which its use is not practicable. The operation of the jackhammer in drilling through wet clay or wet shale requires more than average skill. Open cracks sometimes allow the dust which normally comes to the surface during the process of drilling to escape without appearing at the top of the hole, with the result that it is difficult to determine the exact nature of the rock passed through. Estimates of the cost of

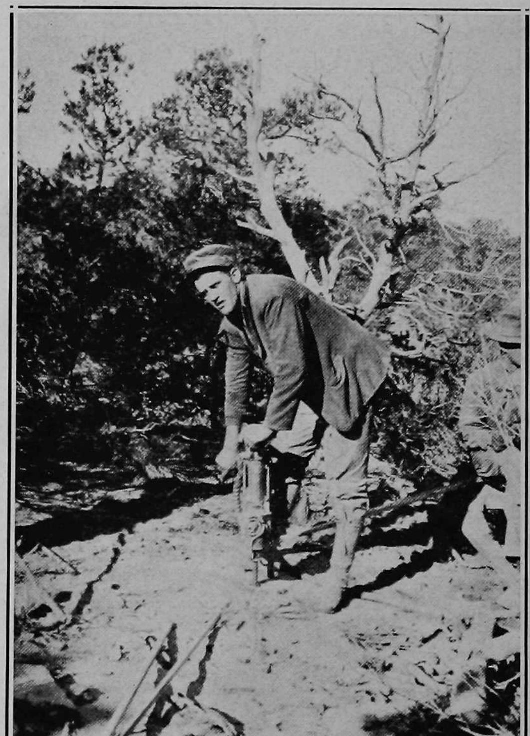

Fig. 40. Prospecting for ore in Long Park by means of a jackhammer.

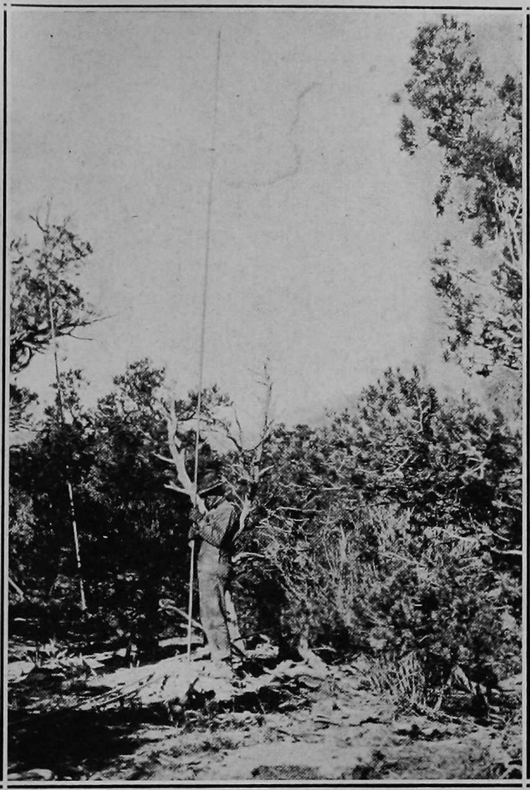

Fig. 41. Jackhammer drill raised from hole.
Length of the drill indicates the depth of the hole in Fig. 40.

jackhammer-drilling for holes less than 25 feet deep, range from 18 to 25 cents per foot.

The ideal installation for development on a large scale would include both diamond drill and jackhammer equipment. The use of the diamond drill would indicate the areas within which the ground would be prospected by the 25-foot limit of the jackhammer.

PROBLEMS IN EXPLOITATION OF "CARNOTITE" CLAIMS

The operator in the carnotite field is confronted by two sets of problems; those which are typical of pioneer conditions in any new field, and those which arise through treating an unusual ore and marketing its refined products.

The aridity of the climate is such that water, even for the needs of a small camp, is often hard to find. Some camps now obtain their water from points 1 to 3 miles distant, and the operation of diamond drills is prohibited in some areas in the dry season because of the scarcity of water.

It must be emphasized that, on the average, deposits of carnotite are small and pocket-like. The cost of finding the ore will necessarily remain one of the largest items of expense. A single pocket containing 100 tons of ore carrying 2 per cent U_3O_8 is good, and one that yields 1,000 tons is indeed excellent.

In as much as the size of pockets seldom justifies the building of roads, transportation to and from many claims will be partly by pack-train. In some places this pack charge is equal to the wagon-haul to the railroad. In as much as mines are from 40 to 75 miles to the nearest railroad, the freight charge is the largest single item of expense. In 1919 this freight charge ranged from approximately $20.00 per ton from Long Park to $40.00 per ton from Gateway properties.

Mining these ores under present conditions will probably show less profit than refining them. The tendency has been for companies to include the mining operation as a part of their work, not so much to lower the cost of obtaining a ton of ore as to insure themselves a constant supply. The cost of producing ore in 1919 by one company equaled the market price of such ores, and for another company it was approximately three-fourths of that amount.

The average ore pocket is small and the reward for its discovery is not large in comparison to the risk involved. Prospecting on a large scale is more apt to succeed because the loss in prospecting barren ground can be equalized by the success which comes by well-directed and extensive prospecting.

It must be emphasized that any operator in the carnotite field should work to the end that the low-grade ore be used eventually. Carnotite mining under present conditions is essentially a "big man's" game. The company or individual who is able to mine his own ore and refine it will be more certain of success than the miner who is compelled to sell his ore on the open market.

GRADES AND PRICES OF ORE

All deposits contain ore of many grades, but the ratio of high-grade to low-grade ore differs in different deposits. In some deposits 75 per cent of the uranium-bearing material can be made to assay 2 per cent U_3O_8 by using the richer ore to "sweeten up" the lean streaks. Again, the work on a single claim often consists of mining a single "tree" which yields several sacks of high-grade ore with almost no waste. On the other hand the exploitation of one group of claims proved that for every ton of ore produced whose uranium content was 2 per cent U_3O_8 there was mined three tons of material whose uranium content was approximately 1 per cent U_3O_8, and whose vanadium content was 2.75 per cent V_2O_5.

The minimum uranium requirement is generally 2 per cent U_3O_8 where the ore is shipped direct, but where a milling scheme is used a lower-grade ore is handled. At present the Standard Chemical Company and the Tungsten Products Company are the only companies concentrating low-grade ores in large quantities. J. I. Mullin, of the Standard Chemical Company, supplies the information that their mill is able to concentrate ore assaying as low as 1 per cent U_3O_8, producing a 4 per cent U_3O_8 concentrate and a 12 per cent V_2O_5 concentrate, with a recovery of 83 per cent.

Ore has been produced in carload lots which contained 5 per cent U_3O_8. Such shipments are generally the result of careful sorting by small producers, and do not represent average conditions. Again shipments of vanadium ore have been made which contained 8 per cent V_2O_5, but the uranium content was so low it did not figure in the sale of the ore.

Prices of ores have advanced somewhat since 1918, and at the same time there has been a reduction by some buyers of the minimum uranium requirement. Although the usual requirement is ore containing 2 per cent U_3O_8 and 3 per cent V_2O_5, some shipments have been made which contained 1.50 per cent U_3O_8. Such ores command approximately $75.00 per ton at Placerville or at other shipping points.

Schedules by which ore is bought differ slightly. Some schedules stipulate a minimum vanadium oxide (V_2O_5) content and value the ore by the pounds of U_3O_8 present, using a sliding scale by which lower-grade ores bring less and higher-grade ores bring more per pound of U_3O_8. Other schedules determine the value of the ore by the pounds of V_2O_5 present and determine the value of the uranium by a sliding scale, as in the previous schedule. Ore containing 2 per cent U_3O_8 and 3 per cent V_2O_5, valued by the different schedules, is worth from $130 to $140 per ton at the railroad.

PRODUCTION

The ore mined in 1919 included the following: (1) ore shipped direct to chemical plants, which averaged 2 per cent or more U_3O_8; (2) ore concentrated by the Standard Chemical Company, which averaged from 1 per cent to 1½ per cent U_3O_8; (3) and milling ore mined and stored by other companies. The first two groups include material which is available for the immediate production of radium and vanadium.

From figures supplied by the larger companies, and estimates made of the production of small operators, the ore of groups 1 and 2 mined in 1919, expressed in equivalent values of ore containing 2 per cent U_3O_8, was approximately 9,300 tons[83]. The vanadium content of these ores averaged from 4 to 4½ per cent V_2O_5.

At the market price of such ores the value of this mined product, exclusive of the stored milling ore, is approximately $1,100,000. Information available in October, 1920, suggests that the production in 1920 will equal and, possibly, slightly exceed the production of 1919.

It must be understood that the production of radium and vanadium from any quantity of mined ore is difficult to determine, as the several plants which refine these ores differ in their per cent of material recovered. One operator estimates that 75 per cent of the radium and vanadium in the treated ore is recovered. Ore which is concentrated suffers a loss in both the milling and refining process.

