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R. D. GEORGE, State Geologist

BULLETIN 24

(Reprinted with parts of Bulletin 23,
"Some Anticlines of Routt County)

SOME ANTICLINES OF WESTERN COLORADO

BULLETIN 24 BY
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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, June 3, 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 24, (combined with parts of Bulletin 23), of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,

State Geologist.

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INTRODUCTION

The intense interest in oil has created such a demand for the Survey publications bearing on the oil possibilities of the state that Bulletins 23 and 24 are out of print. The present bulletin is a reprint of the greater part of Bulletin 24 with which are included the most important parts of Bulletin 23. The parts of Bulletin 23 omitted are chiefly descriptions of formations, as the same formations are described in Bulletin 24. One of the maps accompanying the Bulletin is taken from Bulletin 23, and the other is taken from Bulletin 24.

ANTICLINES IN ROUTT AND MOFFAT COUNTIES

GENERAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

In most of the area covered by this report sedimentary rocks of Cretaceous age or younger predominate and occupy the greater part of the surface. In a few places, however, igneous rocks are found as remnants of former sheets, dikes, necks or craters. In general, it might be stated that the area in the vicinity of the Park Range is more likely to contain necks, plugs and craters than that country to the west and northwest.

The drainage of this area is essentially the same as that given by Fenneman and Gale[1] in their bulletin on the Yampa Coal Field. The largest stream, and hence the main channel for run off, is Yampa River. The largest tributary of Yampa River in the field is Williams Fork. In many places this stream has meandered and built up alluvial plains with rich black soil which makes the river bottoms desirable places to farm.

As a general rule the streams follow the crests of anticlinal folds, the Hamilton dome and Craig anticline having streams following the crest of the folds quite closely. It is an observed fact that in some cases the streams cut across the crest of the folds. This was noted in the Pagoda structure and in several other folds.

The relief of the Daton Peak and Monument Butte quadrangles, especially that bordering Williams Fork and its tributaries, is very rugged and irregular. The Mesaverde formation with its sandstone members weathers into cliffs and irregular escarpments sometimes 800 feet in height. In some places the lower part of the Mesaverde formation, where the massive sandstone members are interbedded with shale, weathers into a steplike cliff which resembles, to a great extent, the roof of a Japanese pagoda. This peculiar phenomenon has given the name Pagoda to the postoffice on Williams Fork located at a point where this feature is best developed.

In the same quadrangles high mesas and sharp peaks have been developed and preserved as a result of lava caps and lava sheets which have protected the softer underlying rocks. Other mesas are present which are capped by lava boulders and other detritus.

The valleys and rounded hills, which are present in certain parts

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[1]Fenneman, N. M., and Gale, Hoyt S. The Yampa Coal Field, Routt County, Colorado; U. S. Geol. Survey Bull. 297, p. 8, 1906.

of the quadrangle, are usually formed in the Mancos shale—so in general it might be said that shales are typically valley formers.

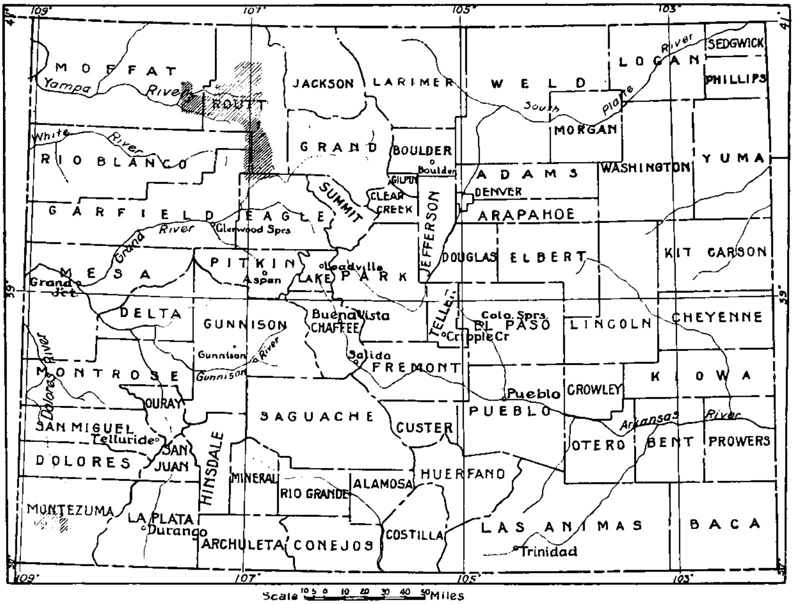

Fig. 1. Index map of Colorado showing position of areas covered by this report

In the vicinity of Yampa, Mancos shale is the outcropping formation and as usual valleys and rounded hills are the prominent physiographic features. Occasionally a neck, plug, or dike towers above the general surface of the country and makes quite a contrast with it. There are calcareous zones in the lower part of the Mancos which are hard and very resistant, and quite commonly form ridges in this district.

WATER AND FUEL

This country is well supplied with water, and in all of the structures considered it would not be difficult to obtain it. In regard to fuel this region is copiously supplied since coal mines or prospects are easily accessible.

SEDIMENTARY AND IGNEOUS ROCKS.

Only rocks of Cretaceous or younger age are described in the report of the Yampa field. Approximately 600 feet of pre-Cretaceous "Red Beds" underlie the Cretaceous rocks. They are not described here as sections taken indicate that they are probably not important in the derivation or accumulation of oil or gas.

"DAKOTA" FORMATION

The prominent "Dakota" formation overlies the Jurassic, and is easily recognized in the field. It is very persistent in its lithological character and continuity of exposure. Very few fossils have been obtained from it throughout this territory, but its identity is based on its position below the fossiliferous Mancos formation and its similarity to the known Dakota of other fields. This formation was studied north of Steamboat Springs and on Grand River where several sections were made. It is made up of sandstones, shales, and conglomerates which vary in texture and appearance.

The upper sandstones are usually hard and often quartzitic. They are composed of quartz grains with a siliceous cement, and vary in color from white to a yellowish gray. Abundant carbonaceous material is often disseminated through the sandstones. The beds vary in thickness from a few inches up to 50 or 75 feet. Beneath these sandstones are thin, black, carbonaceous shales which, at some places, are parted by thin sandstones and sandy lenses. These shales on Grand River showed small seams of lignite and a great deal of finely divided carbonaceous material.

The lower part of the formation contains other beds of siliceous sandstones and carbonaceous shales, and the characteristic basal "Dakota" conglomerate. This conglomerate on Elk River north of Steamboat Springs is 11 feet thick and is made up of flint, jasper, limestone, quartz, feldspar, and granite pebbles. The pebbles are pea sized and usually rounded. In Grand Canyon this conglomerate could not be found in place where the sections were obtained. Float, however, was noted, indicating that it was present. In one section gray, green, and purple variegated shales are beneath the typical "Dakota" sandstone. These shales are probably of Jurassic age and have taken the place of the basal conglomerate. This formation varies in thickness from 100 to 150 or 200 feet.

Section of "Dakota" on Cabin Creek, a Branch of the Grand River, Near McCoy.

	Feet
Sandstone, hard siliceous; underlies black, slaty Mancos shale	75
Shales, sandy and carbonaceous	4
Sandstone, siliceous, carbonaceous	20
Shales, sandy, carbonaceous; small irregular seams of coal	4
Sandstone, siliceous, hard	50
Shales, gray, green and purple, with thin sandstones (Jurassic?)	20
Total	173

Section of "Dakota" on Elk River North of Steamboat Springs

	Feet
Debris-covered slope; Mancos-Dakota contact not determined	--
Sandstone, hard, siliceous, yellowish; beds 3 to 4 feet thick	13
Sandstone, siliceous, hard; beds 1 inch to 1 foot thick	17
Sandstone, massive, hard, gray	7.5
Shales, thin, sandy, carbonaceous	4
Sandstone, soft, yellow	10

Sandstone, coarse grained, and conglomeratic	26
Sandstone, massive, coarse grained, interbedded with thin seams of fine-grained siliceous sandstone	15.5
Conglomerate	11
Total	104

Other exposures of Dakota occur as follows: Three miles east of Elk Mountain; near Hahns Peak; at Steamboat Springs; near Poose Creek about 6 miles southwest of Williams Park. It has been encountered in three wells drilled near the south boundary of Williams Park.

Mancos Formation.

The "Dakota" formation is succeeded conformably by the Mancos. This marine formation includes all the sediments between the "Dakota" and the Mesaverde formations. In order to give a description which may be of more use in the field, it will be better to divide the Mancos formation into three members, namely: lower, middle and upper. This subdivision is based on the lithological dividing lines existing in the strata, and is made as a matter of convenience with no intention of raising them to the rank of formations.

Lower Member

The basal, or lower member of the Mancos shale includes the sediments above the "Dakota" to the base of the first calcareous zone above the Mancos sandstone. This lower member is readily distinguishable as a distinct division and contains the characteristic fossils of the Benton formation of the Colorado group as defined by earlier geologists. The Benton fossils listed below were collected from the lower member, and have been identified by Professor Junius Henderson, as follows:

Scaphites warreni Meek and Hayden
Inoceramus fragilis Hall and Meek
Ostrea lugubris Conrad
Prionocyclus wyomingensis Meek

Thin-bedded, black, carbonaceous, iron-stained shales characterize this member from the"Dakota" to the Mancos sandstone. These shales are often very slaty. Sandy zones are found as the "Dakota" and Mancos sandstones are approached. At some places these shales near the Mancos sandstone change into thin-bedded sandstones and very sandy shales. The shales are often locally calcareous. A dense, black, thin limestone is present locally. A valley is usually formed in this member between the "Dakota" ridge and a minor ridge formed by the Mancos sandstone and calcareous shales.

The Mancos sandstone, which is near the top of the lower member, is easily recognized in the field by its fossiliferous character. The fossils listed above are from this sandstone and the sandy shales which lie above and below it. This sandstone member is usually made up of thin-bedded sandstones separated by sandy shale partings. A heavier, yellowish sandstone bed is often present. The sands of this bed are fine grained and firmly cemented with silica and calcite.

The Mancos sandstone is generally highly bituminous; the bituminous odor is strong when the rock is struck with a hammer. This is usually the case where fossils are abundant. The sandstones and sandy shales are often very crystalline and compact, and have a brown to black color. This color for the most part is given by the bituminous material present. Parts of this sandstone member were studied at five different places in the field, and all indicated that it was an ample reservoir for the storage of gas and oil. The sandstone itself for the most part is compact and tight, but the many bedding planes parting the thin beds and the abundant fracture and joint planes present, make it a porous, open formation. This member was more open and porous in the southern parts of the field than in the northern. The sections obtained give an average thickness of 40 feet for this sandstone member.

Fig. 2. Mancos Limestone on the Yampa-Steamboat Springs road.

Above the Mancos sandstone are sandy, limy shales which underlie the lowest calcareous zone of the middle Mancos member. These shales are also often fossiliferous and contain bituminous materials.

Middle Member

The middle member of the Mancos formation includes the highly calcareous portion of the formation which is probably equivalent to the Niobrara formation of other fields. The fossils obtained from this member as identified by Professor Junius Henderson are:

Ostrea congesta Conrad, on fragments of large Inoceramus
Inoceramus probably deformis Meek
Inoceramus sp.

There are three, and sometimes four, prominent limy zones which can be recognized in the field by the ridges they produce, and by the white-surfaced, hard, brittle shales that result when they are exposed to weathering.

The lower calcareous zone at one place is a massive limestone. (See

Fig. 2.) This limestone is not continuous throughout the field as a limestone, but changes and grades into calcareous shales. The limestone is made up of massive and thin beds from 6 inches to 7 feet thick. It is a very fine-grained, dense, bluish-gray rock which weathers white. Fractures and water courses in the limestone are filled with water-deposited calcite. A similar limestone bed lies below the Mancos sandstone, on the Yampa River three miles north of Phippsburg. Owing to the fact that this lower limestone is not present in other sections obtained, it was decided that a fault must have placed it in the abnormal position it now occupies.

Above this lower limestone or calcareous zone there are two, and at some places three, limy shale zones. As stated before they consist of hard, platy, brittle, white-surfaced shales. The bedding planes are very definite and regular, which allow the shales to part in large perfect sheet-like masses when dug into. The limy zones consist usually of from 50 to 200 feet of calcareous shales separated by less calcareous and sandy gray shales. The two lower zones contain a few fossils. The main fossiliferous zone is the third calcareous zone above the Mancos sandstone where the limestone is present, and the second limy zone where the limestone is absent. This fossiliferous ridge-maker is the key zone to the middle member on account of the abundant fossils present. These fossils at some places form solid fossiliferous shale beds from 2 to 5 feet thick and are often scattered in the shales for greater distances. This zone is from 500 to 700 feet above the Mancos sandstone, and makes a handy division line when the Mancos thickness is being determined. In nearly every section obtained this ridge was used as a dividing line within the formation. In certain areas beds above this ridge are exposed while the beds beneath it are covered by wash and vegetation. It was only by the use of this dividing line that a complete study and the measurement of a section of the Mancos formation were made possible.

The calcareous zone at the top of the middle Mancos member contains few fossils.

Upper Member

The upper member of the Mancos formation is distinguished from the middle member by the sandy gray shales present, and the absence of so much calcareous material. There are, however, a few very local limy shale beds of little consequence. The shales of the member are more like the Pierre formation of other fields. Two very sandy zones and a black shale zone are present in the upper Mancos. The black thin shales are between 500 and 700 feet above the upper calcareous zone of the middle Mancos member. These shales are thin bedded and fine. The color is probably due to the iron and small amounts of bituminous material present. A few fossils are found in this member similar to those of the middle member.

The two sandy zones are respectively about 400 and 1,000 feet below the base of the Mesaverde formation. Local small sandstone lenses occur at these places and when they are not present sandy shales predominate. The sandy shales of this member gradually increase in their sand content until they change into the thin-bedded yellowish sandstones of the next succeeding Mesaverde formation. An exact dividing line at no place could be determined with any degree of accuracy. It was therefore necessary to use a prominent known sandstone in the Mesaverde formation as a stratum to tie section measurements, and then divide the two formations approximately at the known zone of transition from thin sandstones to sandy shales. With this method more accurate information can be gained as to the distances to the known beds of the Mancos formation.

*The lower part of the Mancos formation is composed mainly of black carbonaceous shale. This is overlain by a sandstone member that was seen by the writer in only three exposures. Near the south border of Williams Park the exposed part of this member is composed of alternating sandstones, shales, and limestones. The beds are dominantly sandstone with some limestone and numerous shale partings. Individual layers range in thickness from less than an inch to five inches. The limestone is fossiliferous and on breaking, gives a distinct though not strong bituminous odor. The sandstone is of medium grain and only moderately porous. The zone as a whole is a fair water carrier as shown by the spring at one outcrop. Both sandstone and limestone weather to brownish gray. From surface indications the thickness of the sandy member was estimated at 20 to 40 feet. The log of the first well drilled by the Twentymile Oil Company shows "sand and shale" at depth 1,266 to 1,309 feet with an estimated dip of 29°. These figures give an actual thickness of 38 feet. Near Poose Creek, about 6 miles southwest of Williams Park, the sandy member is 25 feet thick. The well log mentioned gives 450 feet as the distance from the top of the Mancos sandstone to the top of the "Dakota" sandstone. Using the same dip as before, which the writer thinks is a little too high, the thickness of the Mancos sandstone and underlying shale is about 390 feet. On Poose Creek where measurements were taken the sandstone and underlying shale have a thickness of about 425 feet. Owing to difficulty in accurately locating the boundary between the "Dakota" and Mancos formations, on account of mantle rock, the figure given may be in error 10 to 20 feet.

On Poose Creek 30 feet above the sandstone member is a limestone stratum 15 inches thick. Another limestone stratum 12.5 feet thick lies 217 feet above the sandstone. The same limestone strata are found near the south border of Williams Park.

The remainder of the Mancos formation is nearly all shale. For some distance above the limestone the shale is at intervals very calcareous and weathers to thin plates. At least one thin limestone layer an inch or two in thickness and composed principally of Ostrea fossils is found in the shale. Much of the shale higher in the formation is dark and carbonaceous, but near the top, for several hundred feet, it is ligther in color and weathers to a light gray clay. A few hundred feet below the top of the Mancos is a limestone bed at least 18 inches thick. Outcrops of this may be seen near the northwest part of Williams Park.

The Mancos shale was long ago shown by its fossils to be of marine origin. No systematic search for fossils was made for the present report*

*From Bulletin 23 of the Colorado Geological Survey.

In Bulletin 23 a shaly sandstone succeeding the great mass of shale is taken as the basal member of the Mesaverde. The boundary between the Mesaverde is generalized on the maps.

The thickness of the Mancos formation has been determined as follows: Fenneman and Gale 2,000 to 2,500 feet; K. M. Willson, north of Yampa River, 2,100 feet; Gale, for northwestern Colorado in general, about 5,000 feet; Lee, for Axial, 5,800 feet; George, Milk Creek, T. 3 N., R. 92 W., 4,100 feet.

In their wells in Williams Park the Twentymile Oil Company found only 300 feet of Mancos. In the area covered by Bulletin 23 the average thickness of the Mancos is probably about 4,400 feet. Near the south border of the Williams Park, the exposed part of the lower part of the Mancos is composed of alternating sandstones, shales and limestones, with the sandstone predominant. The limestone is fossiliferous, and gives out a bituminous odor when broken.

The table below gives the approximate thickness between the main horizon of the Mancos, and the average thickness of the formation. (See also Fig. 12 on Plate I.) The variation in thickness indicates a probable irregular shore line at the time of deposition.

Location	Tow Creek sandstone to base of Mesaverde	Base of Mesaverde to main fossiliferous calcareous zone of Mancos	Main fossiliferous calcareous zone of Mancos to top of Mancos Sandstone	Top of Mancos sandstone to top of "Dakota"	Thickness of Mancos
Oak Hills, west of Oak Creek and east of Oak Creek	±1,700	±3,200			
Junction City on Oak Creek to east	±1,400	±2,700	±400	±500	±3,600
Yampa River west of Steamboat Springs		±3,800			
Chimney Creek, northwest of Steamboat Springs	±1,400	±2,200			
Elk River at Trull anticline.			±600		
Yampa River east of Oak Creek			±700		
Grand River near Catamount Creek				±400	
Poose Creek				±400	
Yellow Jacket Pass, near Pagoda				±426	±4,000
Average	±1,500	±3,000	±550	±450	±4,000

MESAVERDE FORMATION

The Mesaverde formation lies conformably above the Mancos formation. It is readily distinguished from this formation by the presence of massive sandstone ledges and the absence of large bodies of shale. In general, the formation is composed of sandstones parted by sandy and carbonaceous shales and coal beds. It is from 3,500 to 4,500 feet thick. A complete description of the formation may be found in Bulletin 297 of the United States Geological Survey, which deals with the coal beds within the Mesaverde formation of this area. The formation as a whole was not studied in detail, but sections were measured to the lower group of workable coals in order to have a known stratum for the purpose of determining the depth to horizons within the Mancos formation.

The lower part of the Mesaverde formation is composed of thin sandstones interbedded with carbonaceous shales and silts. There is a more massive sandstone, known as the Tow Creek sandstone which lies beneath the lowest workable beds of coal. The thin-bedded yellowish to brown sandstones at the base of the formation overlying the Mancos shales, are very characteristic in this field. The bedding planes are usually very irregular and discontinuous, and there is some local cross-bedding. These sandstones often contain many marine fossils which are different from the fresh and brackish-water fossils of the middle Mesaverde.

