COLORADO GEOLOGICAL SURVEY
BOULDER

R. D. GEORGE, State Geologist

BULLETIN 28

OIL AND WATER POSSIBILITIES OF PARTS OF DELTA AND MESA COUNTIES COLORADO

BY

HERBERT J. WEEKS

DOI: https://doi.org/10.58783/cgs.b28.oxdo7992

BOULDER, COLORADO
CAMERA PRINT
1925

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 28

OIL AND WATER POSSIBILITIES OF PARTS OF DELTA AND MESA COUNTIES COLORADO

BY
HERBERT J. WEEKS

BOULDER, COLORADO
CAMERA PRINT
1925

GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, Nov. 29, 1924

Governor William E. Sweet, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 28 of the Colorado Geological Survey.

Very respectfully,
R. D. GEORGE,
State Geologist.

CONTENTS

CONTENTS---Continued

ILLUSTRATIONS

WATER AND OIL POSSIBILITIES OF PARTS OF DELTA AND MESA COUNTIES, COLORADO

INTRODUCTION

The area covered by this report embraces all the territory north of the Gunnison River to an east-west line from the northeast corner of T. 13 S., R. 94 W. of the 6th Principal Meridian and all the territory east of the Gunnison River to a north-south line from the same corner.

At various times, efforts have been made by oil companies to obtain oil in the Gunnison River valley and surrounding territory. Very few companies employed men having a knowledge of Geology, but went ahead blindly without any success. Some companies got no farther than making a survey of the land.

The present survey was undertaken for the purpose of determining the oil, gas, and water possibilities of the area.

The field work was begun in July, and completed in November, 1922. The field party consisted of H. J. Weeks, in charge, R. H. Durward and C. L. Mohr.

FIELD METHODS USED

A plane table and telescopic alidade were used throughout the work. This was supplemented by triangulation, use of Brunton compass, and pacing to a small extent. For mapping straight east-west or north-south roads, the speedometer of the car was used, but for most of the crooked roads traverses were made if they could not be accurately mapped by some other means. Practically all of the streams were traversed unless they could be mapped by sketching from a traverse line near by.

C. L. Mohr did the plane table work until he left the party in September, after which time it was continued by H. J. Weeks. The mapping in the field was done on a scale of two inches to the mile.

As a north-south base, a line of U. S. Geological Survey land corners along the east side of T. 14 S., R. 96 W. was used. This gave a magnetic declination of 14 degrees, 30 minutes east, and was the amount of declination used throughout the area, although the chart of the isogonic lines of the United States will show that there is some disturbance in the regularity of these lines in this area, probably caused by the magnetic basalt of the top of Grand Mesa. Whatever the cause, its tendency has been to spread out the isogonic lines rather than to concentrate them, making the normal declination for one point apply to a larger area, so that an error due to the retaining of a single normal is less than if there were no irregularity in the lines.

All traverses were tied in to one another to check both altitude and location.

It was practically impossible to locate any great number of section corners. On the side of the mesa, where it was necessary to pick a traverse through the forest, it would have been a waste of time to try to locate all section corners. Many of them are marked merely by rock piles, indistinguishable from other rock piles, some of which were placed by oil surveys. In some townships, corner monuments are entirely lacking. Whenever they were discovered, they were used for checking locations. In general, corner monuments were more numerous in the southern part of the area than in the northern. Most of the roads are crooked, and could not be used to check locations.

The finished maps were drawn by C. L. Mohr. The data on the thickness of formations and locations of horizons above or below a contact were computed by R. H. Durward from the field notes.

GEOGRAPHY

The area covered by this report is immediately north of the city of Delta and the Gunnison River. It is part of a great synclinal basin that dips toward Grand Mesa and includes parts of Delta and Mesa counties.

Many of the roads between towns are surfaced with gravel and are kept in first class condition. Others are dirt roads which, with a large amount of travel, become very dusty. In rainy weather they become very slippery. Quite extensive use is being made of the gravel along the Gunnison River bottom and upon the lower mesa top for road surfacing. The side roads are not surfaced and are more or less neglected.

Delta, the largest town in the area and county seat of Delta County, is situated at the junction of the Gunnison and the Uncompahgre rivers, and has a population of about 2,500 people. It is the trading center for the farmers both north and south of the river. The industries of the town are largely those related to and dependent on the agricultural industry of the valley. The factory of the Holly Sugar Company handles the beets from the Gunnison, the Grand, and the Uncompahgre valleys. Another industry, based upon the agricultural resources of the valley, is the raising of fruits, vegetables and grains. Hundreds of carloads of fruit are shipped from this town each year. A fruit canning factory preserves a large part of the crop. Cattle and sheep are raised in large numbers, and are shipped to markets east of the range. A brick and tile factory, located at Delta and using Mancos shale, furnishes practically all the brick and tile used in and near Delta.

Cedaredge, a town of 350 people, located on Surface Creek in T. 13 S., Range 94 W., serves as a packing center for the farmers north of there.

Ekert is a small crossroads of less than 200 population, located about three miles southeast of Cedaredge on the Delta-Cedaredge road.

Austin, with less than 200 population, is the only other town in the area. It is a busy little shipping center for the fram produce packed at Cedaredge.

A few small coal mines, producing a subbituminous coal from the Mesaverde, and depending upon wagon haulage, supply the limited needs of the valley. The Denver and Rio Grande Railroad serves the towns along the Gunnison River.

SOIL AND TIMBER

All the soil within the area results from the breaking down of the underlying formations and takes its character from them, except in places along the Gunnison River where it is alluvium. A sandy soil overlies a sandstone: a clay soil overlies a shale. Nearly all of the farms are located on the Mancos shale area because the soil retains moisture well, is very fertile and is readily accessible. There are, however, a few farms above the Mancos shale where showers are more frequent, but the slopes above the shale are usually too steep for farming. Irrigation is necessary to successful agriculture.

The timber consists almost entirely of small growths of cedar and scrub oak, except in the higher altitudes where quaking aspen and large pines grow. The Battlement National Forest includes much of the timber of the area. The cedars are largely confined to the lower levels near the top of the Mancos shale, but some grow as low as the "Dakota" sandstone. The lower portion of the Mancos shale is practically treeless except along streams where scattered trees are found. Above the cedars and in the flat valleys between the cedar-covered hills, scrub oak grows.

TOPOGRAPHY

The topography is influenced by the underlying rocks. The resistant, ledge-making rocks produce benches, above and below which are gently sloping flats. The sandstones in the Gunnison and "Dakota" formations form the cliffs of the Gunnison River canyon. The shales of the same formation form rounded smooth slopes between the cliff-making sandstones.

The Mancos shale, being an easily eroded formation, is cut into deep gullies between smooth, bare, rounded hills. In other parts where dissection is less, are found the remnants of a previously graded surface sloping gently toward the Gunnison. These remnants now form mesas that slope at one to two degrees. Above the Mancos shale is a series of cliffs and flats in the Mesaverde formations, the result of differential weathering of the sandstones and shales of which the Paonia member of the Mesaverde is composed. The Rollins sandstone beneath the Paonia shale is a cliff-maker and an easily recognizable horizon.

The top of Grand Mesa, which forms the highest part of the area, is a flat table-land, from which it gets its Spanish name, and is the result of the resistance of weathering of a great series of balsaltic flows. Extending from the base of the cliff bounding the mesa is slide rock of balsaltic boulders circling the edge for a distance varying between a quarter of a mile and a mile.

The vertical distance between the top of Grand Mesa and the bottom of the Gunnison River canyon is about 5,400 feet, which makes an average relief of about 450 feet per mile. Nearly half of this difference in relief comes above the top of the Mancos shale in a horizontal distance of little over two miles. Here the relief is about 1,300 feet per mile which explains why most of the farming is beneath the level of the Rollins sandstone.

DRAINAGE

The streams that drain the area are mostly intermittent, coming from the top of Grand Mesa and about its edge as cool, sparkling, refreshing waters from springs and lakes. Before they reach the Mancos shale they are either totally dry or so salty as to be undrinkable. The water that sinks into the ground in the higher levels comes out as small salty seeps that dry as fast as they reach the surface, leaving it coated with a white salt. A few streams, however, like Kahnah Creek and Tongue Creek, fed by several smaller ones, and Dry Creek are about the only ones that flow continuously to the Gunnison, the only large river in the area. Deer Creek, Indian Creek, Wells Gulch, and Alkali Creek are some of the larger intermittent streams.

Owing to the steep slopes and scarcity of vegetation, the runoff is enormous compared to the amount of water which gets into the ground. After each heavy rain, the streams and gullies, normally dry, are filled with thick, muddy, light chocolate colored water carrying tons of mud, mainly from the Mancos shale, to the Gunnison River.

On top of Grand Mesa are found numerous small lakes and reservoirs which feed the streams and irrigation ditches of the area. Their basins are the results of slides in the formation just beneath the basalt capping of the mesa and are rather shallow. It is from these lakes that the cities and towns obtain their water supply which is transported the entire distance by piping.

Reservoirs have been built by water companies and by individuals to store water from the rains and melting snows of the mesa. Some of the reservoirs are made by building dams across the streams at favorable places. Others are formed by damming the outlets of lakes. Down in the lower levels, at favorable places, reservoirs are built of sufficient size to supply irrigation water for one or several ranches. These fill with silt very rapidly because of the abundance of mud carried by the streams after heavy rains.

Aside from lakes and reservoirs, water for irrigation is obtained by conducting it from streams to ranches through ditches several miles long. Some of the ditches conduct the water to reservoirs during the wetter seasons where it is stored for summer use. The water from others is used as it flows along.

CLIMATE

The climate of the valley is semi-arid, as the vegetation in the lower levels indicates. Sage brush and cactus are about the only plant growths in the unirrigated parts, except up in the hills where there is sufficient precipitation for the growth of cedars and scrub oak.

During the wintetr, snow caps Grand Mesa and the hills to a depth of several feet, but in the valley, snow hardly ever remains more than a few days.

The temperature in summer may reach 100°, and in winter occasionally falls to 20° below zero.

EFFECT OF MAN ON RATE OF DENUDATION

The effect of man on denudation is to increase the rate of erosion largely through lengthening the time of action of the water and through the tilling of the soil. Before man came to this valley, waters from rains and snows ran off to streams in very short time. Their action on the surface was largely limited to the time it took them to collect in gullies and creeks. Since most of the stream beds are bottomed by basaltic boulders, the material gathered along their courses was but little in comparison to that gathered on the surface.

Today, the water does the same amount of erosion as it did before man came, plus that due to the effect of cultivation and irrigation. The water, after it has done the work of erosion preceding its collection in streams, is caught in reservoirs and run through small ditches over the tilled, easily denuded fields carrying with it large quantities of soil that is not returned to the field. The material carried by the streams and deposited in reservoirs is cleaned out and is soon carried on down to the river. Reservoirs do not check denudation; they may delay the progress of the eroded material on its way to the river. The water run through the small irrigation ditches is usually heavily charged with soil from the fields and has a muddy gray color. The main ditches and laterals are constantly being deepened and widened by use, and the eroded material keeps the streams of the irrigated area turbid the entire summer.

GENERAL GEOLOGY

The area covered by this survey includes sedimentary formations ranging in age from Triassic to Eocene. Unconformities prove the occurrence of erosion intervals during which some formations may have been completely removed, and others greatly reduced in thickness. Some of the deposits are of the continental type, some are marine, and some show the existence of conditions favorable to the making of coal.

TRIASSIC SYSTEM

DEFINITION AND BOUNDARIES

The "Red Beds" of beautiful red color occur along the Gunnison River at places where it has cut down through the overlying formations. The lower boundary of the series is not exposed, and the upper limit is set at the base of the Gunnison formation, the lower part of which is of a lighter red color than the sediments beneath.

It is believed probable that an unconformity exists at the top of the "Red Beds," but the uniformity of color, composition and texture of the strata, and their apparent parallelism in that part of the section where the dividing line must be, obscures the contact and makes it very difficult to closely delimit the group. In a few places there appears to be some evidence of an unconformity, but what is taken for an angular unconformity may be cross-bedding.

This definition is in accord with that of W. T. Lee[2] for this area, and with that of R. C. Coffin[1] in the area to the southwest. It is the upper part of the Dolores formation as Coffin has described it.

GENERAL CHARACTER

The part of the Dolores formation exposed below the Gunnison formation is remarkable for its uniformity in color, texture and structure throughout the entire part exposed. From top to bottom, the beautiful maroon color does not vary. Bedding, except cross-bedding, is almost entirely lacking. The entire formation exposed is cross-bedded with long sweeping fore-sets as the general rule. Some of the fore-set beds measure 20 feet in length and most of them dip at a rather gentle angle, but some of them approach the angle of repose. They dip in every direction, and no evidence could be gained as to the direction from which the sediments came.

The sandstone weathers into smooth, rounded outcrops sloping at a rather steep angle except where the cutting of the river has made almost vertical walls. It is fine to medium grained, most of the grains being recognizable with the unaided eye, and is cemented by iron oxide which gives it its beautiful color. It is composed largely of sub-angular white quartz sand. There is no evidence from springs that the Dolores is a water bearing horizon.

