OIL RECONNAISSANCE IN NORTHWESTERN COLORADO

BY

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INTRODUCTION

Purpose of the Investigation

Due to the fact that the Wyoming oil fields have proved to be rich producers of high-grade oils, and that some of the formations that carry these oils extend into northwestern Colorado, showing occasional seeps of oil, a rather active search for oil and gas is being made throughout this field. The Colorado Geological Survey, with the hope of promoting this activity, sent a party of men into this field during the summer of 1919 to search for, and map geological structures that might carry gas or oil. The Survey also desired to find structures that would probably not be favorable for the accumulation of oil and gas thereby eliminating any unnecessary speculation that might take place.

Acknowledgments

In presenting this report the writer desires to express his thanks to Dr. R. D. Crawford for valuable suggestions and criticisms, and to K. M. Willson, John C. Myers, and Russel Murphy, for their assistance in the field work. He also desires to thank other individuals who have contributed in many ways to the success of the investigation.

Area Covered

This report covers the southern part of the Tow Creek anticline, the Curtis anticline, the Trull anticline, and a hurried reconnaissance trip covering a small area near Yampa, Colorado. The work was done by Russel Murphy, John C. Myers, and the writer, members of the Survey. Dr. R. D. Crawford was in charge of the parties.

Location

The part of northwestern Colorado herein described lies in the eastern part of Routt County, west of Steamboat Springs and the greater part south of the Yampa River, in Townships 5 N. to 6 N., Range 85 W. to Range 88 W., Latitude 40° 25' N., Longitude 107° 00' W.

The principal towns are Steamboat Springs to the east, Hayden to the west, Mount Harris, Bear River, MacGregor, and Milner, in the central part on the Yampa River. The Denver and Salt Lake Railroad from Denver to Craig, Colorado, follows the Yampa River and traverses the central part.

Field Methods

The field examinations were made during the months of July and August, 1919. In mapping the Tow Creek anticline, and the Curtis anticline a plane-table, stadia rod, a telescopic alidade and a Brunton compass were used. The work was started from a base line established on the township line between T. 6 N., R. 87 W. and R. 88 W. A flag was placed at the north base at the land corner separating sections 6 and 7, T. 6 N., R. 87 W., and sections 1 and 12, T. 6 N., R. 88 W. A flag at middle base was placed 1,297 feet south from the section corner between sections 18 and 19, T. 6 N., R. 87 W., and sections 13 and 24, T. 6 N., R. 88 W. This was a stadia measurement. A flag at the south base was placed 1,340 feet south of the township corner separating townships 6 N., R. 87 W and R. 88 W., and townships 5 N., R. 87 W. and R. 88 W. This was also a stadia measurement.

The courses and distances between the land corners in accordance with the recent resurvey, were obtained from the Department of the Interior, Office of the United States Surveyor General, at Denver, Colorado.

From these points located, a system of control points were extended throughout the area of the Tow Creek anticline and the Curtis anticline. Nearly all of the locations were made by triangulation and by the use of the stadia rod. The elevations were determined by means of vertical angles recorded from the telescopic alidade and the Brunton compass. A bench mark of the United States Geological Survey, was located at the town of Bear River, and all subsequent elevations were based upon its elevation, 6,491 feet above sea level.

In mapping the Trull anticline an enlargement of part of the Hahns Peak Quadrangle topographic sheet was used. This quadrangle was surveyed in 1910-1911 by the United States Geological Survey. The locations made on this sheet were found by intersection and resection from known points with a Brunton compass. The elevations were determined from the contour lines given.

The small area where the Trull anticline crosses the Yampa River was mapped with plane-table, stadia rod, and telescopic alidade. A base line was established from the one-quarter section corner between sections 9 and 16, and the one-quarter section corner between sections 10 and 15, T. 6 N., R. 85 W. The methods used in establishing this line were similar to those used for the main base line.

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GENERAL PHYSIOGRAPHY AND DRAINAGE

Much of this region may be described as being low in comparison with the Park Range of the Rocky Mountains to the east. This range is part of the Continental Divide separating the waters of the Mississippi River system on the east from the Pacific ocean drainage on the west. The highest part of the area west of the Park Range is within the central part of the Tow Creek anticline which rises to an elevation of about 7,800 feet above sea level south of the Yampa River, and 8,500 feet north of the river. The elevation of the Yampa River is approximately 6,400 feet above sea level. The higher hills to the east average 5,000 to 7,000 feet in elevation. Twentymile Park and the low hills to the west that surround Hayden ARE average from 100 to 400 feet above the Yampa River. This river drains westward to the Green River. Elk River, Cow Creek, Trout Creek, Tow Creek, Wolf Creek, Grassy Creek, and Sage Creek are the main smaller streams that drain into the Yampa River along its course in this area.