Above these sandstones there is a bed of gray carbonaceous shales and silts which varies in thickness within short distances. These shales contain more carbonaceous and sandy materials than the Mancos shales. Above these shales to the base of the Tow Creek sandstone there are alternating sandstones and carbonaceous shales. The sandstone beds increase in thickness, and less shale is present. The Tow Creek sandstone is the most continuous and characteristic member in the lower Mesaverde. It is a massive sugary, rather coarse-grained sandstone which varies in color from white to gray. In the northern part of the field this sandstone has more of a brown color. Its thickness varies between 50 and 100 feet. Above the Tow Creek sandstone, sandstones and shales alternate with the lower beds of workable coals which they include. These coals are of an excellent bituminous grade and form a large economic resource in this area. Further discussion of these coals is omitted here as a detailed explanation may be found in the above named bulletin.

The lower Mesaverde formation is represented by a rugged country with many cliffs and ridges as the more massive sandstones offer greater resistance to erosion than the softer alternating shales and sandstones.

LEWIS FORMATION

The Lewis formation is composed of soft clay shale, dark to light gray in color, and it lies conformably on the Mesaverde. It is often almost black at some places. Calcareous zones are common to this shale. Small lenticular masses of limestone and calcite seams are found in these limy zones. The shales at some places are sandy, but this is not a characteristic feature of the formation.

There are no complete or continuous sections of the Lewis formation in this field to determine its thickness[2]. Other geologists have estimated it to be between 1,000 and 1,200 feet.

LARAMIE FORMATION

*Along the Yampa River in the vicinity of Hayden the Laramie formation, as determined by previous workers, overlies the Lewis shale with apparent conformity. It is composed for the most part of friable sandstone

*From Bulletin 23 of the Colorado Geological Survey.
[2]U. S. Geol. Survey Bull. 415, p. 72.

that commonly is cross bedded. The sandstone locally carries bands of concretions several feet in diameter. In a few gullies may be seen outcrops of gray shale. At least one coal seam has been opened in the Laramie near Hayden*

TERTIARY OR QUATERNARY FORMATIONS

At one locality on Beaver Creek, a tributary stream of South Fork Creek, an exposure is found which showed a conglomerate bed about 8 feet thick unconformably overlying the Mancos shale. Immediately overlying this conglomerate bed is 20 feet of sandy material, more or less arkosic in character, with several thin beds of conglomerate intercalated with the sand. Capping this sandy horizon is a bed of sandstone several feet thick with

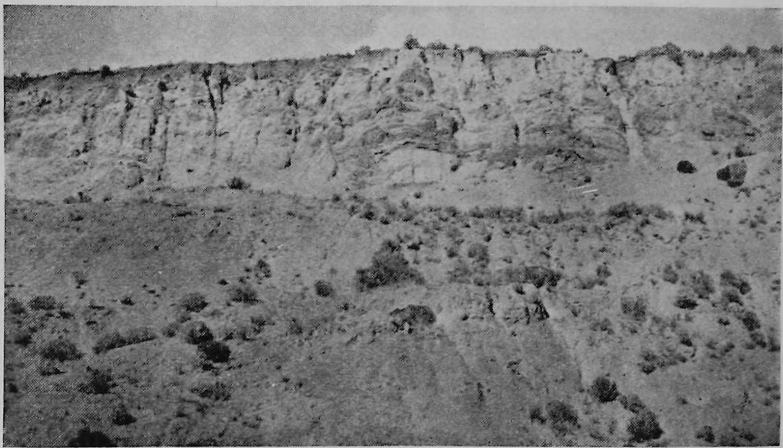

Fig. 3. Tertiary (?) or Quaternary Sandstones of the Pagoda fold.

large angular basalt bowlders scattered irregularly through it. At another locality the conglomerate was not present, but approximately 200 feet of white coarse sandstone, rather soft on account of its calcareous cement, was observed to occupy essentially the same stratigraphic position. And in parts of the sandstone there were tubular forms which suggested plant stems, worm tubes or burrows. From the lithological character and the stratigraphic position this formation would probably correspond more or less closely to the Browns Park group found a few miles west of the area under discussion in Axial Basin. In some places this sandstone is capped by sheets of basalt which forms high mesas. Most of the flat tops within this area showed this sandstone member associated with the basalt sheets. The character of the sediments, the close association of the basalt and this sandstone formation indicate that it is at least Tertiary or younger in age. There would have to be a sufficiently long time for erosion to remove the Mesaverde, (possibly the Lewis and Laramie), and part of the Mancos before this formation could occupy the horizon which it does. And if this period of erosion took place previously to the deposition of the sandstone it would probably be later than the beginning of Tertiary, because the period of erosion would mark a time interval between the Cretaceous and Tertiary.

The thickness of the Browns Park group varies from 150 to 400 feet. It is probable that the formation under discussion will approach 400 feet in thickness in most of the localities where a fair exposure can be found. Similar deposits, which probably belong to this group, are present near Yampa.

*South of Williams Park soft, friable cross-bedded sandstone, protected by a basalt flow or sheet, stands in a nearly vertical cliff 300 or 400 feet high. The white to gray rock above the green timber of the lower elevations and below the green timber of the basalt-capped table-land makes a conspicuous landmark visible for many miles. The thickness of the sandstone is not readily determined since sandhills from the disintegration of the sandstone that breaks from the cliff are piled up near the cliff as well as throughout an area about half a mile wide. Small remnants of sandstone in place and near the base of the formation are found farther west.

Inasmuch as the sandstone lies nearly level while the underlying Mancos shale has a pronounced dip in its nearest exposure, it is evident that the unconformity at the contact between shale and overlying sandstone is angular. Since no fossils were collected from these beds their age has not been determined. In appearance the sandstone cliff resembles the cliff of Green River sandstone west of the Grand Hogback, in Garfield and Rio Blanco counties, Colorado. Lithologically and structurally the sandstones south of Williams Park resembles the Laramie sandstone north of Hayden; but the unconformity below the former, representing a long erosion period, points to an age younger than Laramie for the beds under consideration.*

SURFICIAL DEPOSITS

At numerous localities within the area described there are alluvial deposits of sand, gravel and soil. The character of the material composing these deposits depends to a large extent upon the nature of the land from which the detritus or eroded material is derived. If the stream in general follows a sandstone formation, the nature of the deposit would probably be sandy and if it follows a shale formation, the deposit would probably be clayey in character varying from gray to black in color.

Another form of surficial deposit frequently encountered in the field is talus. A great many talus deposits are present in the Daton Peak quadrangle, and in many places they entirely obscure the geology.

POST-CRETACEOUS IGNEOUS ROCKS

The purpose of investigating the igneous rocks near Yampa was to determine the possibilities of oil accumulation in the sediments in connection with the igneous intrusions present. The problems offered in the field, therefore, dealt more with the mode of occurrence of the bodies relative to the structure of the sediments than to the petrography, and no microscopic work was undertaken for this report.

*From Bulletin 23 of the Colorado Geological Survey.

The sedimentary rocks have been intruded by igneous rocks in the form of dikes, plugs, necks, and sheets. As far as known all of the igneous rocks of this area may be classified as intrusive and of the same period of igneous activity. There are two general basalt types; the dense basalt type and the agglomeratic basalt type. The dense basalt type is the predominating rock It is a dark gray to black rock on fresh surfaces and weathers to a light

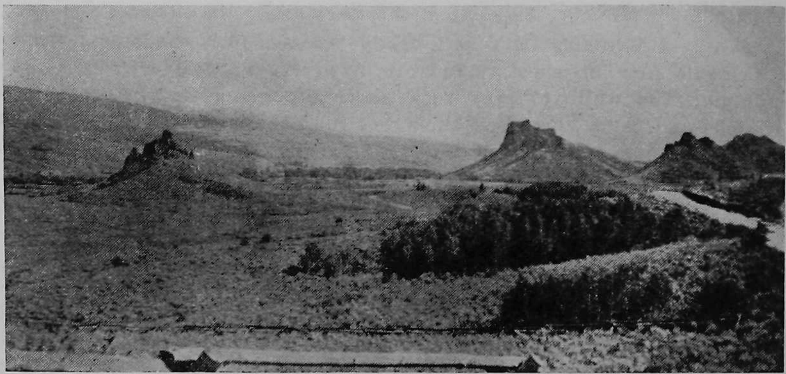

Fig. 4. Igneous Intrusions Near Yampa

gray or reddish brown. Locally, at the contact with sediments, the basalts have a more or less cellular structure. The scattered amygdules are composed of secondary calcite which gives the rock a spotted appearance. Water-deposited calcite and quartz veins are also at some places near the contact with the shales. Slaggy crusts are not common. Wherever the dikes project above the surface columnar structure is usually present. The mass is made up of horizontal columns several inches in diameter, which are often regular hexagons.

The basaltic agglomerates which make up parts of the larger intrusions are composed of angular pieces of quartz, feldspar, chert, granites, limestones, sandstones, and basalts which are held together by other basalt materials. The agglomerates weather to a reddish brown and are usually spotted by lighter patches where calcite has been deposited. These agglomerates indicate an explosive stage of eruption or the basalt lava may have picked the angular particles from the rocks through which they have intruded.

The igneous activity took place after Cretaceous times and probably late in Tertiary times. The greatest amount of igneous activity has taken place near Yampa. There are many plugs, necks, and dikes present to the southeast toward Toponas and to the northwest toward Phippsburg. The necks and plugs are usually large irregular bodies that stand high above the general level of the valley. The main outcrops of dikes north and west of Yampa are from 6 inches to 8 feet in thickness, though the majority are from 2 to 4 feet. These dikes decrease in thickness and number when they enter the sandstones of the Mesaverde formation. This is general and not the case in every instance. They usually have a straight or slightly curved course and stand almost vertical At some places where the dikes outcrop, they project above the surface as wall-like masses for many feet (See Fig. 7.) The dikes vary in length from a few hundred feet to a mile or more. The outcrops are not always continuous for this distance, as they have been covered with wash materials, and in some cases may have never reached the surface. The outcrops also show that they have been displaced at many places by minor faults and have split into smaller dikes. Whether or not faulting has been the cause of the irregularity is questionable. The basalt lava may have filled smaller fissures in the general fissure system which would cause the interruption in the outcrops and would shift them to a parallel position some distance from the main outcrops. The general course of the outcrops indicates that they are of the same dike system and probably have connections not far below the surface.

Another center of activity may have been at Pinnacle Mountain to the northwest of Yampa, where there is a large necklike intrusion with connecting dikes. This may, however, be a part of the main Yampa system of dikes which are united beneath the surface. A more detailed discussion of the modes of occurrence of the igneous bodies relative to the structure of the sediments can be found in the description of the folds and the Devils Grave "structure."

Metamorphism

The contact metamorphism produced by the intrusion of the igneous rocks in the sedimentary rocks has generally been very slight throughout this field. At many places there are well exposed contacts which show little or no metamorphism. At other places, however, there has been a partial fusion of the wall rocks but no metamorphic minerals are at the shale or sandstone contacts. Generally, there is less alteration at the sandstone contacts than at the shale contacts. The sandstones at the immediate contact usually have not been perceptibly hardened. On the southeast slope of Pinnacle Mountain, where a dike cuts the lower sandstones of the Mesaverde formation, considerable metamorphism was noticed. At this place the dike has split into several small dikes which have baked the sandstones for approximately 50 feet on each side of the main intrusion.

The contact zones in the shale formation are usually marked by a slight hardening of the shale. This may have developed new planes which can be seen at right angles to the normal bedding planes. This alteration seldom reaches but a few feet from the intrusion. Wherever the dikes have split into several small parallel intrusions more metamorphism is noticed. At these places and at others where the main intrusion is rather large the shales are black where they have been baked and burnt. These shales may show alteration for 10 or 15 feet from the intrusion. It appears that the liquid basic magna suddenly followed and filled definite fissures. This probably accounts for the slight amount of metamorphism. The fact that no noticeable tilting of the sediments accompanied the intrusion of the dikes also indicates that the dikes are fissure fillings.

The large intrusions in the form of necks and plugs have caused more metamorphism than the dikes. Definite contact zones are scarce and little detailed study could be made. These larger intrusions have tilted and at some places overturned the sediments.

POSSIBLE OIL AND GAS BEARING ZONES

The Mancos formation is lithologically an ideal formation for the accumulation of oil and gas. The Mancos sandstone is a suitable reservoir for oil and gas, and the shales above and below it are sufficient for capping purposes. There are other possible reservoirs in sandstone lenses that may be in the Mancos shales. The limestone and calcareous shales show jointing, fracturing, and water courses which might make them open enough to receive oil or gas. The lower members of the Mancos formation are highly bituminous and carbonaceous. They probably contain sufficient material from which oil and gas may be derived.

Oil has been found in the Mancos formation at Rangely, Colorado, and in similar formations in Wyoming.

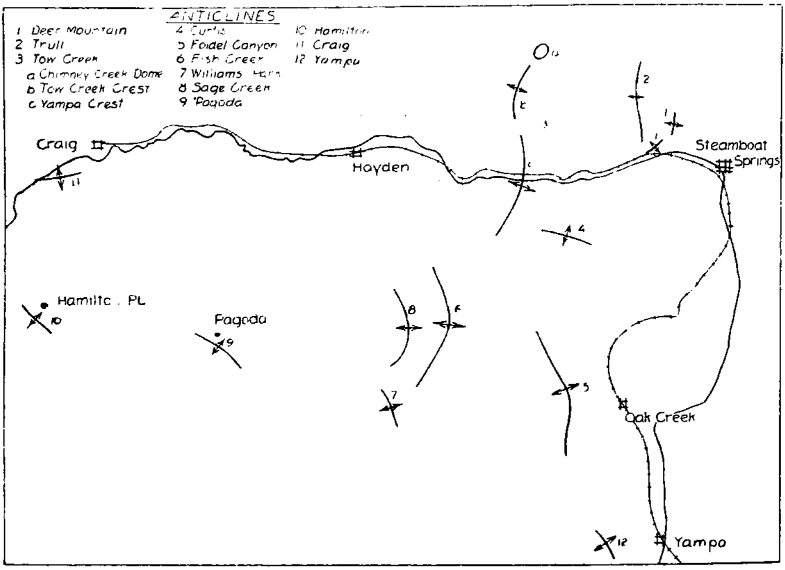

Fig. 5. Index map showing position of known anticlines of Routt and Moffat counties.

The Wall Creek horizon, also called the Frontier and the Nio-Benton, is in the lower third of the Mancos.

The "Dakota" sandstone is another possible reservoir. It has furnished considerable gas in three wells which have recently been drilled in Williams Park.

The highest sandstone of the "Dakota" is the Muddy sand of the Wyoming fields.

STRUCTURE

MAJOR FEATURES

The Yampa coal field, as described by Fenneman and Gale in Bulletin 297 of the United States Geological Survey, occupies a huge basin. The axis of this basin seems to have a northwest-southeast trend extending through Yampa on the southeastern end to a point some miles northwest of Craig. The large basin is bisected by a cross fold which is known as the Tow Creek anticline. As a result of this, a small basin is formed to the southeast of the Tow Creek anticline in the region drained by Fish Creek, Trout Creek, and Oak Creek.

Axial Basin, although somewhat to the south and west of the area described, occupies a valley roughly following the crest of the Axial Basin anticline. This anticline, was formed by the inceptive forces of the Uinta uplift, and the trend of the axis is northwest-southeast in general. A few miles northeast of Axial Basin is a syncline, which passes through Round Bottom, with an axis which is roughly parallel to that of the Axial Basin fold. The folds of the Yampa field with few exceptions have the same general trend as that of the Axial Basin structure. In some parts of this field there has been some cross folding such as the Tow Creek fold, and there are numerous other minor folds trending in the same general direction as the Tow Creek structure.

FAULTS

North and northwest of Yampa and east of Williams Park there are several large faults and many smaller ones. The major system of fracturing follows a northwest-southeast course which coincides with the fissure-filled dike system near Yampa. Minor fractures follow a northeast-southwest course. This system is apparent in the minor faults which have displaced the main dikes. The faults do not influence the structure of the sediments to any great degree as the displacements are usually less than 100 feet.

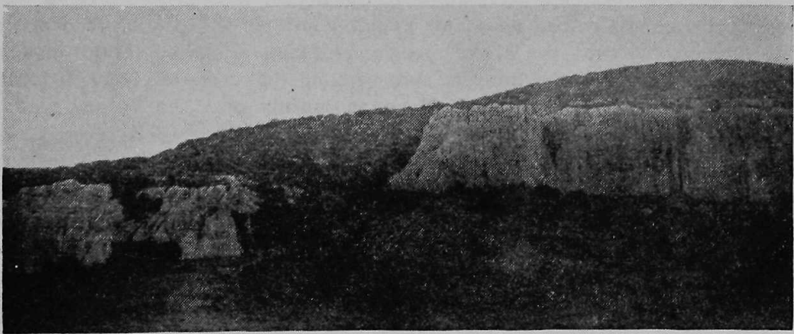

Fig. 6. Fault in the Twenty-Mile sandstone in Foidel Canyon.

The most easily recognized fault is in Foidel Canyon south of the Foidel-Williams Park road, where the Twenty-mile sandstone member of the Mesaverde formation has been displaced approximately 100 feet. (See Fig. 6.) It is probably a normal fault with the downthrow on the south block. This fault trends northwest. South of Fish Creek and between Williams Park and Foidel Canyon it may be traced nearly to Dunkley Canyon. The upper thin sandstone of the Mesaverde and parts of the Lewis shales have been tilted and buckled by this fault. Abnormal south dips were found in the fault zone, which are probably due to a pivotal movement which raised the south block of sediments to the northwest and lowered them to the southeast in Foidel Canyon. This area is partly covered by wash materials which make a detailed study impracticable.

Another fault is present on Middle Creek in the Trout Creek sandstone member of the Mesaverde. In the displacement the north block has dropped about 50 feet.

Faults are reported in the coal mines near White City. Mr. Guy S. Newkirk, Engineer for the Moffat Coal Company, stated that there are three faults present which have a northwest trend and have displaced the lower coal groups from 25 to 90 feet.

A small fault shows on the east bank of Trout Creek one mile south of Pinnacle postoffice. The downthrow is on the south block with a displacement of about 25 feet. This fault is questionable as the sediments are for the most part covered, and the fault shows only in one massive sandstone.

About 4½ miles north of Phippsburg on the Yampa-Steamboat Springs road the "Dakota" and the lower members of the Mancos formation have been faulted considerably. Since sufficient time was not available to study this fault system in detail, only a very general discussion will be possible. The "Dakota" formation at this place has been overturned, and a block fault appears to be present in Yampa Valley. The "Dakota" and "Red Beds" have been thrown to the south in an abnormal position. A pivotal motion appears to have accompanied the fault which has raised the sediments to the south. This fault may run close to Yampa River and extend nearly to Yampa. North of Yampa the middle members of the Mancos formation are above the upper members, and the Mesaverde beds to the east are also in an abnormal position in respect to the beds to the west. The Yampa River apparently follows this fault plane to the north.

Approximately one mile and a half south of the "Dakota" overturn on the Yampa river at the above mentioned place, a diagonal fault has placed the Mancos limestone below the Mancos sandstone member. Small faults are noticeable between Yampa and Toponas, mainly near the county road. The folding and overturning which have taken place have been accompanied by minor faults and fractures.