It outcrops west of Delta along the Gunnison River almost continuously from the mouth of Wells Gulch to a point a mile and three-quarters south of Kahnah Creek. No measurements of the exposed portion of the "Red Beds" were made, but an estimate of this thickness places it between 150 and 200 feet.

AGE

No fossils were collected from the "Red Beds," so no evidence was found by this Survey as to their age. W. T. Lee in Bulletin 510 of the U. S. Geological Survey, places these beds in the Pennsylvanian with a question mark. R. C. Coffin, in Bulletin 16 of this Survey, designates them as Triassic sediments on the basis of their lithologic character and their stratigraphic position. The latter correlation has been followed in this report merely because of Coffin's more intimate study of the formation where it is exposed to the southwest.

JURASSIC SYSTEM

GUNNISON GROUP

The formation of the Jurassic system as defined in this report comprise the rocks between the red colored Dolores at the base and the "Dakota" conglomerate at the top and make up the Gunnison formation which is composed of the La Plata and McElmo members. This definition is in accord with that of W. T. Lee in Bulletin 510. Coffin, in the area to the southwest, places the top of the McElmo, the upper member of the Gunnison formation, at the base of a thick conglomeratic sandstone. This exclusion of the sandstone would reduce the thickness of the Gunnison formation, as first described, by about 125 feet. As there is no fossil evidence for separating the two parts, and as variegated shales occur both below and above, the massive sandstone, there does not seem to be adequate reason for separating them into two formations.

The great variety of color in the Gunnison formation is in strong contrast with the uniform color of the "Red Beds" below it. This formation, although composed of two members, was mapped as a unit.

LA PLATA FORMATION

The rocks included in the La Plata member of the Gunnison formation are those between the Dolores below and the top of a fine to coarse sandstone above. The variegated shales and sandstones of the McElmo lie conformably on the sandstone. The color of the lower strata is pink and blends very beautifully with that of the sediments beneath. As thus defined, this member is about 270 feet thick.

The fine to coarse sandstone of the top of this formation is very regular in thickness and forms cliffs from the bottom of which slope the weathered surfaces of the variegated shales, sandstones, and limestones of the lower part. It is above this sandstone that Coffin[1] finds an unconformity in the area to the southwest. There is no evidence of such an unconformity at this horizan in the area here considered. He also finds one beneath it which accounts for the removal of a large amount of the lower part of the La Plata formation in that area. The only evidence of such an unconformity in this area is the coarse sandstone itself. There appears to be no thinning of the lower part of this member that would indicate one. There are small beds of sandstone in the lower part that form benches, but they are not identified from place to place as readily as the thick, massive sandstone of the top. The shales and sandy shales form smoothly weathered, very steep surfaces that are very difficult to climb because of the lack of irregularities in structure or texture. They are evenly bedded and many colored and form less than half of the rocks of the La Plata beneath the upper sandstone.

The sandstones are usually white or grayish white, cross-bedded, fine grained, and composed of white quartz sand cemented by lime carbonate and silica. Some beds have a thickness of six feet. The sand grains are generally quite well rounded and are fairly well cemented. In a few places ripple marks are found.

The sandstone of the top of the formation is cross-bedded, massive, fine to coarse grained, and grayish white. A measured section at Wells Gulch gives a thickness of 35 feet. It is moderately well cemented and is composed largely of fine to coarse quartz sand. Sandstone makes up over half of the La Plata formation beneath the top sandstone member.

A few limestone beds occur in this member of the Gunnison formation, their total thickness being about 15 feet. They are even bedded, dense and grayish white.

At three places north from Wells Gulch, a section of the La Plata was measured up to the massive sandstone which is quite uniformly 35 to 40 feet thick. The base was exposed at none of these places. The section, including the massive sandstones, as measured one mile north from Domingo:

Top	Feet
1. Massive sandstone, cross-bedded	35
2. Shales and limestones interbedded	19
3. Limestone, evenly bedded	6
4. Shales and limestones interbedded with a greater amount of limestone in the upper portion	12
5. Sandstone, fine grained, white	3
6. Shale, limy, sandy, with small beds of sandstone	21
7. Limestone, evenly bedded	8

8.	Shale, variegated, evenly bedded	6
9.	Sandstone and sandy shale	4
10.	Shale with interbedded sandstone	27
11.	Sandstone, white, cross-bedded	5
12.	Talus	26

Section as measured a mile and three-quarters north from Domingo to the top of the massive sandstone is:

Top		Feet
1.	Sandstone, massive cross-bedded (top of La Plata)	40
2.	Sandstones and shales, variegated	15
3.	Limestones, evenly bedded	4
4.	Sandstone, massive, fine grained, light colored	11
5.	Limestone, dense gray in color	7

A little farther down the river the section to the top of the La Plata is:

Top		Feet
1.	Massive sandstone	45
2.	Sandstone and shale, variegated	12
3.	Shale, variegated	3
4.	Sandstone, cross-bedded, fine grained	3
5.	Shale, variegated	11
6.	Talus	100

McELMO FORMATION

The McElmo member of the Gunnison group includes those beds of variegated shales and sandstones that lie between the upper part of the La Plata and the "Dakota" conglomerate. As thus defined it includes the part designated Post-McElmo by Coffin in the area to the southwest, and is as it was first defined by H. S. Gane in the McElmo canyon. Rather than separate the McElmo, as first defined, into two formations without fossil evidence for such division, it is divided into the lower and upper members. That there is some basis for such a division of the formation is recognized, but there does not seem to be sufficient evidence to make a separate formation of the upper part which is very much like the lower. The dividing line between the two members is an unconformity at the base of a thick, massive, conglomeratic sandstone, which, in places, is composed of much coarser pebbles than the conglomerate at the base of the "Dakota" formation and is of much greater thickness. That there is valid basis for such division is borne out by the fact that the unconformity is not merely a local one but is found in the Crested Butte area described by Eldridge in U. S. Geological Atlas, Folio 9, as well as in the area worked out by Coffin.

LOWER McELMO MEMBER

The lower McElmo member, as thus defined, consists entirely of variegated shales and sandstones having a thickness of 300 feet. They weather into rounded, smooth sloping outcrops very beautiful because of the numerous shades of colors in a single exposure. Sandstones are more numerous in the middle and lower portions and form benches in the smoothly weathered shale. The total thickness of sandstone in a typical section is not over 80 feet. They have a color varying from white to gray and very light shades of red or pink. They are even bedded, composed of fine to medium grained quartz sand cemented largely by silica and lime carbonate. Cross-bedding is present, but not as abundant as it is in the sandstones of the La Plata. Some of the beds are quite friable owing to the solution of part of the cement, and are water-bearing.

Shale makes up the largest part of the formation. Much of it is very sandy, but some is almost pure kaolin as analyses have shown. Most of the shale when weathered and wet becomes very plastic and is very readily molded. The color is decidedly varied, and that, together with the shades of color in the sandstone, gives to the region its scenic character.

A typical section of the Lower McElmo taken 1¾ miles north of Domingo is:

Top	Feet
1. Shale, sandy, light to red color	5
2. Sandstone, white to pink	10
3. Shale, variegated	150
4. Sandstone, cross-bedded, fine grained, light colored	17
5. Shale, variegated with small sandstone beds	225
6. La Plata member of Gunnison group.	

UPPER McELMO MEMBER

The rocks included in the upper McElmo member of the Gunnison group are sediments whose description fits that of the Post-McElmo described by Coffin in his report on the Radium, Uranium and Vanadium deposits of Southwestern Colorado, but for reasons stated above, this series of sandstones, shales and limestones is retained in this report in the McElmo formation where it was first placed by Gane. The base of this member is marked by an unconformity below a thick conglomeratic sandstone bed. The "Dakota" limits the formation at the top. As thus defined, the upper McElmo member is composed of a basal conglomerate grading up into a conglomeratic sandstone and shale. The lower contact of the massive conglomeratic sandstone is a more or less undulatory one resulting from erosion. In places the conglomerate contains pebbles from the underlying member, but most of them are of foreign material and range in size from a quarter of an inch to two inches in diameter. In parts of the conglomerate, there has been practically no sorting. At various horizons throughout the conglomeratic sandstone bed, conglomerate lenses are found, each of which represents an erosion interval. The sandstone is different from that of either the lower McElmo or the "Dakota," but resembles the former in color. Concretion-like forms composed of dense, light colored sandstone occur in the upper McElmo member. This portion of the sandstone is well cemented and resembles quartzite, and forms the cliff above the variegated shales. The cliff is almost vertical, and in many places cannot be scaled. As the more easily weathered shales beneath are removed, great blocks break from the rim of the Gunnison Canyon and roll down the slope, keeping the cliff almost vertical. Thin green and red shale beds occur between the sandstones in some places, but where the entire cliff is sandstone they have been removed by erosion.

The shale which ovelies the sandstone conglomerate is much like the other shales of the Gunnison formation. Its thickness varies greatly because of erosion before the deposition of the "Dakota," but at no place is it very thick. The dominant color is green, but there are variations to gray. In texture, appearance and structure, it is like the shales beneath. About nine miles west of Delta is found a chalky white shale above the thick sandstone. In some places it is yellowish and in others has a light bluish cast. It is very dense and breaks into conchoidal fragments on weathering Here the shale has a thickness of 10 feet, but it thins in both directions from this point. Above it the "Dakota" conglomerate is whitened by the white shaley material it contains.

A section of the upper McElmo member about nine miles west of Delta is:

Top	Feet
1. White shale	10
2. Sandstone conglomerate	100

In other places, the section has red or green shale replacing the white shale, but is is usually less than 20 feet in thickness. The total thickness of this member is between 100 and 150 feet.

AGE OF GUNNISON GROUP

No fossil evidence was obtained by this survey from which to determine the age of the La Plata member, and correlation is based on lithologic and stratigraphic evidence. Its position above the "Red Beds" and its variegated color are the diagnostic characteristics which according to Lee[2] and Coffin[1] put this member of the Gunnison group in the Jurassic.

As no fossils were found in the upper and lower members of the McElmo formation, they must be correlated upon stratigraphic and lithologic evidence. The variegated shales and sandstones are so characteristic that it is safe to correlate these strata with similar shales and sandstones of other areas where fossils are found.

W. T. Lee[2] gives the age of the entire Gunnison group as Jurassic. The correlation is based on its similarity to Jurassic beds elsewhere. According to the same author, E. S. Riggs found "a species of Viviparus and reptilian remains near Grand Junction that prove the beds containing them to be equivalent in age to the Morrison of the Eastern Rocky Mountains," thus placing the McElmo in the Jurassic.

Eldridge, in the United States Geological Survey, Folio 9, places the entire Gunnison group in the Jurassic because of its stratigraphic and lithologic correspondence to fossil-bearing beds of that age on the eastern flanks of the Rocky Mountains.

R. C. Coffin[1] places the McElmo formation in the Jurassic or Cretaceous, and what he calls Post-McElmo (equivalent to the upper McElmo of this report), in the Cretaceous. There is no paleontological ground for placing the upper part of it in the Cretaceous, and since the formation is like the other beds of known Jurassic age it seems proper that they should be correlated with these until evidence disproving such correlation is obtained.

The Gunnison formation is exposed continuously in 700 foot cliffs along the Gunnison River from a point about 6½ miles west of Delta to the point where the Gunnison River leaves the area mapped. In places, the river has not cut down through the La Plata but in nearly all this distance the upper part of the formation is exposed. Gullies and small creeks cutting the McElmo extend the exposures of this formation farther back from the river than those of the La Plata. Both the La Plata and the McElmo are exposed along the Gunnison River east of Austin to the edge of the area mapped. They do not extend far back from the river as the exposures form almost vertical cliffs. In much of this distance, the lower part of the La Plata is not visible.

CRETACEOUS SYSTEM

The Cretaceous system in this area includes four formations having a combined thickness of 7,000 to 8,000 feet, mainly of sandstones and shales. The "Dakota" at the base of the group is composed of coal-bearing and marine sediments, the lower part of which may be of Comanche age. Above the "Dakota" is the Mancos, composed of 4,000 to 6,000 feet of marine shales. The Rollins sandstone succeeds the Mancos, and is separated from the Paonia by an unconformity representing the Bowie which was removed by erosion before the Paonia was deposited.

"DAKOTA" FORMATION

The "Dakota" formation as defined in this report includes those beds between the top of the Upper McElmo member of the Gunnison formation and the typical Mancos shale above. The lower boundary is very definitely marked by the conglomerate at the base of the "Dakota" formation. The upper limit is the top of the first sandstone beds below the Mancos shale. The thickness of the "Dakota" ranges between 80 to 150 feet depending upon the thickness of the basal conglomerate and sandstones.

There is no difficulty in mapping the upper limit of this formation as thus defined because the topographic change to the Mancos shale is very abrupt. Wherever the "Dakota" is found on the north side of the river, the sandstone determines the character of the topography. Weathering has stripped the Mancos shale from the resistant flinty sandstones which dip away from the Gunnison River. As a consequence, the slower cutting streams that flowed toward the Gunnison before the Mancos shale was removed now flow away from the river down the dip slopes of the "Dakota" to the larger streams that have been unable to cut their channels through the sandstones. Along the Gunnison River, at the heads of these small streams and gullies, hanging valleys afford convincing evidence that their waters once flowed to the river.