GEOLOGY

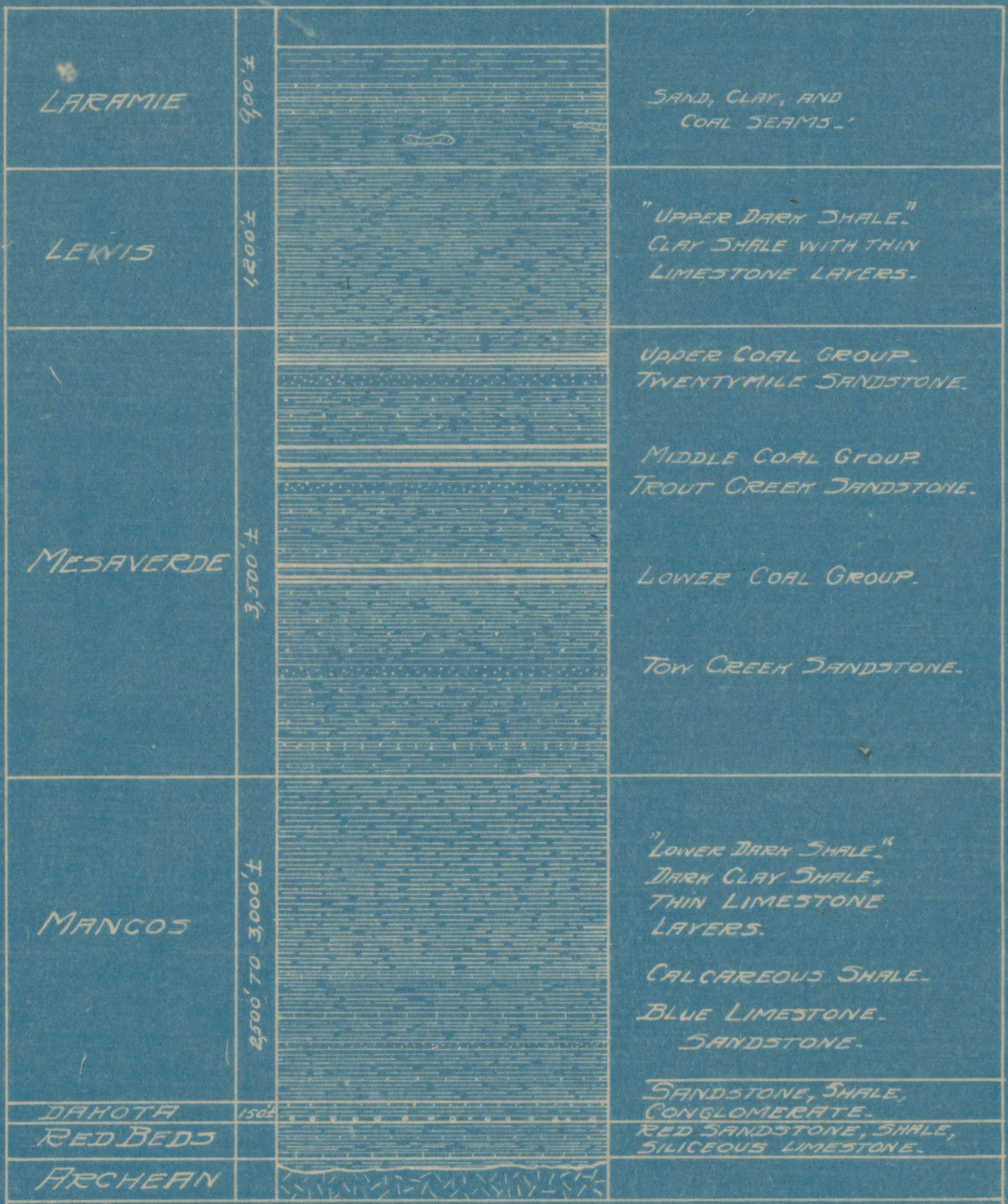
Stratigraphy

The stratigraphic column is made up of rocks mostly of the Upper Cretaceous age. There are some unconsolidated gravels and boulders that lie unconformably upon the Cretaceous rocks that probably belong to the Tertiary or Quaternary period.

In studying the formations the report by Fenneman and Gale[1] was used almost entirely. A generalized section of the rocks was taken from this report and studied and followed wherever possible. A check was made of the thickness of the Mesaverde formation in Yampa canyon. A complete section of the Mancos fformation could not be found in this vicinity, but a part was obtained on Poose Creek, southwest of Williams Park. A generalized columnar section of the rocks is shown on Page 9, Fig. 1.

The previous study and the correlation of the formations with other formations of this state, may be summarized

[1] Fenneman, N.M., and Gale, Hoyt S., The Yampa coal field , Routt County, Colorado. U.S. Geol. Survey Bull. 297, 1906.



GENERALIZED COLUMNAR SECTION

Fig. 1

<table>
<tr><th>PERIOD</th><th colspan="3">CORRELATION</th></tr>
<tr><td></td><td colspan="3">LARAMIE</td></tr>
<tr><td rowspan="5">CRETACEOUS</td><td rowspan="3">MONTANA GROUP</td><td rowspan="3">FOX HILLS

PIERRE</td><td>LEWIS</td></tr>
<tr><td>MESAVERDE</td></tr>
<tr><td rowspan="2">MANCOS</td></tr>
<tr><td>COLO. GROUP</td><td>NIOBRARA
BENTON</td></tr>
<tr><td colspan="3">DAKOTA</td></tr>
<tr><td>JURA-TRIAS?</td><td colspan="3">RED BEDS</td></tr>
<tr><td>ARCHEAN</td><td colspan="3">ARCHEAN</td></tr>
</table>

Fig. 2.

in the following paragraphs from Fenneman and Gale.

"The mapping of the rock formations in the vicinity of the Yampa field fell within the province of the geologists of both the King and the Hayden surveys. These investigators adopted the classification for the Cretaceous strata that had been previously established from measurements and study of the rocks in the upper Missouri River region by Meek and Hayden. In that region the classification was adopted mainly on lithologic grounds, and seemed satisfactory as applied over a considerable area of western Cretaceous rocks. Below the Laramie each of the major lithologic groups thus established was found to contain a distinct and characteristic fauna. In brief, the grouping there adopted is summarized in the following table:

Classification and nomenclature adopted in previous surveys.

Tertiary.

CRETACEOUS	1. LARAMIE	
	2. FOX HILLS	MONTANA GROUP
	3. PIERRE	MONTANA GROUP
	4. NIOBRARA	COLORADO GROUP
	5. BENTON	COLORADO GROUP
	6. DAKOTA	

"In the early surveys of northwestern Colorado it was found quite impossible to recognize the established groups of the Cretaceous system either by lithologic or faunal breaks. Distinct lithologic groups were clearly present, but as these did not conform to the established groups of the Meek and Hayden section they were in part ignored and in part misinterpreted. In the Yampa district several formations are distinct and persistent throughout the entire field, but the arbitrary boundaries that the early investigators adopted for the purposes of description and mapping were placed at indefinite horizons within the natural groups, to the confusion of all succeeding geologic work that has attempted comparison or correlation with this field."

Because of this irregularity of formations they dropped the Colorado and Montana groups and adopted a new basis for subdividing the formations. This was done by incorporating the names of the formations in southwestern Colorado, as established by Mr. Whitman Cross[2], because they so closely resemble each other, and because they occupy a similar position above the Dakota. The correlation and local names adopted are shown on Page 10, Fig. 2.

Descriptive Geology

Dakota Formation

This formation is approximately 150 feet in thickness and is made up of sandstones, shales and conglomerates. The lower part at some places contains a conglomerate composed of gray quartz flint and feldspar pebbles. The upper

[2]Description of the Telluride district; Geologic atlas U.S., Folio 57, U.S. Geol.Survey, 1899. Description of the La Plata district; Geological Atlas U.S., Folio 60, U.S. Geol. Survey, 1899.

part is characterized by a grayish-white, even-grained, massive sandstone and beds of sandy shales and slabby sandstones.