A small fault with a displacement less than 100 feet was noted in Section 9, T. 4 N., R. 90 W. The sedimentary rocks, in which the evidences of faulting were noted, are lower Mesaverde in age. The nature of the fault was not definitely determined but, in general, it seems to have been of the normal dip-slip type. It seems probable that the movement of one block was towards the west in the direction of the dip, but owing to the fact that evidence was meager, the conclusions put forth above are more or less speculative in character. It is not probable that this fault was of magnitude enough to materially affect the oil possibility of the Beaver Creek structure.

On Williams Fork, on the western side of Peck Homestead Gulch, a small vein or fissure of solid bituminous material about one inch in thickness similar to elaterite was found. This vein was exposed in two places. The presence of this bituminous material in such a deposit indicates that some movement has taken place of sufficient magnitude to develop a fissure through which the hydrocarbons could pass. The vein has a northeast trend and is so narrow and local that the writer does not consider it large enough to have drained whatever accumulations of oil may have taken place below the surface.

FOLDS IN RESPECT TO OIL AND GAS POSSIBILITIES

Foidel Fold

The axes of the Twentymile Park-Toponas syncline and the syncline roughly parallel to Williams Park converge as they extend to the north in Twentymile Park. (See Pl. I, in pocket.) Between these two synclines there is a large terrace-like fold in the Mesaverde formation which extends almost to Flat Top Mountains to the south. It has been called the Foidel fold as Foidel Creek has cut its channel through the prominent Twentymile sandstone member of the Mesaverde formation in Foidel Canyon. This stands as a high white cliff and follows the lines of the fold to the east and the west in the shape of a horseshoe. Fenneman and Gale[3] mapped part of this fold.

The sediments along Foidel Creek, Middle Creek, and Trout Creek dip 7° to 11° to the north and northwest. In Foidel Canyon the direction of the dips starts to swing to the northeast. The amount of dip increases to the southeast. East of Foidel Canyon the dip is about 15° and increases to 35° and 40° at Trout Creek. Between Trout Creek and the Devils Grave mesa the dips gradually decrease. About a mile west of the town of Oak Creek they average 5° northeast. East of Oak Creek valley and about about three miles west of Phippsburg the dips vary from 1° to 3° northeast.

The greater part of the area is covered by vegetation and a mantle of soil and rock. This is especially true between Oak Creek and Trout Creek where there are few outcrops. The outcrops are usually made up of thick-bedded sandstones which have either been eroded a great deal or show signs of slumping. For this reason most of the slight dips recorded are questionable. The general direction of dip is to the northeast and northwest. These gentle dips give a broad and almost flat crest to this fold between Oak Creek and Trout Creek. The general amount of dip increases to the south from 4° to 12° in a north and northeast direction.

This broad gentle crest makes the determination of the position of the axis almost impossible. The fold was mapped by the general methods used in reconnaissance work, and no structural contour map was attempted which would determine the position of this axis accurately.

The upper and middle members of the Mesaverde formation are exposed around the outer limb of the fold, and lower members outcrop along Trout and Oak creeks and near Pinnacle. West of Pinnacle Mountain along the Pinnacle-Williams Park road the carbonaceous shales and silt of the lower Mesaverde are exposed. The lower thin sandstones of the Mesaverde extend from Pinnacle Mountain to the east to Devils Grave Mesa. Some distance to the south of the above-mentioned road the Mancos shales

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[3] U. S. Geol. Survey Bull. 297, Plate I.

outcrop occasionally where they are not covered by wash materials and soil.

Pinnacle Mountain, a prominent land mark between Trout and Oak creeks, stands as a high, sharp knob. (See Fig. 7). It is an igneous intrusion of basalt, probably in the form of a neck or plug with dikes extending from it to the northwest and southeast. The dikes are similar to the Yampa dikes and have the same general course. It is believed

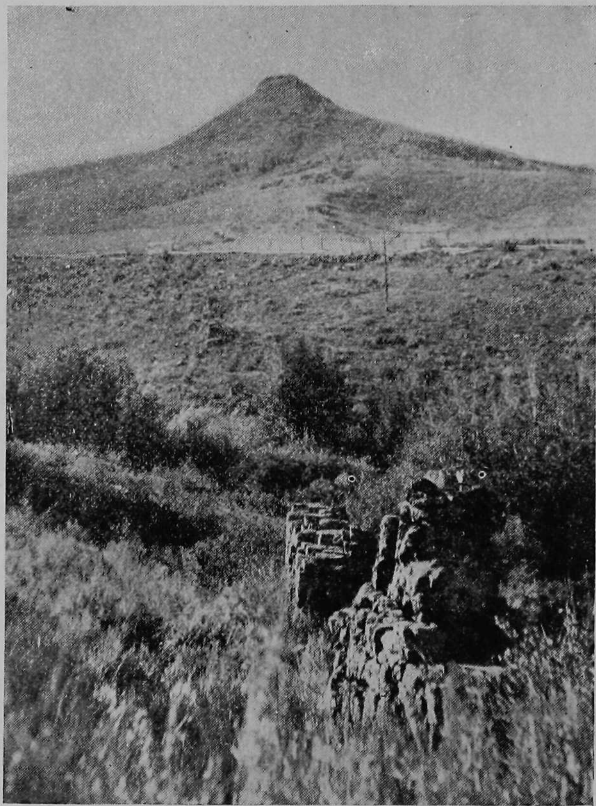

Fig. 7. Pinnacle Mountain, Showing Connecting Dike.

that the Pinnacle and Yampa dike systems came from a common reservoir and are probably connected not far below the surface of the ground. Outcrops of this dike were searched for between the known outcrops, but none could be found. The dikes extend almost to Trout Creek.

Oil and Gas Possibilities.—There are two possibilities of oil and gas accumulation in this fold. The fold may be considered as a terrace type which is shown by a marked lowering of the angle of dip; at places the fold becomes almost flat. Any oil and gas migrating up the steep dip might accumulate in the reservoir where the beds start to flatten. The water pressure would have to be low enough not to produce further movement to the south. Or, if the water pressure were great enough to produce movement to the south, there is a possibilty of another accumulation to the north and northeast of the dikes. If there is a laccolith present which has caused the arching of the strata, favorable and unfavorable occurrences of igneous bodies may or may not be present. If a laccolith is below the reservoir, the dikes and plug at Pinnacle must have extended through about 4,500 feet of sediments. This is possible, especially when continuous dikes are thought of which extend for many miles at the surface. If this extension is present there is a possibility of oil and gas accumulation. The dike itself may change from a small plug or short dike beneath the surface and radiate and widen as higher beds are reached. Any occurrence of these bodies which is not continuous through the reservoirs and which does not seal it tightly would be unfavorable. A laccolith, if present, may have replaced the reservoir entirely, which would make chances for oil and gas accumulation at its borders slight. There is also a possibility of many sprouts from the main igneous body being present which do not outcrop and which may easily trap possible oil, or ruin the reservoirs for any accumulation.

The dikes and plug may extend from the basalt complex through the entire series of sediments with no laccolith present at all. The outlet at Pinnacle might have been large enough to prevent the formation of a large sill or laccolith.

In the section on faults (page 21) the different displacements occurring in this area have been discussed. The displacements have not been great enough to seriously affect any great leakage as they probably do not extend as faults through the Mancos shales. An oil seep was reported at the Foidel Canyon fault, but the writer could not find any traces of bituminous matter. Investigation brought out the possibility that the oil was "canned oil" placed there with the idea of helping a stock-selling scheme.

In order to ascertain a fairly accurate depth to the Mancos sandstone throughout the fold, the lowest seam of the lower beds of workable coal of the Mesaverde was used as a reference bed. The Mancos sandstone lies about 5,100 feet below this seam, and the top of the "Dakota" is about 450 feet lower. The Tow Creek sandstone was not used as a reference bed as it is considerably covered, while the coal beds have been exposed by mining. The thickness between the Tow Creek sandstone and the lowest coal bed varies from 20 feet to over 100 feet.

According to the topographic work done by Fenneman and Gale, Trout Creek has a rise of about 700 feet between the junction of the Trout Creek-Oak Creek road at a point on Trout Creek due west of Pinnacle Mountain. With this rise in elevation to the south the creek cuts lower strata in the lower Mesaverde formation and finally into the Mancos formation. In a line not far from the Pinnacle plug an dikes to the north, and on a level with Trout Creek, the Mancos sandstone lies at a depth of about 3,700 feet. In Trout Creek Canyon about three-fourths of a mile south of the Oak Creek road the Mancos sandstone lies about 4,500 feet below the level of the creek.

The formations along this limb dip about 30°. This dip was considered in the above estimate.

Until the known domes and closed anticlines of this area are completely tested, and until the Mancos formation is known to contain oil in commercial quantities, the writer does not recommend that this fold be tested. The expense involved in the deep drilling which would be necessary is too great to warrant any test in an unproven formation under these circumstances.

The Devils Grave "Structure"

Anticlines, domes, synclines and other structural features are usually the result of mountain-making movements. Structure means the attitude rocks have acquired since they have been formed. The popular word structure, however, is probably used incorrectly in many cases to mean a definite structural feature as a dome, syncline, anticline rather than the attitude of the rocks which gives form to these features. It has also been used as a name for any area which may have an oil or gas possibility even if no definite structural feature is present. This name, for example, has been given by other persons to the area under discussion near a narrow dike where there is a possibility of oil and gas accumulation.

The Devils Grave mesa lies approximately 3½ miles northwest of Yampa, north of the Yampa-Pinnacle road. This mesa is a prominent landmark and stands several hundred feet higher than the Hunt creeks to the west and to the south. The thin-bedded, yellowish and gray sandstones of the lower Mesaverde form the cap rocks of the mesa. These sandstones look like a Tertiary deposit from a distance and form cliffs at the edges of the mesa. At the southeast end of the mesa a high tomblike remnant of these sandstones stands out from the main body of the sandstones forming the cliffs. It was this tomblike mass that suggested the name Devils Grave. Beneath the sandstone cliffs are slopes in the easily eroded Mancos shales. At places badlands topography has been developed. The so-called Devils Grave "structure" includes the area to the north and northeast of a dike which is south and southeast of the Devils Grave mesa. This dike is about four miles long and is the most significant dike in the area. There are many other shorter and narrower dikes present.

The main dike can be found south of the Cromer ranch where it crosses the main road to Heart Mountain. From this point it may be traced northwest to Middle Hunt Creek, where it disappears. It outcrops again west of the Gumlick ranch and may be followed to the Yampa-Pinnacle road. (See Pl. I, in pocket.) From a point south of Cromer's ranch it may be traced in a southeast direction approximately one-half a mile from the Wood-Stark ranch. This dike is not found at every place as it often disappears under the wash materials. It has been faulted or shifted at many places, which also makes it difficult to follow.

Another dike about one mile long is half a mile south of the tomb of the Devils Grave mesa. The southeast end of this dike stands above the general level of the surrounding land as a sharp knoll.

The axis of the main Twentymile Park-Toponas syncline passes through the northwest corner of the Devils Grave mesa. The lower Mesaverde sandstones dip 25° due west at the northwest end of the

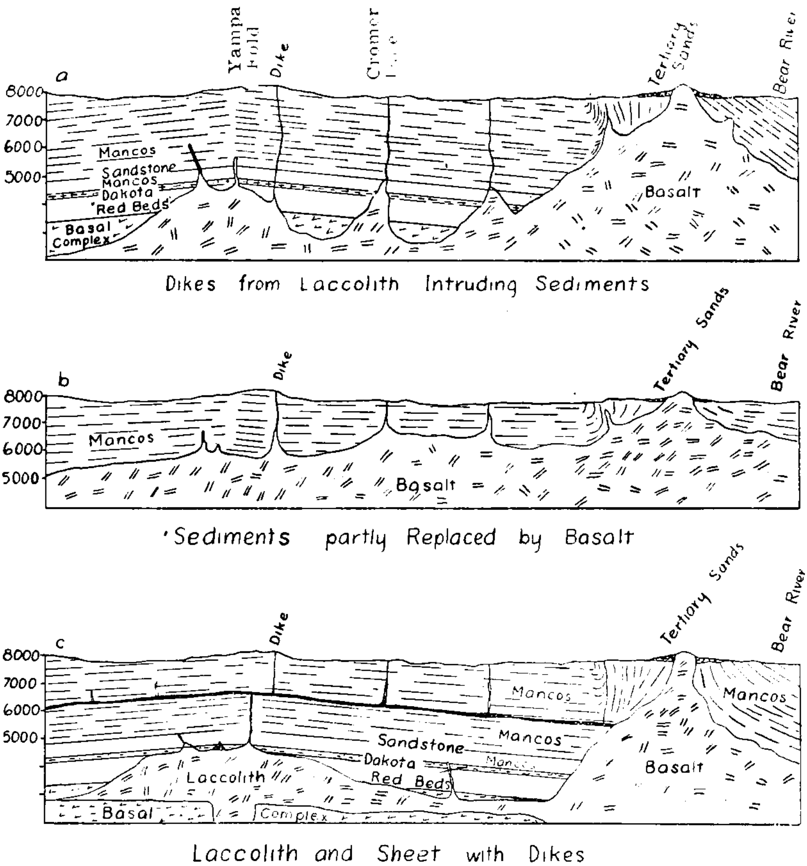

Fig. 8. Hypothetical cross-sections showing possible relationships of rocks in the Devils Grave "structure."

mesa. The Mancos shales on the east limb of this syncline near Yampa are overturned and dip 60° to the northeast. The dips on the west limb are more gentle, and are from 2° to 20° northeast.

The Mancos shales south of the Devils Grave mesa and north and northeast of the main dike have a general northeast dip. This is especially true along the northeast exposures of the dike. The dips recorded vary between 2° and 12° N. 5° E. to N. 30° E. The direction of dips to the north along the dike changes slightly to the north and northwest, but northeast dips were also found. The dips average approximately 5°. The shales south of the dike also dip to the northeast and northwest, and are a part of the northeast limb of the Yampa fold. Owing to the fact that the sediments dip away from this dike, and that the dike itself follows a slightly curved course which would form a possible check or trap for oil or gas in any reservoir below, there is a possibility of oil and gas accumulation to the north and the northeast of the dike. The mode of occurrence of this dike and other dikes, and their relationship to the sediments below is the paramount problem which must be considered. If this main dike, which averages about 3 feet wide at the outcrops, continues as a dike through approximately 4,000 feet of sediments, there is a possibilty of oil and gas accumulation. (See figure 8a.) This would be the ideal occurrence. These dikes are possibly stringers from a laccolith which may have caused the arching of the Yampa fold. (See figure 8a.) It is probable that these dikes, or igneous bodies below have cut the "Dakota" or pre-Cretaceous rocks, as a sulphur spring giving off hydrogen sulphide gas is on the north side of the dike at the Wood-Stark ranch. Field study leads to the conclusion that all of the sulphur springs originate in the "Dakota" or older rocks. This spring, therefore, indicates a leak in the sediments below with a water course along the dike to the surface.

Other possible occurrences must be taken into consideration. The presence of several sheets north and northeast of Yampa suggests that the dikes are stringers from a larger sheet following the bedding of the Mancos shales (Figure 8c). This would account for so many small stringers from 6 inches to 1 foot wide that are present at some distance from the main longer dikes. If this were true there would be no possibility of oil and gas accumulation other than in the sandstone lenses that may be present in the Mancos shales. One of the most prominent sheets follows the strike of the overturned and almost vertical shales. It is possible that these are dikes which have been intruded subsequent to the folding and have followed the bedding planes in this shattered and fractured zone. Other possible occurrences, such as a laccolith or thick sill near the surface, would take the place of the sediments below (Figure 8b). Or the dikes and larger plugs may fill channels from the basal complex below, through which the lava has come to the surface and now forms the basalt sheets of the Flat Top Mountains. The other dikes north of the main dike, the plug and dikes on the Devils Grave mesa and the dikes northwest of this mesa may affect this area to a considerable degree. These bodies may localize the oil and gas if present and thereby limit the gathering area of the main "structure." For instance, the dike south of the Devils Grave mesa may connect with the main dike beneath the surface. This would extend in a line passing south of the Cromer ranch house and would probably trap any gas or oil to the north of this point.

In areas where intruded igneous rocks are found, the possibilities for oil and gas accumulation are usually questionable. In certain Mexican fields, however, intrusions are found in many of the productive fields, so it would not be fair to condemn a field on account of the presence of igneous activity. The dikes were probably intruded subsequent to the folding or simultaneously with it. The slight amount of metamorphism would not seriously carbonize the bituminous materials for any great distance from the intrusions. The general belief that the entire area has been "burnt out" is incorrect. This, of course, depends on the form of the intrusions below the surface and also their position relative to the sediments, but surface conditions do not suggest this. If this "structure" is tested by wells drilled at no great distance from the main dike, or by wells drilled near the Cromer ranch, the Mancos sandstone, if present, should be encountered at a depth of about 3,200 feet below the general level of Hunt creeks.

The writer does not feel justified in recommending that any test wells be drilled in this area. The Mancos formation in this field has not as yet been proved as an oil-bearing formation. The closed anticlines* and domes, which are present near this area and which are almost structurally perfect for the accumulation of oil, should be thoroughly tested. If it is then proved that these folds contain oil in commercial quantity other possible traps such as the Devils Grave "structure" might be tested. It also appears that the depth of this reservoir is almost prohibitive under the rather questionable structural conditions.

The Yampa Fold

About 5 miles west of Yampa there is a slight fold in the Mancos shales. This fold is in the nature of a "nose" which plunges to the northwest and gradually opens to the southeast. Southwest dips are at Heart Mountain and to the west in the sandstones of the lower Mesaverde formation. The dips are from 5° to 8°. The direction of the dip gradually swings to the north and northeast on the northeast limb and then swings again to the north and northwest, which opens the fold. Most of the dips are low and vary from 2° to 10°. The sediments forming the southwest limb are mostly covered by a dense mantle of wash materials and vegetation which made close study impossible. Southwest and west dips from 2° to 5° are found, but no closing southeast dips could be accepted. The sediments at the southeast end of the fold dip gently to the north and northwest. Occasional reverse dips are present, but they are not accurate, as they change in very short distance. Horizons in the upper Mancos were followed as closely as possible, but no closure could be obtained. There are several dikes near the axis of this fold, which are probably stringers from a sill or laccolith which has arched the strata. (See Figure 8c.)

A nose or a pitching anticline is not generally accepted as a suitable structural feature for the accumulation of gas and oil. There would be a leakage at the open end which would allow the escape of any oil or gas which might migrate up the dip when associated with water under pressure. The writer does not recommend that any test wells be drilled in this anticline.

*Colorado Geological Survey Bull. 23, 1920.

Pagoda Fold

The Pagoda structure is composed of two anticlines having axes trending northwest and southeast with a syncline between them.

The anticline to the north, or that structure which lies along Williams Fork River, has a small dome on the western end of the structure in the immediate vicinity of Deakins ranch. To the east of this dome, along the same axis, it is found that this anticline proper does not close on the eastern end, but swings around more or less in the shape of a horseshoe. This anticline has a curved axis, as a whole, pitches gently to the northwest so that the eastern end is the structurally highest point. The dips along the northern limb of the structure are fairly uniform, averaging about 12°. Along the southern limb of the structure the dips are steeper than those of the northern limb and range from 9° to 30° in most cases. The fold is therefore asymmetrical in character and the axis will be closer to the southern limb than to the northern.