The basal conglomerate of the "Dakota" ranges in thickness from 5 or 6 feet to 40 feet, but is usually less than 20 feet. It is composed, in the main, of quartz, chert, and sandstone or shale pebbles, the latter being derived from the weathering of the shale and sandstone of the formation beneath. The pebbles range in size from an eighth of an inch to an inch and a half in diameter. The cementing material is largely composed of the ground up material from the formations underlying it. The conglomerate is usually dark yellow or brownish-yellow except where the underlying rock is a white shale. At these places, the conglomerate takes on a lighter hue owing to the abundance of white shale mixed with it.

The conglomerate is followed above by about 100 feet of sandstones and shales. In places the lower sandstone is interbedded with thin shales. The lower part of the sandstone contains beds two to four feet thick, but grades upward into less massive beds, most of which are less than a foot in thickness. In places, shales are interbedded with the sandstone.

The middle part of the "Dakota" formation varies greatly in thickness and is sometimes merely a succession of shales and sandstones in about equal amounts. The shales are more carbonaceous than those in the base of the Mancos, and locally grade into coal. One seam of subbituminous coal, according to Bulletin 510 of the U. S. Geological Survey, ranks in heating value with that in the base of the Paonia shale of the Mesaverde formation. The seam is rarely over four feet thick and thins out into shaly coal and carbonaceous shale. All the shale of the "Dakota" is dark and quite sandy.

The sandstone above the coal is like that below it in color, texture, and structure. The thickness of the sandstone ranges between 20 and 30 feet and it is made up of beds from a few inches to several feet thick. The upper part forms a transition to the base of the Mancos shale. This transitional zone is about 50 feet thick and is a series of alternating thinly bedded sandstones and shales which grade into shales above, and into sandstones below.

Most of the "Dakota" sandstone is fairly well cemented, fine grained, cross-bedded, and ripple marked. It is composed of clean, subangular, to well rounded grains of white quartz sand cemented by silica and, to a lesser extent, iron oxide, especially near the surface. At some horizons in the upper part, the oxide of manganese coats the surface of the sandstone giving it a black color. Fresh surfaces are brownish-yellow. The case-hardened surface is so well cemented that water scarcely penetrates the rock.

The "Dakota" formation outcrops about the base of the Mancos shale and forms quite even flat surfaces. It is cut by canyons only where weathering has exposed the rocks beneath it. Along the Gunnison canyon, the sandstone and conglomerate form cliffs which slope upward to a second cliff formed by the upper sandstone. The intervening slope between the cliffs is occupied by the coal and carbonaceous shale of the middle part of the formation.

The "Dakota" formation is found from a point about six miles west of Delta to the west edge of the area worked, and from the bridge east of Austin to the east edge of the area. The north boundary in the west part of the area is very nearly the line of the Grand Junction-Delta road. In the east part of the area, it does not extend very far north from the river.

A section of the "Dakota" west of Delta about one-half mile from where it first appears is:

Top	Feet
1. Sandstone, cross-bedded, ripple marked	16
2. Carbonaceous shale	15
3. Sandstone, thinly bedded, flinty	15
4. Sandstone, more massive, cross-bedded, beds about three feet thick	7
5. Carbonaceous shale	6 inches
6. Sandstone	4
7. Conglomerate	5-6

A section one-half mile farther west is:

Top	Feet
1. Sandstone, cross-edded, ripple marked	30
2. Carbonaceous shale	9
3. Sandstone, cross-bedded	14
4. Carbonaceous shale	1
5. Sandstone	2
6. Conglomerate	3

A section on the north side of Wells Gulch west of where the road crosses is:

Top	Feet
1. Sandstone, cross-bedded, ripple marked	20
2. Carbonaceous shale	5
3. Sandstone, thinly bedded	3
4. Carbonaceous shale	3
5. Sandstone, thinly bedded	2
6. Carbonaceous shale	5
7. Sandstone	3
8. Conglomerate	10-12

AGE

The age of the "Dakota" formation can not be definitely determined. Lee[2] says it is of Benton age down to a horizon below the coal and classifies all above the conglomerate as of that age, and places it in the Mancos shale. He says, "However, in these sandstones above the coal, the writer found Inoceramus labiatus Schlotheim, a well-known Benton fossil, and Beale states that a scaphite was found below the coal near the mouth of the Gunnison River. In the light of this fossil evidence, the line marking the base of the Mancos shale can not be drawn at the top of the sandstone where previously it has been drawn, and there is no natural line of divison within the transitional zone of sandstone and carbonaceous shale." He places the top of the "Dakota" "at the top of the conglomeratic sandstone." Since the "Dakota" formation is distinct from the Mancos shale, and there is a decided change of conditions from the sandstone to the shale, and since it controls the topography where it is found, it seems advisable to retain the old definition including in it all the sandstones below the Mancos shale and above the first unconformity below that shale.

The fossils found in the "Dakota" formation were identified by Prof. Junius Henderson and are:

Location: 1 mi. S., 5 mi. W. of Delta bridge in NE. cor. sec. 19, T. 15 S., R. 96 W., near the top of "Dakota" sandstone;—rude casts of plant stems or worm trails.

Location: ½ mi. S., 6½ mi. W. of Delta bridge in SE. cor. sec. 14, T. 15 S., R. 97 W., near top of "Dakota;"—2 Cephalopoda, undeterminable. Associated with *Inoceramus* resembling I. fragilis Hall and Meek. It proves the marine origin of the bed in which it was found. It is a very strongly ribbed form, about nine inches in diameter.

Location: ¼ mi. S., 7 mi. W. of Delta bridge in center of sec. 14, T. 15 S., R. 97 W., near top of "Dakota;" Cephalopoda, two undeterminable fragments.

Location: ¼ mi. S., 7¼ mi. W. of Delta bridge near W. ¼ of sec. 14, T. 15 S., R. 97 W., near top of "Dakota" sandstone;—*Inoceramus* resembling I. fragilis Hall and Meek.

Location: ¼ mi. S., 7½ mi. W. of Delta bridge, W. ¼ of sec. 14, T. 15 S., R. 97 W., about 55 feet below top of the "Dakota;"—undeterminable plant fragments.

Location: 4 mi. N., 12½ mi. W. of Delta bridge, center of sec 18, T. 4 S., R. 3 W., north side of Wells Gulch, quartzite at base of "Dakota;"—undeterminable plant fragments.

Location: 4 mi. E. of bridge east of Austin, on east line of sec. 2, T. 15 S., R. 94 W., top of "Dakota;"—*Inoceramus* sp. undeterminable.

From these fossils, it is plainly seen that the age of the upper part of the "Dakota" formation of this area is undoubtedly Cretaceous. Its age can not be more definitely fixed from the material available, but it can be said that it is of Benton or later age for lower Coloradoan fossils have been found in the upper part. That leaves the age of most of the sandstone and conglomerate still in doubt.

MANCOS SHALE FORMATION

The Mancos formation is a great body of more or less carbonaceous shales bounded at the base through a transition zone by the upper "Dakota" sandstone and at the top of the thick massive sandstone of the base of the Mesaverde formation. As thus defined, the Mancos shale has a thickness between 3600 and 3900 feet on the west side of the area and between 5700 and 6000 on the east side of the area. These figures were obtained by adding to the difference in altitude between top and base the correction for dip. This shows the Mancos formation to be somewhat wedge-shaped in this area. Lee[2] places the thickness east of Grand Junction at about 3000 feet. This is farther west than where this Survey's most westerly estimate was made. Coffin[1], in an area still further west and south, although stating that the exact thickness was not measured, estimates that the Mancos shale probably exceeds 1500 feet in thickness. These figures show that the Mancos formation thins notably to the west or possibly southwest.

The formation is mainly shale, but a few minor sandy layers occur near the base and true sandstones in the upper part. A few limestone beds (some of lenticular shape) occur about 2000 feet from the top, and there are also limestone or limy shale beds about 400 feet from the base.

The base of the shale is more carbonaceous than the central and top portions, but there is no abrupt break between them. The shale is very thinly bedded. There are a few beds and some strata which if once

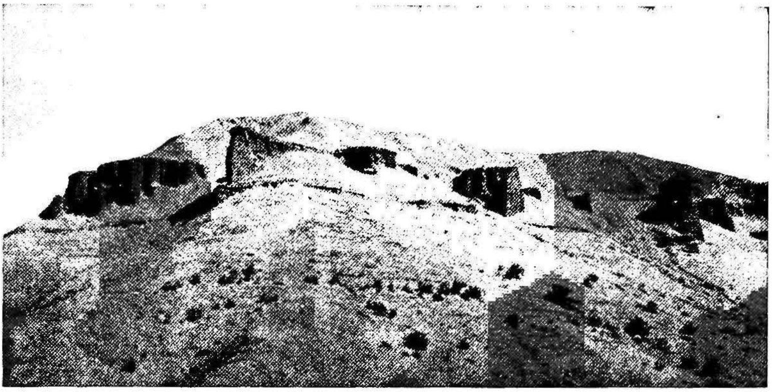


Fig. 1. Showing the lower black shale of the Mancos formation. There is an arenaceous fossiliferous horizon at the top of the cliffs. About 250 feet of the Mancos shale shown.

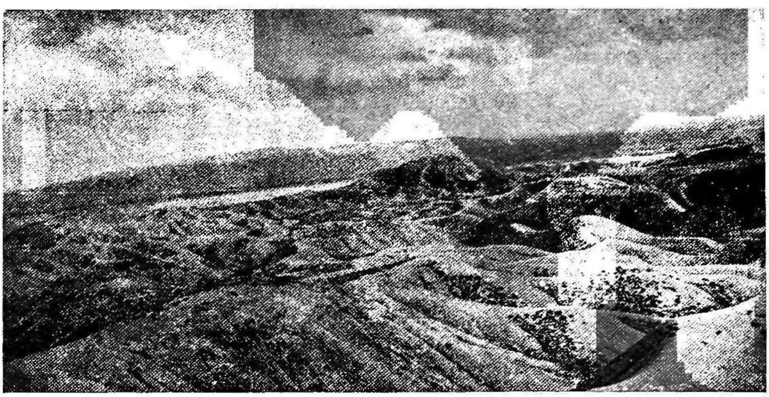


Fig. 2. Showing the dissected bad land topography of the Mancos shale north of Delta. Highest hills about 125 feet high.

recognized can be identified in separated area of the Mancos shale. The interval between them does not vary greatly over the area. About 480 feet above the base of the shale occurs a series of fossiliferous beds which are identified by the sandy, flinty character of the fragments. The fossils are usually broken and stream-worn. This makes another quite easily identified and good plane of reference. The shale above and below is fissile and cleaves into thin sheets.

Another very readily identified horizon occurs about 250 feet above the base of the Mancos shale. It is described by Lee[2] as "a zone of concretions and lenticular bodies, some of them ten feet or more in diameter, composed of brittle, yellow, earthy limestone." The concretions outcrop about the base of a cliff in the lower part of the shale in a zone about 20 to 30 feet in thickness. Above some of them are thin beds of well cemented sandy shale. The entire zone weathers by breaking across the bedding into a more or less honey-comb mass of slender fragments about four inches long. This is especially true of the shale immediately beneath the limy concretionary forms making it appear somewhat as though it had been baked. Nearly all of the concretions are fossil-bearing and are divided into irregular blocks by fractures filled with sphalerite and calcite. The sphalerite was deposited first and occurs in honey-comb masses along the edge of the fracture. Calcite usually fills the openings not filled by sphalerite. Waters carrying these minerals in solution circulated through the shales, and when they reached the limestone the calcite and sphalerite were precipitated by it. Not only is the sulphide found in fractures in the limestone; sphalerite also occurs in a calcite vein that cuts the shale. The amount of sphalerite is small.

Another, less well defined, part of the Mancos shale is a group of calcareous strata 400 to 500 feet thick in which lenticular beds of limestone occur. These beds contain Inoceramus fossils and are about 1800 feet above the Mancos shale on the west side of the mapped area, and about 3500 feet on the east. The distance from these beds to the top of the shale is a few hundred feet greater at the east end of the area than it is at the west, showing that the wedging is not all in the lower part. The limestones are all very dense, dark gray, and weather to a brownish yellow surface and break with conchoidal fractures.

About 200 to 300 feet below the top of the Mancos shale is a very persistent bed of massive sandstone containing many fossils. It is about 15 feet thick and forms a bench below the sandstone beds of the upper part of the shale.

The upper part of the Mancos shale (Fig. 3, p. 28) passes through a transition zone represented by the sandstone beds to the massive Rollins sandstone.

The Mancos shale is of a slate to drab color throughout, but is a little darker in the lower part than the upper. It weathers to a buff color and varies but little from place to place. Where cut by gullies, it weathers into the characteristic bad land topography in which the relief may be as much as 200 feet. Where not cut by gullies, it forms gently sloping surfaces that reach to the foothills of Grand Mesa. The shale weathers very readily, and after rains, tons of the material are washed down the Gunnison River and carried away. (The water which, at other times, has a yellowish color, assumes a chocolate muddy color for a few hours after heavy rains.)