At Steamboat Springs, this formation forms a prominent ridge and the beds are clearly shown where a railroad cut has been made through part of the formation. The strata dip about 35° to the west at this place, and are found overturned to the north of the Yampa River. See Plate IV, Sect. B B'.

The characteristic cross bedding, ripple marks and flow and plunge structures, that are usually found in this formation of other regions, were not found to any great extent.

Mancos Formation

Shales are the predominating rocks of this formation and they comprise approximately 1,800 feet of the total Mancos thickness of about 2,500 feet. The thickness of this formation varies from 2,500 to 3,500 feet at different places in northwestern Colorado.

The shales of the lower part contain sand, and where weathered are very brittle and light colored. Some of the shales found near Steamboat Springs in the vicinity of Deer Mountain, are platy and exceedingly hard. When dug into they separate into large, regular, smooth-surfaced sheets. They are usually thick bedded with regular bedding planes.

The shales of the upper part are dark, calcareous, and thin-bedded. In some places, however, the beds are thicker and rather hard with very definite bedding planes.

A 38 foot bed of sandstones and sandy shales was found south of the Elk River near the Trull School house, Section 28, T. 7N., R. 85 W. The section of this bed is as follows:

Fine-grained, fossiliferous sandstone---	7' 0"
Alternating sandstones and shales-------	16' 8"
Thin-bedded sandstones-------------------	14' 7"
	38' 3"

It was impossible to determine how far this bed occurred above the base of the Mancos. It probably lies approximately 400 feet above the base as a similar bed found on Poose Creek southwest of Williams Park, and the bed shown in the columnar section in Bull. 297, United States Geological Survey, are about this distance from the base.

The blue limestone and calcareous shale beds shown in the general columnar section were not found in this local area.

This formation is discussed further under the heading, "Wells, Possible Oil Reservoirs, and Known Oil Seeps."

Mesaverde Formation

This is the most conspicuous formation in the field, and it is approximately 3500 feet in thickness.

The coal beds of the different groups will not be treated, as they are so elaborately discussed by Fenneman and Gale. Since their report was published in 1906, a great deal of coal mining has been done. The principal coal camps are, Mount Harris, Bear River, MacGregor, and

Oak Creek.

The more prominent sandstones and coal beds form rather definite horizons which are the basis of this formation being divided into lower, middle, and upper coal groups. From the base of the Mesaverde to the lower coal group, alternating beds of sandy shales and sandstones are found. The sandstones are massive at some places,the beds being from 60 to 100 feet thick. There are also thin sandstones which alternate with the sandy shales. The sandstones are usually hard and fine-grained. They differ in color from a cream to a grayish white and in some places have weathered to a dark yellow.

The Tow Creek sandstone is the most outstanding rock of this group. It is very massive and at some places is 100 feet thick. The freshly broken surfaces are cream-colored which weathers to a distinctive yellow. The texture differs at the various outcrops, but in general it may be classified as a medium-grained sandstone.

The most prominent exposures of these sandstones and shales are found on the eastern limb of the Tow Creek anticline where the Yampa River has cut its channel through them.

The Trout Creek sandstone is the most important stratum between the lower and middle coal groups. It is a massive white rock, and usually forms ledges wherever it is exposed. These ledges are 50 to 100 feet high which are weathered in part into artistic pinnacles. Wherever the slightly dipping sandstone has been exposed to any great extent, cracks appear at the surface making odd-shaped outlines. These cracks form an easy place for erosive agents to work, and the surface is usually roughly and irregularly marked by five-sided and six-sided figures. The cracks are probably formed by expansion and contraction due to the differences in daily temperatures.

The beds between the Trout Creek sandstone and the top of the lower coal group consist of alternating shales and thin sandstones.

Between the top of the middle coal group and the top of the Mesaverde, sandstones and shales are found. The lower part consists of alternating beds of sandy shale and thin sandstones with an occasional stronger bed of sandstone.

The Twentymile sandstone is very similar to the Trout Creek sandstone. It is also white and massive and forms prominent ledges. The most prominent ledge found was on the western limb of the Tow Creek anticline where the dip averages 9° to the west. Here the sandstone forms a vertical ledge about 75 feet high which is almost continuouc around the southern end of the anticline. This sandstone is generally softer than the Trout Creek sandstone and usually weathers into more prominent pinnacles. These pinnacles stand from 4 to 10 feet high at the northern exposure around Twentymile Park. Some have small diameters and their pitted markings indicate that they were probably formed by wind erosion. They are sometimes capped by a harder sandstone layer.

On the eastern flank of the Tow Creek anticline where the dip averages about 25°, this sandstone has been eroded to a greater extent. It forms a series of white humps which are separated by shallow depressions. This condition probably is due to the atmospheric agents, which have more erosional effect on the upturned edges.

Above the Twentymile sandstone, shales, thin sandstones and a prominent white sandstone are found. This white sandstone is massive with an average thickness of about 50 feet.

Lewis Formation

This formation overlies the Mesaverde formation, and is approximately 1200 feet thick. It is composed mainly of soft dark calcareous shales which are thin-bedded. The bedding planes are usually indefinite and irregular. Thin lenticular beds of limestone and sandstone were found throughout the shale.

The main ourcrops of Lewis shale are found on the western flank of the Tow Creek anticline, and in Twentymile Park.

Laramie Formation

The Laramie formation consists of massive sandstones and light-colored sandy and clay shales. There are also many lignite or subbituminous coal beds in this formation.

The Laramie is found on the north side of the Yampa River and is not found in this local area. Its thickness near Hayden is approximately 900 feet.

Tertiary or Quaternary Formations

The hills east of Trout Creek and south of the Yampa

River towards Steamboat Springs are, in part, covered by a mantle of recent gravel and boulders. This mantle lies unconformably on the Mancos shales and is conspicuous on the rounded hill tops to the east of Trout Creek.

The gravel is unconsolidated and made up of a mass of coarse igneous material. Pegmatites, granites, gneisses and basic rocks were found which were probably washed from the crystalline rock area to the east.

There is also a mantle of the same material covering the tops of Deer Mountain. The material found here is coarser and more angular than the material east of Trout Creek. When Deer Mountain is viewed from a distance, the top of the mountain and the crystalline area to the east appear to have been a continuous slope at one time. This indicates that the gravels were probably washed from the area to the east. Deer Creek has cut a deep valley through this material and the shales beneath, and now separates Deer Mountain from the main range.