Fig. 9. Upper beds of the Mesaverde formation on the Williams Fork dome

There appears to be somewhat of a constriction or closure on this structure in the vicinity of Pagoda postoffice. The only part of this anticline that holds any structural possibility whatsoever of oil or gas would be the small dome extending in general from Pagoda postoffice to Deakins ranch. There is one dip shown on the map, Plate I, of this area, of 17° S. 70° W, which does not adjust itself well to the rest of the data taken for this structure and might indicate local movement of some kind, possibly faulting. No other evidence of faulting was observed in that locality, but evidences may have been obscured that they were not noted.

The syncline, which parallels the anticline just described, is pitching from the southeastern end in Section 28, T. 4 N., R. 89 W., to the northwest.

It can be traced more or less accurately to Peck Homestead Gulch in Section 35, T. 5 N., R. 90 W. The dips on the northern limb of the syncline range from 10° to 30°, but those of the southern limb are not so steep. They range from 4° to 10°, thus effecting an asymmetrical syncline.

The southernmost anticline, or the Beaver Creek structure, pitches rather gently in a northwesterly direction. The dips on the northern limb of the fold vary from 5° to 10°. On the other limb the dips are higher, and range from 10° to 58° probably averaging 30°. A closure on the western end of the anticline was found in Section 9, T. 4 N., R. 90 W. In Section 5,

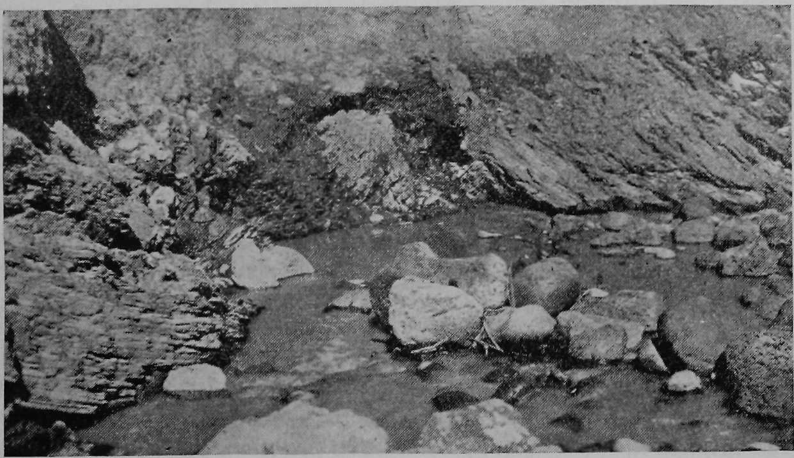

Fig. 10. Showing Intense Folding of Mancos Shale, Beaver Creek

T. 3 N., R. 89 W., the swing in the strike of the beds indicates a closure on that end, but inasmuch as no northeast dips were obtained nearer than the northwest quarter of Section 32, T. 4 N., R. 89 W., there is a possibility that this axis curves and does not close. Had it been possible to obtain dips and thus find the general attitude of the formation in Section 35, T. 4 N., R. 89 W., and in Section 5, T. 3 N., R. 89 W., the general structure could have been worked out more closely. In view of the fact that the only evidence tending to complete a closure on this end of the fold is the swing in the strike of the beds taken on the southern limb and considering the deficiency of dips and reliable information concerning the southeastern end of this anticline the writer does not feel justified in asserting that there is an unquestionable closure for this structure. It was very difficult to determine the true geologic relations of this end of the fold because of the covering of the Mancos shale and Mesaverde formation by the Browns Park (?) formation and the lava sheets which are very numerous in this part of the field.

Near Shirkey's ranch in Section 31, T. 4 N., R. 89 W., the dips indicate a constriction, but probably not a closure, since the sandstones on the south limb are very constant and continuous. In Section 15, T. 4 N.,

R. 90 W., a dip of 9° N 70° E. was obtained in the shale of a newly made gully. This dip was the only one obtainable on the northern limb of this anticline owing to the capping of basalt and sandstone which seems to be ever present in the Daton Peak quadrangle above elevations of 7,500 feet. This dip of 9° would indicate a constriction at this point, but since other dips were not available it is not conclusive or worthy of great consideration.

Oil and Gas Possibilities.—The dome located on Williams Fork, previously described, is a structural possibility for oil and gas since the dips taken point to a closed structure. The outcropping formations in this structure are the lower part of the Mesaverde formation and the upper part of the Mancos. Approximately 200 feet of Mancos has been eroded from the crest of the anticline. The possible oil sands in this region are the "Dakota" sandstone, the Mancos sandstone lying about 400 feet above the base of the Mancos, and possibly some lenticular sands within the Mancos formation. From a section taken of the Mancos formation in the vicinty of Yellow Jacket Pass near Wyman's ranch the thickness was found to be 4,000 feet. It is possible that this thickness may be a trifle low because of the following facts: (1) Exposures were so scarce that the exact attitude of the beds may not have been determined; (2) The contact between the Mancos and "Dakota" was not sharply defined.

In calculating the depths of wells necessary to reach the "Dakota" formation, the thickness of the Mancos was taken as 4,000 feet. Taking the above thickness for the Mancos the "Dakota" sand could probably be reached at a depth of 3,800 to 4,000 feet in this dome, but the sandstone in the Mancos should be reached at approximately 3,500 feet. This would mean a deep well, and the structure is so small that the writer does not see fit to recommend it for drilling until production is found in the general region.

From the crest of the Beaver Creek anticline about 1,600 feet of Mancos shale has been eroded. On account of this fact a well drilled to the "Dakota" formation would probably be at least 2,500 feet deep. The highest point on the structure, according to data collected, is in Section 5, T. 3 N., R. 89 W., very close to the center of the section, and this would probably be the proper position for a test well. Until production is assured in Williams Park or neighboring structures which look more promising than this one, the writer would suggest that definite action be delayed and that a very thorough examination be made of the geology in Sections 5 and 8, T. 3 N., R. 89 W. As mentioned previously, there is a possibility that this end of the structure swings rather than closes, and to effect a closure the strike symbols of beds in outcrops two miles apart must be prolonged to an intersection.

HAMILTON DOME

In Section 33, T. 5 N., R. 91 W., and in Section 4, T. 4 N., R. 91 W., there is a dome, elliptical in shape, known as the Hamilton dome. The axis of this elliptical dome trends almost due northwest. The dips along the northeastern limb of the structure are fairly gentle and range from 5° to 12°. The southern or southwestern limb has dips considerably higher than those of the other limb. Dips on this limb vary from 13° to 34°, averaging about 25°, and thus make an asymmetrical dome. The formation which outcrops in this structure is the Mancos.

Oil and Gas Possibilities.—The Mancos shale, to a depth of 800 feet, has been eroded from the crest of the Hamilton dome. Judging from the thickness of the Mancos to the north of Yellow Jacket Pass and allowing 10 per cent for possible error the "Dakota" formation should be reached at a depth of 3,500 feet. This figure would be much higher if the thickness of the shale should be more than 4,500 feet. This structure is one of the most favorable structures for a possible oil reservoir in Moffat county, but is at a disadvantage because of its size. It is very small and would be expensive to drill, but it would make a splendid location for a test well. For a test well the writer would suggest a location about three-eighths of a mile S. 20° west of Weyand's house.

CRAIG ANTICLINE

There is a small structure about 3 miles southwest of Craig with a general northeast-southwest trend. The Yampa River follows the axis of this anticline very closely. The outcropping formation on which the dips were taken was mapped by the United States Geological Survey[5] as upper Mesaverde, and, since this structure was not mapped in detail, the geology as worked out by the United States Geological Survey was accepted. The general map accompanying this report agrees closely with that shown in the bulletin mentioned. The dips on the northern limb of the structure range from 5° to 10°. On the southern limb the dips are slightly higher, averaging about 9°. This structure is small and probably about 500 feet of upper Mesaverde has been eroded from its crest. This figure is a very rough estimate since the work done by the writer and party was more in the nature of a general reconnaissance.

Oil and Gas Possibilities.—Owing to the fact that the surface of this structure is in the upper Mesaverde formation and that the most probable oil sands in this region are located in the lower part of the Mancos formation and the "Dakota" which lies below the Mancos, the writer is not disposed to recommend this structure as favorable for oil. It has been suggested by some people that there is a possibility of finding oil in some of the lower sandstone members of the Mesaverde formation. There are three sandy horizons in the lower part of the Mesaverde formation, alternating with shale beds. These conditions would make it possible for the sand members mentioned to be oil bearing, but in the well drilled by the Richmond Petroleum Company on Wilson Creek these sandy horizons were

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[5]Gale, Hoyt S., Coal Fields of Northwestern Colorado and Northeastern Utah; U. S. Geol. Survey Bull. 415, Plate XVI, 1910.

not found to be productive. In no locality has the writer observed any oil seeps or other favorable signs of oil in the lower sandstones of the Mesaverde formation and hence is disposed to regard them as more or less barren. However, should oil in commercial quantity be found anywhere within the Yampa field this structure would be worthy of further investigation. On account of the depth of possible oil-bearing sandstone a test well would be expensive.

WILLIAMS PARK ANTICLINE

*This name is here applied to the highest structure in the Park—that lying southeast of Willow Creek. The structure might be considered a bulge on an extension of the Sage Creek anticline, but it is separated by at least one synclinal fold from a closed structure several miles north of the anticline named. Whether or not it opens directly into Fish Creek anticline without intervening synclinal folding has not been determined because of the absence of outcrops from a considerable area.

The thickness of Mancos shale remaining along the axial plane of this fold is less than 300 feet. Erosion has removed the Mancos sandstone from the crest and exposed this member for short distances along both limbs of the fold. The limestone bed that lies a little higher in the formation outcrops on the east limb, but is covered with mantle rock on the west limb. These lowest exposed beds have a dip of 35° to 60° on the east limb and a fairly uniform northward strike throughout the area of limited exposure. The sandstone on the west limb of the fold has a dip of 5° to 10° where it is exposed, and the direction of dip changes greatly and frequently along the short line of outcrop. Several of the determined dips are shown on Plate II. It is evident that there are local wrinkles on the main fold; this is brought out more clearly when the strike of the lower beds is compared with the strike of the shale beds higher in the formation. Although the southernmost determined dip on the west limb indicates a northward pitching anticline, it is obvious that the southward convergence of the strike directions of the higher beds on opposite limbs of the fold tend to close the structure. (See Pl. II.) Further, the presence of gas in the "Dakota" sandstone, as shown by the flow in two wells, points to the possibility of a closed structure. Owing to the scarcity of outcrops the structurally highest point on the anticline has not been located.

FISH CREEK ANTICLINE

A prominent anticline with curving axis can be followed along the east side of Williams Park, thence west of north to a point two miles or more northwest of Grassy Gap. Near the south border of the park the axis of this fold trends southwest. This anticline was mentioned as part of the Tow Creek anticline by Fenneman and Gale,[10] but since it is separated from the main Tow Creek anticline by a deep synclinal fold while

*From Bulletin 23, Colorado Geological Survey.
[10]U. S. Geol. Survey Bull. 297, p. 14.

the axis near its north end trends in a direction greatly different from that of the Tow Creek anticlinal axis it seems advisable to treat this structure separately. Owing to the fact that Fish Creek runs near its axis for several miles it is here called the Fish Creek anticline.

Like most of the anticlines in this general region this fold shows a higher dip on the east limb than on the west. The dip on the west limb is 15° or less throughout the length of the fold excepting at the north part where it increases to more than 20°. For the most part the dip of the east limb is between 15° and 50°. The anticline pitches northward throughout its known length. Toward the south side of Williams Park the axis bends sharply toward the west, and the anticline merges with the Williams Park structure previously described. There is, however, an area of about a square mile in which no outcrop appears and which may possibly contain a structural terrace or even a shallow syncline.

SAGE CREEK ANTICLINE

The Sage Creek anticline was mapped by Fenneman and Gale[11] from Williams Park to a point about four miles south of Hayden where it dis-

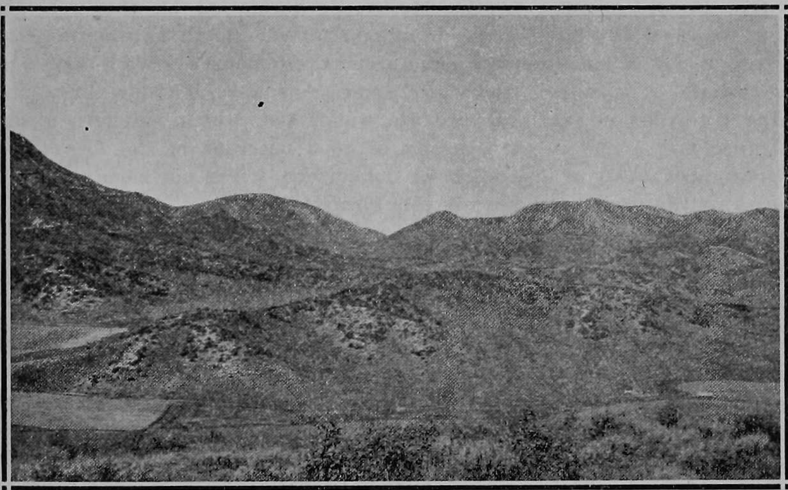

Fig. 11. Sage Creek anticline looking north from Williams Park

appears under the Lewis shale. These geologists, who were concerned chiefly with the coal-bearing Mesaverde formation, did not work out the structural details in the Mancos shale in Williams Park. This anticline also is asymmetric with the east limb dipping more steeply than the west. One prominent nose on the west limb in section 15, T. 5 N., R. 88 W., is the only notable minor feature where the Mesaverde beds are exposed.

The Sage Creek anticline, pitching northward, can be easily followed

[11]Op. cit., pp. 15, 54.

from section 35, T. 6 N., R. 88 W., southward for seven miles or more to Williams Park. In the park the most evident broader structural and topographic features seem to combine to obscure the details of structure, and in a rapid reconnaissance one might easily receive the impression that this anticline passes without interruption into the Williams Park structure previously described. It was only by close attention to details and after much digging with pick and shovel that a closure about half a mile north of the Dunkley schoolhouse was proved. Dependable readings of southeastward dips of 3° to 40° were taken. While some of these observations were made where weathering may have increased the dip of the shale near the surface there is no evidence that weathering has affected the strike. It will readily be seen from the convergence of the strike directions on the opposite limbs of the fold that there is a good closure between the schoolhouse and B. A. Long's farm house. (See Pl. II.) It is further evident from the approximate parallelism of strike of the beds on the opposite limbs that the intersection of the axial plains with any bedding plane is nearly horizontal for about a mile.

MINOR FOLDS

One prominent nose in the Mesaverde formation on the west limb of the Sage Creek anticline has been mentioned. South and southwest of Hayden in a few localities the general north to northwestward dip of the Lewis shale is very low and even approaches zero. About three miles south of Hayden a southeastward dip was noted, which indicates a small anticline; but, owing to the scarcity of good outcrops of the Lewis shale and the unreliability of dips taken at the surface, it has not been practicable to work out details of structure in this formation.

OIL AND GAS POSSIBILITIES OF THE STRUCTURES DESCRIBED

The chief factors to be considered in connection with the oil and gas possibilities of the region are: (1) the capacity of the sedimentary rocks for the formation of oil and gas; (2) the presence or absence of suitable reservoirs for the reception and storage of oil and gas; (3) the depth of such possible reservoirs from the surface; (4) the ground-water conditions; and (5) the degree of regional alteration to which the beds have been subjected.

The lower beds of the Mancos shale are highly carbonaceous, and there is no apparent reason to doubt their capacity for the generation of oil and gas. In Wyoming, sandstones in similar shales of approximately the same age have in recent years yielded much petroleum. In the Rangely, Colorado, field, near the Colorado-Utah line, oil has been found in the Mancos formation. Formations below the Mancos in the region under consideration contain a relatively small amount of shale. In the Mesaverde formation overlying the Mancos there are, in addition to the coal seams, many shale beds that carry considerable carbonaceous material.

The "Dakota" sandstone, though in places quartzitic and nearly tight, is usually open enough for the free circulation of ground water. In the Williams Park anticline a considerable flow of gas is reported from two wells that have been drilled into this sandstone since the Survey party was in the field.

About 400 feet above the "Dakota" sandstone is a persistent sandstone member of the Mancos shale. (See p. 13.) This member, which is 25 feet or more in thickness, is composed chiefly of sandstone with intercalated beds of shale and limestone. The sandstone is only moderately porous, but these beds have openings enough for the circulation of ground water as evidenced by at least one spring at the outcrop in the Williams Park anticline. It is believed that the porosity is sufficient for the reception and circulation of oil and gas. The overlying shale furnishes a compact cover that would prevent the escape of petroleum where structural conditions are favorable to accumulation.

Several anticlines of this region are open at one end and have a fairly constant angle of pitch. Owing to the probability of leakage at the open end such anticlines are generally not suited to the accumulation of oil and gas. Only those will be considered here which are closed or which do not furnish conclusive evidence of being open.

Conditions indicating the southward closure of the Williams Park anticline were mentioned on page 34. Even if the change in dip and strike of the beds should not be sufficient to effect a closure, leakage might be prevented by basalt dikes. A dike, or sheet, dipping 20° southward, may be seen a mile or two southwest of the exposed crest of the fold. This rock is in part nearly compact and similar to the basalt that overlies the sandstone of the cliff farther east; it is in part vesicular, with cavities that have a maximum diameter of about two inches. It is obvious that the basalt might form either an impervious cover or a good reservoir, depending on the degree of compactness and the dip of the dike or sheet.

The removal of part of the sandstone member of the Mancos shale and consequent outcropping of the sandy beds afford opportunity for the leakage of any oil that may have found its way to these beds. The chances of finding oil or gas in commercial quantity in the remaining Mancos beds in this anticline are slight. However, the remaining Mancos shale is 200 feet in thickness, or more, and is probably ample to form an impervious cover for the "Dakota" sandstone. The gas already found in this sandstone may have been generated in underlying beds or, possibly, in the overlying Mancos shale.

From the crest of the Sage Creek anticline there has been removed by erosion perhaps 700 or 800 feet of Mancos shale. If the thickness of this formation has not been materially affected by folding it may have been originally about 4,400 feet in all, or about 4,000 feet from the top down to the first prominent sandstone. (See p. 13). The sandstone would accordingly be about 3,200 or 3,300 feet below the present surface. But accurate determination of the thickness of the formation and depth to the sandsone must await the drill. It is not improbable that local thickening has accompanied folding and that the thickness of the shale in the anticline a few miles south may be different from the thickness here. Uniformity of thickness is hardly to be expected in a heavy shale formation between competent sandstone strata in a region of much folding. Hewett and Lupton[12] have found that the shale on opposite limbs of a single anticline may differ several hundred feet in thickness, being thicker on the steeper side.

The same factors that could produce local thickening might cause a bulge on an anticline and show a closed structure at the surface where none exists at depth. There is, however, no observed indication that the closure of the Sage Creek structure does not hold through the Mancos shale. Of those mentioned in previous pages it should be the first to be tested. Fully to test the structure to and including the "Dakota" sandstone the driller should be prepared to bore 4,000 feet, but it is possible that the Mancos sandstone would be reached within 3,000 feet. Whether or not sandstone lenses or other possible reservoirs exist above the main sandstone member can only be determined by drilling. Jointing, fracturing, or solution might make the limestone or calcareous platy shale sufficiently open to receive oil and gas. Though the highest part of the anticline is limited in width by the syncline on the east, the most promising drilling area extends much farther in a general north-south direction where the axis of the folded sandstone is evidently nearly level for about a mile. A further advantage is found in the wide area of possible drainage which extends far north of Yampa River and includes much of the general synclinal basin.