It is of interest to note that the ore mined in 1919, exclusive of the milling ore stored, contained approximately 47 grams of radium. Assuming a 75 per cent recovery in the refining process, and allowing for losses in the concentration, from 27 to 30 grams of radium should eventually be produced from the 9,300 tons of ore, as estimated above. It must be understood that the treatment of ore is often delayed many months after it has been mined.

At the average price of $110 per milligram for radium, and $5 a pound for ferro-vanadium, the refined products which should eventually be available from the production of the field in 1919 will have a value of between four and five millions of dollars.

PRESENT AND FUTURE ASPECTS OF "CARNOTITE" MINING

In 1919 over 95 per cent of carnotite ore produced from the region was mined by four companies: The Standard Chemical Company, operating largely along lower San Miguel River, in Long Park, south of East Paradox Valley, and in Bull Canyon; the Radium Luminous Material Corporation, operating in Long Park; the Radium Company of Colorado, operating in Long Park and vicinity, and on Roc Creek; and the Carnotite Reduction Company, operating in the vicinity of Calamity and Maverick gulches. In general, the situation was no different in 1920, except that the properties of the Carnotite Reduction Company were worked the latter part of the period by the Tungsten Products Company.

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[83]This production as estimated from incomplete data in a preliminary statement of this bulletin was given as 9,550 tons.

Although the vanadium market was not so encouraging at the end of 1920 as at the beginning, the radium produced was disposed of readily.

Any prediction as to the future production of the region is little more than a guess. Within certain limits the total ore available will be determined by the price of the refined products. An increase in the price of radium and vanadium would make it possible to prospect beyond a limit which will be determined by present prices. It might appear that pro-rating the acres mined against the area yet to be mined would be a means of getting at the mineral resource. In such a computation only such areas as are promising in light of their present prospecting should be figured. Considering such camps as Monogram, Calamity Creek and vicinity, parts of the McIntyre district and other districts, and including only areas which can be prospected by drilling methods now in use, it would appear that the present production of ore, equivalent to approximately 9,000 tons containing 2 per cent (U_3O_8), could be maintained for a period of from 5 to 15 years, depending upon the factor of safety used in making such calculations. Such an estimate cannot be made except within wide limits, and it becomes of little value in figuring the total radium available. The total radium and vanadium which can be recovered from the field could be increased beyond that which will be available under present conditions by any one of three factors: By an increase in the price of the refined products which would warrant extensive prospecting; by an improvement in the present milling schemes which would utilize lower-grade ores; or by any improvement in the transportation system which would make available material that will not stand the present transportation charge.

CHAPTER V

GEOLOGY OF SPECIAL AREAS

INTRODUCTION

The description of the geology of individual areas and of individual mines is impracticable in a reconnaissance of this sort; nor are such descriptions necessary because of the similarity of different deposits both in character and position.

In the following pages a typical group of claims (the Dolores group) has been described in more or less detail, not because of their great importance, but because they represent typical conditions. The important areas are mentioned but are not described unless their geology involves some special feature which is difficult to understand or the ore is unusual. In considering the many claims it is convenient to refer to them in groups which take their names from the camps from which they are worked. The order in which the different groups are mentioned or the length of the discussion is not an index to their relative importance.

AREAS ADJACENT TO SAN MIGUEL RIVER BELOW NATURITA

At the village of Naturita, San Miguel River has cut its canyon 200 feet deep, the lower half in the McElmo formation. The depth of this canyon increases downstream until the main carnotite-bearing sandstone is exposed 6 miles below the mouth of Tabequatche Creek. Below this point the McElmo sandstones are present in both walls of the canyon to the mouth of San Miguel River.

CLUB GROUP

The claims known as the Club group, which are worked from the Club camp (see sub-map, Pl. 1 in pocket) of the Standard Chemical Company, have produced more ore than any similar area in the district. The deposits of this group, as developed up to June, 1919, are approximately as shown by fig. 37, p. 172. Since that time an area which adjoins the one represented has been found equally productive.

The ore occurs near or at the base of the massive sandstone which is the capping rock to the bench. Mining has been done through inclines which lead down to a level below the ore and connect to drifts and cross cuts which lead to the ore bodies. Areas which are adjacent to the rim are mined through tunnels. In this group of claims many ore bodies are of such horizontal extension that their exploitation results in a series of rooms and pillars not unlike those seen in some coal mines. The procedure in the exploitation of this group shows the advantage of running tunnel levels well below the lowest ore and raising to the ore bodies rather than keeping the floor of the ore body near the base of the working level. The cost of handling the extra waste is more than offset by the fact that ore can be mined "clean" without being mixed with other material.

The unusual feature of this group is the regularity and the size of its deposits. The largest single ore body, which is in the Rambler claim, produced approximately 2,000 tons of ore carrying over 1 per cent U_3O_8, and approximately 3 per cent V_2O_5. The exploitation of this group of claims has been directed largely by information obtained from numerous drill holes. Over 1,000 holes were drilled by jackhammers and diamond drills incident to the exploitation of the ore bodies represented by fig. 37 (p. 172).

The production from this group has maintained a more or less constant supply for the concentrating mill of the Standard Chemical Company, situated at the Ford Camp on the San Miguel River (fig. 42). The method of mining and handling ore as worked out at this group of claims is on a larger scale and probably represents production of ore at less cost than on any other claims in the region. It is interesting to note that in 1915 this area was supposed to be "worked out."

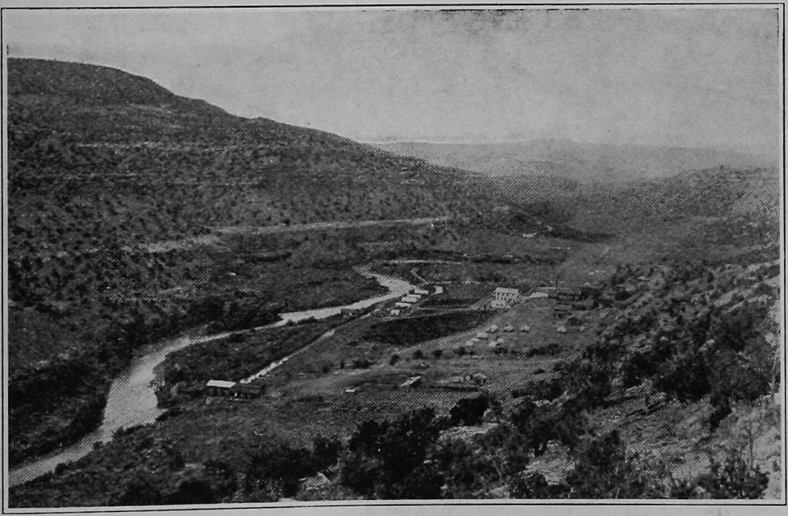

Fig. 42. Concentrating mill and camp of the Standard Chemical Company (Ford and Joe Junior camps).

DOLORES GROUP

In as much as the development of the Dolores group of claims shows the typical occurrence of these ores, the group is described somewhat in detail. The claims lie north of San Miguel River and west of Atkinson Creek (see sub-map, Pl. 1, in pocket). The claims of this group cover practically the entire outcrop of the carnotite-bearing sandstone from Atkinson Creek to the point where this outcrop turns north to parallel Dolores River. All but two of these claims belong to the Standard Chemical Company, who carry on mining operation from their Dolores Camp situated on the bench formed by the productive beds (see fig. 15) which are 700 feet above the river. The claims are reached by trail from Atkinson Creek or the main trail to the Dolores Camp, both of which connect with the road that follows a bench cut from the Dolores formation. Most of the mining has been done on the claims west of the camp, where a gasoline engine and compressor unit has been installed, and with it jackhammer equipment. These power drills have made possible the rapid development of these claims which include the Black Bird, Ophir, Blue Bird, Last Chance, Last Chance No. 1, Little Dick, and Big Dick. All the ore bodies occur in or near the base of a white massive sandstone bed which dips northeast at angles from one-half to two degrees.

Black Bird and Ophir Claims.—These two claims were worked through the same incline that dropped from the bench to the base of the massive sandstone, a distance of about 15 feet. Drifts were run from this point along the bedding to the ore bodies. Here, as elsewhere on the bench, core-drills (Ajax shot drills and diamond drills) have been used to prospect the ground from the top by means of a series of vertical holes.

Blue Bird and Last Chance Claims.—The boundary lines of these two claims were not located, but as their ore streaks and workings are more or less continuous, they are considered under the same head. The first development was shallow work done from the top of the bench. A 300-foot tunnel was run in from the west rim, and a shorter one from a south rim.

