THE MULE CREEK OIL FIELD, WYOMING.

By E. T. Hancock.

INTRODUCTION.

LOCATION AND EXTENT OF THE FIELD.

The Mule Creek oil field, as shown in Plate VII, is in the northeastern part of Niobrara County, Wyo., about 4 miles from the east line of the State. It lies about 100 miles almost due east of the Salt Creek oil field and about 35 miles northeast of the Lance Creek field. The field, as mapped and described in this report, includes about 30 square miles of territory immediately south of Cheyenne River, in Tps. 39 and 40 N., Rs. 60 and 61 W. In this field there are two rather well defined anticlines, which for convenience of description will be referred to as the eastern and the western anticline. The top of the eastern anticline is about 18 miles almost due west of Edgemont, S. Dak., a flourishing town on the Chicago, Burlington & Quincy Railroad, from which most of the supplies going to the field are hauled. At a station called Argentine, some distance northwest of Edgemont, the railroad lies within 12 miles of the field.

ACKNOWLEDGMENTS.

In presenting this report the writer desires to express his thanks to David White for valuable suggestions and criticisms and to Carroll E. Dobbin for assistance in the detailed mapping. He also wishes to call attention to the public service rendered by the oil and gas operators, who very willingly furnished the records of deep borings.

PURPOSE OF THE INVESTIGATION.

A geologic investigation of this character requires, first of all, a thorough study of the outcropping strata. Such a study is made for two reasons. In the first place, a geologic report, to be of the greatest practical value, should describe each conspicuous bed or set of beds so vividly, with respect to composition, general appearance, effect upon topography, and other salient features that the oil operator, land owner, or prospective investor will be able to recognize it in the field. In the second place, it is very important to make a thorough study of the strata so as to be able to determine the structure accurately. In working out the structure it is necessary to ascertain the elevation and dip of many of the beds that come to the surface, but there is nothing to be gained by making careful instrumental determinations unless the investigator is reasonably certain regarding the relation, in the stratigraphic column, of the beds that crop out in different parts of the field. After the outcrops of the different beds have been traced and located on the map, both as to horizontal position and as to elevation, and after such well logs as are available are examined, it is possible to show by means of structure contours the attitude of any particular bed such as an oil sand throughout the field. The oil sand whose attitude is shown by contours on the map in this report is that in the Ohio Oil Co.'s producing well in the NE. ¼ sec. 24, T. 39 N., R. 61 W. At this point the record of the well shows the elevation of the sand, and nearly everywhere else the elevation has been calculated by means of other criteria.

FIELD WORK.

The field investigation that furnished the basis for the present report was made between July 8 and 17, 1919. The observations were made and the maps prepared under the immediate supervision of the writer, who was ably assisted in the field by C. E. Dobbin.

In the process of mapping nearly all locations were made by the triangulation method and elevations determined by means of vertical angles. A base line (A-B, Pl. VII) 7,900 feet in length was carefully measured along the high land from the south end of the western anticline to the SE. ¼ sec. 24, T. 39 N., R. 61 W., and the extremities were designated by means of a white flag. After the plane table had been oriented at the points designated, certain monuments and a number of the drilling rigs were located by intersection, and a system of triangulated points was extended throughout the field. In the absence of a permanent bench mark an elevation of 1,000 feet was assumed for the flag at the northwest end of the base line, and all other elevations were based upon the assumed elevation. Later on the elevation of the sandstone in the NE. ¼ sec. 5, T. 39 N., R. 60 W., was determined by reading a vertical angle on the Chicago, Burlington & Quincy Railroad track at Argentine, S. Dak., and the assumed elevations were revised in accordance with the new elevation thus determined. It is apparent, therefore, that the elevations shown on the accompanying map (Pl. VII) are only approximately correct.

In view of the purpose of the investigation, it was necessary to trace out and map the boundaries between the different formations and to determine the elevation and record the strikes and dips of the beds at many points. Where it was possible to trace a definite horizon within a formation and especially where the beds are inclined at a very low angle the structure was determined by means of elevations taken at short intervals.

LAND SURVEYS.

Only a small proportion of the section and quarter-section corners in this field are marked by pits and set stones. The locations of most of the corners have been established by local surveys and are at present indicated by means of plainly marked square posts.

SURFACE FEATURES.