Should the Sage Creek anticline prove to be productive a careful examination of other hitherto untested areas within the region would be advisable. Among these may be mentioned the Fish Creek anticline northeast of the Williams Park anticline and sections 11 and 15, T. 5 N., R. 88 W. Though the writer has not examined in detail the area in the two sections named the dip and strike of the beds, as mapped by other members of the party, are significant.

GROUND WATER

Very little is known about ground-water conditions at depth within the area under consideration. Shallow wells in the Lewis and Mancos shales furnish sufficient water for stock and household use. In all probability any sandstone within the region is sufficiently porous to carry water. Mr. W. A. Dawson, of the Twentymile Oil Company, states that when the first well of his company reached the "Dakota" sandstone water rose in the well 1,000 feet, that is, to within 725 feet of the surface.

[12]Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyoming: United States Geol. Survey Bull. 656, 1917.

DEGREE OF CARBONIZATION OF MESAVERDE COAL

David White[13] has pointed out the close relationship that exists in oil fields between the character of oil and the degree of carbonization of coal in the same or overlying formations. He says:[14]

Noting the gradual elimination of the volatile hydrocarbons—the so-called volatile matter—from the oil shale simultaneously with the devolatilization of the associated coals in the course of the progressive regional alteration of the organic deposits, I have called attention to several other points which seem to indicate a mutual relationship between coal and petroleum in the second or **geochemical stage** of development, and that both react to the same geophysical influence, as follows: (1) That in regions where the coals and other carbonaceous debris in the strata are of the rank of brown lignites, the oils in the same or closely associated geological formations are also of low rank, averaging 20° to 26° Baume; (2) that where the organic debris (coals, etcetera) has advanced to the sub-bituminous rank, the oils of the same or of nearly contemporaneous underlying formations are of higher rank, averaging 28° to 35°; (3) that when the deposits of organic debris have been regionally transformed by elimination of volatile matter) until they have reached the bituminous rank, the oils have in general attained a rank of 35° or more, the highest grade of petroleum being formed in the areas where the regional alteration of the organic debris has progressed farthest; **except** (4) that in those regions where the organic debris, whether it be represented by beds of coals, by bogheads, or by carbonaceous matter in shales, has passed the point corresponding to a content of 65 per cent of fixed carbon, pure coal basis, the oils which may formerly have been present in the same or in the underlying formations have mostly disappeared; and (5) that wherever the devolatilization of the coals, etcetera—that is, the solid residues in the strata—has progressed so far that they have a fixed carbon content of 70 per cent or more, **oils**, if present, will be "freak" oils, and in pockets or amounts too small to be of commercial importance, though gas pools may persist. I know of no commercial oil pools in the world that are found in or beneath formations in which the regional carbonization of the organic debris has passed 75 per cent fixed carbon, pure coal basis; in fact, I have not yet been able to learn of an oil pool in or beneath a formation in which the fixed carbon percentage of the organic debris exceeds 70, and it is most improbable that oil pools exist under such conditions.

It will at once be seen that these conditions seem to define a law restricting the distribution of productive oil pools, and to afford a basis on which to eliminate many areas of great extent in which fruitless and costly exploration by the drill is now going forward.

In Doctor White's third paper cited, page 5, he states:

More observations and tests are necessary to fix more exactly the stage of regional alteration beyond which commercial oil pools, though formerly present, will not have survived, but it is probable that the limit falls, in general, slightly lower than the point at which coals of the ordinary bituminous type show a fuel ratio of 2.2 or 68 per cent of fixed carbon in the pure coal; it may approach nearer the ratio of

[13]White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

———, Late theories regarding the origin of oil; Geol. Soc. Am. Bull., vol. 28, pp. 727-734, 1917.

———, Genetic problems affecting search for new oil regions: Mining and Metallurgy, No. 158, pp. 1-20, 1920.

[14]Geol. Soc. Am. Bull., vol. 28, p. 732.

2.0, or 66 per cent fixed carbon. Coals verging toward the sapropolic type, such as are believed by many to approach more closely the typical mother substance of oil, are more fatty and accordingly richer in hydrogen and lower in fixed carbon (pure coal basis) than the other types, until, in the course of alteration by geologic processes, they approach the above limit, when the volatile matter seems to disappear rapidly. At the semi-bituminous stage (fuel ratio 3.0, fixed carbon 75 per cent), their carbonization is approximately on a parity with typical bituminous coal.

Gale[15] gives analyses of 43 samples of Mesaverde coal from mines and prospects over a wide area extending from Pilot Knob north of Yampa River to Meeker on White River. Of these 43 analyses 39 show fixed carbon between 52 and 62 per cent on a pure coal basis—that is, after eliminating moisture and ash. Only 2 of the 39 contain over 60 per cent fixed carbon. Two others, from Pilot Knob, where the coal has been locally affected by basalt intrusion, show respectively 71.6 and 95.6 per cent fixed carbon. The remaining 2 of the 43 fall considerably below the general lower limit of 52 per cent, having 46.4 and 48.6 per cent fixed carbon, respectively. Gale states that these two analyses were made from weathered samples.

Insofar as the Mesaverde beds are concerned, excepting the areas of local metamorphism, alteration, as shown by coal analyses, has been sufficient, yet not too much for the production of oil, according to the limits set by White. It is to be expected that the regional alteration of the older Mancos beds would be somewhat more than that of the Mesaverde, yet well within the limits mentioned.*

PRE-CRETACEOUS AREA NEAR McCOY

PRE-CRETACEOUS FORMATIONS

The area of pre-Cretaceous rocks near McCoy is distinctly marked off from the Cretaceous area of the Yampa coal fields by the absence of shales and the presence of many strata of red and white sandstones. An alternating succession of these older sediments comprising several thousands of feet exists between the metamorphic and igneous pre-Cambrian rocks to the east and the Cretaceous "Dakota" formation to the west. These older sediments occupy the area around McCoy and are also found to the north and west in the Cretaceous region where folding or river erosion has exposed them.

The Cretaceous outcrops to the west are composed mainly of the typical yellowish siliceous sandstones of the "Dakota" and scattered portions of the basal black slaty shale of the Mancos formation.

Sections of the older rocks may be examined on Rock Creek, on the south bank of Grand River west of McCoy, and northeast of Yarmony. The "Dakota" Cretaceous, Jurassic (?), Triassic (?), and the Permian (?), and part of the Pennsylvania of the Carboniferous system are excellently exposed on the west limb of an anticline on Grand River. The Mississippian (?) series and older rocks are partly exposed northeast of Yarmony and

[15]Gale, H. S., Coal fields or northwestern Colorado and northwestern Utah: U. S. Geol. Survey Bull. 415, pp. 248-249.

east of Rock Creek. There are several other places within this limited area where portions of sections may be obtained owing to the extensive folding which has taken place.

Generalized Columnar Section

	Feet
Cretaceous: Dakota sandstone, shale and conglomerate	±150
Jurassic (?): Light colored sandstones and shales	±500
Triassic (?): Bright red thin-bedded sandstones, sandy shales, and thin beds of limestone	±1,100
Carboniferous: Sandstones, conglomerates, shales, limestones (overlap?)	±3,000
Devono-Carboniferous (?): Limestones, quartzites, sandstones, shales	±200
Archean: Crystalline and metamorphic rocks	-----
Total	4,950

DEVONIAN-CARBONIFEROUS (?) SYSTEMS

Lying unconformably on the metamorphic and igneous rocks are 200 feet of massive limestones, sandstones, and clay shales. The limestones are very hard and fine grained. They usually have a blue color on fresh surfaces and weather to a white or a light yellow or brown. The sandstones are often quartzitic and when not altered are coarse grained. The small beds of shales are limy and sandy and have a red and yellow tinge. No fossils were found in these lower beds, but they may be correlated in a very indefinite way on a lithological basis with the Devonian-Carboniferous rocks of the Rico Mountain[6]. These rocks include the lower Paleozoic rocks of the Hayden atlas.[7]

Section of the Lower Paleozoic Rocks East of McCoy, Colorado

	Feet
Sandstones, massive, soft sugary; somewhat conglomeratic	30
Shales, red and yellow, calcareous, sandy (partly covered)	50
Sandstones and sandy micaceous shales	12
Limestones, massive, bluish gray, fine grained	14
Sandstones and shales, alternating sandstones are coarse grained and pink; shales are limy, considerable crumbling and alteration shown	28
Limestones and calcareous sandstones; beds are massive and weather to a light yellow and brown	55
Shales, quartzites, sandstones; shales are blue and calcareous	55
Sandstones, white, coarse grained, some conglomerate seams	5
Metamorphic and igneous rocks	--
Base of formation	--
Total	249

CARBONIFEROUS SYSTEM

Above the lower Paleozoic rocks and below the so-called "Red Beds" is a series of sandstones, shales, and limestones. The fossils found indicate that the greater part of these rocks belong to the Pennsylvanian system. Invertebrate fossils are numerous throughout parts of the formation. Brachiopods predominate over the mollusks, and the characteristic foraminifer,

[6]Cross, Whitman, and Ransome, F. L., Description of Rico Quadrangle; U. S. Geol. Survey, Geol. Atlas, Rico folio (No. 130), p. 2, 1905.

[7]Hayden, F. V., Atlas of Colorado: U. S. Geol. and Geographical Surveys of the Territories, Pl. XI, 1881.

Fusulina cylindrica, is also present. The fossils are most nearly characteristic of the Hermosa formation of southwestern Colorado. Collections from these beds near McCoy were examined by Professor Junius Henderson, who has identified the fossils that are listed below:

Hyalostelia (?) sp.
Fusulina cylindrica (Fischer)
Crinoid plate and stems
Syringopora sp.
Fenestella sp.
Bryozoa undetermined
Chetetes? milleporaceous Milne, Edwards and Haime
Campophyllum torquium (Owen)
Productus cora d'Orbigny
Productus gallatinensis Girty
Productus punctatus Martin
Productus semireticulatus Hermosanus Girty
Marginifera haydenensis Girty
Marginifera muricata (Norwood and Pratten)
Composita subtilita (Hall)
Squamularia perplexa (McChesney)
Spirifer boonensis Swallow.
Spirifer cameratus Morton
Spirifer rockymontanus Marcou
Allorisma terminale Hall
Pelecypod undetermined
Cf. Pleurotomaria scitula Meek and Worthen
Worthenia tabulata (Conrad)
Euomphalus catilloidea (Conrad)
Euomphalus pernodosus (Meek and Worthen)
Naticopsis altonensis (McChesney)
Platyceras parvum Swallow
Soleniscus cf. anguliferus (White)

Sandstones are by far the predominating rocks of the Carboniferous system. Some of the beds attain a thickness of 300 feet, while others are thin bedded and intercalated with sandy shales and limestones. The sandstones are usually coarse grained and of even texture, having siliceous and calcareous cementing materials. Many, however, change in texture and become conglomeratic, arkosic, or fine grained in very short distances. Red, maroon, and pink are the predominating colors, with an occasional white or mottled sandstone. The reddish sandstones are often banded with white stringers and some are highly micaceous.

The shales are for the greater part very sandy and increase in their sand content until they change into thin-bedded sandstones. They also have the different red colors and when fossiliferous are dark and bluish gray. The small bodies of dark shales contain carbonaceous material, and at two places there is a seam of poor coal. Highly micaceous sandy shales predominate in the lower rocks.

A columnar section of the more calcareous and fossiliferous part of the Pennsylvania series is given on plate I. The limestones are generally blue and gray in color and very fine grained. In nearly every case they are hard and are often fossiliferous.

Above this more calcareous division and below the typical "Red Beds" alternating coarse and fine-grained red sandstones and shales are present. There are several thick strata of thin-bedded sandstones and sandy shales.

and an occasional massive bed of coarse-grained sandstone or conglomerate. Several hundred feet of thin-bedded buff and brown sandstones, a massive white sandstone and grayish shales are near the top of the Carboniferous series. These rocks are interbedded with red and white-banded coarse sandstones and sandy shales.

Section of Part of the Pennsylvanian Rocks Northeast of Yarmony

	Feet
Conglomerates, red, massive and coarse grained	160
Sandstones, red, coarse grained alternating with red and gray sandy shales; partly covered	34
Clay shales, red	25
Sandstone, massive, coarse grained, with white bands	40
Sandstones, thin bedded, alternating with sandy shales	30
Shales, sandy, micaceous, in occasional bluish gray shale layer	38
Sandstone, coarse grained, red and sandy shales; sandstones and shales highly micaceous	40
Conglomerate, red, and contains small quartz and feldspar pebbles	10
Talus slope	243
Sandstone, massive, gray, coarse grained	18
Shales, red, yellow and sandy, a few thin-bedded sandstones, partly covered	171
Coarse-grained sandstones alternating with light red micaceous shales	343
Total	1,151

TRIASSIC (?) SYSTEM

A series of over a thousand feet of bright red thin sandstones and sandy calcareous shales is made up of typical "Red Beds." The dividing line between these beds and the Carboniferous rocks below is questionable. At the base are variable beds of thin sandstones, thin limestones, and calcareous shales. Above these variable beds is a more persistent succession of thin-bedded sandstones and shales interbedded, occasionally, with gypsum. These beds vary in thickness, and are at some places massive. A limestone bed is present near the base of these sandstones, which varies in thickness and is discontinuous at several places. Fresh surfaces show that it is a white limestone which weathers brown and black. From a distance it appears to be blue. It usually has a conglomeratic appearance with a honeycombed surface There is a rather massive bed of coarse white conglomerate near the top divided by red sandy shales. Very little carbonaceous material is found in this formation.

Section of Triassic (?) Rocks on Grand River

	Feet
Sandstones, bright red, thin bedded; fine grained and sandy shales	285
Conglomerate, white, coarse grained	2
Shales, sandy, red	10
Conglomerate, white, coarse grained, with pebbles, mostly quartz, and feldspar	20
Sandstones, red, thin bedded, fine grained	75
Shales, red, sandy, gypsiferous	15
Sandstones, red and thin bedded, and sandy shales (commonly calcareous)	550
Limestone, brown and black, sandy, conglomeratic	15
Sandstones, red, thin bedded, and sandy, gypsiferous shales	180
Shales, red, blue, gray, interbedded with thin sandstones and limestones, Carboniferous (?)	132
Total	1,285

JURASSIC (?) SYSTEM

The bright red sandstones of the supposed Triassic system stand out in contrast to the lighter-colored sediments of the overlying probably Jurassic beds. At the base of this system is a rather massive thick and thin-bedded sandstone. It is rather fine grained, and south of Grand River attains a thickness of over 150 feet. Approximately 35 feet from the top of this sandstone there is a 10-foot bed of slightly bituminous and calcareous shales. The bituminous odor was noticeable when the rock was struck with a hammer. These shales divide the sandstone member into two parts. The lower part of this sandstone member probably corresponds to the La Plata and White Cliff sandstones of southwestern Colorado. Between this sandstone and the overlying "Dakota" sandstone are beds of shale, clay, sandstone, and limestones similar to the McElmo formation. The shales are gray, red and green, and often show no bedding planes. They are usually sandy and calcareous. The calcareous shales and limestones predominate near the base of the formation while the sandstones and sandy shales are at the top.

The shales are divided by an occasional strong bed of sandstone or limestone. A massive coarse-grained sandstone 20 feet thick is present approximately 200 feet from the top of the formation. The limestone beds are thin and have a grayish blue color. They are hard and fine grained. One fossil *Unio sp.* was found in this formation where it is exposed northeast of Yarmony. This formation is between 400 and 550 feet thick.

Section of Part of the Jurassic Rocks as Found Near Burns, on the Grand River

	Feet
Debris-covered slope	--
Shales and clays, hard, green, compact, with few or no bedding planes	75
Shales, coarse grained, massive and white	20
Limestone, hard, grayish blue	2
Shales and limestones, gray, calcareous shales; limestones, thin and hard; occasional thin sandstones	35

Section of Part of the Jurassic Rocks as Exposed West of McCoy, on the Grand River

	Feet
Shales and clays, green, red, sandy and calcareous shales	50
Sandstones, white, thin bedded, fine grained	34
Shales, carbonaceous and bituminous	10
Sandstones, white, thick and thin bedded, fine grained	135
Sandstone, red, thin-bedded Triassic (?) (base of formation)	--
Total	229

OIL AND GAS POSSIBILITIES

Reconnaissance work was done on the structural features in this area merely to find the approximate position of the folds. Detailed work was not attempted.

There are two parallel anticlines several miles west of McCoy, whose axes cross Grand River in an almost north and south direction. These folds are probably closed anticlines. The Pennsylvanian series of the Carboniferous system is exposed on the limbs of these folds near the axes.

There are also folds on Cabin, Derby, and Red Dirt creeks west of Burns. These creeks are branches of Grand River and flow in a southeast direction along the axes of the folds. The Jurassic (?) rocks are exposed on Cabin and Derby creeks, and the Upper Carboniferous on Red Dirt creek.

Northwest of McCoy there are two prominent folds. In Smiths Basin in the western part of Egeria Park there is a probably closed anticline in the "Dakota" formation, whose axis trends northwest. King Mountain to the southeast of Smiths Basin is structurally a dome. This fold was not examined in detail, but the position of the formations indicates that the "Dakota" formation dips away on all sides from a central point. The Triassic (?) and probably part of the Carboniferous systems are exposed by this folding.

The greater part of the pre-Cretaceous rocks is made up of sandstones and conglomerates. Of the entire series there are two possible horizons where oil may have originated. The rest of the formations appear too "dead" or "dry" with little or no chance of any oil formation. The greater part of the sandstones is coarse grained with no fossils or carbonaceous materials present. The shales when present are usually sandy and micaceous, and probably would not generate any gas or oil.

The fossiliferous part of the Pennsylvania series is shown in Figure 13 on Plate I. These beds are about 3,800 feet below the top of the "Dakota." In this section there are five fossiliferous beds of limestones and shales. Each bed contains many fossils and in places shows as many as fifteen species. (See page 42.) Others who have collected fossils from this area have reported many more. These animals buried in the marine sediments may give sufficient material for the formation of oil. The oil would be derived from the decomposition of the bodies which would later accumulate into so-called "pools" It is very probable that oil and gas have been distilled by the heat generated by the pressure of the overlying sediments and the folding which has taken place. This, of course, is questionable, and it is not known how much was generated. Small amounts of bituminous materials under certain conditions may generate commercial bodies of oil and gas, and it is also equally proper to believe that under other conditions they may generate little or no oil or gas. In this section the most important question appears to be the position, character, and amount of sandstones present, and their position in relation to the fossiliferous beds. The fossiliferous beds alternate with sandstones, conglomerates, shales, and limestones for about 500 feet. The sandstones are very probably suitable reservoirs for oil and gas as they are coarse grained and not tight. The capping shales, however, do not appear sufficient to retain oil and gas in commercial quantities. It may be stated that, in general, the sandstones are too extensive for the small amounts of shale and fossiliferous beds present.

Near the base of the Jurassic (?) system there is a bituminous shale and sandstone member about 10 feet thick. The source of this bituminous material is not known, but there are probably fossils within it. There is little chance that this could develop oil or gas in commercial quantities.