On the Last Chance claim, ore was found practically at the surface, being near the top of the productive bed. This ore was in irregular lenses which cut across the bedding in some places and followed it in others. Layers of ore a foot thick followed the bedding for several feet, only to be abruptly terminated by barren sandstone, without apparent cause. Local thin-bedded streaks within the massive sandstone apparently influenced in places the deposition of the ore. In general, these surface deposits did not appear to be as continuous or as productive as those under cover.

Two so-called "trees" were encountered in the upper workings of the claims; the form of one of these peculiar ore bodies is shown in fig. 36 (p. 164). This "tree" was a cylindrical mass of ore about 25 feet long, 3 feet in diameter at one end, and 1½ feet at the other. Both "trees" roughly followed the bedding and were characterized by Mr. Wilson, foreman of the camp, as containing " good" and "high-grade" ore. Neither of these deposits showed in their walls any carbonaceous material, but gypsum made up a portion of the materials from one of them.

Another peculiar form of ore pockets observed in these claims is the so-called "bug holes." Pockets of ore sometimes terminate in these cone-like deposits which carry "high-grade." It is the experience of Mr. Wilson that these "bug holes" run to, or from, ore bodies.

At one place on these claims, ore was found at two levels about 15 feet apart. The lower level, which came near the base of the massive sandstone, contained an unusual deposit, which was roughly circular in outline, with a diameter of 40 feet. Over this area the ore ranged from 1 to 4 feet thick. Numerous projections extended out from the main mass and gave a very irregular outline to the pocket. The ore streaks followed roughly the bedding of the sandstone, but the floor and roof possessed many undulations which exceeded the irregularities due to uneven deposition of the sandstone. Mr. Wilson supplies the information that the bottoms of these depressions, and the highest points in the ore streaks where they curve upward, contain better ore than is found elsewhere in the seams. Of these two critical places he found ore from the upper points richer than that in the lower ones. He further observes that the top or bottom of an ore seam is often richer than the central part. At one point on the edge of this ore body layers of sandstone were highly charged with red vanadium mineral with a secondary amount of yellow carnotite. Within this vanadium-bearing sandstone seams of fibrous calcium vanadate were formed. These red ores showed no peculiarity of position but were only a continuation of the yellow carnotite body with a diminution of carnotite and a corresponding increase in the vanadium mineral. The fibrous seams followed the bedding of the sandstone in all observed cases. Much ore had been taken from this deposit that carried better than 3 per cent U_3O_8, and up until July, 1918, it was the largest single ore body that had been developed on this bench.

Little Dick Claim.—This claim was worked from the rim by tunneling on the ore seam and running numerous cross-cuts. The main tunnel was driven in the massive sandstone and, with the exception of a gap of 20 feet, encountered ore its entire length, a distance of 300 feet. Several drifts developed ore pockets through this tunnel. In all the work done on this claim up to 1919, overburden did not exceed 35 feet at any point. Prospecting from the surface by power drills had located much of the ore.

The ore streaks in this claim were more regular than the deposits of other claims already described. The material immediately overlying the ore was the usual massive sandstone. The floor was either sandstone or shale, and followed practically the same level. A bed of black ore carrying uranium minerals was an unusual feature of this claim. One such bed consisted of a 2-foot streak of dark to black ore-bearing sandstone containing coal-like seams of an undescribed mineral carrying considerable selenium. Some of these coal-like materials assayed 9 per cent U_3O_8.

Big Dick Claim.—The claim adjoined the Little Dick on the east and had been worked through openings from the rim. The claim was not examined in detail.

Other Claims.—Toward the east end of this bench several claims belonging to this group showed ore of unusual grade at the surface. The Lucky Dog Claim produced ore from the top of the bench, or in the upper part of the massive sandstone, and in a bed 10 feet lower. The Mix-up Claim covered an exposure of carnotite-stained sandstone that followed near the base of the usual productive bed for a distance of 200 feet. The ore was, for the most part, confined to a layer made up of laminae one-half to 3 inches thick, which, in the aggregate, made an ore streak approximately 10 inches thick. The sandstone that overlies the ore is here 20 to 30 feet thick and constitutes the only overburden. A continuation of the same ore streak contains excellent ore at the surface in the Squirrel Claim which adjoins it on the west. Little development had been done at this part of the bench up to 1919.

Two claims along the bench on which the Dolores Camp is situated are the property of the Radium Company of Colorado. These claims, Club No. 3 and Club-sandwich, contained good ore along the rim near the base of and in the massive sandstone that forms the bench. In the early summer of 1918, this company established their Hydraulic Camp below these claims and began the development of their properties. Shipping ore was being produced in June. It is understood that their operations did not continue at these claims through the winter of 1918-1919.

OTHER GROUPS

Other claims (see sub-map, Pl. 1, in pocket) within the area adjoining lower San Miguel River include those of the Outlaw group, Julian group, Wright group, and Shamrock group. These groups have been operated by the Standard Chemical Company, but with the exception of the Shamrock group the claims, up until 1920, had been prospected only along the outcrop of the ore-bearing sandstone.

The Radium Luminous Material Corporation operated claims in Eagle Basin from their Hart Camp, and in 1918 established their Nabob Camp opposite the Dolores camp. Up to 1920 these claims had been prospected but little.

DIVIDE BETWEEN SAN MIGUEL RIVER AND EAST PARADOX VALLEY

The exploited deposits along the divide between San Miguel River and East Paradox Valley occur in Long Park at the head of Hieroglyphic Canyon, and in Saucer Basin. These deposits outline approximately the tilted edge of the main carnotite-bearing sandstone which can be traced without interruption along Hieroglyphic Canyon to the deposits at Club camp and vicinity. The structural relation between these two areas is shown in section E-E of the sub-map of this area (see Pl. 1 in pocket).

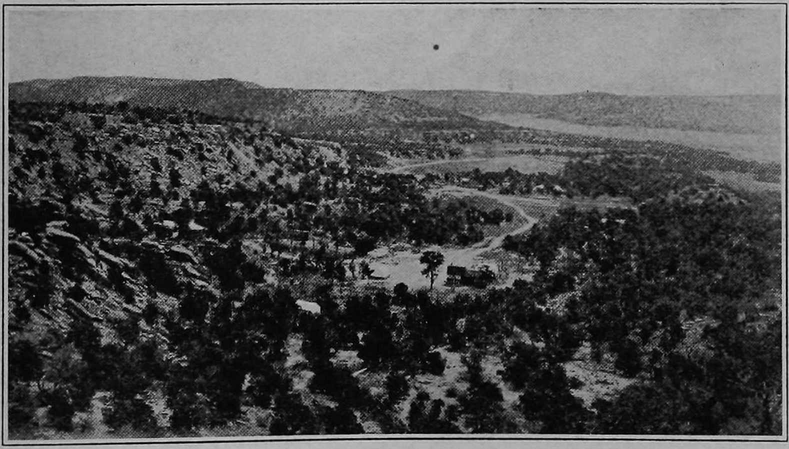

Fig. 43. Looking east into Long Park.

Camp Marvel of the Radium Company of Colorado in the foreground: Long Park camp of the Radium Luminous Material Corporation in the middle distance.

LONG PARK

The development of claims in Long Park has been carried on from three camps. They are: Sunny Jim camp of the Standard Chemical Company (formerly Wilmarth's camp), Long Park camp of the Radium Luminous Material Corporation, and Marvel Camp of the Radium Company of Colorado.

The surface deposits of the Sunny Jim group of claims have been mined, and further development will probably be directed by drill-prospecting, some of which has been done since the claims were last worked.

The claims which are worked from the other two camps include an almost continuous strip which extends from the Cripple Creek claim to Hieroglyphic Canyon. The claims which have produced most of the ore from the group are the Cripple Creek, Maggie C, Henry Clay, Honeymoon, and Florence. A detailed description of the early developments on many claims in this group has been written[84].

The ore body of the Cripple Creek claim has been described. (p. 161). Officials of the Radium Luminous Material Corporation give the record of production for this claim up until January 1st,

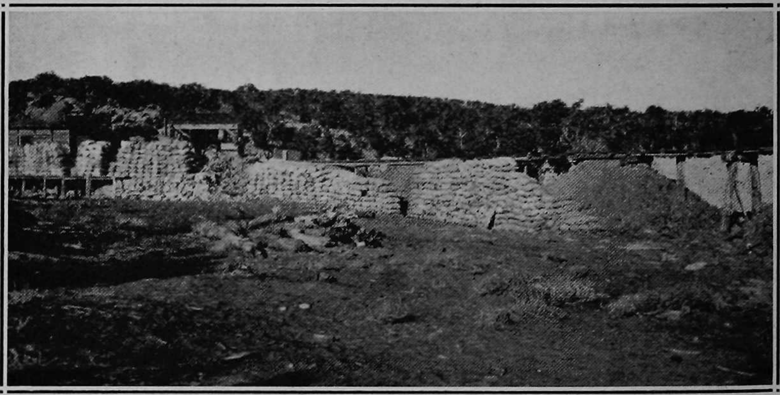

Fig. 44. Partial workings of the Cripple Creek mine, Long Park.
Ore sacked ready for shipment.