The many fractures in the shale are filled with clear selenite sheets usually less than half an inch thick. The cause of the fracturing is not known, but it occurs in fresh cuts along streams and appears to reach a considerable depth. There is no order or system to the fracturing, such as would be found in a more competent formation.

AGE

The Mancos shale is fossil-bearing throughout, but in some strata fossils are more abundant than in others, and in some they are better preserved than in others.

Fossils collected from the formation show its base to be of Benton, the middle portion of Niobrara, and the top of Pierre age, but there are no natural divisions between these parts.

The fossils collected from this formation were identified by Prof. Junius Henderson, and are:

BENTON:

LOCATION: 3 mi. N., 4½ mi. W. of Delta bridge, NW. of center of sec. 32, T. 14 S., R. 96 W., about 1546 feet above base of Mancos shale;—*Inoceramus fragilis* Hall and Meek. Probably upper Benton.

LOCATION: 5 mi. W. of Delta bridge, on cliff NE. of center of sec 18 side of Delta-Grand Junction road about 480 feet above base of Mancos shale;—*Scaphites warreni*, Meek and Hayden, *Prionocyclus wyomingensis*, Meek, *Inoceramus fragilis*, Hall and Meek.

LOCATION: 3½ mi. N., 10 mi. W. of Delta bridge, NW. of center of sec. 22, T. 4 S., R. 3 E., north of Delta-Grand Junction road, about 220 feet above base of Mancos shale. This is lower than usual for the species;—*Ostrea lugubris*, Conrad.

LOCATION: 2½ mi. N., 8 mi. W. of Delta bridge, in NW. of sec 25, T. 4 S., R. 3 E., north of Delta-Grand Junction road, about 580 feet above base of Mancos shale;—*Inoceramus* sp. cf. I. *fragilis*, Hall and Meek.

LOCATION: 2½ mi. N., 7½ mi. W. of Delta bridge, south line of sec. 25, T. 4 S., R. 3 E., north of Delta-Grand Junction road, about 560 feet above base of the Mancos shale;—*Inoceramus fragilis*, Hall and Meek.

LOCATION: 1 mi. N., 6¼ mi. W. of Delta bridge in center of sec. 12, T. 15 S., R. 97 W., north of the Delta-Grand Junction road, about 565 feet above base of the Mancos shale;—*Ostrea lugubris*, Conrad.

LOCATION: 9 mi. N., 15½ mi. W. of Delta bridge on the south line of sec. 15, T. 3 S., R. 2 E., in concretionary horizon, 244 feet above base of Mancos shale;—*Exogyra ponderosa* Roemer, immature; *Ostrea cf. soleniscus* Meek, fragments.

LOCATION: 8¼ mi N., 14¾ mi. W. of Delta bridge on south line of sec. 23, T. 3 S., R. 2 E., about 244 feet above base of the Mancos shale;—*Ostrea* cf. *soleniscus* Meek, fragments.

LOCATION: 6½ mi. N., 13 mi. W. of Delta bridge, east of center of sec. 36, T. 3 S., R. 2 E., about 244 feet above base of Mancos shale;—*Ostrea* cf. *soleniscus* Meek, fragments.

LOCATION: 5¼ mi. N., 12 mi. W. of Delta bridge, NE. of center of sec. 8, T. 4 S., R. 3 E., about 200 feet above base of Mancos shale from weathered surface;—*Gryphea newberryi* Stanton, aboundant. Usually in lower part of the Benton.

LOCATION: 10 mi. N., 16½ mi. W. of Delta bridge in SE. cor. sec. 9, T. 3 S., R. 2 E., just below concretionary horizon about 240 feet above base of the Mancos shale;—Mollusk (perhaps Teredo) tubes in decayed fossil wood (?).

LOCATION: 3¾ mi. N., 7½ mi. E. of Delta bridge, east of center of sec. 30, T. 14 S., R. 94 W., from about 526 feet above base of Mancos shale;—*Ostrea lugubris* Conrad; *Inoceramus dimidius* White.

NIOBRARA FOSSILS

LOCATION: 2 mi. north of Delta bridge, NE. of sec. 1, T. 15 S., R. 96 W., from about 1400 feet above base of Mancos shale;—*Ostrea* sp. and *Inoceramus* sp., undeterminable fragments.

LOCATION: 3 mi. N. of Delta bridge, east of center of sec. 36, T. 14 S., R. 96 W., from about 1770 feet above base of Mancos shale;—*Ichthyodectes* sp. (fish scales); fish jaw unlike any American species is belief. *Ostrea congesta* Conrad; marine plant (?) fragments, undeterminable.

LOCATION: 4 mi. N. of Delta bridge, from limestone in the east side of sec. 25, T. 14 S., R. 96 W., upper Benton or lower Niobrara;—*Inoceramus* sp. cf. *vanuxemi*, one poorly preserved specimen.

LOCATION: 5 mi. N. of Delta bridge, from the NE. part of sec. 24, T. 14 S., R. 96 W., about 2560 feet above the base of the Mancos shale, upper Benton or lower Niobrara;—*Cephalopoda*, undeterminable, resemble small flattened examples of *Heliococeras corrugatum* Stanton, a species of lower Niobrara of Huerfano Park. Similar remains have been found in the middle or lower Benton west of Berthoud, so this material, which can not be specifically or even generically determined, is valueless for exact determination of geological horizon. From its location vertically in the Mancos shale, it is probably quite high up in the Niobrara.

LOCATION: 5¾ mi. N. of Delta bridge, near south line of sec. 13, T. 14 S., R. 96 W., about 2765 feet above base of Mancos shale. Probably upper Niobrara or lower Pierre;—*Inoceramus*, one undeterminable specimen.

LOCATION: 2 mi. N., ½ mi W. of Delta bridge, west of center of sec. 1, T. 15 S., R. 96 W., from about 1400 feet above base of Mancos;—*Ostrea congesta* Conrad.

LOCATION: 2 mi. N., ½ mi. W. of Delta bridge, near east line of sec. 2, T. 15 S., R. 96 W., from about 1400 feet above base of Mancos;—*Ostrea* sp., possibly poorly preserved O. *congesta* Conrad.

PIERRE FOSSILS

LOCATON: 6½ mi. N., 2¼ mi. W. of Delta bridge, south of center of sec. 10, T. 14 S., R. 96 W., from about 3056 feet above the base of the Mancos shale;— *Baculites* sp. cf. B. *anceps obtusus* Meek. The Baculites can not be distinguished from material found at the base of the Pierre shales near Boulder, which has been referred to *Baculites anceps* Lam. or its subspecies *obtusus* Meek. The only reason for sonsidering it *obtusus* is the fact that *obtusus* is a western form. The material shows no sutures. Stanton long ago doubtfully reported B. *anceps* from the Niobrara of Kansas. *Inoceramus*, too poorly preserved to determine satisfactorily, but apparently not referable to any of the Benton or Niobrara forms.

LOCATION: 8½ mi. N., 10½ mi. W. of Delta bridge, SW. part of sec. 32, T. 13 S., R. 97 W., from about 1891 feet above base of Mancos shale. The difference between the vertical location of this one and the one just above is due to the wedge shape of the Mancos;—*Inoceramus* cf. *barabini* Morton; *Inoceramus* cf. *vanuxemi* Meek and Hayden; *Baculites* cf. *anceps*, possibly *obtusus* Meek.

LOCATION: 12 mi. N., 4 mi. E. of Delta bridge, north of the center of sec. 15, T. 13 S., R. 95 W., from about 200 feet below the top of the Mancos shale;—*Inoceramus barabini* Morton; *Inoceramus sagensis* Owen; *Pteria nebrascana* E. and S.; *Crenella elegantula* Meek and Hayden; *Pinna lakesi* White; *Modiola* sp.; *Dentalium* sp. cf. D. *gracile*. This fauna is strongly suggestive of the Hygiene member of the Pierre of northeastern Colorado. It is a middle Pierre fauna.

LOCATION: 8 mi. N., 11½ mi. E. of Delta bridge, near the west line of sec. 1, T. 14 S., R. 94 W., from about 3600 feet above the base of the Mancos shale, middle Pierre horizon;—*Baculites ovatus* Say.; *Inoceramus barabini* Morton.

Benton fossils are present through a thickness of 1400 to 1500 feet of shale. This formation thins westward. There is nothing in the shale that marks the boundary between it and the Niobrara.

The top of the Niobrara is a little more definitely placed, but it can not be fixed within 200 or 250 feet because of lack of a definite horizon marker. However, it can be said that most of the limestone lenses at about 3600 feet on the east end of the area and about 1800 feet on the west end, are in the Niobrara. The boundary between this formation and the Pierre is a little distance below the top of these limestone lenses, for fossils of Pierre age are found in the upper lenses and fossils of Niobrara age are found in the lower ones. The vertical range over which these limestones are found is between 400 and 500 feet. This gives a thickness for the Pierre of a little over 2000 feet.

THE MESAVERDE FORMATION

The Mesaverde formation as defined in this report is that series of sediments between the top of the Mancos shale and the Tertiary rocks that underlie the basalt that caps the mesa. This report simply defines it as it was defined by Lee[2] who had an excellent opportunity to study it in detail when studying the coal bearing formations at its base.

A portion of the Mesaverde of this section of Colorado was eroded before the deposition of the Paonia shale. The missing formation is called the Bowie shale, and comes in stratigraphic sequence above the Rollins sandstone, the formation above the Mancos shale.

The thickness of the Paonia formation, as nearly as could be determined, is 1600 feet. It is very hard to get an accurate measurement because of the lack of exposures, especially of the top. In the area worked, no exposure of the top of the formation was found.

THE ROLLINS SANDSTONE

The Rollins sandstone is a very definite formation bounded at the base by the Mancos shale and at the top by the coal bearing base of the Paonia formation. No coal is found in the Rollins which consists entirely of massive white sandstone 100 feet thick. The base is placed at the base of the first massive bed at the top of the Mancos shale. The Rollins sandstone, (Fig. 3, p. 28) is an easily recognized formation because it forms cliffs about the base of the Paonia shale, and because of its uniformly white color. The sandstone is medium to coarse grained, fairly well cemented, cross-bedded, and composed of subangular to angular grains of white quartz sand and minor amounts of undecomposed feldspars. It contains a large number of fossil Halymenites. The Halymenites major fossils are of various shapes and sizes; some are branching, some are straight, and some are bent. One was found over a foot long with both ends broken off. This formation represents the transition zone between the marine Mancos conditions and the coal-forming conditions of the Bowie shale, the missing formation.

Fossils collected from the sandstone were identified by Prof. Junius Henderson, and are:

LOCATION: 15½ mi. N., 9½ mi. W. of Delta bridge, taken from N. of Grand Junction city water intake on Kahnah Creek, near the center of sec. 27, T. 12 S., R. 97 W.;—*Halymenites major* Lesqueraux. According to Lee, the Rollins sandstone is characterized by this marine alga. However, the genus is found in sandstone from the "Dakota" to the Laramie, and only one species can be distinguished. The Rollins fossils are just like those from the Fox Hills and the Laramie of eastern Colorado. The associated fossils in various formations indicate that *Halymenites* lived in both marine and brackish water. These fossils are very abundant in the Rollins sandstone, but they can also be found in the lower part of the Paonia formation. Fragments of large *Inoceramus* shells were found in the Rollins sandstone, but none were collected because the material was too poorly preserved.

THE PAONIA FORMATION

The Paoni formation consists of sandstones, shales, and coals, the sandstones making up the greater part of the formation. For this reason it is designated as the Paonia formation instead of Paonia shale.

The lower boundary of this formation in this area is an unconformity above the massive Rollins sandstone. It is usually easily identified because the sandstone below is a cliff-maker, and because the coal just above the sandstone is burned at the outcrop giving to the clinker and rocks a deep red color. In places the ash has been fused quite completely giving it the appearance of an igneous rock. Where the Rollins sandstone is covered by soil, fragments of the burned coal bearing formation beneath show where the base of the Paonia shale lies. From the basal coal bearing horizon, the sediments grade upward to a dominance of sandstones through poorer grades of coal and carbonaceous shales interbedded with sandstones. The shales above the coal become more arenaceous higher in the series and of less importance. The sandstones are massive, coarse grained, arkosic, cross-bedded, and of a yellowish color. The arenaceous shales are in places almost as variegated as those of the Gunnison formation, but the most abundant color is gray or grayish green.

The top two-thirds of the Paonia formation is interbedded shales and sandstones. Some of the sandstone beds are 50 feet thick, but most of them range between 20 and 30 feet. Small conglomerates exist at various horizons in the sandstones, produced by the partial solidification of the sandstone followed by its being broken up, for the pebbles of the conglomerates are flat lens-shaped sandstone pebbles of the same formation. A pebble of basalt three-quarters of an inch in diameter was fôund in one of these conglomerates. It had all the characteristics of a pebble from the basalt of the top of Grand Mesa proving the presence of igneous material of the nature of the basalt at an earlier time than the extrusion of the flows above. This was the only foreign pebble found in any of the conglomerates in the Paonia formation. The rest came from the formation itself.