AN ANTICLINE IN MONTEZUMA COUNTY

BY R. C. COFFIN

GENERAL CONSIDERATIONS

NAME AND LOCATION

The fold which is discussed in the following pages has been named the McElmo anticline. It lies in Montezuma county, Colorado. The center of the area affected by the fold is approximately 25 miles north and 12 miles east from the southwest corner of the state. Dolores, which is the nearest railroad point, is situated on the Rio Grande Southern 13 miles north and east of Cortez, or 22 miles from the highest point of this fold.

Only the important points which are involved in the oil possibilities of this fold are considered.

FIELD WORK

The field work which supplied data for the present discussion was done by the writer in the Spring of 1918.[1] A triangular skeleton had been established in this region during a reconnaissance of the carnotite area of western Colorado.

PHYSIOGRAPHY

The beds of the area are essentially horizontal except in the immediate vicinity of the fold. In the northeastern part of the area examined the surface is, in general, smooth, but in other parts McElmo Creek and its tributaries have cut canyons which are separated by flat-topped divides. The area in which erosion has reached a maximum lies in Sand Gulch which crosses the fold at approximately its highest point.

Goodman Point, which includes the highest ground north of McElmo Creek, is approximately 1,500 feet above the bottom of the canyon. South of McElmo Canyon the Ute Mountains rise to an elevation of slightly more than 9,500 feet, 3,000 feet above the surrounding country. Sedimentary rocks dip gently away from these mountains on all sides.

STRATIGRAPHY

GEOLOGIC SECTION

The following geologic section represents the thickness of formations above the Dolores in the walls of McElmo Canyon, and the thickness of lower formations as found in areas contiguous to the McElmo Canyon.

Approximate Thickness of Formations in McElmo Canyon and Contiguous Areas

System	Name of Formation	Thickness in Feet
Cretaceous	Mesaverde	880±
Cretaceous	Mancos	500 to 1,000
Cretaceous	"Dakota"	100 to 200
Jurassic or Cretaceous	McElmo	650
Jurassic	La Plata	175 to 210
Triassic	Dolores	1,000 to 1,600
Permian (?)	Cutler or Moenkopi	300 to 1,800
Pennsylvanian	Hermosa or Goodrich	1,000±

[1]—Coffin, R. C., Report on the Main Carnotite Area of Southwestern Colorado; Colorado Geol. Survey Bull. 16, 1920.

In the region of the McElmo Canyon the streams have removed practically all the sedimentary rocks down to the "Dakota" formation which caps the mesas and which constitutes the surface material over large areas. Where the "Dakota" has been cut through, the sandstones and conglomerates of this unit form the so-called "rim rock." In the canyon proper, cutting has reached the Dolores formation, and in places along Sand Gulch depths of 300 feet have been reached within this formation.

ROCKS EXPOSED IN McELMO CANYON

Inasmuch as the formations exposed in McElmo Canyon are of secondary importance they are described briefly.

Upper Part of the Dolores Formation.—The upper 300 feet of Dolores formation is exposed along Sand Gulch. The materials consist of massive and thin-bedded standstones separated by seams of red shale. Two of these massive beds form separate cliffs which characterize the exposures of this unit.

La Plata Formation.—This formation consists of a massive sandstone which is characterized by its smooth-weathering outcrops. This sandstone forms a white to pink cliff 200 feet high, which generally forms the base of a steep slope extending from the bottom of the canyons to the "Dakota" formation above. (See Fig. 11.)

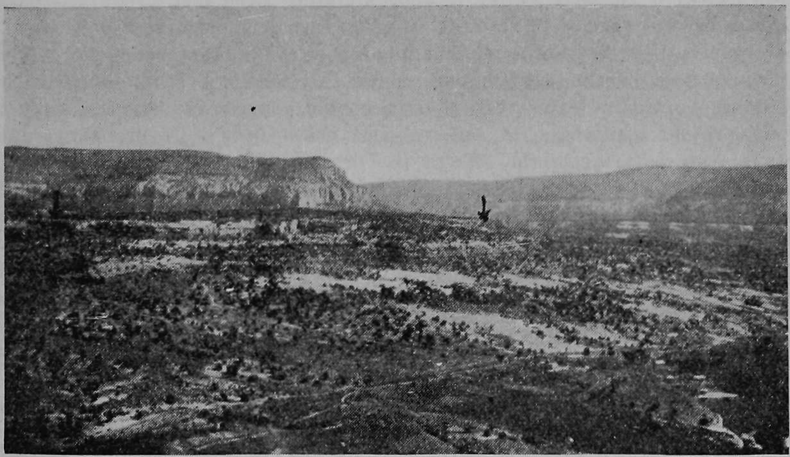

Fig. 12. View looking northeast from Battle Rock
Arrow to the right indicates recommended drilling site; arrow to the left indicates position of shallow well previously drilled.

McElmo Formation.—The McElmo formation consists of a lower portion predominantly sandstone and an upper portion predominantly shale. The lower portion includes massive and thin-bedded sandstones separated by lenses or seams of red to maroon shale. The upper portion includes variegated shales, and a massive conglomerate near the top. This conglomerate forms a cliff secondary to the "Dakota" above and can generally be separated from the upper one by its brown color and an abundance of green pebbles which characterize this bed.

"Dakota" Formation—This formation consists of a massive sandstone conglomerate at the base and a sandstone near the top of the formation with shales and shaly sandstones intervening. The outcrop of this unit forms the top of most of the canyon walls.

Other Formations.—Mancos shale occurs as remnants along the foot of the Ute Mountains and in an area south of Cortez. This formation and younger ones need not be described.

Instrusive Rocks.—The different intrusive rocks which form the Ute Mountains are of the same general composition but different in texture. They include coarse and fine-textured andesite porphyries. Metamorphism due to this intrusion has affected the shales in one place at least one-fourth mile from any known igneous rock. The sandstones, however, have been practically unaffected.

FORMATIONS NOT EXPOSED IN THE McELMO CANYON

No exposure of beds below the Dolores formation occurs within 25 miles of the McElmo anticline and it is impossible to determine the exact nature of beds which are not exposed in the anticline.

Lower Part of the Dolores Formation.—These beds as exposed in the Dolores Canyon north of the area consist of maroon to red shales and thin-bedded sandstones. The total thickness of the Dolores formation as determined in Paradox Valley is approximately 1,000 feet.

Cutler Formation.—The beds of this formation which are exposed in Dolores Canyon to the north include deep red shales near the top, and arkose, sandstone and conglomerates at the base. A study of these beds at many points indicates that their probable source was north and east of their present outcrops. It follows that these beds will probably contain less coarse material in the site of the present fold than is included in the sections along Dolores River. The general character of the Moenkopi formation (equivalent to the Cutler) farther south indicates such a change.

Hermosa Formation.—Beds of this formation are exposed in the Rico Mountains 45 miles southeast of the McElmo anticline, in Gypsum Valley and vicinity, 35 miles north, and along the San Juan River near Bluff, 45 miles to the west of the anticline. It is not to be expected that the exact order of beds as shown in any one exposure will prevail in the McElmo anticline.

A section of this formation which occurs in Klondyke near the head of Gypsum includes approximately 500 feet of beds which show the following sequence:

Section of Carboniferous Rocks in Klondyke

Top

1. Limestone
2. Sandstone, red, very friable
3. Sandstone, massive
4. Limestone, highly fossiliferous
5. Sandstone, coarse grained
6. Limestone, fossiliferous
7. Conglomerate sandstone, gray and red
8. Limestone
9. Shale, fossiliferous
10. Sandstone
11. Limestone, abundantly fossiliferous

12. Sandstone, thick bedded
13. Limestone and shale, fossiliferous
14. Limestone and shale, about 300 feet
15. Limestone
16. Limestone and shale, about 100 feet

Gypsum occurs stratigraphically below the section given but its exact position could not be located. Over 75 per cent of the fossils collected from these exposures occur in the Carboniferous beds of the San Juan oil field.[2]

The section of the Goodrich formation (equivalent to the Hermosa) of the San Juan oil fields as measured by Woodruff[3] includes 1,541 feet of beds not unlike those exposed in Klondyke. The Hermosa formation in the Rico Mountains[4] includes over 1,800 feet of sandstone, grits, shales, and limestones. The limestones are generally fossiliferous.

A correlation of individual beds of the three sections mentioned cannot be made. Fossils collected from the three regions show conclusively that the beds are of the same age and their general character shows that they are essentially the same formation.

STRUCTURE

NATURE OF THE FOLDING

The area involved by the folding of the McElmo anticline is approximately 20 miles long and 8 to 10 miles wide. Beds dip away from this fold at small angles, 10 degrees being the maximum dip recorded. These maximum dips occur on the south side of the anticline and suggest that this is the direction from which the forces came which produced the fold.

The structure as indicated by the map is that of a distinct dome whose major axis is curved. This axis extends north from the east edge of the Ute mountains crossing McElmo Canyon and extending west to Yellow Jacket Canyon. An axis of secondary folding extends from the top of the dome in a direction N. 30 degrees E. Another secondary axis passes through the town of Cortez running in a westerly direction. This axis is not well defined west of Trail Canyon.

HEIGHT OF THE DOME

The height of the dome indicated by the contour map is 200 feet. This 200-foot closure occurs at the foot of the Ute Mountains where the sedimentary rocks are upturned very gently along the main axis toward the south. These adverse dips were limited to the immediate vicinity of the igneous rocks. Inasmuch as the elevation of the "Dakota" formation south of Ute Mountains is less than it is at any point north of the Ute Mountains it is probable that the deeply buried beds in this region are not affected by the igneous material as suggested by the "Dakota" formation now at the surface. If so, the height of this dome may not be limited by the 200 feet as indicated, but may be determined by the position of the syncline

[2]Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, pp. 83-85, 1910.

[3]Op. cit., pp. 81-82.

[4]Cross, Whitman, U. S. Geol. Survey, Geol. Atlas, Rico folio (No. 130)

which follows Yellow Jacket Canyon, and the lowest closing contour is the one whose elevation is 5,700 feet, making the height of the dome 450 feet.

FAULTS

The faults indicated on the map are such as to have practically no effect on the structure as an oil reservoir. Displacements of over 30 feet are unusual, and most of the dislocations are less than 15 feet. The outcrop of the La Plata sandstone is such as to reveal all faults even to displacements of one foot, and many here visible would under ordinary conditions be passed over without notice.

AREAS TRIBUTARY TO THE STRUCTURE

Applying generally the anticlinal principle of oil accumulation, a considerable area is structurally so situated that if its beds ever contained oil, it has probably accumulated in this structure.

Beds which dip southwest from the McElmo anticline maintain their gentle dips without interruption to the southwest over areas which include parts of Utah and Arizona. The same conditions prevail on the southeast side of the structure where beds dip south from the secondary axis which passes near Cortez, extending without interruption into the San Juan basin. To the east of the structure drainage is cut off by the syncline which comes within the area mapped and on the north by the one which follows Yellow Jacket Canyon. The interruption offered by the Ute Mountains to these southern dipping beds is not serious.

This structure is situated along the edge of a huge structural basin which comprises the northeast part of New Mexico and adjoining parts of Colorado. The relation of this structure to this huge basin is such that if its deeply buried beds ever contained oil its partial accumulation is to be expected in the McElmo anticline.

RELATIONSHIPS AND OIL POSSIBILITIES

POSSIBLE OIL-BEARING FORMATIONS

Inasmuch as the beds above the Dolores formation are all exposed, only those below this formation need be considered.

The lower part of the Dolores formation and the beds of the Cutler formation are deposits of sand and shale which contain no appreciable amount of either animal or carbonaceous residues. They cannot be considered possible sources of oil in the present structure. The Cutler formation, however, includes a combination of beds—the arkose beds at the base capped by shales above—which might constitute a reservoir for oil if it were present. It is possible that oil migrating upward would be caught in these basal sandstones.

The Pennsylvanian beds which underlie the Cutler are known to be oil-bearing in the San Juan oil field, and oil seeps elsewhere in this part of the Plateau country are reported to be in beds of this system. In connection with the occurrence of oil in the San Juan oil field and known seeps in different parts of southeastern Utah Woodruff[5] says: "* * * * It seems probable * * * that oil in varying quantity is deposited over large areas in Utah and contiguous regions to the south."

STRUCTURE OF UNDERLYING BEDS

The structure of the deeply buried Pennsylvanian beds is not without its uncertainties. An unconformity is known to exist at the base of the Permian formation in different parts of Colorado. In Gypsum Valley and vicinity Pennsylvanian beds abut against Triassic beds at an angle of 30 degrees. Gypsum Valley appears to be an old line of weakness established in pre-Permian times by a folding process which resulted in the removal of the Cutler formation and most of the Hermosa formation previous to Triassic deposition. A similar order of events may explain a series of folds which is parallel to the Uncompahgre Plateau. The Dolores anticline, 30 miles north of McElmo Canyon, appears to be a southern limit beyond which these parallel folds do not exist.

The unconformity at the base of the Permian (?) will admit of three posibilities: that the area of the McElmo anticline was folded and beds of the Hermosa formation were removed previous to Triassic deposition; or that the region was gently folded and these beds partially removed; or that the unconformity noted in Gypsum Valley is not pronounced in the McElmo anticline and that the Hermosa beds exist in this area folded in the same manner as those now at the surface.

No evidence is recorded that would indicate that this area was mountainous or subjected to any extreme folding between the time of the deposition of Pennsylvanian beds and those next above. No angular unconformity has been reported in the beds in question south of Disappointment Valley.

H. E. Gregory[6] who examined a large area in New Mexico and Arizona gives as his opinion the following:

> It seems probable that strata of Pennsylvanian age underlie the entire Navajo country, and that deep burial by Mesozoic sediments permits their exposure only at the summits of eroded domes and in the bottoms of profound canyons.

There is every reason to believe that Pennsylvanian rocks exist below the structure in question. However the exact sequence of the several sandstones as found in the Goodrich formation of the San Juan oil field or elsewhere is not to be expected.

RELATION OF THE STRUCTURE TO THE IGNEOUS MASS OF UTE MOUNTAIN

The existence of a large mass of igneous rock adjacent to the structure needs consideration. The Ute Mountains have been considered a mass of igneous rock which was intruded between layers of sedimentary rock, the present mountains are considered remnants of this laccolithic intrusion whose capping sediments have been removed. Such an origin would suggest that the McElmo anticline might have been formed by a similar intrusion

[5] Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, p. 104, 1910.

[6] Gregory, H. E., Geology of the Navajo Country; U. S. Geol. Survey Prof. Paper 93, page 19, 1917.

which does not appear in the present stage of erosion. This point can not be definitely settled without drilling, but certain facts tend to show that the present fold has not been formed by such a process. The McElmo anticline does not present the usual circular outline which is possessed by folds resulting from such intrusion. The present anticline extends 25 miles east and west and possesses its maximum deformation opposite Ute Mountain. There seems to be little doubt that the intrusion of such a mass as Ute mountain would necessitate a shortening of the beds into which it was intruded; this shortening of beds could have been accomplished by the formation of the McElmo anticline and the syncline which separates it from the Ute Mountains. The sagging of the beds near the mountains was probably due to the removal of material from great depths to the present site of the intrusion. No evidence of hydro-thermal action was noted in the vicinity of the McElmo anticline. There is some evidence that the present Ute Mountains were formed by an igneous mass whose bounding walls were more or less vertical, forming a huge igneous plug or column. Such an origin of these mountains would argue against the probability of the structure being complicated by masses of buried igneous rock.

RELATION OF THE STRUCTURE TO THE SAN JUAN OIL FIELD

The San Juan oil field is the nearest point where oil has been found in strata of the same age as those involved in the McElmo anticline. This field lies along San Juan River 45 miles west of the area examined. In the San Juan Canyon several beds of the Carboniferous formation are exposed which are known to be oil-bearing.

The San Juan oil field has been studied by E. G. Woodruff[7] and H. E. Gregory.[8] Some of the points which they established are summarized as follows:

1. Oil was found in the Goodrich formation.

2. At least five sands are known to contain more oil than others. These sands are distributed within the top 400 feet of the formation but others which lie 1,000 feet below the top of the formation are supposed to be oil-bearing.

3. The ability of the field to produce oil in commercial quantities has not been determined.

4. The oils which yield more than the average amount of gasoline and burning oil are unusually light in specific gravity and are of good quality.

5. Productive wells are located down on the side of an anticline or up on the side of a syncline.

6. The aridity of the region and the deep cutting of the adjacent San Juan River have been controlling factors in the present location of the oil.

[7]Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, pp. 74-199, 1910.

[8]Gregory, H. E., The San Juan Oil Field, San Juan County, Utah; U. S. Geol. Survey Bull. 431, pp. 11-26, 1911.

PROSPECT OIL WELLS

About the time of the drilling in the San Juan oil field local excitement resulted in the drilling of a well in McElmo Canyon. The location of this well is shown on the map, and the information available was supplied by Mr. Downey of Cortez, who gave the following points concerning the prospect.

Well started in 1911.

At 150 feet, showing of oil and fresh water in considerable quantities.

At 500 feet, more water.

At 1,370 feet, salt water carrying gas; water flowed after well stood two days.

At 1,500 feet, showing of oil in last 130 feet with some water.

Tools caught in the hole and well abandoned.

The casing record is given as follows:

First 300 feet cased with 14-inch casing.
From 300 to 500 feet, 12-inch casing.
From 500 to 800 feet, 10-inch casing.

The well was started 150 feet below the top of the Dolores formation, but in as much as no log was kept of the drilling, the position of the bottom of the hole within the series can not be determined. The character of the material brought from the well would indicate that the drilling was confined to the Dolores and Cutler formations. The showings of the well have little, if any, bearing on the structure. The other prospect well shown on the map south of Cortez was drilled entirely in Mancos shale and its findings have no bearing on the present structure.

DEPTH OF PENNSYLVANIAN BEDS

The depth of the Pennsylvania formations cannot be estimated except within wide limits. The thickness of the several formations as determined in different exposures is not uniform. The exposures near Bluff include the following:

Dolores	1,330 feet
Moenkopi (Cutler)	1,280 to 1,264 feet
Total	2,610 to 2,594 feet

In the Navajo county south of Ute Mountain the same interval shows:

Triassic (Dolores)	1,202 to 1,262 feet
Permian (?) (Cutler)	300 to 1,285 feet
Total	1,502 to 2,547 feet

In the Rico Mountains these beds measure:

Dolores	400 feet
Cutler	1,600 feet
Total	2,000 feet

The thicknesses observed in these three rather widely separated areas range from 1,502 to 2,610 feet. In as much as the larger measurements were made nearer McElmo Canyon than the smaller ones, the maximum depths probably prevail in the region of the McElmo anticline. If the distribution of the oil-bearing sandstones, as they occur at Bluff, prevails in the McElmo anticline, 1,000 feet should be added to the thickness of the Dolores and Cutler formations to determine a depth which is necessary to thoroughly prospect the dome. Such a computation gives 2,500 to 3,600 feet, which must be the depth of a well below the top of the Dolores formation in order to make a complete test.

Depending upon the point of starting this depth might be more or less than the figures given. Some points favorably situated may be found where a well could be started 300 feet below the top of the Dolores formation, which gives a necessary depth for such places from 2,500 to 3,400 feet. There is no way of limiting these depths to narrower estimates than the figures given, and any scheme of prospecting would start with a possibility of reaching the greater depth.

OIL SEEPAGE AND RESIDUES

Oil occurs in a sheeted zone which passes through Battle Rock in cavities in calcite, and minor saturation occurs at several points south of McElmo Creek.