1920, as follows: Approximately 1,400 tons of ore containing 2 per cent U_3O_8, and over 4,000 tons milling ore containing over 0.6 per cent U_3O_8. It is doubtful if any single claim has equaled this production.

[84] Kithil, Karl L. and Davis, John A., Mining and concentration of carnotite ores: U. S. Bur. Mines Bull. 103, 1917.

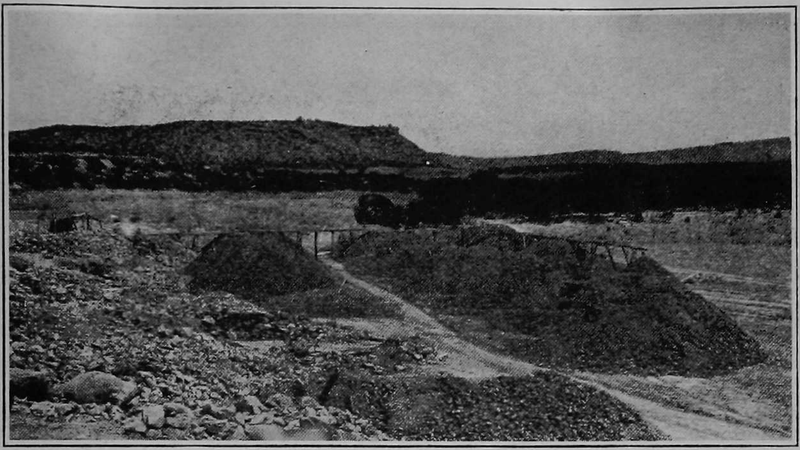

Fig. 45. Milling ore produced from the Cripple Creek mine.

The method of developing most of the claims in the group has been by prospecting with power drills. The practice of one company has been to drill holes at 20-foot intervals throughout their claims.

A series of minor dislocations along joint planes running northwest and southeast has affected the position of the ore at several points. In general these dislocations have produced a downward movement of the block on the southwest side of the fault planes. At all but one place where these dislocations were observed, the faulting was less than 15 feet and generally less than 5 feet. A narrow block which occurs between two parallel joints has been faulted down in the west end of the park, approximately 40 feet. The Nucla claim is situated near the east end of this block.

HIEROGLYPHIC CANYON

Several highly productive claims have been exploited at the head of Hieroglyphic Canyon. The important ones are the Sharkey, Bobcat, Yellow Bird, and Pegleg. Many other claims occur in the group in different stages of development.

The interesting feature of the group is the fault block which extends northwest from Long Park. The Sharkey claim is on the southwest edge of this block (see fig. 46) which, at that point, is not well defined, but its downward movement has been accomplished by several minor faults. Dislocations in the ore bodies of this claim have generally resulted in a relative movement upward of the beds on the southwest side of any plane of displacement..

Jointing is so common in the claims of this group that the use of power drills which require water in prospecting would probably

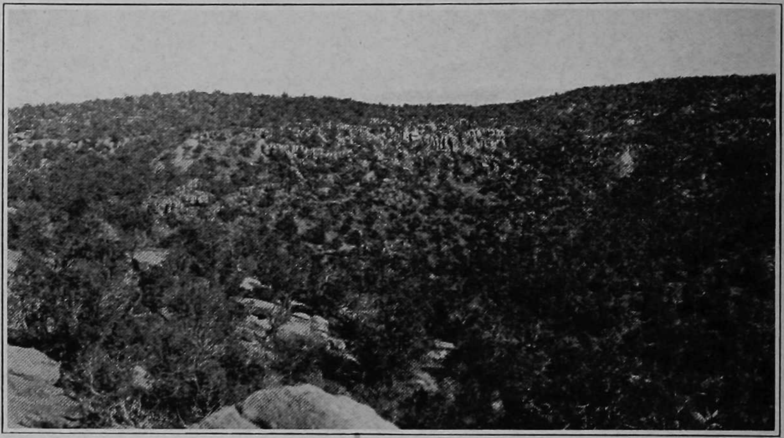

Fig. 46. Gap formed in the east wall of upper Hieroglyphic Canyon by a fault block.

The fault block extends through the depression to the right: the white spots near the black are workings of the Sharkey claims.

meet with difficulty. However, there is a large fraction of the area covered by these claims that can be prospected within the 25-foot limit of the jackhammer.

SAUCER BASIN

The Cliff mine (fig. 47) is the only one of importance in the basin. The ore in this claim occurs in the same stratum as the other large deposits of the region, but the claim is unusual in that the exploited ore bodies were so near the outcrop of the productive bed. A mill to concentrate ore by the dry method has been installed, but up to 1920 it had been run only in an experimental way. The claim includes much ground that can be economically prospected by diamond drills.

Another feature of this basin is the occurrence of ore in a sandstone approximately 125 feet above the La Plata. Sporadic occurrences of ore exist in this sandstone at several points. In 1919 a camp was established in this basin by the Radium Company of Colorado, who worked some of these deposits. The writer understands that this camp was maintained for only a short time.

The south end of Saucer Basin includes outcrops of the La Plata sandstone which show a remarkable system of jointing (fig. 22). A series of parallel faults which have caused minor displacements in these beds continues southwest from this basin. An inspection of these faults within this area makes an understanding of conditions in Long Park less difficult. . . . .

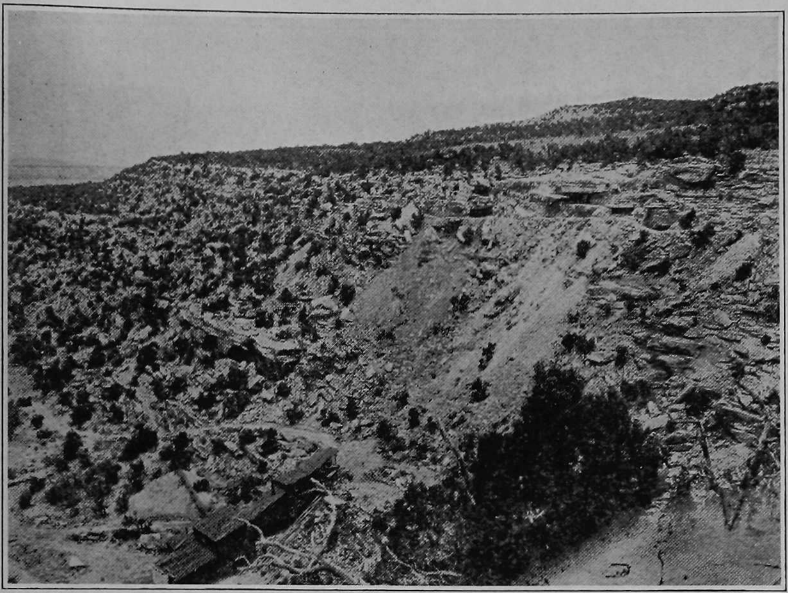

Fig. 47. Cliff mine and concentrating mill in Saucer Basin.

Other claims along this divide include those in the vicinity of the Jack Rabbit camp along Hieroglyphic Canyon, and claims near the east end of Long Park.

SOUTH SIDE OF EAST PARADOX VALLEY

The areas along the south side of East Paradox Valley which have thus far produced ore, include those adjacent to the Thunderbolt camp, Joe Dandy camp, Monogram camp, and points along Wild Steer Canyon. The developments at the Thunderbolt camp and those along Wild Steer Canyon were not visited by the writer and cannot be discussed.

JOE DANDY GROUP

The claims of the Joe Dandy group contain ore in the same general bed in which large deposits are found elsewhere, but faulting and slumping have made it difficult to follow the different strata. Prospecting with diamond drills is impracticable in this group of claims, and the location of ore bodies must be made by tunneling and cross-cutting. The group was supposed to have been worked out in 1916, but later (1918) prospecting by the tunnel-method was highly successful and, up to the present (1920), the group has been a constant producer.

The types of ore from these claims include dark, hard ore that contains more than 4 per cent V_2O_5 and a content of uranium that

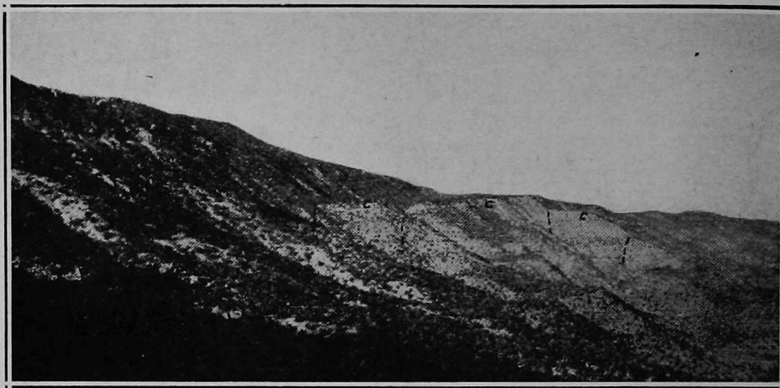

Fig. 48. Faulting along the south side of East Paradox Valley.
C indicates the different segments of the carnotite-bearing bed.

is by no means uniform. Even in ores that outwardly appear alike the uranium content is different. Fibrous calcium vanadate occurs in the gypsiferous ores, and an orange-colored uranium mineral which appears as crusts and coatings is peculiar to this group of claims.