There are numerous concretionary bodies in the sandstone whose size and shape vary considerably. Some are lenticular, others are round or ellipsoidal. They seem to be merely sandstone better cemented than the enclosing strata, usually by iron oxide, which gives them a darker color than the main mass of the bed. They are bedded and cross-bedded as is the rest of the sandstone, and may have been formed in small pools the shape and size of the concretionary bodies. The contact between the Mesaverde and the overlying is very problematical in the area worked. The slope about Grand Mesa is soil covered except in a few places where no contacts are shown. The line separating the two formations, the Paonia and the one above, was drawn along the lower boundary of slide material which, it is supposed, is all in the later formation, the Wasatch. The material of which the Paonia formation is composed is unfavorable to the development of slides of such extent as those about Grand Mesa. The thickness of the Paonia formation is about 1600 feet.

The topography of the Paonia formation is the result of the differential weathering of the alternate beds of sandstone and shale. The sandstone forms great benches (Fig. 4, p. 28) about the steep slope of which, the weaker, less resistant shale outcrops. On the flat tops of these benches, sage brush is the usual vegetation, whereas on the slopes, cedars and a few pinion pine grow. In the higher levels, dense scrub oak takes the place of the cedars and in the better watered places, scrub oak and quaking aspen grow.

AGE

The only fossils collected from the Paonia were a few leaves of trees found near the base of the formation. Numerous fragments of plants occur in the carbonaceous shale of the lower portion, but they are poorly preserved.

The age, as given in this report, is based on correlations made by W. T.

Fig. 3. The white massive Rollins sandstone above the Mancos shale and overlain by the Paonia coal-bearing beds. Shows the sandstone beds in the top of the Mancos shale. Trees about 10 feet high. Rollins sandstone 90 feet thick.

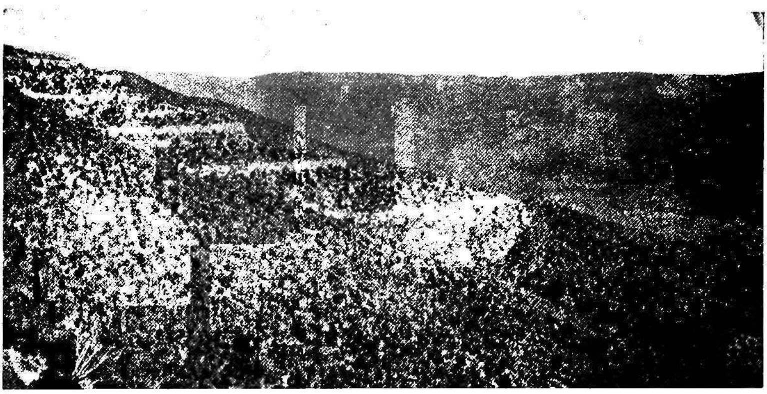


Fig. 4. Typical exposure of the upper part of the Mesaverde formation showing the sandstone benches. Flat top of Grand Mesa in the background. Trees less than 20 feet high.

Lee[3], who had better opportunity for studying it, and who places it in the upper part of the Mesaverde formation of Cretaceous age.

The fossil leaves found were identified by Prof. Junius Henderson, and are:

LOCATION: 9 mi. N. and 1½ mi. W. of Delta bridge at Rollins mine, from near base of Paonia shale;—*Ficus speciosissima* Ward, *Ficus* cf. *planicostata* (Lesqueraux). These species are assigned to the genus that includes figs.

LOCATION: 12¼ mi. N., 6¼ mi. E. of Delta bridge, at States mine, from near the base of the Paonia shale;—undeterminable plant stems and leaf fragments of land plants.

These fossils, together with the coal beds at the base of the Paonia formation, prove the brackish water and near land conditions during the deposition of the base of this formation. The coal seams are not continuous over the entire area, showing that the basins in which they were formed were more or less local and were separated only by slight barriers.

The upper part of the Mesaverde formation appears to have been deposited in shallow fresh or brackish waters. The sand is not very well sorted, and its arkosic nature proves incomplete decomposition. The lenticular bodies in the sandstone indicate shallow water and variations in the rate of deposition. The numerous conglomeratic lenses composed of fragments of the sandstone of the formation itself prove the presence of conditions such as would break up the sands already deposited and partially cemented. These sediments were, perhaps, formed under shallow water and semi-terrestrial conditions.

TERTIARY SYSTEM

WASATCH FORMATION

The Wasatch formation includes all the sedimentary beds above the Mesaverde formation. The top of the formation is covered by a basalt flow, the slide rock from which hides the contact between the two. There are very few good exposures of this formation in the area covered by this survey, and no very good study of it could be made. One exposure of sandstone and shale, near the top, was the only place where the rock in place could be studied. At various places about the mesa may be seen slide material from the Wasatch. Where exposed in place, the sediments consist of about 200 feet of light colored shales and fine grained sandstones, from which fresh water shells and a vertebra were collected.

Elsewhere, the slide rock was the only means of determining the character of the formation. The material in all of the slides is variegated clays and sands. Red shales predominate in the slides and much of the clay is sandy, but whether the sand is an original constituent of the shale or comes from the associated sandstone was not determined.

In some places, the sides of the hills slipped off piling the material at their bases and leaving bare slopes several hundred feet wide in the rear. In other places, the fact that the ground is sliding or has slid is shown by large cracks commonly running parallel to the edge of the

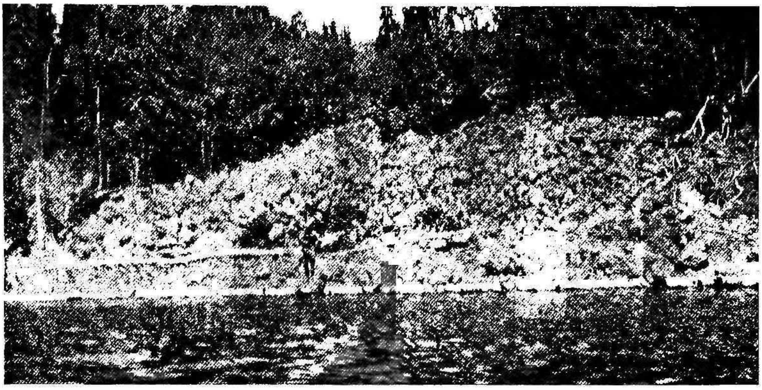


Fig. 5. Portion of a lake in the slides of the edge of Grand Mesa. Basalt boulders at the edge.

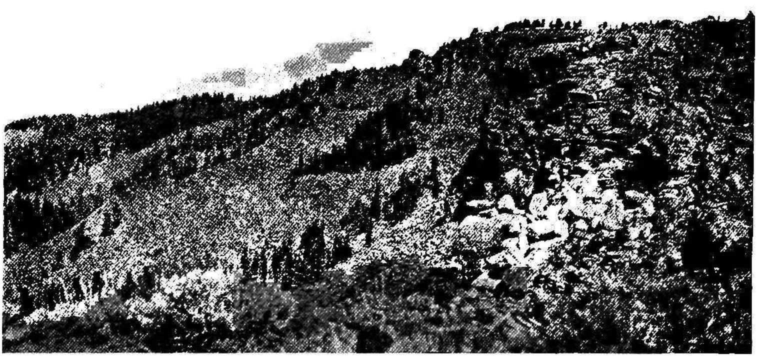


Fig. 6. The basaltic slide rock of the edge of Grand Mesa. Also shows the flat top of mesa to the right and in the background with the slope of the ground from it. Trees from 50 to 60 feet high.

mesa or hill. This is the character of most of the ground about the mesa at the elevation of the Wasatch formation, and it was on such information as this that its base was determined. The shales are of many colors, but red, purple and white are the most abundant. At various places are found thin conglomerates, proving the presence of unconformities within the formation. The fossils are of Eocene age and prove the fresh water origin of the sediments as well as the presence of land areas on which mammals could live. It seems probable that the sediments were laid down in fresh water lakes surrounded by land areas of low relief.

The fossils were identified by Prof. Junius Henderson, and are:

LOCATION: 13 mi. N., 2 mi. W. of Delta bridge in sec. 10, T. 13 S., R. 96 W., from about 855 feet above the base of the formation;—Mammal vertebra; *unio washakiensis* Meek.

QUATERNARY FORMATIONS

The Quaternary formations consist of river gravels, alluvium, landslide material and residual soils.

The river gravels are of two separate periods, the earlier being formed at the time when the graded slopes of the mesas were developed and before the Gunnison River cut its canyon. These gravels are found on the tops of the mesas on the Mancos shale. Some have been consolidated into conglomerates with the more or less sun baked, disintegrated Mancos shale as the cement. Such conglomerates from cliffs at the edge of the Mancos shale mesas, and, in the western part of the area, are composed almost entirely of basalt boulders and pebbles; but in the east part of the area, especially east of Tongue Creek, are composed of basalt, granite, gneiss, quartzite and various other materials. The boulders in the conglomerate show that the streams depositing them in the west drained the Grand Mesa basaltic area, while those depositing them in the east drained an area underlain by a greater variety of rocks. These gravel beds range from eight to fifty feet in thickness.

The other river gravels are those now forming and being deposited in the Gunnison River valley and canyon. They are coarse, well worn pebbles and boulders of various classes of rocks, and are derived from the reworking of the river gravels above described. The present streams are not depositing very much, but are at work carrying away the deposits of former aggraded streams.

Along the Gunnison River are cultivated flats made up of alluvium underlain by river gravels. The deposits are not very extensive and are best developed around Delta.

Along some of the intermittant stream gullies, alluvium is present in quite thick deposits, especially in the bad land areas where erosion by rains is at a maximum. In places, fine silt from shale is exposed to a depth of 20 feet.

Landslide material is most abundant in the area underlain by the Wasatch formation, and for this reason is limited almost entirely to the upper part of the Grand Mesa slopes.

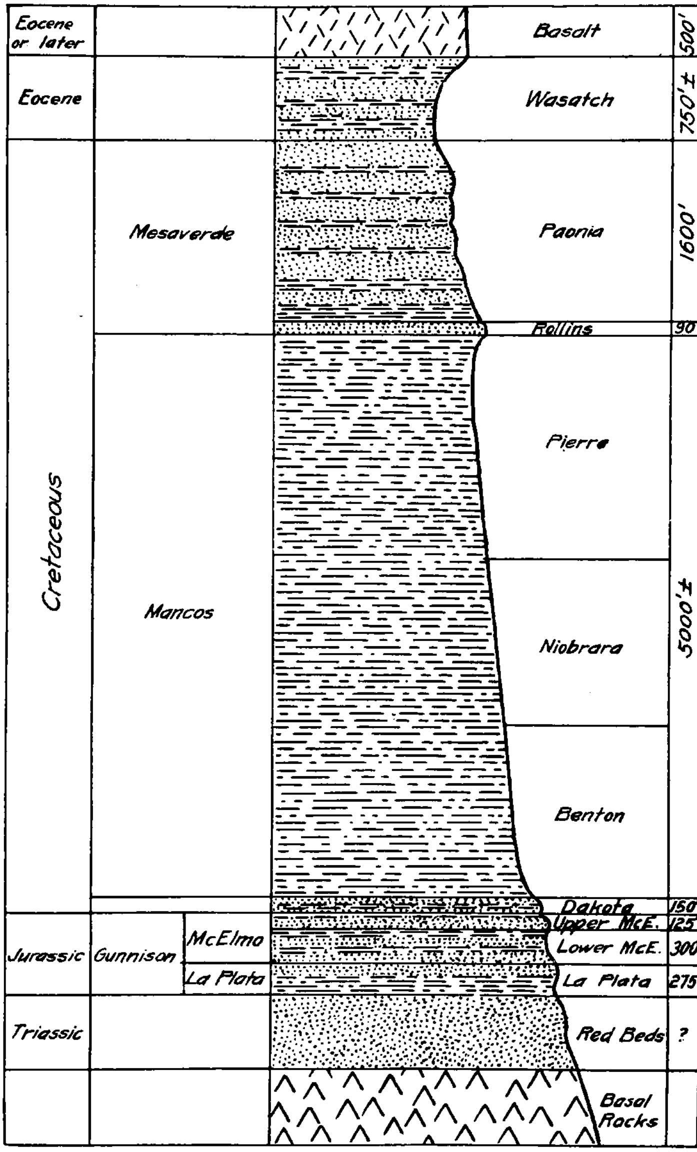


Fig. 7 Stratigraphic column showing character and approximate thickness of formations.

All of the soil of the area except that composed of alluvium is residual, and is derived from the weathering of the underlying rocks.