A BRIEF SUMMARY OF THE GENERAL FACTS RELATING TO THE ACCUMULATION OF GAS AND OIL

There are several theories which attempt to explain the accumulation of oil and gas at definite points within the rocks of the earth's crust. These theories will not be discussed, but there are certain facts that have been given us by a study of places where oil and gas have been found, that are important and will be briefly summarized. This summary is given for the benefit of those who know nothing of oil geology, and might make a clearer understanding of the discussion of oil structures, reservoirs, etc.

A suitable reservoir capable of containing the oil and gas until it is tapped by wells is the first requisite. Sandstones, limestones, or any porous bed may make a suitable reservoir if confined beneath and above by an impervious bed such as a shale. If there is a suitable reservoir there are usually three factors that control the accumulation of the oil and gas within the reservoir. These factors are : (1) The attitude of the beds (whether level or tilted.); (2) Water within the rock; (3) The porosity of the rock.

The first factor is the most practical factor to the prospector for oil or gas, as it is the only one he can see and study on the surface of the ground. The other two factors are important but can be only partially determined in the field.

Gas tends to reach the highest point in the rocks regardless of the amount of water present. Oil, however, if water is present, climbs to the highest point if the rocks are porous enough to permit it, due to the differences in specific gravity. If water is not present within the strata the oil tends to travel to the lowest point of the containing rocks. The main point is the stopping of this migration up or down which results in the accumulation of the oil or gas. The drainage or gathering areas are the areas from which the gas and oil have migrated.

Inclined strata containing water are the most favorable for the accumulation as conditions more often exist which tend to stop the upward migration of the oil or gas, which results in the formation of a pool.

The most important condition is a reversal of the dip of the porous oil containing beds forming an anticline, (Fig. 3, Plate V.) or the flattening of the inclined strata forming a terrace. (Fig. 2, Plate V.) The oil migration may also be stopped by the pinching out of the oil sands in either inclined or level strata, (Figs. 1 and 2, Plate V.) of by the intrusion of igneous rocks, (Fig. 4, Plate V.). Where water does not exist in the strata containing the oil, the oil, if present, will seek a trough or syncline. (Fig. 5, Plate V.).

There are many other types of structures and combinations of the above that have yielded gas and oil, but the above types are the most important.

WELLS, POSSIBLE OIL RESERVOIRS AND KNOWN OIL SEEPS

There are no wells in this region that have produced oil in commercial quantities. Three wells have been drilled in Williams Park, of which one is reported to have encountered a small amount of oil in the Dakota sandstone. The other two have produced gas from the same sandstone. Several other wells have been drilled throughout this region, as reported in Bulletin 297, of the United States Geological Survey. Most of the information is very indefinite and not valuable as the logs of the wells, their accurate positions, and the results obtáined are not available.

The Dakota sandstone is a proved reservoir for gas and a possible reservoir for oil. This formation produces oil in Wyoming and oil seeps are found within it at several places in Colorado. The gas formed at Williams Park was probably derived from the black shales within the Dakota formation, or as some have suggested, the downward migration from the shales above might have been the source.

The Mancos sandstone member in this local area, consists of thin-bedded, fine-grained, sandstones, and alternating beds of sandstone and shales. The cementing material of the sandstone is mostly silica, which binds the sand grains together and fills the greater part of the pore space. This fineness and lack of pore space would hinder the migration and storage of oil and gas within the beds. The shales also have very fine pores and will probably hold very little oil. There is a possibility, however, that during the time of folding these sandstones and shales were shattered to some extent. If this is true, the oil might migrate and be stored at the higher levels. The largest oil reservoirs usually occur where there is enough pore space to allow the convenient migration and storage of oil and gas. Wells drilled will be the only real test of the capacity of this reservoir, but the data at hand gathered from this very local area indicate that it is probably an insufficient reservoir.

The Mancos formation of equivalent formations in other fegions have produced gas and oil. The Boulder, Florence, and Wyoming fields are the most prominent producers. The lower part of this formation contains a great deal of dark bituminous material which yields a strong bituminous odor. Black carbonaceous shales exist at the top of the formation and below the Mesaverde. Observation showed that the organic material is widely disseminated throughout the formation, the richest shales were, however, within the lower members.

The shales when in their normal condition are, for the greater part, very dense and probably would not allow the migration and accumulation of the oil and gases derived from the organic material. If there has been any migration it must have been after the main folding had occurred and fissures and cracks within the shales had formed. As stated before, this would allow the oil and gas to segregate and seek higher levels according to their respective specific gravities.

The lower sandstone and shale members of the Mesaverde formation are more porous and probably would be sufficient storage reservoirs for oil and gas. It is questionable as to whether the oils and gases have migrated to this possible reservoir, or have been stopped because of such a large thickness of dense shale. These sandstones and shales are open in this area and, therefore, cannot be considered as oil reservoirs.

Oil seeps are reported to have been found in Sec. 4, T. 6 N., R. 86 W., Sections 32 and 33, T. 7 N., R. 86 W., and in Sec. 12, T. 6 N., R. 87 W.

OIL AND ITS RELATIONSHIP TO THE CARBON RATIOS OF COAL

With the great amount of oil development that is in progress in the United States and foreign countries, oil geologists and drillers have been offered new facts and theories that are important problems affecting the search for oil and gas in new territories. An important discussion offered that has a bearing on this field is that which treats of the stage of carbonization of the organic materials in oil bearing formations.

Several papers have been published on this subject digested from facts covering nearly all the important oil fields of the world. David White, Chief Geologist United States Geological Survey, has recently published an excellent paper on this subject.[3] The important principles derived from his discussion may be partly concluded as follows:

(1) That, "A study of the incipient regional metamorphism of carbonaceous deposits in the coal and oil fields of the United States and other countries shows that no commercially important oil fields have yet been discovered in any area where the fuel ratios of the coals, occurring in the formations in which oil is sought or in overlying formations, exceeds 2.3. ------- 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 2.0, or 66 per cent. fixed carbon."