East of the Joe Dandy group the beds dip toward the valley, which, with a certain amount of slumping of the overlying shales, have so covered the McElmo sandstones that they are difficult to prospect. Ore has been found intermittently along the rim as far west as the Monogram camp.

Since the compilation of the present map a road has been constructed from the Joe Dandy camp to the main Paradox Valley road.

MONOGRAM GROUP

The claims developed from the Monogram camp include ground that shows a repetition of the main carnotite-bearing sandstone by a series of parallel faults. These faults are not all indicated on the map, nor does the reconnaissance of this group of claims adequately show the conditions.

The upper bench on which the camp is situated has produced less ore than the faulted segments. Figure 48 shows the general character of the displacements. The claims include considerable ground that can be prospected by the diamond drill.

Considering the fact that the group has been exploited thus far without the use of power equipment, its steady production is remarkable.

WILD STEER CANYON AND VICINITY

The main carnotite-bearing stratum is well exposed along the edge of Paradox Valley from Monogram camp to Dolores River. This stratum appears in two parallel outcrops, one representing the unfaulted bed and the other the outer edge of a faulted segment. This segment has an average width of an eighth of a mile and has been lowered from its original position from 50 to 200 feet. Some ore has been produced from this region.

BULL CANYON AND VICINITY

In Bull Canyon commercial bodies of ore have been mined from two ore-bearing sandstones. The relative position of these two sandstones is shown in figure 29 (p. 154). No structural feature, other than the gentle synclinal warping of the region, has disturbed the horizontal position of these beds, and they are easily followed in two outcropping ledges which parallel the exposure of the Upper La Plata sandstone. Ore has been produced from the upper productive zone at several scattered points. The region includes many areas which can be prospected by jackhammers.

The same strata that appear in Bull Canyon are exposed in continuous outcrop around Spring Canyon and along Dolores River as far north as Wild Steer Canyon. Although the writer is not aware of any deposits having been found along these outcrops beyond a point 2 miles west of Bull Canyon, the area should be prospected.

GYPSUM VALLEY

The carnotite-bearing sandstones are exposed in small areas near the mouth of Gypsum Valley on both sides of Dolores River. Carnotite has been found east of the river near the center of the valley in a folded mass of these sandstones, and west of the river the Haymaker and adjoining claims have produced considerable ore. Aside from these two places there is little opportunity to prospect the productive bed along the south side of the valley in its lower part. In its upper part the sandstones of the McElmo formation are exposed for a short distance west of the gap through which the road to Cedar leaves the valley, and east of this gap they outcrop along this ridge in beds dipping away from the valley.

On the north side of Gypsum Valley the productive beds are well exposed from Radium Hill to a point about 2 miles southeast of the Mexico mine. From this point to the head of the valley the exposures are tilted away from the valley in narrow outcrops which would be difficult to prospect. Ore has been produced from the north side of this valley near its head, and some from the south side near Klondyke.

Scarcity of water makes it difficult to prospect this ground except in the spring of the year.

KLONDYKE

The ridge which divides Gypsum Valley from Disappointment Valley is terminated at its east end by a bluff which faces the west and overlooks a basin in which Carboniferous beds are exposed. The beds in this basin, which is known as Klondyke, include remnants of several formations. The north half of the basin is floored

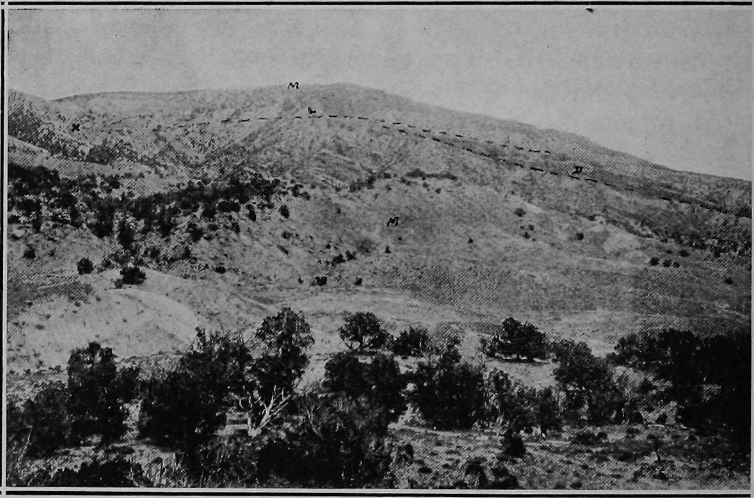

Fig. 49. Angular unconformities in Klondyke.

Dolores beds at D make an angular unconformity with underlying Pennsylvanian beds, and La Plata beds at L lie unconformable upon both Pennsylvanian and Dolores beds: the block of McElmo in the foreground has been faulted down: X indicates deposits of manganese ore in the La Plata formation.

with beds of the Hermosa formation (Carboniferous), and the south half is covered with McElmo beds which have been let down from their normal position by two intersecting faults. In the east wall of this basin (fig. 49) the Dolores formation overlaps the Carboniferous beds and it is in turn cut off by the La Plata formation. There are in this cliff two angular unconformities. The geology is somewhat obscured along a part of the northern rim of the basin by the presence of post-Cretaceous gravels which stand out in nearly vertical cliffs. West of this basin the McElmo beds overlap those of the La Plata sandstones.

The basin is unusual in that it contains manganese in considerable quantity, copper showing of more than passing interest, and showings of carnotite. The carnotite-bearing beds are exposed along the south and east sides of this basin.

LITTLE GYPSUM VALLEY AND SILVEY'S POCKET

Carnotite ore has been produced from several different points in Little Gypsum Valley and Silvey's Pocket. The faulting and folding of the region are so intricate that no continuous exposures of the productive sandstones occur in either locality. In general, the exposures of the McElmo sandstones in Little Gypsum Valley are confined to its southern edge, and those in Silvey's Pocket occur near the center of depression. Carnotite is found in Silvey's Pocket in its usual stratigraphic position, and in one place in a conglomerate somewhat higher. The stratigraphic position of these two occurrences is difficult to determine because of faulting, but they are probably less than 60 feet apart.

McINTYRE DISTRICT AND VICINITY

The monoclinal folding which affects the beds in the McIntyre District has caused the sandstone portion of the McElmo formation to become exposed over large areas which adjoin Summit and Bush canyons. Prospecting in this area has been general, but extensive mining is limited to few claims. The important claims of this region are shown by Plate III[85] (in pocket). The region contains many flats formed by the main carnotite-bearing bed, which can be prospected by drill holes 25 feet deep.

Claims which adjoin Stevens Camp are the only ones of this district which have been extensively exploited since 1914.

Developments in most of the other claims have consisted of removing ore from ground which was easily prospected.

Since the compilation of the present map ore has been discovered on claims located south of the mouth of Disappointment Creek near Dolores River, and claims have produced ore from the usual McElmo sandstones which overlook Dolores Canyon from the north. The last group of claims is situated along the north edge of the river where it makes its sudden bend to the south before entering the deepest part of the canyon.

McINTYRE CANYON AND VICINITY

Prospecting, which has been done in McIntyre Canyon, has met with some success, but so far as known no ore has been shipped from this region. In the upper part of the canyon a series of fault blocks

[85] This map was prepared by C. L. Harrington at the expense of C. H. Ocumpaugh and J. H. Overall, who own many of the claims shown.

causes the outcrops of the McElmo sandstones to become discontinuous.

Near the upper end of Bull Pen Creek which drains into McIntyre Canyon several claims have produced ore. Those adjacent to Morrison's camp have been the only ones exploited. A high-grade vanadium ore containing calcium vanadate (metahewittite) occurs in some of these claims.

AREA EAST OF DOLORES RIVER AND NORTH OF BLUE CREEK[86]

The carnotite-bearing sandstones in the areas adjacent to Dolores River near Gateway occupy their normal position above the La Plata sandstone, and they are nowhere difficult to recognize. The beds of the region have been warped gently by the San Miguel syncline and farther east have been steeply upturned by the Uncompahgre uplift.

The region differs from those already mentioned in that the canyon of Dolores River and tributary canyons are so deep that the different camps are reached only by trail. The main outlet is by way of "Pickett's trail" to West Creek, and thence by way of Unaweep Canyon to Whitewater.