DEVELOPMENT OF THE GRAND MESA LAKES

Numerous lakes are found around the edge of Grand Mesa in the area underlain by the Wasatch formation. Most all of them are shallow and range in size from little pools to lakes a mile in length and are formed in the rear of slides in the Wasatch formation. The surface of the ground about the edge of the mesa, especially, in the slide rock of the basalt is a succession of basins developed by separate slides. Where these basins are formed across stream valleys, the openings between the rocks become filled with detritus and pools form in the basins. Where the slides occur in the Wasatch away from the basalt slide rock or where the basins in the basalt slide rock are bottomed by the sediments of the Wasatch, pools form immediately behind the slide material. This has been the manner of formation of all of the lakes around the edge of Grand Mesa.

The largest lakes are to the north and northeast of the area worked where the slides are less numerous but of greater size. Ward Lake, outside of the area surveyed, is an exception to the manner of formation described, and its manner of formation is discussed with that of the source of the basalt.

IGNEOUS ROCKS

Above the Wasatch formation is a great thickness of basalt formed by a succession of flows. Another igneous rock occurs in the form of boulders of volcanic material on the sides of the mesa. Some of these are forty feet in largest dimensions and are composed of bomb-like masses cemented together by great rosettes of zeolitic minerals. These volcanic masses occur in greater abundance on the slopes of the area than on the western, suggesting that their source is nearer the east side than the west. The material is like that of the flows in color, texture and structure, but contains a greater abundance of cavities than the true flows.

The basalt capping of the mesa is several hundred feet thick, but its exact thickness could not be determined because its base is concealed by slide rock which covers the slopes for half a mile or a mile from the foot of the cliffs. Measurements made at two places gave a thickness of about 400 feet. The flat top of the basalt is covered with a very thin mantle of soil in which are minor undulations produced by weathering. The edge is a cliff 400 feet high through much of its length. The interval between successive flows appears to have been short as there is no evidence of sediments between them, but it is possible that sediments may have been caught up and assimilated with the mass of the flow as the molten lava spread out. At one place seven flows were counted. The tops of the flows are more vesicular and are usually of redder color. In places, a ropy flow structure is preserved.

Some of the vesicles are six inches in diameter, and lie with their long dimensions parallel to the flow surface. In the center of the flows, the few cavities which occur are much smaller than those near the surface and are not flattened. The texture of the basalt is very fine, but with the aid of a hand lens small cleavage surfaces can be detected. These suggest the probable presence of feldspars.

In some basalt boulders found on the slope of the Mancos shale mesas there are small amounts of metallic sulphides. In one boulder sphalerite and bornite were found. It is quite possible that the sphalerite found in the earthy limestones near the base of the Mancos and in the limestones higher up in the shale had its source in the basalt.

The basalt is very resistant to weathering and is practically the only kind of rock that is not disintegrated before reaching the Gunnison River. Chert pebbles on the bare surface and in the soil over the basalt appear to prove that the capping was once covered by sediments.

The source of the basalt can only be conjectured. The presence of volcanic material on the slopes of the east end of the mesa and not on the west indicates that there was a crater nearer the east end than the west. No evidence was obtained from an examination of the flows as to the direction from which they came. It was said in the discussion of the origin of the lakes that those in this area were formed in basins developed behind landslides and that they are all rather shallow. But Ward Lake, to the north of the area mapped, is 1700 feet deep and could not have been formed as the result of slides. It is probable that it occupies a volcanic crater. The lavas of the top of the mesa may have been extruded more quietly as flows from a single crater or fissure craters. If this is correct, the source of the basalt was vents north of the area worked and nearer the eastern end than the western end of the mesa.

STRUCTURAL GEOLOGY

The general dip of the formation of the area is monoclinal toward the Grand Mesa, and may be due to a combination of two causes; the first, more or less substantiated by field evidence; and the second, largely hypothetical. The field evidence for the first cause is the great thickness of the Mancos shale and its wedge shape as explained in the description of the formation. In a general way, the dips in the lower part of the formation, where it appears to be less affected by folding and faulting, have a more southeasterly direction than those taken higher up in the formation. It is believed that as sedimentation continued, the eastern or perhaps northeastern part of the area subsided more rapidly than the western part and produced the wedge shape of the formation below the lenticular limestone beds that occur about 2200 feet below the base of the Rollins sandstone. This might account for the dips in the upper part of the formation. Definite information could not be obtained as to whether the greatest wedging is directly toward the west, or slightly to the southwest or northwest, but it is undoubtedly dominantly toward the west as shown by its thickness measured at Grand Junction by Lee, and estimated in the area to the southwest by R. C. Coffin. These results show continued thinning toward the west. As sedimentation went on, the basin in which these sediments were being deposited subsided more in the east than in the west. By the time the lenticular limestone beds were being deposited, subsidence stopped or was equal over the entire area, giving a horizontal surface on which the lenticular limestone beds and shale above them were deposited. In this way, the lower beds of the Mancos shale would have a north-south strike if wedging were all to the west, and would have an easterly dip. The upper beds would be horizontal or would dip slightly eastward, due to a greater amount of settling in the thicker portion. This accounts for the wedge shape of the shale formation and an easterly dip of the lower beds of this series.

If the basaltic lavas came from a source beneath Grand Mesa, as an analysis seems to indicate, it would leave a chance for the settling of the whole area from which they came producing a northward dip, which, in combination with the eastward dip of the lower sediments, would result in a northeastward dip for the lower beds and a northward dip for those in the upper part of the shale. Elevation of the southern part of the area relative to the north would produce the same result.

FAULTING

Superimposed on the monoclinal structure are faulting and folding, neither very abundantly developed. However, the former could, in a great many cases, be entirely concealed in the area of the Mancos shale because in a large part of the formation there is nothing to aid in the discovery of faults. The shale is an incompetent mass of sediments in which the evidence of faulting in the sandstones beneath would be concealed. Slickensiding, lenticular limestone beds, and and a calcite vein extending for nearly three miles are evidences of faulting or fissuring of the shale at places where all other evidence is wanting.

About 2½ miles east and ½ miles south of the NE. corner of T. 3 S., R. 2 E. in sec 17 are found slickensided fragments of limestone. A portion of the bed is apparently in place and dips 37° NW. and strikes N. 47 E. in an area where the regional dip is about 4° to the northeast and the strike is N. 33 W. The excessive dip, the abrupt change in strike, and the slickensiding are proofs of a fault whose strike is nearly that of the limestone bed. If it is a normal fault, as most of the faults are, the south side was raised relative to the north.

About 3 miles east and ¾ mile north of the northeast corner of T. 3 S., R. 2 E. in sec. 5 are found slickensided fragments of limestone on the weathered surface of the shale where limestone beds outcrop. No further evidence could be found as to the offset, the amount or kind of faulting.

Where the Grand Junction-Delta road crosses Wells Gulch is a normal fault that cuts the Gunnison and "Dakota" formations, and is lost in the Mancos shale. The fault is about ¾ of a mile in length and has a displacement of 10 or 12 feet. The strike of the fault plane is approximately N. 57 E. The dip could not be taken, but the downthrow is to the north.

Three-quarters of a mile southeast along the Gunnison River from the Delta-Mesa county boundary line, a fault cuts the Gunnison and "Dakota" formations. It could be traced northeast almost continuously for one and three-quarters miles from the river to a point where it passes beneath soil and talus. The surface evidence is slickensided sandstone boulders and fragments and in places a small escarpment. At one point the displacement was 8 or 9 feet. The strike is approximately N. 87 E., and the dip of the plane is 61° to the north. Striations on the slickensided face show that there was a horizontal component of the movement. At this place the south side went up relative to the north side, but at a point about one and one-quarter miles to the east the movement was reversed and the displacement was between 10 and 11 feet. A fault gouge about three feet wide is developed.

CAUSE OF FAULTING

The faulting is all of the normal type and can not be related to any folding movements, but may be related to adjustment during or following uplift. There have been at least two periods of uplift since sedimentation ceased; the first was before the graded Mancos shale mesa slopes were formed; and the second, at the time erosion began cutting canyons and gullies into this graded surface. Whether the faulting was confined to a single period of uplift or occurred in both can not be said, but it is likely that it was all caused by the same force and was of the same age, as the rude parallelism of the faults would suggest.

BLACK CANYON ANTICLINE

The most prominent fold in the area is that just east of the bridge at Austin where the "Dakota" sandstone appears abruptly from beneath the Mancos shale. It is a northwestward pitching anticline extending from south of the river to a point near the center of the north side of T. 14 S., R. 95 W., where it disappears under the soil of the mesa. The folding has had no effect on the overlying Mesaverde formations, having spent itself in the incompetent Mancos shale. The fold does not appear to be closed at the south end, but seem to merge into a northward dipping monocline.

The folding could have been due only to shearing forces as an examination of the jointing system indicates. The best developed set of joints trends N. 22 E., and is present only in the folded area of the "Dakota" sandstone from the bridge east of Austin to the east side of the area. In some parts of the sandstone, it is more pronounced than in others. The other system of joints, striking N. 80 W., is not so well developed nor so extensive as the first. The west side of the fold, where the "Dakota" passes beneath the Mancos shale, merges into a thrust fault and the sandstone formation stands almost vertical. This is especially true just south of the river. The forces that produced this fold were applied between the two systems of jointing and in the obtuse angle between them.[3] If straight compression forces acting in the obtuse angle between the two systems of jointing produced the folding, the trend of the axis of the fold would be approximately N. 40 E. On the other hand, shearing forces acting in the obtuse angle between the jointing systems would produce the overthrust fold having an axial trend west of north and develop the system of jointing that is found. It would appear that the force which produced the folding acted from the southeast.

The dips on this anticline are almost vertical on the west side, but rarely exceed 4° or 5° on the east side. The dips in the Mancos shale, especially on the west side, are perhaps erratic because of the broken character of the shale which slumps readily.

RANGE LINE ANTICLINE

The western side of a northward pitching anticline lies within the eastern margin of the area studied. The strike of the beds on the western limb of the fold is N. 60 and the dip 4½to 5 degrees to the northwest. The absence of an outcrop of Dakota on the north fork of the Gunnison River suggests that the strike changes to the east and then to the southeast. A set of prominent joints trending N. 22 E. corresponds to the major jointing in the anticline already described.

TONGUE CREEK SYNCLINE

On the west side of the Black Canyon anticline is a northwestward pitching syncline formed by the west-southwestward dipping beds of the west limb of the anticline and the normal northeasterly dipping sediments to the west.

THE DELTA FLEXURE

The dip of the Mancos shale flattens and becomes nearly horizontal in the area north of Delta. This includes the southern part of T. 14 S., R. 96 W., where the dip has decreased from three or four degrees north to one degree north. The change in dip is gradual proving that the flexure is not a terrace. South of the south boundary of this township, the shale is hidden beneath alluvium and weathered shale making it impossible to measure the dips. The fold is a low northward pitching flexure closed on the east by the northwestward striking sediments. Dips measured west of Delta along the river, although in a much fractured cliff of the shale, show that it does not close on the west or southwest. It would be impossible to make a structural map of this flexure because of the lack of a distinct horizon marker at this point. The observed dips are not very trustworthy because of the slumping and cracking of the shale.

Very little can be said as to the cause of this flexure because it can not be related to any folding or igneous intrusion. Its origin may be connected with the extrusion of the lavas of the top of the mesa.

AGE OF FOLDING

The folding was later than the deposition of the Mancos shale as that formation is involved in the Black Canyon anticline. The forces causing the folding acted from the southeast, and as folding and faulting are quite often related to igneous intrusion, it is suggested that this folding may have been caused by thrusts accompanying the intrusions in the Gunnison and West Elk mountains, in Eocene time.

OIL AND GAS POSSIBILITIES

POSSIBILE RESERVOIRS

The formations above the Mancos shale, although suitable for oil and gas reservoirs, are all exposed about the edge of the mesa and have no capping to confine oil and gas.

The "Dakota" sandstone, although well cemented, hard, almost a quartzite in some parts, is porous enough in others to act as a reservoir. It has also fractures, joints and bedding planes capable of containing oil and gas. Springs in Wells Gulch show that this formation is water-bearing. Most of the surface sandstone is case-hardened by the deposition of oxides of iron and manganese. This well cemented surface prevents the escape of water from the exposed "Dakota" except in ravines and along the base of the Mancos shale, where a strip of ground is water soaked, salt laden and soft due to the continuous escape of water from the underlying "Dakota." The salts are so abundant that crops will not grow, and at certain seasons of the year mire holes are formed. These facts all indicate that the "Dakota" is a water-bearing formation and porous enough to hold oil where the structural conditions are right.

The sandstones of the Gunnison formation are of sufficient thickness and porosity to hold considerable quantities of oil and gas, and are covered by formations impervious enough to prevent the oil and gas from escaping. Springs issue from the Gunnison sandstones at several places along the river, and wells drilled into the formation get water from the sandstones, but it is usually salty. Most of the water circulating through this formation must come from south of the river, for it is nearly all covered to the north by the Mancos shale, which would prevent the ingress of much water.

POSSIBLE SOURCES OF OIL AND GAS

As the organic theory of the origin of oil and gas is probably correct, it will be necessary to look for their source in sediments whose origin and composition are such as to make possible their generation. Only two formations in this region answer the requirements. These are the "Dakota" and the Mancos, both of which are marine in part, at least, and contain organic material. Of these two, the Mancos shale is the better suited for oil or gas production.