(2) That, "The progressive devolatilization by which the coals in any region or formation have been transformed from peats to lignites, bituminous coals, etc., and finally

[3]White, David, Genetic Problems affecting search for new oil regions. Am. Inst. Min. Eng., Paper 158, Sec. 21, Feb., 1920.

to graphite, is the first indication of incipient metamorphism of the rocks of the area. The proximate analysis of the coal or coaly deposits, as the writer has shown, is a sort of "ultra-violet" method of observing this initial stage of regional metamorphism of the ordinary type."

(3) That, "It is important that, in a new region under consideration as to oil possibilities, every precaution be taken to ascertain whether the alteration of the rocks, as indicated by the stage of carbonization of the carbonaceous deposits, has not gone so far as to preclude the survival of oil in commercial amounts."

In discussing the causes of carbonization (alteration) of the organic debris and residue in sedimentary formations, White further states, "The transformations or geochemical changes are intimately associated with, if they are not actually caused by mainly horizontal stresses, under loading, with consequent molecular displacement, and some incidentally generated heat." Other causes of advanced carbonization are dependent on the heat caused by the pressure developed by overlying strata, contact metamorphism and all dynamic stresses. The element of time is also probably very important. It appears that with this natural distillation of

[4]Campbell, Marius R., Hypothesis to account for the transformation of begetable matter into the different grades of coal. Econ. Geol. Vol. I, p. 33, 1905.

the organic debris there must be some space where the gases formed may escape, or probably little distillation will result. Any joints or cleavage planes present will aid distillation.[4] (Page 23.) This factor should be thought of when considering the carbonization within the dense shales of the Mancos formation.

It is known that in this area of northwestern Colorado, there has been sufficient stress to form anticlines from loaded strata. It is also known that there has been sufficient igneous activity to cause dynamic stress and contact metamorphism. A combination of the above stresses and contact metamorphism must have been sufficient to cause the generation of petroleum and a high state of carbonization in the organic debris of the formations.

The stage of carbonization is estimated from the analyses of the coal mined in the Mesaverde formation. The fuel ratio of coal is determined by dividing the fixed carbon by the volatile hydrocarbons present and is shown by the proximate analyses of the coals. The coals of northwestern Colorado cannot be satisfactorily classified according to their fuel ratios asmany of the bituminous, subbituminous and lignites cannot be distinguished by its use. It is more satisfactory, when discussing the relationship of carbonization in coals to petroleum, to use the term carbon ratio, which has been designated as the percentage of fixed carbon in pure coal. The water and ash present in the proximate analyses, must be eliminated before the percentage of fixed carbon can be computed. The carbon ratio is determined by dividing the fixed carbon of the proximate analysis, by the sum of the fixed carbon and volatile matter of the same analysis.[5]

The proximate analyses of the coals of this field, obtained from several sources,[6] were not sufficient in number and distribution to prepare a map showing isovolves (lines of

[5]Fuller, Myron L., Carbon ratios in carboniferous coals of Oklahoma, and their relation to petroleum. Econ. Geol., Vol. XV, No. 3, 1920.

[6]Fieldner, Arno C., Smith, Howard I., Paul, J.W., and Sanford, Samuel, Analyses of mine and car samples of coal collected in the fiscal years 1913 to 1916. U.S. Bureau of Mines, Bull. 123, p. 32, 1918.

Lord, N.W., Analyses of coals in the United States. U.S. Bureau of Mines, Bull. 22, Part I, p. 78, 1913.

Gale, Hoyt S., Coal fields of northwestern Colorado and northeastern Utah. U.S. Geol. Survey Bull. 415, p. 248, 1910.

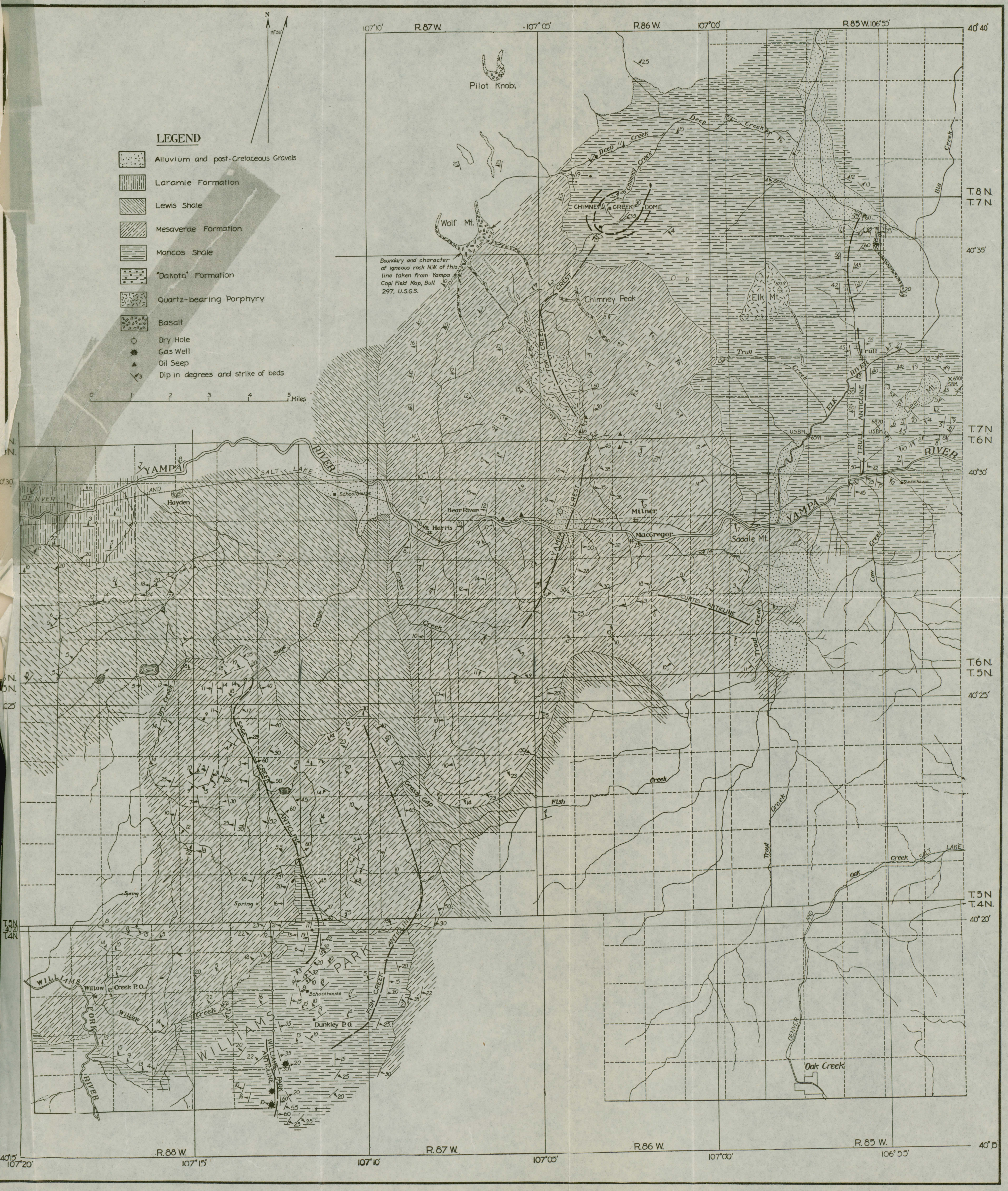
Fenneman, N.M., and Gale, Hoyt S., The Yampa coal field, Routt County, Colorado, U.S. Geol. Survey Bull 297, pp. 84-86, 1906.