MAVERICK GULCH AND UPPER CALAMITY GULCH

The area between Maverick Gulch and Dolores River includes Flattop (fig. 31) and an area immediately north, which is capped by the carnotite-bearing sandstones. Claims along the north and west side of Flattop have been developed by the Radium Company of Colorado. Farther north, Tenderfoot camp, now owned by the Tungsten Products Company, is the center of operations which have developed claims in this vicinity. Prospecting has been done near the head of Larsen Bend Canyon and along upper Maverick Gulch near Harvey's camp.

East of Maverick Gulch a group of claims known as the Maverick group has produced considerable ore from points scattered along the outcrop of the productive sandstone for a distance of 2 miles. The area has thus far been exploited without the use of power drills.

Near the head of Calamity Gulch the productive sandstone has been successfully prospected on either side of the gulch. On the west side a group of claims, now being exploited by the Tungsten Products Company, is unusual in that it has produced ore from so many points along the outcrop of the productive sandstone (fig. 50). The divide between Maverick Gulch and Calamity Gulch includes much ground that can be prospected by diamond drills.

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[86] See sub-map in upper right hand corner of Plate I (in pocket) for a detailed representation of a portion of this area.

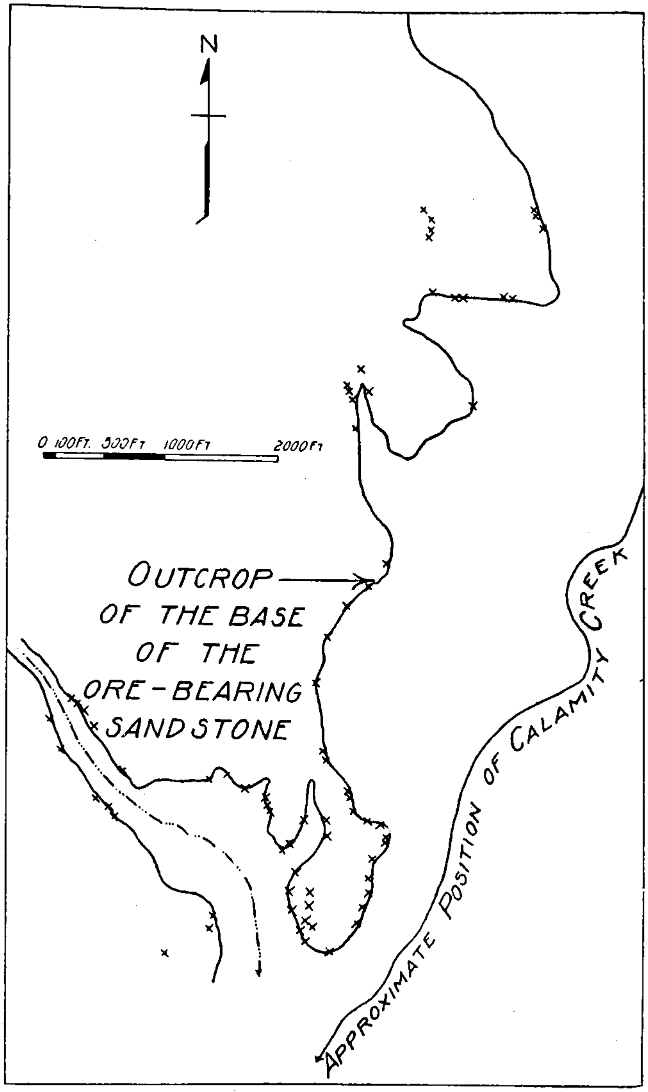

Fig. 50. Outcrop of the ore-bearing sandstone on the Calamity group of claims, Upper Calamity Gulch.
Points from which ore has been mined indicated by X.

East of Calamity Gulch several claims have been worked from camps known as Foster's camp and Outlaw camp. This area includes much ground that can be prospected by jackhammers.

BLUE CREEK

The area adjacent to upper Blue Creek includes many exposures of the McElmo sandstones. North of Blue Creek a group of claims (not shown on the map) known as the Blue Creek group have produced considerable ore. Prospecting has been done with some success south of Blue Creek in this same general region.

So far as known to the writer, carnotite has not been mined from the McElmo sandstones near the mouth of Blue Creek or from exposures along Dolores River in the same region.

MESA CREEK AND VICINITY

The carnotite-bearing sondstones are exposed along Mesa Creek near the foot of the Uncompahgre Plateau and again at the mouth of this creek. The Grub-stake group of claims has produced ore from the upper exposures and a small quantity of ore has been produced from those near the mouth of the creek. The lower exposures are unusual in that they contain showings of carnotite in three different beds (fig. 30).

ROC CREEK

The scale of the mapping is not large enough to show the details of faulting which occurs in the region of the mines near the Uranium post office. The general relation of the fault block in which the mines are situated is shown by cross section A-A' of Plate I (in pocket). The beds in this block are tilted steeply along the north edge but flattened somewhat toward the south.

The shattering of the rock has made transfers of ore possible, and secondary changes in the ore bodies are probably numerous. These claims have been worked intermittently since the mining of the first carnotite, and their record of production is unusual, in that it included a continued output of good grade ore. Opportunity did not present itself to study these claims in detail.

So far as members of this survey could learn, no carnotite has been found in the exposures of the McElmo sandstones which border Roc Creek near the Colorado line.

DIVIDE BETWEEN ROC CREEK AND WEST PARADOX VALLEY

The divide between Roc Creek and West Paradox Valley includes areas in which the McElmo sandstones are well exposed. Prospecting has been done along the west end of this divide in what is known as Carpenter Flats (not indicated on the map).

Toward the east end of this divide the different sandstones of the McElmo formation form a series of tilted benches which extend down from the edge of Paradox Valley to Dolores River. Each sandstone forms an individual bench whose edge measures many miles in length and affords excellent opportunity to prospect the different sandstones. Ore has been produced in this region from beds below the main productive zone.

AREA NORTH OF SINBAD VALLEY

The McElmo sandstones are well exposed in the McElmo outcrop north of Sinbad Valley at only a few places. Production in this area has been limited to Kunkle's claims and those immediately north. So far as known to this survey no ore has been found between Kirk's Canyon and Sinbad Valley.

LA SAL CREEK AND VICINITY

The exploited deposits on La Sal Creek are limited to those of the Yellow Bird and adjoining claims. The deposits in these claims show no peculiarity of position but are unusual in that they contained several "trees" of extremely high-grade ore. Several prospects on the divide between La Sal Creek and West Paradox Valley contain large deposits of low-grade vanadium ore. No carnotite has been reported in the McElmo outcrop which extends from La Sal Creek to Coyote Wash.

OTHER AREAS IN THE NORTHERN PART OF THE MAP

Areas within which the sandstones of the McElmo formation are exposed, but which lie beyond the limits of present production, include several isolated exposures. They occur along the foot of the Uncompahgre uplift from Mesa Creek to North Fork Tabequatche Creek as disconnected outcrops tilted at different angles. These sandstones occur along Tabequatche Creek below its north fork and above Templeton's ranch in such positions that they would be easy to prospect. A large part of Spradlin Park and an area adjoining Bucktail Creek are covered by McElmo sandstones. They occur along San Miguel River above Pinion and in places along Horse Fly Creek.

The exposures of these beds which appear in Little Red and Big Red canyons and in Tabequatche Basin are covered with vegetation, and they would be hard to prospect. The same condition prevails along the top of the Uncompahgre Plateau.

AREAS IN McELMO CANYON AND VICINITY

The exposures of the McElmo sandstone which occur south of the Dolores anticline are limited to three regions: McElmo Canyon, Yellow Jacket Canyon, and Cross Canyon and vicinity.

McELMO CANYON

In this canyon the McElmo sandstones which correspond to the productive ones farther north are, in general, not as thick as those in the productive areas. Their outcrops are confined to a narrow strip in the immediate vicinity of the La Plata sandstones. They extend down the canyon to a point 4 miles below Battle Rock and extend up the canyon to a point 3 miles above the mouth of Trail Canyon.

The vanadium-bearing sandstone which occurs in this canyon in the Dolores formation is found one-quarter of a mile north and east from Battle Rock. The vanadium-bearing material occurs in the thinner bedded portions of a sandstone which is exposed at the surface over considerable area. The bed is opened up in only one place. A sample taken from several points across a 3- to 6-inch streak assayed 1.05 per cent V_2O_5, and .09 per cent U_3O_8. Traces of copper were present in the material.

YELLOW JACKET CANYON

The sandstones of the McElmo formation are exposed from approximately the head of the canyon to a point 6 miles from its mouth, a distance of approximately 15 miles. No carnotite has been reported in this canyon.