The analyses given by Lee[2] of the coal both both above and below the Mancos show that the fixed carbon (pure coal basis) ranges from 56.5 to 60.9%, with 59.1% as an average. The coals analyzed were taken from the Palisades district and the mines northeast of Austin. White[4] says that commercial oil pools will not be found in any formation where devolatilization of organic deposits has passed a point, which for most areas is below 65% or 70% fixed carbon (pure coal basis). According to the analyses given by Lee, metamorphism has not devolatilized the coal either above or below the Mancos shale to such an extent as to preclude the formation of either oil or gas in commercial quantities.

STRUCTURES

There are three structures in this area, none of which, in the opinion of the writer, is likely to contain oil in commercial quantity. The structure at the east side of the bridge east of Austin, the Black Canyon anticline, has been tested by a well which is bottomed in granite. The structure is too much fractured, has a limited gathering ground, and may not be closed. Gas is escaping along the west side of the fold where it merge into a fault. An analysis of the gas shows that it is almost pure carbon dioxide. The gas escaping at the springs is very likely the same. The well seems to prove that there is no oil in this anticline.

The other pitching structure, the Range line anticline, is just to the east of the one discussed, and only half of it was mapped, but the presence of the other limb was suggested by the shape of the exposure of the "Dakota" on Lee's map of this area. Its axis is close to the east range line of T. 15 S., R. 94 W. This anticline is fractured, is not closed, and pitches quite steeply. Sulphide springs at the river level and back from it in short deep ravines about 50 feet above the river suggest geological conditions like those at the Black Canyon structure. These springs give off hydrogen sulphide which precipitates ferrous sulphide in the basin-like pools and on the surface about the points of issue. Sulphur is also thrown down and coats the sides of the pools. An attempt was made to light the gas as it came from the pool, but probably owing to the abundance of carbon dioxide it would not light. Since the gases issuing from the two anticlines seem to be the same, it is probable that second structure would yield neither oil nor natural gas.

The last structure is located north of Delta. It has a monoclinal dip to the north which flattens gradually to a point about 3½ miles north of the town. From this point south there are no exposures from which to get strikes and dips on the north side of the river, but dips taken on the south side of the river show that it is not closed. This structure is less likely to be fractured than those above described because it is not folded as closely, and it commands a larger possible gathering ground. There are no oil or gas seeps anywhere on this flexure.

That this part of the area contains natural gas is proven by the finding of combustible gas at the Holly Sugar factory where two wells put down for water struck gas above the base of the Mancos. The gas was probably collected in cracks in the shale beneath an impervious layer for there is no part of the lower portion of the Mancos shale that is otherwise porous enough to act as a reservoir for oil or gas.

About 3½ miles north of Delta, it would be necessary to drill at least 1400 feet to strike the top of the "Dakota," and between 125 and 150 feet deeper to test it for oil. If it contained no oil, it would be useless to drill deeper. At the Sugar Company's factory the "Dakota" should be reached at about 600 feet, or about 315 feet deeper than their deeper well.

PREVIOUS EXPLORATION FOR OIL AND GAS

There have been many oil companies formed to develop the territory that this survey covered, but only one, so far as could be ascertained, had the service of a geologist. Some of them were organized so long ago that the people now living in the area have only a faint recollection of their history. Some went no further than a preliminary survey by a civil engineer.

In 1902, a company, without any geological advice, drilled a well about 1¼ miles east and ¾ of a mile north of the southeast corner of T. 14 S., R. 95 W., to a depth of about 1700 feet without getting water, oil or gas. This information was furnished by Frank Drain of Delta who worked on the well. Lehman Brothers of east Kansas drilled the well, and had to haul water from the Gunnison River to run the drill.

A well drilled on the Black Canyon anticline at the south side of the river went down to granite. No oil was obtained, but gas under very great pressure was struck, shooting rocks from the well to the top of the derrick and water to a height of 158 feet. The test was well located and proves the anticline so far as oil and gas are concerned.

The gas was analyzed by Cornell and Van Valkenburgh, and proved to be 98 per cent. carbon dioxide. An odor of hydrogen sulphide is given off by the well. It is probable that the springs along the wagon road and near the river also have a high percentage of carbon dioxide. The well is closed off and plans are being formed for the utilization of the carbon dioxide gas, the initial flow of which was estimated to be close to one million cubic feet per day. Its average daily flow for 15 years is estimated at 250,000 cubic feet.

An analysis of the salts in solution in the water by W. E. Rennie gave the following results:

Insoluble	00.99
KCl	7.89
$CaSO_4$	12.62
Fe	.17
NaCl	78.06
Total	99.73

The two wells drilled for water, near the river, in Delta, by the Holly Sugar Company, struck natural combustible gas at a depth of 160 and 200 feet, but not in commercial quantities. The wells came in with a pressure of 25 pounds to the square inch, but soon it died down to 15 pounds. No water was obtained.

Logs of wells furnished by N. W. Draper, Mgr. of the Sugar Company:

No. 1	feet
Adobe	12
Gravel	5
Gray shale	162
Depth	179

No. 2, same as well No. 1, with more shale, total 285 feet.

Mr. N. W. Draper also furnished the following log of a water well on the cemetery road 1½ miles south of Grand Junction:

	feet
Rock and gravel	20-70
McElmo Formation,	
Red rock (shale)	70-115
Hard white sandstone (poor water)	115-125
Red rock (shale)	125-195
Blue shale	195-220
Blue shale (lighter color)	220-270
Soft white sandstone (salt water)	270-280
Blue shale	280-400
Red rock (shale)	400-415
Blue shale	415-445
Red rock (blood red)	445-465
La Plata Formation,	
Very hard white sandstone	465-500
Red rock (like paint)	500-520
Red and white rock	520-605
Whitish shale	605-620
White sandstone (good water)	620-625
Hard white shale	625-650
Hard shale (white and red streaks)	650-725
Blood red shale	725-735
Soft white sandstone	735-815
Water began to flow at 740 feet,	
"Red Beds,"	
Red sandstone	815-870
White sandstone	870-930
Red sandstone	930-1190
White sandstone	1190-1193
White material (like lime)	1193-1197
Blood red material	1197-1210
Granite	1210-1213

CONCLUSIONS

There is no possibility of obtaining oil or gas in commercial quantities in any part of the area covered.

WATER FOR DRILLING

Water, throughout the entire area, is very limited in amount and in many places would have to be hauled some distance. Wells located on the anticlines east of Austin could get water for running the drill from the Gunnison River.

Water for drilling wells north of Delta would have to be hauled from the Gunnison, a distance of two or three miles, depending on the location of the well. During some seasons of the year, it could be got from an irrigation ditch about 1½ miles north of the river.

FRESH WATER POSSIBILITIES

The lakes about the edge of Grand are the source of most of the irrigation water used north of the Gunnison River. Without these lakes, most of the orchards and farms could never exist. They are the sources of the perennial streams.

Water can be obtained from the "Dakota" and Gunnison formation by drilling. These formations obtain their water from the hills to the south and southwest where the rainfall is heavier and where these formations outcrop. The topographic map of Colorado shows the elevation of the Uncompahgre Plateau to be roughly 9500 feet. This plateau and Grand Mesa are high enough to cause precipitation throughout the year. The waters of the snows and rains enter the porous sandstones of the "Dakota" and Gunnison formations and follow down their dips to the north. The shales in the Gunnison formation act as impervious layers that prevent the upward movement of the water. The streams flowing down the north side of the Uncompahgre Plateau have their source far down the side of this divide in springs issuing from the Gunnison formation, and not from rains and melting snows on the top of the plateau. The fact that they do not have their source at the top of the plateau indicates that the water falling on the plateau is nearly all absorbed by the sandstone, becomes entrapped beneath the shales and finds its first escape at the heads of these small streams where the "Dakota" and some of the shales of the Gunnison formation are cut through. (Unless the sediments of the Gunnison contain soluble salts, the water of the formation is likely to be fresh, because there is little chance of concentration of salts by evaporation before or after it enters the sediments.) Springs along the Gunnison River are salty, and, although no gypsum was recognized in the area covered by this survey, Coffin states that the McElmo member of the Gunnison formation is gypsum-bearing throughout the area to the southwest, and this is probably the cause of the salinity of the water from this member. The La Plata formation, although in part of semi-arid origin, contains good water in the sandstones of the lower portions as the well drilled for water south of Grand Junction shows. Sufficient water for home use and stock should be obtained from wells drilled to this member of the Gunnison formation and should supply several ranches.

The "Dakota" formation can not be expected to produce anything but salty water for it is exposed all over the northward slope of the Uncompahgre Plateau and would have its waters contaminated with salty surface waters from irrigation. The salinity of this water would also be increased by concentration due to the evaporation of a part of the water.

At Delta, the fresh water horizon should be reached by wells drilled to the depth of 1300 and 1350 feet. Wells drilled to the north, east or northwest of this would necessarily be of greater depth because of the increase in elevation and the prevailing northward dip that would bring the water bearing horizon to a still lower elevation than at Delta. At three miles north of Delta, the depth necessary to drill for water would be nearly 2300 feet. At six miles north of Delta the depth would be about 3650 feet, and at eight miles north, fresh water would not be reached at less than 5300 feet. South of Delta, the depth necessary to drill for water becomes less the farther south the well is located; and where the "Dakota" sandstone comes to the surface, this depth would be about 750 feet. Structural contours on this water bearing horizon strike about N. 45° W., and wells drilled at the same elevation on the lines of strike through the points above mentioned, would reach fresh water at about the depths given for wells at those points. The depth necessary to drill for water along these lines would vary from the depth given as the elevation at the point where the well is drilled varies from that of the points above mentioned. From the above figures, it is seen that the depth to fresh water increases greatly the farther north or northeast the well is located, but this is party compensated for by the fact that water can be quite readily obtained from the Grand Mesa Lakes and streams. At Austin, the depth to fresh water, is about 1750 feet.

A potential fresh water supply is found in Ward Lake at the edge of Grand Mesa. This is said to have a depth of 1700 feet. At present, the water available is limited to the amount which can be stored by damming its outlet. All the water in the lake could be used if a small tunnel were driven through the upper part of the Mesaverde formation to the bottom of the lake. Its length would be quite certainly under four miles. The flow of water would be regulated at its opening. Whether such a tunnel would pay for itself would depend upon the demand for water, the amount that would be supplied, and the cost of supplying it. There are thousands of acres of land that might be cultivated were sufficient water available. The cost of such a tunnel would be about $20.00 per linear foot. The sandstone through which the tunnel would run is more or less friable and would probably need some support, which would increase the cost. For comparison of the estimated cost above given with the cost of similar tunnels, the following table is given and was taken from Lauchi's book on Tunneling, page 29.

Name of Tunnel	Cress-section	Cost Per Linear Foot
Gunnison	12.3 x 10.5 feet	$70.66
Laramie Poudre	9.5 x 7.5 feet	39.54
Elizabeth N. side	12 x 12 feet	43.55
Elizabeth S. side	12 x 12 feet	38.00
Lucania	8 x 8 feet	23.00
Mission	6 x 7 feet	19.91
Rawley	8 x 7 feet	19.87
Roosevelt	10 x 6 feet	27.27
Stilwell	7 x 7 feet	23.37

This tunnel is suggested as a possible means of increasing the fresh water supply for the area north of the Gunnison River. There may be lakes similar to Ward Lake that are more favorably situated and could be used more economically.

ECONOMIC RESOURCES

Although the purpose of this report, as stated at the outset, was to discuss the oil and water possibilities of the area north of Delta, it seems proper that a brief summary of other resources should be given.

COAL

The coal of the Grand Mesa field has been studied in detail by W. T. Lee and is treated in Bulletin 510 of the U. S. Geological Survey.

ROAD MATERIAL

Along the Gunnison River, in its valley and upon the cliffs on both sides, are Quaternary river gravels in places over 50 feet in thickness that are being used for road material. The gravel in the bottoms is rather coarse and needs grading to make it more suitable for road surfacing. When used on the shale roads where the rather large pebbles become bedded in the shale, it makes a road surface almost as good as paving and is much less expensive. The gravels on the cliffs and mesas on both sides of the river are very excellent road material. They have a larger amount of fine aggregate than those in the river bottom, but they, too, contain boulders and large pebbles which make grading quite necessary. However, much can be used without grading, for the boulders can be thrown out in loading.

BUILDING STONE

Building stone of two kinds may be had, but neither is used very extensively. The basalt boulders found on the mesa surfaces are used for building houses and churches and make very beautiful and attractive buildings. Although the basalt is not easily shaped, it is abundant, durable, and beautiful.

The "Dakota" sandstone is used very little as a building stone largely because of its unattractive appearance. In some parts of the formation it is flaggy and easily quarried and dressed. Its distance from a market also limits its use.

SHALES

A brick factory at Delta uses the Mancos shale for brick and tile. The bricks are of very good quality, but there is some waste owing to the generation of carbon dioxide from the carbonaceous matter in the shale. This causes "bloating" and deformation of the brick.