equal fixed carbon percentages) that would be accurate enough to be valuable.

The table on the following page divides this region into districts and shows the maximum, minimum, and average of all the carbon ratios available in each district.

In collecting this data it was noticed from the position of the mines and outcrops that only a small portion of the coal in this area had been analyzed. The greater part of the coal lies beneath the surface and has never been touched by human hands. It must not be forgotten that the carbon ratios as given in the table do not represent the carbon ratios of the coals of the entire field, but merely give an estimate at local spots within the field. It is a question as to whether or not these ratios should stand as a fair analysis of the entire field. The data also show that most of the mines and outcrops are in regions where probably the greatest amount of dynamic stress has occurred. That is, near the axes of the anticlines. For example, the Harris coal mine, the Bear River coal mine, and others in Yampa Canyon, are within the western flank of the Tow Creek anticline. The samples from Sage Creek are within the Sage Creek anticline. Samples from the Curtis camp are within the Curtis anticline. There are also many other similar examples. The high carbon ratios near Pilot Knob represent the anthracite coals resulting from the metamorphism caused by the intrusion of the igneous bodies.

It follows that the greatest amount of mining will take place where the coal beds are brought to the surface,



SOME ANTICLINES OF ROUTT COUNTY, COLORADO

Geology by R. D. Crawford, K. M. Willson, V. C. Perini, J. C. Myers and J. R. Murphy. Land lines and drainage taken from United States Geological Survey topographic maps of the Hahns Peak and Daton Peak quadrangles and United States Surveyor General's township plats

District and Location.	Carbon Ratios Maximum	Minimum	Average
Mount Harris, Sec. 10 and 15, T. 6 N., R. 87 W. - - - - - -	59.60	53.22	55.85
Bear River, Sec, T. 6 N., R. 87 W. - - - - - - - - - - - -	55.73	55.73	55.73
Butcher Knife Creek, Sec. 1, T. 6 N., R. 87 W.- - - - - - -	56.20	55.50	55.56
Milner, Sec. 8 and 9, T. 6 N., R. 87 W. - - - - - - - - - - - -	55.40	54.50	55.96
Curtis Camp, Sec. 21 and 22, T. 6 N., R. 86 W.- - - - - - -	54.16	54.16	54.16
Eddy, Sec 1 and 12, T. 5 N., R. 86 W., Sec. 7, T. 5 N., R. 85 W. - - - - - - - - - - - - -	59.05	57.10	57.86
Oak Creek, Sec. 20, 29, and 32, T. 4 N., R. 85 W.- - - -	58.19	54.39	56.77
Sage Creek, Sec. 35 and 36, T. 6 N., R. 88 W., Sec. 2, 3, and 4, T. 5 N., R. 88 W.-	56.98	56.15	56.56
Dry Creek, Sec. 16, 21, and 22, T. 5 N., R. 88 W.- - - - - - -	58.60	58.28	58.44
Hayden Gulch, Sec. 36, T. 5 N., R. 89 W. - - - - - - - - - - - -	59.00	58.94	58.98
Crawford, SW of Pilot Knob, - -	96.76	57.20	74.94
Miller Gulch, SE of Pilot Knob,- - - - - - - - - - -	59.00	58.96	58.93
Deep Creek, SE of Pilot Knob,	57.30	57.30	57.30
Averages - - - -	60.46	56.26	58.23

and wherethe best coal is found. From what has been stated before, the best coals will be found where the greatest amount of carbonization has caused the formation of bituminous and semi-bituminous coals from the lignite. The highest carbon ratios,representing the best coals, are therefore, expected to be found at these places. The analyses of the samples obtained probably give a higher carbon ratio to the entire field than the actual average would otherwise be. The coals that have not been examined further from centers of carbonization, may be lignite or even of a lower grade, which would very pronounceably lower the carbon ratio of the coals of this field.

There was probably a great amount of carbonization in the Mancos formation which underlies the Mesaverde. This formation was possibly even more altered than the Mesaverde, so in comparison the relative amount of carbonization must be high. This amount of carbonization can probably be applied to local places where the greatest amount of folding has occurred, but not in general to the whole formation . The writer does not believe that carbonization has advanced far enough to cause a disappearance of the oils, or seriously affect this field. If oils have been accumulated they will probably be of low gravity and of high grade with a considerable amount of gas..

STRUCTURE

General Features

Sedimentary rocks are usually laid down by water in an approximately horizontal position. At a later period, by the processes of mountain making movements, these rocks are sometimes lifted many thousands of feet. Anticlines, domes, synclines, and other structural features are the result of these movements. Structure means the attitude which the rocks have acquired since they were formed. Faulting usually accompanies these movements, especially in the sandstones.

Due to the fact that there has been such intense folding in this region, there are probably many faults and fractures that do not express themselves at the surface. It can not be determined as to how much faulting has occurred in the underlying Mancos formation, and in the lower sandstone members of the Mesaverde formation. If there has been any considerable amount of faulting in the Mesaverde formation, the accumulation of gas and oil would be seriously hindered, and the greater part that may have accumulated would probably escape through the fissures and other openings caused by the faulting. If the faults do not extend beyond the lower sandstone members of the Mesaverde formation, the oils and gas, if accumulated in the Mancos formation, may find a way to the sandstones of the Mesaverde formation, and there be sealed , making a large reservoir.