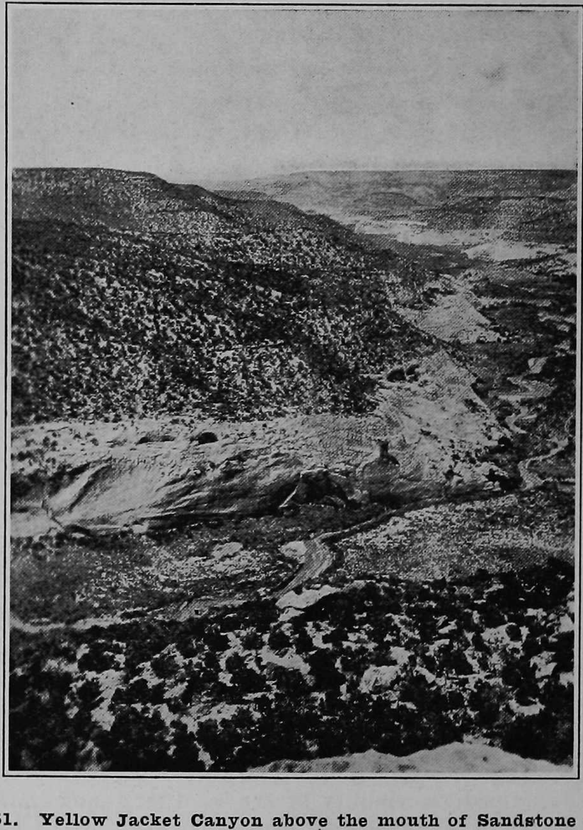

Fig. 51. Yellow Jacket Canyon above the mouth of Sandstone Creek.
La Plata formation exposed at the bottom of the canyon; McElmo sandstones are not prominent in this area.

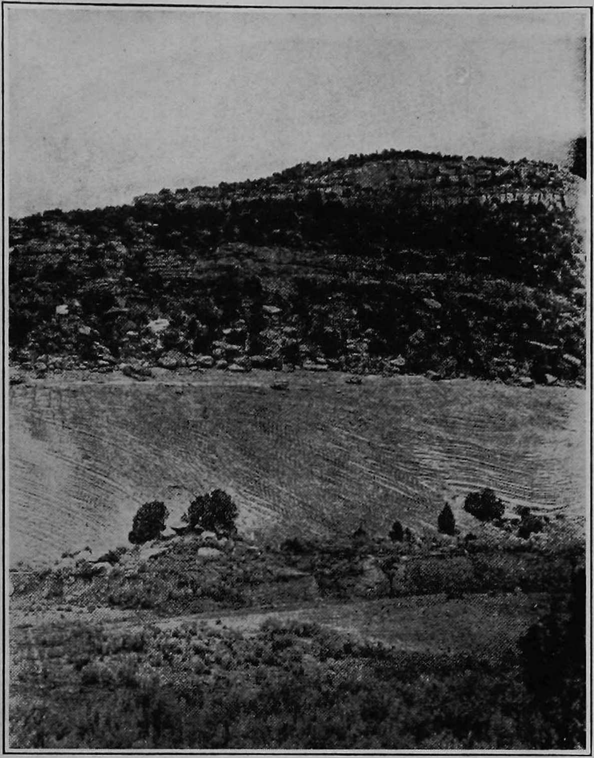

Fig. 52. Cross bedding in the La Plata sandstone in Yellow Jacket Canyon.

Although the canyon may not prove worthy of the prospector's attention, the outcrop of the La Plata sandstone is deserving of some comment. This sandstone displays a variety of erosion forms. Cross bedding (fig. 52), erosion remnants of different sorts (fig. 10), and a jointing probably produced by diurnal changes in temperature (fig. 53), all contribute to the scenic value of the canyon.

CROSS CANYON AND VICINITY

Exposures of McElmo sandstones extend from a point one mile below the junction of Cross Canyon and Dove Creek to the Colorado line. It has been reported that carnotite ore has been found in this canyon.

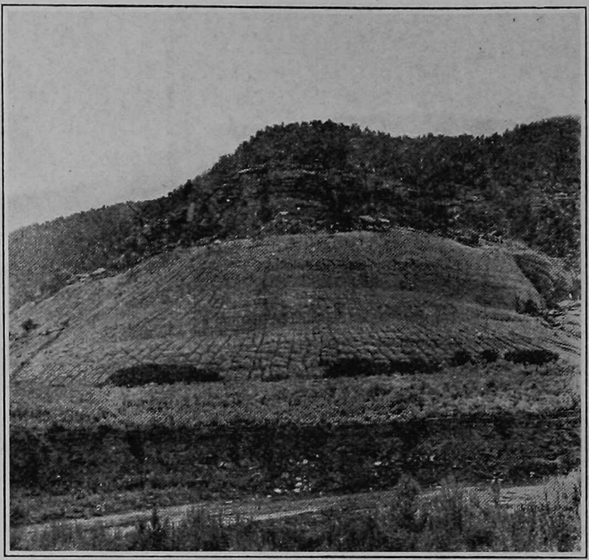

Fig. 53. Jointing in the La Plata sandstone in Yellow Jacket Canyon.

West of this canyon these same sandstones are exposed in the lower part of Squaw Creek, which is shown in the map. It is of interest to note that carnotite has been found along Coal Beds Creek in that part of its course which lies in Utah, west of this area.

CHAPTER VI

MISCELLANEOUS ECONOMIC MATERIALS

The materials of economic interest other than those already described include copper, coal, oil, manganese, placer gold, gypsum, salt, and "hallerite." What follows is a brief statment of facts which pertain to the occurrence of each of these materials.

COPPER

La Sal Creek.—Copper occurs in different formations within the area of this report, but the commercial deposits that have been found thus far occur in the massive sandstones of the Dolores formation.

The important deposits are those of the Cashin and Cliff Dweller mines, the first of which has been described by W. H. Emmons[87]. The ore in the Cashin and Cliff Dweller mines occurs along two intersecting fault fissures which bound a wedge-shaped block. Displacement along either of these fissures is approximately 50 feet. The ore occurs chiefly as chalcocite impregnating the sandstone which adjoins the fissures, and as native copper in the brecciated zones. Considerable fracturing of the sandstone has occurred in places, and at such points the fissure contains its richest ore. The position of sulphides and native copper is reversed from the usual arrangement, in that the native copper generally occurs lower down in the fissures than the copper sulphides. Native silver occurs with the native copper.

At the time of visiting the mine, December, 1919, the main tunnel, which started 50 feet above the level of La Sal Creek, was over 1,700 feet long, and a winze had been driven downward 255 feet preparatory to prospecting the fissure at lower levels.

The deposits of the Cliff Dweller mine are essentially the same as those of the Cashin mine. The deposits had been worked through two tunnels which followed the fissure at two levels about 100 feet apart. When visited in 1918 the upper tunnel was approximately 900 feet long and the lower one 500 feet. Ore shipped from this mine contained from 35 to 50 per cent copper and from 8 to 10 ounces of silver per ton. The minimum copper content of a material which could be profitably worked in 1919 was approximately 20 per cent.

[87] Emmons, W. H., The Cashin mine, Montrose County, Colo.: U. S. Geol. Survey Bull. 285, p. 127, 1906.

The important minerals in these deposits include, besides chalcocite and native copper, azurite, malachite, covellite, and bornite. The walls of many of the openings were coated with hydrous copper sulphate. The gangue minerals include calcite and barite.

The Cashin mine contained the first mineral deposits of the region to be exploited. In its early development it is reported to have produced ore valued at more than one-half million dollars. In 1918 the Michigan Colorado Copper Company started the further development of the Cashin and Cliff Dweller mines and adjoining property. A road was constructed up La Sal Creek from Bedrock, the mine was reopened, and the construction of a mill was begun, by which to handle low-grade ores. The work was discontinued in the summer of 1920.

West Paradox Valley.—Prospecting has been done on the south side of West Paradox Valley on what is supposed to be the northern extension of the Cashin fault. The Fairview claim in this region includes a tunnel which follows a fault and which has encountered a little ore. Very little, if any, ore has been shipped from these properties.

On the north side of this valley the Sunrise mine is located along a fault which has resulted in a downward movement on its east side of about 40 feet. This fault, which trends N. 22° E., was not located on the present map. Mr. Worcester contributes the information that the deposits of this mine are essentially of the same character and come in the same part of the formation as those on La Sal Creek. The mine has produced 12 cars of ore assaying better than 30 per cent copper and containing from 6 to 10 ounces of silver per ton.

Other prospecting on this side of the valley includes some work at the Morning Glory mine.

Sinbad Valley.—Copper minerals were found in places in this valley in sufficient quantity to encourage considerable prospecting at three points. Prospecting has been done along the south side of this valley in Carboniferous and Cutler beds. In the west end of the valley copper minerals were found near the Pyramid mine in the Cutler beds, and in the north wall they were found in the Copper Rivet property in a fault fissure cutting beds of the Dolores formation. So far as known, none of these prospects shipped ore.