Both members of the Gunnison formation contain shales which weather to a readily molded plastic clay. The predominating colors are red or purple and blue, but some are almost pure white and resemble pottery clay. At a place about ¼ of a mile north of Gunnison Gardens, a spring issues from the base of a cliff at the level of the railroad tracks and softens the white shale. Mr. Williams, the owner of Gunnison Gardens, says that he sent a sample from this place to the Smithsonian Institution. It proved to be a high grade kaolin. The wet clay found at the spring molds as readily as putty.

Due to the limited objects of this survey, the Gunnison formation was not studied as thoroughly as it might have been. It contains limestone and shale suitable for cement making in close proximity to one another. The limestone is not very abundant and is usually less than eight or nine feet thick.

BIBLIOGRAPHY

1. Coffin, R. C., Colorado Geol. Survey Bull. 16, 1921.
2. Lee, W. T., U. S. Geol. Survey Bull. 510, 1912.
3. Leith, C. K., Structural Geology, p. 16, 1913.
4. White, David, Some relations in origin between coal and petroleum: Jour. Washington Acad. Sci., vol. 5, pp. 198-212, 1915.

INDEX

PUBLICATIONS OF THE SURVEY.

* FIRST REPORT, 1908: Out of print.

BULLETIN 1, 1910: Geology of Monarch Mining Dist., Chaffee Co.

BULLETIN 2, 1910: Geology of Grayback Mining Dist., Costilla Co.

BULLETIN 3, 1912: Geology and Ore Deposits of Alma Dist., Park Co.

BULLETIN 4, 1912: Geology and Ore Deposits of Monarch and Tomichi Districts, Chaffee and Gunnison Counties.

BULLETIN 5, 1912: Part I, Geology, Rabbit Ears Region, Grand, Jackson, and Routt Counties; Part II, Permian or Permo-Carboniferous of Eastern Foothills of Rocky Mts. in Colorado.

* BULLETIN 6, 1912: Common Minerals and Rocks, Their Occurrence and Uses.

BULLETIN 7, 1914: Bibliography Colorado Geology and Mining Literature.

BULLETIN 8, 1915: Clays of Eastern Colorado.

BULLETIN 9, 1915: Bonanza District, Saguache County.

BULLETIN 10, 1916: Geology and Ore Deposits of Gold Brick District, Gunnison Co.

BULLETIN 11, 1921: Mineral Waters of Colorado.

BULLETIN 12, 1917: Common Rocks and Minerals, Their Occurrence and Uses. 50 cents; $1.00 to non-residents.

BULLETIN 13, 1917: Platoro-Summitville Dist., Rio Grande and Conejos Co.

BULLETIN 14, 1919: Molybdenum Deposits of Colorado.

BULLETIN 15, 1919: Manganese Deposits of Colorado.

BULLETIN 16, 1920: Radium, Uranium and Vanadium Deposits of Southwestern Colorado.

BULLETIN 17, 1921: Twin Lakes District, Lake and Chaffee Counties.

BULLETIN 18, 1920: Fluorspar Deposits of Colorado.

BULLETIN 19, 1921: Foothills Formations of North Central Colorado; Cretaceous Formations of Northeastern Colorado.

BULLETIN 20, 1924: Preliminary Notes for Revision of Geologic Map of Eastern Colorado.

BULLETIN 21, 1921: Geology of the Ward Region, Boulder County.

BULLETIN 22, 1921: Mineral Resources of the Western Slope.

* BULLETIN 23, 1920: Some Anticlines of Routt County, Inc. with 24.

BULLETIN 24, 1921: Some Anticlines of Western Colorado. 50 cents.

BULLETIN 25, 1921: Oil Shales of Colorado.

BULLETIN 26, 1921: Preliminary Report, Underground Waters, S. E. Colorado.

BULLETIN 27, 1923: Part I, Underground Waters of La Junta Area; Part II, Underground Waters of Parts of Crowley and Otero Counties; Part III, Geology of Parts of Las Animas, Otero and Bent Counties.

BULLETIN 28, 1923: Oil and Water Resources, Parts of Delta and Mesa Co.

BULLETIN 29, 1924: Physiography of Colorado. In preparation.

BULLETIN 30, 1924: Geology and Ore Deposits, Redcliff Mining District.

BULLETIN 31, 1924: The Como Mining District. Ready for printing.

REPORT 2, 1922. Geology of Line of Proposed Moffat Tunnel.

OIL MAP OF COLORADO: A reconnaissance map showing locations of seepages, anticlines, etc. $1.00.

TOPOGRAPHIC MAP OF COLORADO, 1913: Scale of eight miles to inch. Unmounted, $3.00; Mounted, $4.00; Mounted with sticks, $5.00.

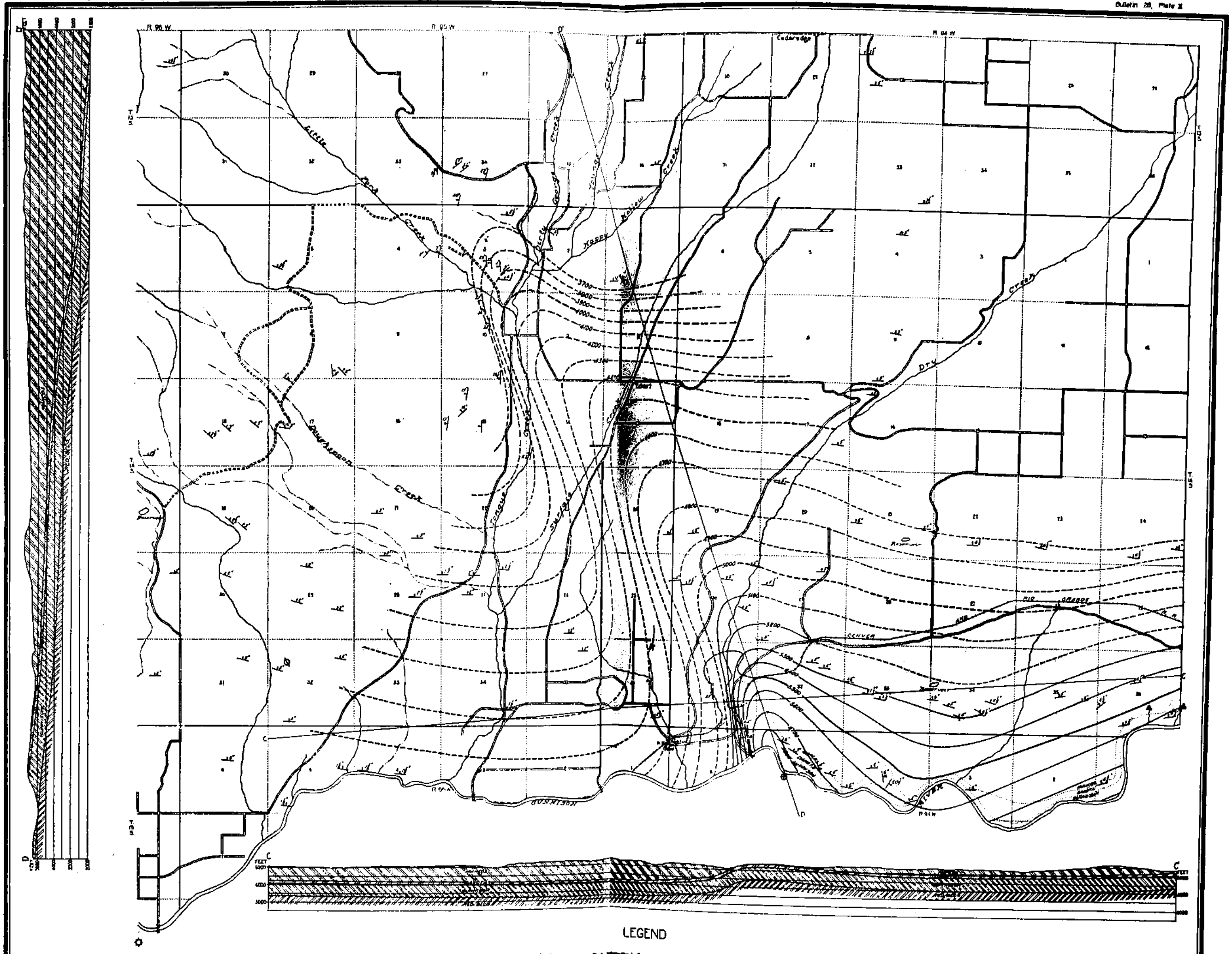
GEOLOGIC MAP OF COLORADO, 1913: Presents by colors and patterns the geological formations of the state. Supply almost exhausted. Prices, $6.00, and $7.00.

COAL MAP OF COLORADO: A reconnaissance map showing known areas underlain by coal in the state. $1.00.

STRATIGRAPHIC SECTIONS, EASTERN COLORADO: $1.00.

*Out of Print.

Address
COLORADO GEOLOGICAL SURVEY
Boulder, Colorado



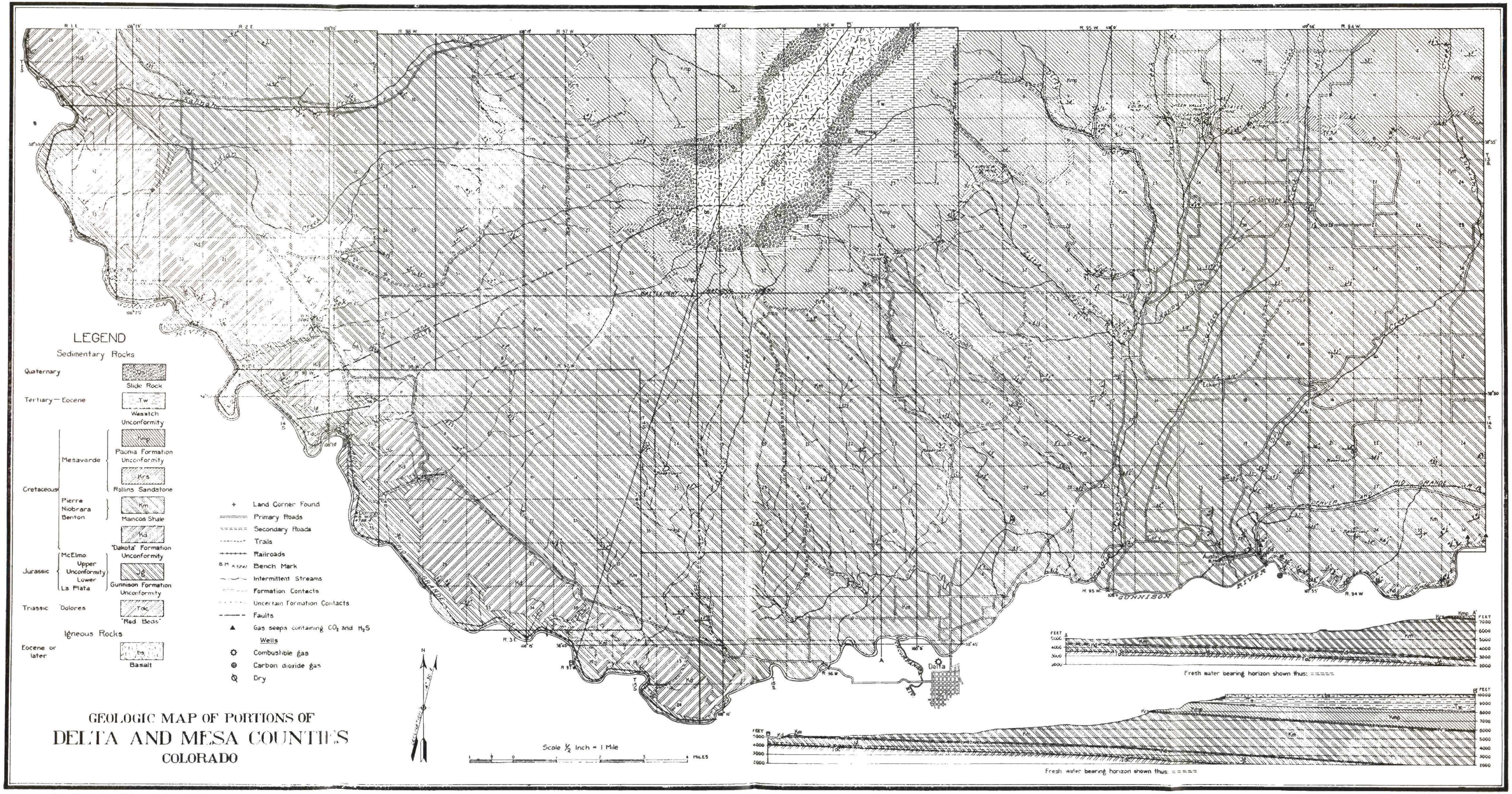
BLACK CANYON AND RANGE LINE ANTICLINES
DELTA, COLORADO

Surveyed by H. J. Weeks in charge, assisted by C. L. Mohr and R. M. Durward, 1922

PLATE II.

Drawn by C. L. Mohr

Colorado State Geological Survey
R. D. George, State Geologist



Surveyed by H. J. Weeks in charge, assisted
by C. L. Mohr and H. H. Durward, 1922

Drawn by C. L. Mohr.