GROUND WATER CONDITIONS

This part of Colorado possesses an arid climate which, considered by itself, would be an important factor in oil accumulation. Dolores River passes about 15 miles north of the structure and runs generally northwest. Its canyon is cut in the Dolores and Cutler formations to depths that in places reach 1,000 feet. From this river the strata dip to the south without interruption to the dome under consideration. This arrangement affords excellent opportunity for intake of water for the lower beds, and when considered with the fact that McElmo Creek crosses the edges of strata near the top of the dome, it is to be expected that the lower strata in this dome will carry more water than might be present under ordinary conditions in such an arid climate. Certainly the scarcity of water in strata of the San Juan oil field, which appears to be a controlling factor in oil accumulation at that point, cannot be duplicated here.

POSSIBLE WELL SITES

The highest point of the dome is probably near the center of Section 25, T. 36 N., R. 18 W. Starting at this point would necessitate the drilling of a thousand feet that could be avoided by a site along Sand Gulch. Points along this gulch can be found which are so near the highest point of the dome that any disadvantage that might arise from such location would be negligible. The writer recommends a drilling site along Sand Gulch in the northeast quarter of Section 25, T. 36 N., R. 18 W. The site should be as far east as consistent with the cutting of the canyon. Points in this quarter section can be found that are on the axis of the folding.

A second choice would be to locate near the point where the main axis crosses the boundary line which divides Section 30, T. 36 N., R. 17W., and Section 25, T. 36 N., R. 18 W. Such a location might be favored by the fact that the secondary axis of folding which runs west from Cortez suggests that accumulation might be greater in the east side of the fold than elsewhere.

WATER AND FUEL

At certain times of the year many water holes along this gulch could supply the necessary water for drilling purposes. It would be reasonable to suppose that a drill hole would supply water from no great depth. The closest available coal, so far as the writer is aware, is south of Cortez.

SUMMARY

The points to be considered in prospecting the McElmo anticline are the following:

Unfavorable points:

1. The strata involved have not thus far produced oil in commercial quantities in this region.
2. Great depth which must be reached to prospect the structure.
3. Distance from market and poor railroad facilities.

Favorable points:

1. A closed anticline of considerable height.
2. The favorable location of this anticline in relation to the San Juan Basin.
3. The presence of oil in adjoining regions within strata which are involved in the structure.
4. Presence of oil seepages or residues in a portion of the structure.
5. The large area which will probably be productive if productive at all.

CONCLUSION

The prospecting of the McElmo anticline would probably determine the worth of neighboring structures which involve the same beds. Although the cost of prospecting this structure would be large the risks involved are not inconsistent with the chances for reward. The writer considers the prospecting of this structure a legitimate venture.

TOW CREEK ANTICLINE*

STRATIGRAPHY

The stratigraphy of the region has to deal with sedimentary and igneous rocks. The sediments consist of sandstone and shale, and the igneous rocks, which are all intrusive, are both acidic and basic in character. The rocks in this district range in age from the pre-Carboniferous gneisses and granites which form the basal complex to later Tertiary in the form of dikes, sheets, and laccolithic, and stocklike bodies, and to Quaternary alluvium.

As the sedimentary formations are fully described elsewhere in this publication, only the following summary will be given here.

Summarized description of the strata

Geologic Age	Formation name	Description	Topographic Forms	Thickness Feet
Cretaceous	Lewis	Composed largely of dark gray to black, calcareous, marine, clay shale containing lenticular beds of limestone.	Slopes, valleys and rolling **plains**	1200-1800
	Mesaverde	Includes a succession of alternating sandstone, shale and clay, and coal seams. Three very prominent ledges of massive sandstone. The shale and clay form valleys and slopes covered with debris and waste. **The coal** seams are generally hidden by debris.	Steep, rough ridges with narrow valleys between the sandstone ledges.	3000-3700
	Mancos	A thick mass of dark shale containing lenticular beds of sandstone and several hard calcareous layers near the base.	Slopes, valleys and rolling **plains.**	2000-2500
	Dakota	Two heavy sandstones with a thin layer of interbedded black shale.	Hogbacks	160±
Undetermined	"Red Beds"	Red sandy clay and shale with a thick, massive red sandstone bed near the middle.	Slopes and valleys.	?
	Basal complex	Gneisses and granite rocks.	Mountainous masses.	--

*The remainder of this bulletin is taken from Bulletin 23, Colorado Geological Survey.

IGNEOUS ROCKS

The main part of this paper is not to consider the petrography of the area, and what is reported here is limited. Specimens and slides were made and examined only from the main bodies of igneous rocks The igneous rocks of this district are all intrusive in character, and consist of two general types. The laccolithic and stocklike bodies are of acidic porphyry, and the dikes and sheets are of basalt. There are two varieties of basalt; one contains quartz and the other does not.

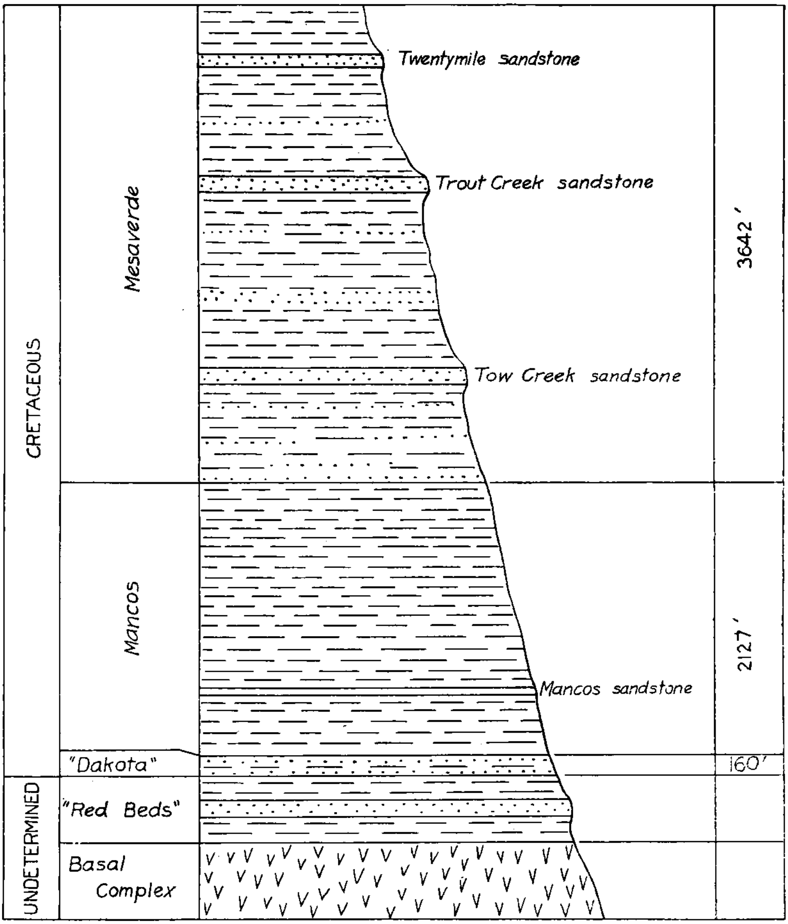

Fig. 13. Vertical section of sedimentary rocks of the Tow Creek anticline

RHYOLITE PORPHYRY

The rocks of acidic type were studied in less detail than the basalts. They occur in the laccolithic body in the Tow Creek crest and on Elk Mountain. They are reported to be present on Sand Mountain. The Tow Creek intrusive, the only body strictly within the area, when seen from a distance was so light colored and apparently stratified, that it was thought to be sandstone. It was found that this apparently bedded part of the intrusion near the north central part of the body changes quite rapidly into a finer-grained and structureless rock toward the borders of the intrusion.

The hand specimen of the most acidic part shows many quartz phenocrysts about one-fourth of an inch in maximum diameter, numerous colorless feldspar phenocrysts of about equal size, and many small but quite perfect hexagonal crystals of biotite embedded in a fine, light groundmass. The rock presented a chalky appearance except where it was stained with iron. The texture ranges from felsite to almost holocrystalline.

OLIVINE BASALT

The quartzless variety of basalt is the most basic of these igneous rocks. It is found in the dikes extending from the south crest of Wolf Mountain into the Tow Creek laccolithic body. It is a very dark, compact rock with many small phenocrysts of olivine.

QUARTZ BASALT

The variety of basalt containing quartz is found in Chimney Peak and in sheets around the Chimney Creek dome. It is a heavy rock of bluish-gray color containing numerous imperfect crystals of bright green olivine about 3 mm. in diameter, and less numerous grains of quartz of about the same size embedded in a dark bluish-gray groundmass.

AGE

The age of these rocks is post-Mesaverde and probably Tertiary, since they came approximately into their present position subsequent to the deposition and solidification of the Mesaverde formation, and accompanying or subsequent to the folding. There seem to have been two periods of igneous activity. The earlier rocks were acidic in type, for the heavy olivine basalt which extends from the south crest of Wolf Mountain cuts the acidic porphyry in the Tow Creek crest. The dikes and sheets may be of the same age, as their close resemblance in composition suggests. Nowhere was a dike found cutting a sheet. The rocks of this area so closely resemble those in the Hahns Peak and Rabbit Ears district that it seems quite probable that they are of nearly the same age, and came from the same general reservoir.

METAMORPHISM

The metamorphism of this area is chiefly confined to very narrow contact zones of intruded igneous rocks in the form of dikes, sheets, and laccolithic bodies.

In the case of dikes very little effect could be noticed. Nowhere was there a well exposed contact of sedimentary beds and dike rocks, but examination a very few feet away from the contact shows nothing beyond a slight hardening, and not always that. The beds into which the dikes were intruded have not been perceptibly tilted, or otherwise changed by the intruded rock. It seems probable that they were fissure fillings in part, with some absorption and minor fracturing.

The sheets intruded into the Mancos shale and showing in nearly circular outcrop in three successive beds around the Chimney Creek dome have caused very little metamorphism. On the upper and under sides the effects seem to be about equal. The effects extend from a foot to 10 feet with a fairly constant average of 18 inches. The shale at the contact has for an inch or two been baked to a material resembling porcellanite, and the succeeding layers vary in hardness from that rock to ordinary shale in about a foot and a half. The effect is most noticeable on the innermost and outermost sheets. The middle sheet is thinner and less continuous than the others, and has caused less metamorphism. The contact metamorphism as seen along the borders of the Tow Creek laccolithic mass is very slight. Though the mass is largely acidic porphyry and must have been intruded at a higher temperature than that of the dikes and sheets, its effect is apparently no more pronounced. No good exposure of this contact with shale was found, but a sandstone at the south end and near the forks of Tow Creek showed only a slight hardening of the rock. None of the intrusions seems to have been accompanied by any appreciable amount of water and this likely accounts for the very slight effects thus produced.

STRUCTURE

GENERAL

The structure in this district is an asymmetrical anticline having three crests located along an axis of northward trend which bends northeast at its northern extremity and slightly southeast at its southern extremity. This axis plunges to the south and hence the northern crest is the highest. These three crests are separated from each other by synclines crossing the anticline almost at right angles to the axis. The fold produced lies approximately parallel with the mountain uplift with the steep side facing toward it. The general trend of the axis is roughly parallel with the major folds in bordering districts, such as the Trull anticline, and the Sage Creek anticline. The west limb has a rather constant dip of about 12° westward and the east limb a steep dip of from 40° to 50° eastward in the Yampa River valley but lessening considerably to the north. (See Pl. III., in pocket.)

YAMPA CREST

The southern and lowest crest occupies the area along Tow Creek below its forks and along the Yampa River in sections 7, 8, and 17, T. 6 N., R. 86 W. The anticline has been tested by two wells, neither of which gave favorable results. The logs are not reliable and there is no certainty of the depth attained. The well along the Moffat Highway in section 7, T. 6 N., R. 87 W., is a dry hole, and from reports concerning its depth went down a considerable distance into the Mancos shale without obtaining any oil. The other well located in section 32, T. 7 N., R. 87 W., is on the east side of Tow Creek about a quarter of a mile below the forks. It flows a small amount of water steadily. This well begins near the base of the Mesaverde and probably went some distance into the Mancos. This well is seemingly fairly well located to test the structure, but perhaps is a little too far to the east and may have gone principally into the Mesaverde beds, which have a very strong dip to the east at this place. This seems to be indicated by the fact that artesian water was obtained. A more favorable and decided test would be about a half mile farther south and on the west side of Tow Creek. The possibility that the intrusion resembling a laccolith, to the north of the well, but separated from it by a syncline, has caused leakage in this dome, cannot be overlooked. Its nearness suggests that it may have fractured or replaced a part of the possible oil reservoir south of the syncline and thus rendered the crest unproductive. From the contact slopes of the intrusion it seems quite probable that downward it breaks into and fractures the possible reservoir rocks.

CHIMNEY CREEK DOME

The northern crest is a quaquaversal structure in Mancos shale on Chimney Creek with its center in section 4, T. 7. N., R. 86 W. This structure is a nearly perfect dome as shown by the almost circular outcrop of calcareous layers and the rather equal dip of about 25° in every direction. These dips flatten out in every direction quite rapidly. It is possible that an intrusion of igneous rock, laccolithic in type, may underline this fold. (See fig. 14.) It may also have been formed by a combination of these forces. The possibilities of igneous intrusion beneath this crest are strengthened by the presence of three dikes or sheets which show in irregular and interrupted outcrop around the dome. These sheetlike bodies of basalt do not follow the bedding planes of the shale exactly, but are intruded at practically the same angle and cut across the bedding only for short distances. That dikes would be intruded in a circular form at such nearly equal distances from the center of the fold seems rather improbable unless connected to a laccolithic body underlying the dome. Assuming this to be the case, oil may still be found in the dome, as their metamorphic effect on the shale is very slight. If the oil had accumulated previous to intrusion there would likely be some seeps around the intrusions. No such seeps were found nor was there anything along the contact to indicate that oily matter had been passed through. In case the accumulation is taking place at present the dikes would not materially injure the chances of obtaining oil from this structure, but it might restrict the district in which it could be obtained to that part of the dome lying outside of the area inclosed by them. The metamorphism of the possible oil reservoirs is probably not much greater than that seen in the shales.

The possibility suggested above that the crest is underlain by a lac-

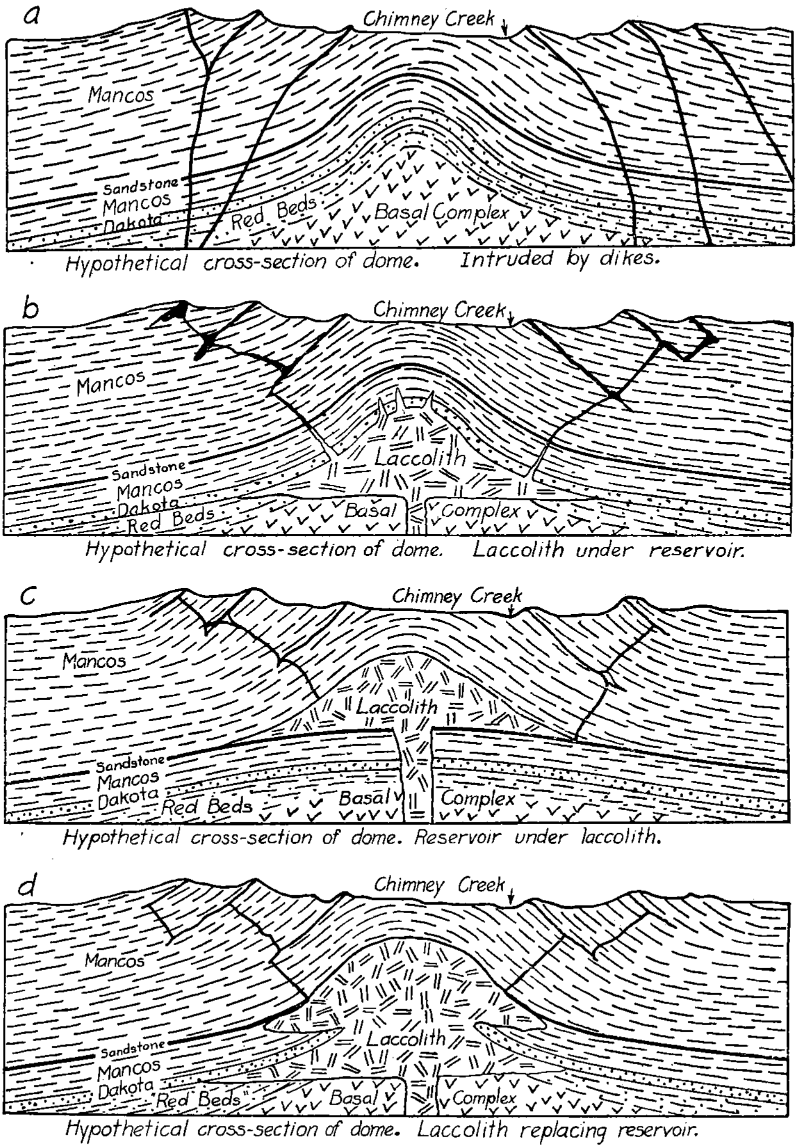

Fig. 14. Possible relationship of rocks in the Chimney Creek dome

colithic body deserves much consideration, but nothing more than hypotheses can be advanced until data obtained from drill holes are available. If a laccolith or thick sill has caused or accentuated the arching and doming of this structure it would still be possible for oil to accumulate under certain conditions as follows·

(a) If an oil reservoir lies above the laccolithic body and it is not materially changed by the intrusion, the possibilities of obtaining any oil which may have accumulated are not affected by the presence of the intrusion. (See fig. 14b.)

(b) If a reservoir lies underneath the laccolith and has not been too much altered it probably has sufficient arching for the accumulation of a commercial quantity of oil. (See fig. 14c.)

(c) If the possible reservoir has been displaced or broken up by the igneous intrusion it would probably be necessary to go beyond the borders of such disturbed area to find an iol reservoir. (See fig. 14d.)

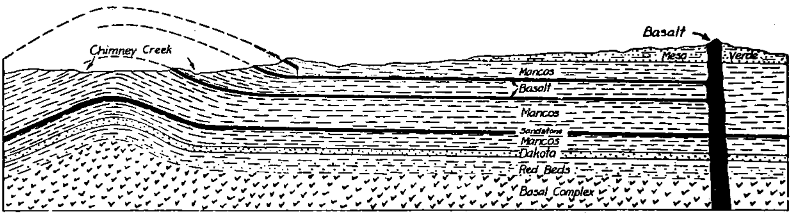

Fig. 15. Possible relationships of sedimentary and igneous rocks in the Chimney Creek dome.

Evidence of channels which would allow the movement of magma upwards is seen in the thickened bodies at four or five places in the line of these intrusions. That these channels seem to diverge upwards from a point near the center of the dome may indicate that arching movement took place subsequent to their opening. That these thickened places probably represent channels which connect the sheetlike intrusions seems likely. If such is the case they would not materially affect the foregoing discussion as they may or may not indicate a laccolithic intrusion. The size of one such body appearing in a hill on the south side of Chimney Creek at the southwest side of the dome is such as to give evidence of outlet sufficient to almost, if not quite, prevent the formation of a laccolith.