Tabequatche Basin.—Prospecting for copper has been done on the north side of Tabequatche Basin at a place known as the Copper King prospect. Conglomerate boulders, impregnated with azurite, occur on the bench at this point. Prospecting to locate the source of these boulders, presumably from the Post-McElmo formation, was done largely by diamond drills.

Klondyke.—Copper minerals occur intermittently along the faults which traverse this basin and are so abundant at places as to justify a careful study of this region. Native copper replacing limestone was observed at several points. All prospecting thus far has been confined to surface workings.

McElmo Canyon and Vicinity.—Material collected from a sheeted zone which occurs in Battle Rock contained minor quantities of copper and iron minerals mixed with calcite. An assay of some of the material showed traces of gold and 8 ounces of silver per ton. Copper minerals occur at several points along the margin of the Ute Mountain igneous mass. No deposits of commercial size have been found in this region.

COAL

Coal in beds thick enough to mine occur in First and Second parks, which lie west of Nucla. H. S. Schneider visited three mines in this area, and the following facts are supplied from his notes:

The coal occurs in the "Dakota" formation approximately 175 feet above the base of the Post-McElmo formation and approximately 15 feet below a massive, well-indurated, locally quartzitic sandstone which comes near the top of the "Dakota" formation.

The Hutchings coal mine, situated near the west end of High Mesa, shows the following section:

Section of Coal in Hutchings Coal Mine

Sandy shale roof	
Coal	16 inches
Shale	4 inches
Coal	15 inches
Shale	3 inches
Coal	4 inches
Shale	4 inches
Coal	24 inches
Total coal	4 feet 11 inches

The Spechts' coal prospect, which is located in the same region, contains coal seams whose total thickness is 4 feet 10 inches, and Oberding's mine farther north contains similar coal seams 3 feet and 6 inches thick.

Prof. R. D. Crawford sampled the beds in the Winkler mine, 3 miles west of Nucla, and measured the following section:

Section of Coal in Winkler Mine

Coal roof		
Clay		4 inches
Coal		2½ inches
Shale		¼ inch
Coal		9½ inches
Shale		2 inches
Coal	4 feet	7 inches
Shale floor.		
Total coal	5 feet	7 inches

Coal from these mines is used locally and by the Standard Chemical Company in their concentrating mill.

The sample from the Winkler mine showed the following approximate analysis:

Approximate Analysis of Coal in Winkler Mine

Fixed carbon	54	per cent.
Volatile matter	32	per cent.
Sulphur	.4698	per cent.
Moisture	4.89	per cent.
Ash	8.6	per cent.
B. T. U.	12,057	

Coal occurs in the "Dakota" formation at many points in Dry Creek Basin, along the edges of Disappointment Valley, and in the vicinity of McElmo Canyon. These beds were not examined in detail.

OIL POSSIBILITIES

The different anticlines of the region were not examined to determine structures favorable for the accumulation of oil and gas. Certain relations of beds in this area need the careful consideration of one examining the area with this in view.

STRATIGRAPHY

The area includes remnants of the Mancos formation which has been so productive in Wyoming, and which contains oil in commercial quantities in Colorado at Rangley, Boulder, and Florence. Most of the area is underlain by Carboniferous formations which are oil-bearing in the Bluff field in southeastern Utah and are known to contain oil seeps at other points. The other beds of the region are of such a character that no interest can be attached to them except as they might act as reservoirs for oil migrating from other beds. Sections of the Carboniferous exposed in Klondyke and in Paradox Valley include bituminous shales and limestones in such quantities as to suggest that they might act as a source of oil. The sections are comparable to similar ones of the Bluff field and to sections in the La Plata Mountains. These isolated outcrops suggest that beds of this formation are generally present in the southern part of the area mapped.

The relation of the beds below the Permian(?) to the overlying formation is uncertain. In Gypsum Valley these older beds abut against overlying beds at an angle of 30° in several places. In general, these older beds have the same strike as the younger ones, but dip away from the axis of the present folding at greater angles. These facts suggest that the present valley is the site of an ancient fold whose central part was eroded before the deposition of the Permian(?) beds. It is probable that many of the anticlines which lie adjacent to the Uncompahgre Plateau represent old lines of weakness whose deeply buried beds do not necessarily reflect the structure of those at the surface.

STRUCTURE

Mancos shale occurs in considerable thickness in Dry Creek Basin and Disappointment Valley, but the predominant structural feature of either place is a syncline. It is doubtful if any local flexing of beds occurs in either valley within the area of this report, which is favorable for the accumulation of oil.

The Paradox and Sinbad anticlines are faulted more than is indicated by the present map, and in as much as the Carboniferous beds are already exposed, the valley is not to be looked upon as a favorable structure.

The folding in the Dry Creek anticline is not seriously affected by faulting, and in the event the Carboniferous formation is found to be oil bearing in this general region, this fold should be studied in detail.

If any structure within the area mapped is to be tested to determine whether or not the Carboniferous formations are productive, such a test should be made in the southern part of this area. By selecting a location away from the Uncompahgre Plateau the uncertainties of the relations of the underlying beds would be partly removed.

The McElmo anticline and the anticline 12 miles south of Dove Creek (see Plate 2 in pocket) are structurally of interest and should be studied in detail. The McElmo anticline is discussed in a report now being prepared.

MANGANESE

Manganese deposits of commercial importance occur in Klondyke[88]. These deposits occur in a basin gouged from the La Plata

[88] For a more or less detailed account of these deposits the reader is referred to: Muilenburg, G. A., Manganese deposits of Colorado: Colo. Geol. Survey, Bull. 15, p. 50, 1919.

formation. The concentration of these ores in this formation is probably related to an unconformity which, at this place, separates the La Plata and the McElmo formations. Prospectors recognized the fact that the deposits were in the La Plata sandstone, and some prospecting for such ores was done along the La Plata outcrop at other points. It is probable the appearance of these ores in the La Plata, and in small quantities in the Carboniferous formation of Klondyke, was brought about by the unconformable relation of these beds, and it is probable these materials do not occur in similar beds where such relation does not exist.

Local concentrations of manganese in the "Dakota" were prospected in the Dry Creek anticline, and similar accumulations occur at several points, but no deposits found in these upper beds were of commercial importance.

GOLD PLACER DEPOSITS

The coarse gravels which flank San Miguel River and Dolores River below the point where they come together, contain placer gold. Some of the land marks of the region are remnants of a flume and ditch which were constructed to carry water from San Miguel River near the Ford Camp of the Standard Chemical Company, to the gravel beds near the mouth of Mesa Creek on Dolores River. Mr. Pacen, of Naturita, supplies the information that the flume was built in about 1885, but washing continued only a short time and was never a success. It is estimated that $40,000 worth of gold was recovered from these deposits. Attempts have been made to wash these gravels by pumping water from Dolores River, and again by using water from Mesa Creek, but both schemes were unsuccessful. The gravels near Pinon, 9 miles above Naturita, on San Miguel River, are reported to have been washed with some success.

GYPSUM AND SALT

Unlimited quantities of gypsum occur in Gypsum Valley, and some occurs in Paradox and Sinbad valleys. Although some of these deposits are extremely pure, their distance from a railroad prohibits any attention being paid to them under present conditions.

Analyses of samples of this gypsum are as follows:

Analyses of gypsum from Gypsum and Paradox valleys

Sample from	H_2O	CaO	SO_3	SiO_2	MgO	Total
Gypsum Valley	20.36	32.98	46.48	.66	.079	100.56
Gypsum Valley	21.28	32.81	45.02	1.38	.086	100.57
Paradox Valley	20.50	32.80	46.08	.93	.10	100.41
Paradox Valley	21.26	32.06	47.08	.34	.09	100.61
Pure gypsum	20.9	32.5	46.6			100.

Salt has been produced from the gypsiferous beds in Paradox Valley by pumping the water from a well which is situated near Dolores River, and allowing the salt to crystallize by evaporation. The salt thus produced has been used locally by stock growers.

"HALLERITE"

A material found at the top of the McElmo formation near the head of McElmo Canyon was supposed to contain a new mineral which was called "Hallerite." This mineral was supposed to have the ability to increase the tensile strength of cast steel. The analysis of this material shows the following:

Analysis of "Hallerite" from McElmo Canyon

SiO_2	81.44%
Al_2O_3	10.98%
Fe_2O_3	1.96%
H_2O	4.58%
K_2O	.30%
Na_2O	.87%
TiO_2	.16%
Sulphur	.15%
Uranium	none
Vanadium	trace
Phosphates	none
Calcium	none
Magnesium	none

The material would appear to have no chemical property that could not be possessed by an ordinary alumina-bearing sandstone.

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INDEX