Throughout this region the basal complex is overlain by thousands of feet of sedimantary rocks. These rocks were probably horizontal at earlier times, and there were minor movements that resulted in the advance and retreat of the sea. This is indicated by the presence of sandstones, shales, and conglomerates. These sediments were uplifted during Tertiary (?) times, and the main folds now present were formed as a result of the forces originated. The folds that were formed at this period were probably those having axes roughly parallel to the Front Range. These folds are: the Tow Creek anticline, the Trull anticline, the Sage Creek anticline, and the fold passing through Williams Park.

There are also anticlines and synclines whose axes are almost at right angles to the above folds. These are: the Curtis anticline, the Twentymile Park syncline, and the syncline roughly parallel to the Yampa River. These folds were probably formed at a later time, and might have been formed in a long, wide syncline, that existed between the Tow Creek anticline and the Trull anticline, by forces from the north or south. Mr. Willson states that the evidence found indicates that the intrusion of igneous rocks forming Elk Mountain, and the many dikes and other igneous bodies north of the river, were intruded after the main folding had taken place. The forces generated by the intrusion of Elk Mountain might have been sufficient to form the Curtis anticline.

Relation to Topography

The topography depends to a considerable extent on the structure and hardness of the underlying beds. Throughout this region wherever the strong resistant sandstones of the

Mesaverde are the underlying beds, the slopes follow the structure of these rocks. When the field is observed from the higher points this feature is well demonstrated. Twentymile Park, which lies to the east of the Tow Creek anticline, is a structural basin about 4 miles wide and 9 miles long, the strata dip towards the center on all sides. The central part is a low-rolling plain in the easily eroded Lewis shales. As the edges are reached the relief increases where the sandstones of the Mesaverde come to the surface and form escarpments to the south. This makes an abrupt slope on one side and a long gentle slope toward the plain within, which follows the general dip of the formation.

The Tow Creek anticline is another example where the slopes on each limb follow the structure of the underlying beds.

Where the sandstone beds are upturned to any great extent, and are of unequal hardness, erosion acts more rapidly on the softer beds and leaves the harder layers as long, narrow, sharp-crested, parallel ridges. The lower part of the Mesaverde develops this kind of topography on the east limb of the Tow Creek anticline near the Yampa River, and also in Dunkley Canyon.

Where the Mancos or Lewis shales are the underlying beds, which are practically of equal hardness throughout, rolling or gently undulating plains usually result. The topographic features are seldom controlled by the shales. In comparison with the sandstone areas, when the shale areas are observed from the higher points, the general structural features can not usually be determined by the slopes of the hills. The slopes are very deceiging at times, and indicate promising reverse dips. Closer examination, however, shows that the dip of the sediments is,at some places, opposite to the slope of the ground. This is especially true near Steamboat Springs and in Williams Park.

It was noticed that scrub oaks control the topography of the shales to a marked degree at several places. Most of the shales are uniform in composition and texture, as far as is known, and no apparent reason was found for the vegetation to seek the tops of sharper ridges more than the slopes. These ridges do not appear to have any general trend, as some extend north and south, some east and west, and others are curved and of odd shapes.

When the shale slopes were in a more horizontal position, the vegetation might have been scattered over the entire surface with more of a concentration along irregular lines. This concentration can possibly be attributed to the differences in composition or texture of the shales, direction and effect of the wind, or the accumulation of snow, etc. At the places of less vegetation, erosion had a more successful chance to weather the shales, and the ridge lines started where there was more vegetation. Vegetation then had its first control on the topography. As time went on, the vegetation became thicker and thicker along these lines, and finally has advanced ahead of erosion, until it now has complete control on the tops of the ridges. This topography was noticed especially in Williams Park, and in the Mancos shale area southeast of Steamboat Springs.

STRUCTURE CONTOURS, SECTIONS, AND DIP AND STRIKE SYMBOLS

Structure is generally shown either by structure contours, by sections, or by dip and strike symbols.

The Tow Creek anticline is represented by dip and strike symbols on Plate I, and by structure contours, and by sections on Plate II. These structure contours are lines drawn on the map to show the elevation of the different points of the Tow Creek sandstone above sea level. That is, each contour represents successive points of the same elevation on the Tow Creek sandstone.

The sections were drawn by plotting the elevations and dips of the rocks at the surface. The position and structure of the beds beneath the surface are hypothetical, and were drawn by plotting the distances between the prominent sandstone members, which were measured on the surface. Minor wrinkles and folds that do not appear on the surface of the ground or in the sections, may be present in the underlying beds. These folds, if present, might reduce the amount of accumulation of gas and oil at the crest of the anticlines.

The dip and strike symbols indicate the dip and strike of the rocks found at the points indicated on the map.

ANTICLINES

The Tow Creek Anticline

The Tow Creek anticline lies in the northeastern part of T. 5 N., R. 87 W., the eastern part of T. 6 N., R. 87 W., the western part of T. 6 N., R. 86 W., in T. 7 N., R. 87 W., and in T. 7 N., R. 86 W.

The Tow Creek anticline is roughly oval in outline with minor modifications to the northwest and northeast where a syncline crosses the axis of the anticline. Mr. Willson, who was in charge of the mapping of this anticline, north of the river, reports that it has a closure of about 600 feet at the northern limit of the axis. The crest is in Sections 5, 6, 7, and 8, T. 6 N., R. 86 W. (See Plate II.). This fold, south of the Yampa River, is in the nature of a "nose" plunging to the southwest. The dips to the east are very steep, especially in the northern part where they average about 40°. The dips to the southeast and south are more gentle and average 20°. The dips to the west and to the southwest average 9°.

The gathering area for this fold, from which the gas and oil, if present, are are accumulated, is limited on the east by a steep syncline that separates it from the Curtis anticline, the syncline parallel to the Yampa River, and the Twentymile Park syncline. It is limited on the southeast and on the southwest by synclines that separate it from the Foidel Canyon fold, and the fold that passes through Williams Park. The main area from which oil or gas may have been gathered is, therefore, the broad low area to the west. Smaller quantities may have accumulated from the Twentymile Park syncline, the syncline parallel to the Yampa River, and from the syncline to the south.

This anticline was partly tested by a well that was drilled in 1902 (?) in the southeast corner of Sec. 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.