TOW CREEK CREST

The middle crest of this anticline, of which the structure contours are shown on the map, is filled with an igneous intrusion which resembles a laccolith. On all sides the Mesaverde sandstone dips away at angles varying from 10 to 45 degrees. On the igneous rock near the central part of the southern half is a small patch of basal Mesaverde sandstone, the lower part of which contains a layer of bituminous sandstone very similar to that from which oil seeps to the east along the creek. Near the border at the south end of the igneous rock is another small patch of Mesaverde sandstone similar to the one above and also to those connected with the oil seeps. The significance of these patches of sandstone seems to be that the Mesaverde formation once covered at last the greater part of the intrusion.

If the igneous rock is a laccolith, it would appear to be intruded between the top of the Mancos and the base of the Mesaverde. Oil, if present, must be in the Mancos below.

OIL POSSIBILITIES OF THE TOW CREEK ANTICLINE

There are various indications of the presence of oil within the strata of this area. At three points along the Moffat Highway water seeps carry small amounts of oil which have accumulated as a residue in the earth around the seeps. That saline matter is also present is shown by the thin crust of alkali around the borders of these seeps, which come from the sandstones lying just above the Tow Creek sandstone. The saturated earth gives a decided oily smell when heated with a match, and in some places where it has been hardened and concentrated by the sun's rays will almost ignite. An oily scum is also present on the small puddles around these seeps.

About three hundred feet above the forks of Tow Creek on the east bank of the east branch is a ledge of sandstone very close to the base of the Mesaverde formation which is saturated with a dark tarry oil. The surface of this ledge has been opened up for about 4 feet vertically and 10 feet horizontally, the top and bottom of the layers are shale contacts toward which the oil decreases in amount. There are occasional shale partings at intervals of from 2 to 10 inches. This layer of sandstone is just full enough of oil so that it does not ooze from the surface. In each direction this ledge is covered with debris from the slope above, and about a half mile up the creek the surface has been uncovered again and here a short tunnel was being driven into the ledge to drain the oil from the rock. The oily rock taken from the tunnel was, in August, 1919, being heated in a small crude still to extract the oil.

In a sandstone ledge the thickness of which was undetermined on account of the debris covering it, and which is about a hundred feet above the still, is an oil spring described in Bulletin 297 of the United States Geological Survey, page 79. A small pool has been formed where it issued form the rock. When examined the surface of this pool was covered with a scum of dark, tarry oil which was very slowly trickling over the edge with some water. The water seemed to be just enough to keep the pool at a constant level and trickle over the side for a few feet where it was absorbed and dried up. The slope below was covered with waste from above, but a considerable amount of brea, presumably overflow from the pool above, had accumulated on the surface from which the earth and brush had been removed over an area about fifty feet wide and two hundred feet down the slope. This layer was not uniform in thickness, and in most places did not exceed three inches. The prospectors had uncovered some chunks six or seven inches thick without reaching bottom. This patch, including the spring, was fenced in to keep out the stock for which these seeps, probably on account of their salt, have great attraction. One of the prospectors working on the little tunnel below, said that he had skimmed about a bucket of oil from this pool, each evening for the past seven years.

Past experience has been largely against the possibilities of obtaining oil in districts into which igneous rocks have been intruded, but in certain Mexican fields their presence has been shown to be favorable to very productive areas. A district in which the structure, rocks, and conditions are quite similar to this is that between Tuxpam and Tampico where very productive wells have been obtained around the igneous intrusions. For a fairly complete discussion of these occurrences consult "The Mexican Oil Fields," by L. G. Huntley, in the Transactions of the American Institute of Mining Engineers, Volume 52, pages 281-321. It is not at all certain that the conditions in Mexico are reproduced exactly enough in this district to warrant drilling on the limbs of the fold adjacent to the intrusion, but provided that the Chimney Creek crest was found to be productive, and other nearby fields show good quantities of oil in the strata below the Trout Creek sandstone, the west limb of this fold would be worth prospecting. In any event the dike running northward from this intrusion to the south crest of Wolf Mountain may trap oil coming up the strata from the south and west, and if such is the case, wells could be drilled to tap the reservoir along a line roughly parallel to this dike and at no great distance from it. On the east side of the structure the seeps indicate a leakage of oil from some reservoir or else the accumulation of very small amounts close to the surface due to the action of circulating waters. The conditions on this side of the structure seem far less favorable to the accumulation of oil in starta than on the west side.

This anticline is as yet unproved. The conditions seem to be favorable to careful tests, and of these the first should be made on the Chimney Creek crest where the sandstone in the Mancos might be reached near the center of the dome at a depth of about 600 feet, and the Dakota sandstone at about 1,100 feet. In drilling, both of these possible reservoirs should be tested. In the southern crest, which seems to have conditions second in favor to the one above, the Mancos sandstones should be about 1,800 to 2,000 feet, and the Dakota sandstone 2,300 to 2,500 feet below the surface, but thickening of the Mancos formation would increase these figures. The conditions in the Tow Creek or middle crest are the least favorable of the three, and prospective drilling should follow the conditions previously discussed.

TOW CREEK ANTICLINE

This anticline was partly tested by a well that was drilled in 1902 (?) in the southeast corner of section 7, T. 6 N., R. 86 W. The well at the present time is inactive, and no reliable information could be obtained as to its depth or sands encountered. The information obtained indicates that it was a dry well. It appears that this well was drilled slightly too far to the east. The axial plane of the anticline, as estimated from the structural map, dips 85° to the west. This would place the crest of the possible Mancos oil-bearing sandstone almost immediately beneath the well. If this anticline produces gas, as the Williams Park anticline from the "Dakota," the well would more probably encounter the oil, if present, if drilled farther to the west on the western limb of the anticline, and farther to the north, nearer to the crest.

The Mancos sandstone at the crest is approximately 1,700 feet below the level of the Yampa River. The "Dakota" sandstone at the crest is approximately 2,200 feet below the level of the Yampa River. This approximation is fairly accurate if there has been no local thinning or thickening of the Mancos formation at this place.

The Tow Creek anticline is structurally favorable for the accumulation of oil and gas. If the petroleum is present in any of the underlying rocks, and is associated with water under pressure, it will probably migrate up the dip. The oil would then be expected to accumulate near the crest of the anticline. The writer did not examine the area to the north to determine the influence of the igneous rocks present on the accumulation of the oil or gas, hence he does not feel justified in recommending or condemning this anticline.

CURTIS ANTICLINE

The Curtis anticline lies in the central and southwestern part of T. 6 N., R. 86 W. (See Plate I.) Its axis, which trends northwest and southeast,, is almost at right angles to the Tow Creek anticline. This anticline plunges to the west and is separated from the Tow Creek anticline by a steep syncline. The dips to the northwest and southwest average 15°. The dips to the north average 20°. The dips to the south average 10°. The dips taken on the massive sandstones west of Trout Creek are not reliable, as these sandstones were almost level and no definite bedding planes could be found. There also appeared to be some slumping caused by weathering. The average dips taken on these sandstones were 2° to the southwest, and 2° to the northwest, which places this fold in the terrace type of folds rather than the true anticlinal type. These dips were probably away from the axis of the fold where the anticline has its broadest limit. The narrowest part is to the west where it closes.

Sufficient time was not available to examine the eastern boundaries of this fold as closely and carefully as was desired. The dips recorded, however, along the eastern side of Trout Creek indicate that the fold opens to the southeast and therefore would allow the escape of any gas or oil.

Bulletin 297 of United States Geological Survey, referred of before shows a probable fault near Trout Creek. This fault was not definitely found by the writer, but the appearance of a massive white sandstone east of Trout Creek below the general level of the Trout Creek sandstone, indicates that there is a displacement of some kind. If this fault is present, and the displacement is of any great extent, there is a probability that it has sealed any gas or oil accumulated to the west of the fault.

The gathering ground for this fold is limited on the west by the Tow Creek anticline, on the north by a narrow syncline parallel to the Yampa River, and on the south by the Twentymile Park syncline.

It is suggested that this fold be studied and investigated more carefully, in order that more definite conclusions may be deduced as to its oil and gas possibilities.

TRULL ANTICLINE

The Trull anticline extends from section 4, T. 7 N., R. 85 W., to section 9, T. 6 N., R. 85 W., where it disappears under the alluvium south of the Yampa River. Mr. Willson mapped this anticline north of the Trull schoolhouse, which is on Elk River.

The dips recorded on the western limb between the Yampa River and the Elk River average 50°. Those north of Elk River, where the anticline becomes broader, average 42°. The dip of the shales on the eastern limb at the Yampa River is 42°. Between this dip and Elk River no reliable dips were recorded on the eastern limb, as the shales are covered by a gravel and boulder deposit, and slumping hindered the obtaining of accurate dips near the Elk River. The dips taken on the eastern limb north of the Elk River average 50°.

This anticline is in the lower part of the Mancos formation, as shown by the outcrops of the Mancos sandstone in sections 28 and 4, T. 7 N., R. 85 W. It closes at the northern end where the dips are 60° to the northeast and 50° to the northwest. These dips were taken on the Mancos sandstone where the Elk River cuts its channel through the fold. The elevations of the two sandstone outcrops were approximately determined, and it was found that the anticline plunges slightly to the south towards the Yampa River syncline, where it then probably opens again to the south. The general dip of the strata south of the river is to the northwest.

The outcrops found along both banks of the Yampa River do not indicate that the anticline closes or plunges to the south. The dip of the shales south of the river could not be obtained as they are covered by a mantle of alluvium.

It was noticed that there is an abrupt change in the trend of the axis where it crosses the Yampa River. This change may be due to a bend in the fold, or it may be due to a fault which crosses the fold. If it is a fault, the displacement, according to the bend of the axis, must be approximately 1,500 feet. There is no expression of such a fault on the surface to the east or west.

The gathering area is limited on the west by the intrusion of igneous rocks which form Elk Mountain, to the south by the syncline parallel to the Yampa River, and to the north by a sharp syncline. The greatest gathering area is to the east, and to the south of Elk Mountain.

If there is a fault present at the Yampa River, it would also limit the gathering area. It might also seal any gas or oil accumulated south of the river. The syncline parallel to the Yampa River is about two miles from the Yampa River, so if the fault did seal any oil or gas, the gathering area would not be sufficient to allow the accumulation of any commercial quantities of gas or oil.

The gentle plunge of the anticline to the south may change before it reaches the Yampa River. There is also a possibility of the presence of minor folds or wrinkles that do not appear at the surface. If these are present they would reduce the amount of accumulation at the highest point of the anticline to the north. The folding is sharp at the crest.

With such folding there was undoubtedly a great deal of fracturing within the sandstones. Any fractures present might allow the escape of gas or oil. The Mancos sandstone is open at two places which would permit the escape of gas and oil. If the "Dakota" sandstone contains gas or oil there is a probability of its being accumulated at the highest point of the anticline in section 4, T. 7 N., R. 85 W.

It does not seem justifiable to recommend a test of the Dakota sandstone as the structural conditions are not pronouncedly favorable, and because this sandstone is the only possible reservoir. The best location for a test well would be about 600 feet south of Elk River near the axis of the fold, in section 4, T. 7 N., R. 85 W. Wells drilled here should encounter the "Dakota" sandstone at a depth of about 600 feet.

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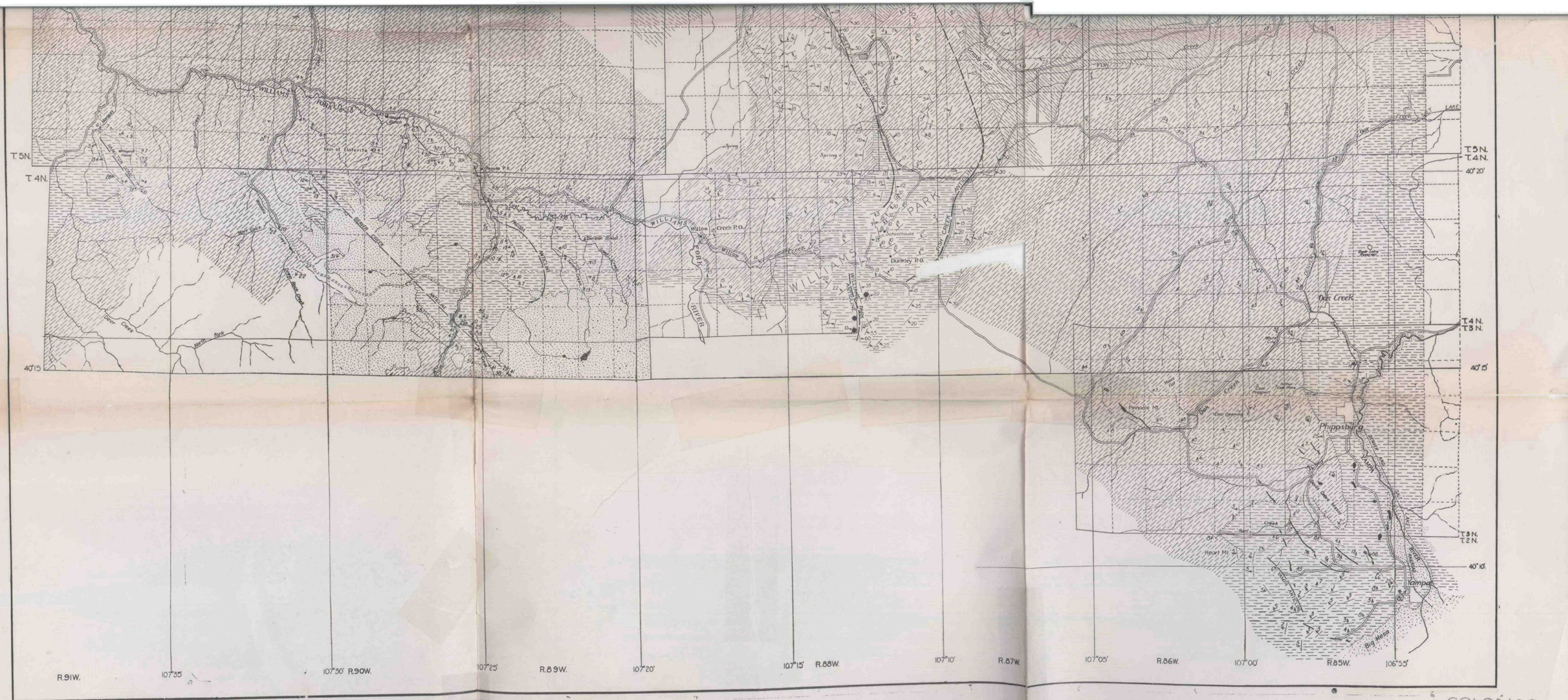
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T.3N.
T.2N.
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40°15'
40°10'
R.91W.
R.90W.
R.89W.
R.88W.
R.87W.
R.86W.
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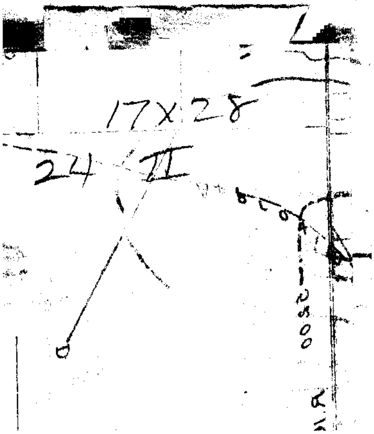
WILLIAMS FORK RIVER
WILLIAMS PARK
WILLIAMS PARK ANTICLINE
Willow Creek P.O.
Dunkley P.O.
Schoolhouse
Pagoda P.O.
PAGODA ANTICLINE
BEAVER CREEK
FISH CREEK
Oak Creek
Phippsburg
Yampa
Pinnacle Mt.
Heart Mt.
Big Mesa
North Fork
Deer Creek
Vein of Elaterite
Spring
VAMPA ANTICLINE
DENVER AND SALT LAKE RAILROAD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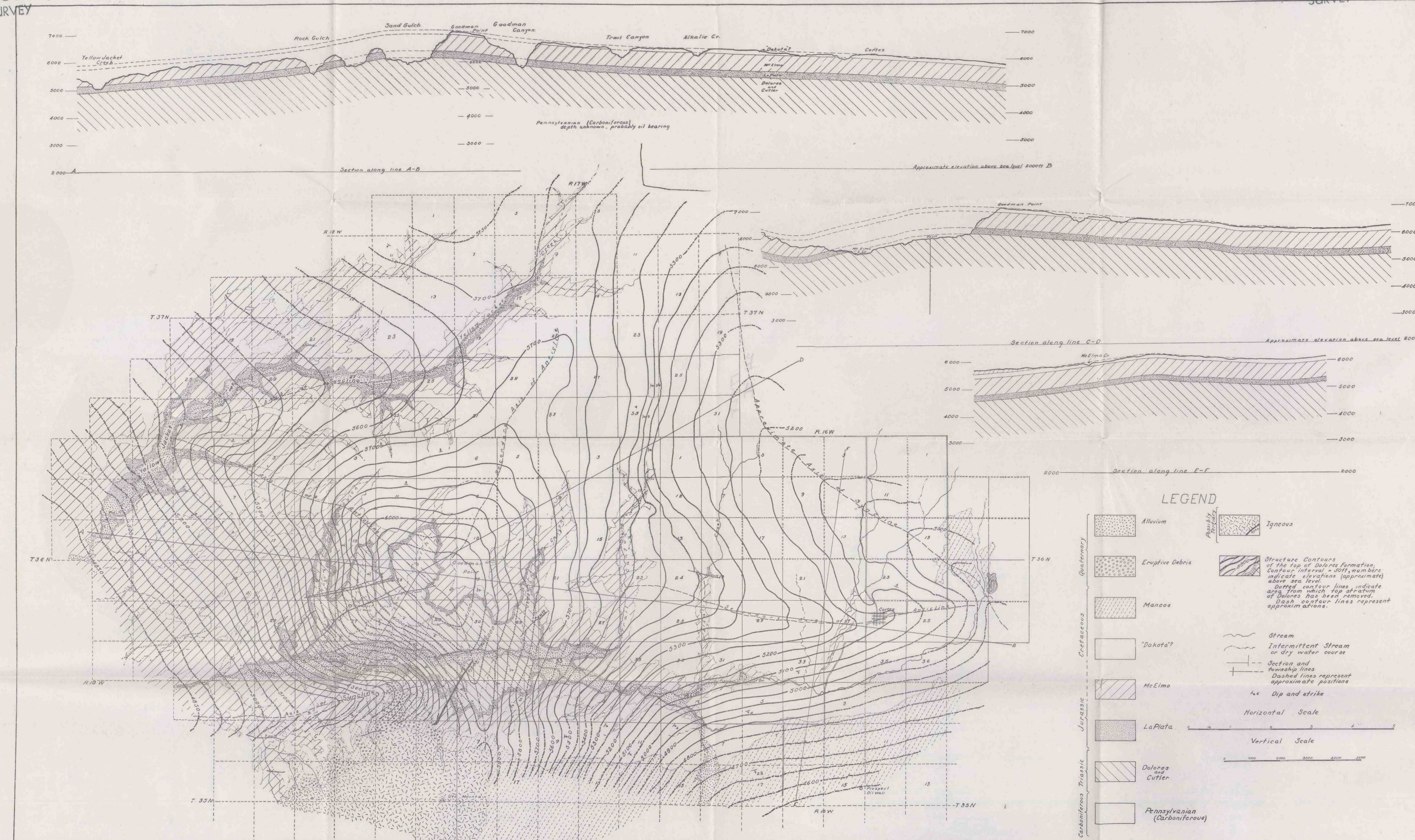

MAP OF THE McELMO ANTICLINE, MONTEZUMA COUNTY, COLORADO
By R. C. Coffin

1-7 FOLDS IN VICINITY OF McCOY