Summary

The Tow Creek anticline is structurally favorable for the accumulation of oil and gas. If 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 absolutely 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. (See Plate IV.).

Bulletin 297, United States Geological Survey, referred to before, shows a probable fault near Trout Creek. This fault was not definitely found, but the appearance of a massive white sandstone east of Trout Creek below the general level of the Trout Creek sandstone, indicates that there was 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 Sec. 4, T. 7 N., R. 85 W., to Sec. 9, T. 6 N., R. 85 W., where it disappears under the alluvium south of the Yampa River. (See Plate III.). 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

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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.

Section C C', Plate IV, shows the approximated position of the Mancos and Dakota sandstones at the Yampa River. Section B B', Plate IV, shows the structure at the northern end of the anticline, and the overturn of the Dakota sandstone. These sections also illustrate the sharpness of the folding at the crest. With such sharp folding there was undoubtedly a great deal of fracturing within the sandstones. Any fractures present might a low the escape of ~~any~~ gas or oil accumulated.

The Mancos sandstone is open at two places which would permit the escape of gas and oil. If the Dakota sandstone contains gas and oil there is a probability of its being accumulated at the highest pointof the anticline in Sec. 4, T. 7 N., R. 85 W.

It does not seem justifiable to recommend a test of the Da ota 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 Sec. 4, T. 7 N., R. 85 W. Wells drilled here should encounter the Dakota sandstone at a depth of about 600 feet.

RECONNAISSANCE NEAR YAMPA, COLORADO

Location

The area near Yampa, Colorado over which a hurried reconnaissance tour was made, lies partly in townships 2, 3, and 4, N. Ranges 85, 86, and 87 W. This area is to the west and northwest of Yampa, north of the Flat Top Mountains and southeast of Williams Park.

A well traveled road connects Yampa with Williams Park. Pinnacle Mountain, a prominent land mark, is to the north of this road on the divide between Trout Creek and Oak Creek.

Rocks Exposed

The lower members of the Mesaverde formation are exposed along a line roughly parallel, and to the north of the Yampa-Williams Park road. Sandy shales, thin-bedded sandstones, and occasional massive beds of sandstones are the main outcrops of this formation.

The Mancos shales are exposed between the outcrops of the Mesaverde formtion and the Flat Top Mountains to the south. These shales are dark, calcareous and usually thin-bedded. They are similar to the shales found near Steamboat Springs described in previous chapters. The thickness of the Mancos formation and the rocks of the lower part are not known. The formation here is probably similar to the Mancos formation in Williams Park, about 15 miles to the northwest. In Williams Park the formation is about 3,500 feet thick and contains the characteristic limestones and sandstone beds in its lower part.

Igneous rocks, probably of Tertiary age, have been intruded in the sedimentary rocks at many places throughout this area. They are basaltic in character, and are found as sheets, dikes and stocks. At some places they appear to follow the bedding planes of the shales. It was also noticed that they cut the shales in the form of long narrow dikes and stocks. The Flat Top Mountains, Pinnacle Mountain, the dikes northwest of Yampa, and the many fingerpshaped intrusions north of Yampa are the main igneous bodies.

These igneous intrustions, where examined, did not metamorphose the sediments to any great extent. At several places where the dikes cut the shales a slate was formed at the contact.

Structure

Pronounced folding has not taken place in this area as in the area to the north and northwest. The dips recorded indicate that there is a fold present whose axis trends north-west and southeast. This axis passes south of Yampa towards Egeria Park.

The lower sandstone and shale beds of the Mesaverde formation north of the Yampa-Williams Park road near Devils Grave dip 8° to the northeast. Approximately two miles west of this point the sandstones and shales dip 9° N. 15° W.

Outcrops in the same formation west of South Hunt Creek dip 5° to the southwest and to the west. This attitude of the sediments gave the first indication of a fold plunging to the northwest. The southern and southwestern boundaries of this fold are not definite. The shales west of Yampa have a general dip to the northeast and northwest which opens the fold to the southeast. There are very few outcrops of the sediments south of Yampa along Bear River and in the northwestern part of Egeria Park. The shales are covered by a thick mantle of igneous wash material which is unconsolidated gravels and boulders.

Many minor folds or flexures were found in the shales, which were probably caused by minor forces acting near the surface, due to the intrusion of the igneous bodies. These folds have no connection with one another and disappear in short distances.

The Mesaverde formation between Pinnacle Mountain and Williams Park dips to the north and northwest. The Mancos shales to the south are covered to a great extent by a gravel deposit and vegetation which hindered the finding of many outcrops. East of the one-quarter section corner between Sec. 30 and Sec. 31, T. 3 N., R. 86 W., the Mancos shales were exposed at several places along a creek. These shales dip 10° S. 40° W., which indicates that there is a fold present. The area to the southwest and to the south, near Pircen's saw mill, which is several miles southwest of Pinnacle Mountain, was searched for more outcrops and the limited amount found was not enough to determine anything definite as to the structural conditions present.

Oil Possibilities

The folds found are not structurally favorable for the accumulation of gas or oil. If folds are found in this vicinity that are structurally favorable, there is the same possibility of oil and gas accumulation as in the area to the north and northwest. The igneous dikes and stocks may, or may not, affect this accumulation. These bodies present and those that may not express themselves on the surface, may be sprouts from a large laccolith beneath. If these sprouts cut the sediments there would be a local stoppage of any gas or oil accumulated, and, therefore, little would migrate to the crests of the folds.

If the igneous bodies are locally in the form of sheets following the bedding planes of the sediments, they may or may not stop the accumulation, but probably would hinder the migration to the sandstone reservoirs.

This field was not studied enough to determine the definite relationships between the folding and intrusion of the igneous bodies. Without this relationship it is difficult to determine the influence of the igneous bodies on the disseminated carbonaceous material within the shales, or on any pools of oil that may have been formed before the intrusions took place.

It is known that in areas that have been folded by mountain making movements that a great amount of heat was generated by the folding. It is also known that high temperatures must have accompanied the intrusion of the igneous rocks. In this area we have a combination of the above and it is probable that a great amount of the carbonaceous material has been altered. Gases and lighter oils seek higher levels, and might easily escape, leaving the solid residue in the rocks. The disappearance of oil pools in areas of too advanced carbonization is a subject of general interest at the present time, and it is a problem that must receive consideration in this field.

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