The Mule Creek oil field forms a part of a relatively high area bordered on the north and east by the broad alluvial valley of Cheyenne River. The elevations in this field range from about 3,550 to 4,100 feet. The highest land is at the top of the eastern anticline, and the lowest is in the broad valley along the Cheyenne River. The eastern and western anticlines are rather well defined, but they differ considerably in relation between structure and surface form. A long period has elapsed since the sandstone which now forms the top of the eastern anticline was removed from the crest of the western anticline. Since the agencies of erosion swept this sandstone and the underlying Greenhorn limestone from the crest of the western anticline they have been actively at work removing the great body of soft shale between the limestone and the Dakota sandstone, and at the present stage of erosion the western anticline is marked by a drainage basin, whereas the eastern anticline is represented by a relatively high dome-shaped hill. The drainage basin of the western anticline is bordered on the south and west by a continuous ridge formed mainly by the Greenhorn limestone. The surface of the field is rather rough, owing to the presence of numerous small gullies, most of which unite to form larger ones extending northward and eventually reaching Cheyenne River. Most of the field is covered with grass and sagebrush. There are numerous cottonwood trees along the valley of the Cheyenne and an occasional cottonwood along the principal gullies, but the remainder of the field is entirely barren of timber. The field is readily accessible either by way of an excellent graded road leading west from Edgemont, S. Dak., or by way of the main road leading northwest from Edgemont along the west side of the valley of Cheyenne River. Most of the traffic seems to be over the road leading west from Edgemont, which enters the field at the south end, follows closely the axis of the eastern anticline, and leads down the slope to the area of Mowry shale at the top of the western anticline.

GEOLOGY.

STRATIGRAPHY.

GENERAL SECTION.

The highest beds in the sedimentary series mapped and described in this report are those which occur at the top of the Niobrara formation. The lowermost beds exposed are those which occur in the Mowry shale, but in a comprehensive discussion of the possibilities of oil and gas concentration it is necessary to consider such of the deeper beds as are within reach of the drill.

In the recently published report on the Upton-Thornton oil field,[1] which lies about 60 miles to the northwest and bears a similar relation to the Black Hills uplift, the writer has discussed, in addition to the formations that crop out, those which were penetrated in the bore hole at the Antelope mine at Cambria, Wyo., and also those in the deep well borings at Cambria. Inasmuch as the lowermost beds exposed in the Mule Creek field occur at practically the same horizon as the lowermost beds exposed in the Upton-Thornton field, the table of formations given in that report is repeated here, with certain alterations in the thicknesses of some of the units above the Dakota sandstone to conform to the writer's interpretation of the identity of some of the sands shown in the well log given on page 52.

FORMATIONS THAT DO NOT CROP OUT BUT ARE WITHIN REACH OF THE DRILL.

The lowest beds exposed in this field occur about 75 feet below the top of the Mowry shale. At some localities not far distant, however, the underlying beds are well exposed. These beds are exhibited where they are upturned along the southwest flank of the Black Hills uplift to the north and east, and also in the vicinity of Wright's camp, near the north end of the Old Woman anticline, a few miles to the southwest. Northeast of this field, in the vicinity of Newcastle, there is immediately above the Dakota sandstone about 225 feet of dark shale that erodes very readily, producing a relatively low area between the long dip slopes formed by the Dakota sandstone and the more or less jagged ridge formed by a sandstone lentil that overlies this shale. The extent of development of this sandstone lentil along the flanks of the Black Hills uplift and in the adjacent area is a matter of vital interest to oil and gas operators, not only because oil issues from it in considerable quantities at Newcastle, but also because it is one of the main oil-producing sands at other localities in Wyoming. In the Upton-Thornton oil field it is a reddish-brown, moderately soft sandstone encircling the central portion of the Thornton dome and occurring as isolated patches near the top

[1] Hancock, E. T., The Upton-Thornton oil field, Wyo.: U. S. Geol. Survey Bull. 716, pp. 17-34, 1920 (Bull. 716-B).

Rock formations in the Mule Creek field, Wyo.

[From outcropping beds and deep borings at Cambria, Wyo.]

System.	Series.	Group, formation, and member.			Character.	Thickness (feet).
Cretaceous.	Upper Cretaceous.	Colorado group.	Niobrara formation.		Soft shaly limestone or impure chalk, including some clay and sand.	200
Cretaceous.	Upper Cretaceous.	Colorado group.	Carlile shale.		Dark shale with thin beds of soft sandstone (Wall Creek sandstone member) near the base.	700
Cretaceous.	Upper Cretaceous.	Colorado group.	Greenhorn limestone.		Impure slabby limestone.	50
Cretaceous.	Upper Cretaceous.	Colorado group.	Graneros shale.		Dark-gray to black shale, including many large calcareous concretions, especially in the upper part.	575
Cretaceous.	Upper Cretaceous.	Colorado group.	Graneros shale.	Mowry shale member.	Hard light-gray sandy shales containing numerous fish scales. Contains bentonite beds near the top and to some extent near the base.	100
Cretaceous.	Upper Cretaceous.	Colorado group.	Graneros shale.		Dark sandy shale grading upward into typical Mowry shale.	25
Cretaceous.	Upper Cretaceous.	Colorado group.	Graneros shale.	Newcastle sandstone member.	Reddish to light-yellow sandstone associated with black carbonaceous shale.	3 to 15
Cretaceous.	Upper Cretaceous.	Colorado group.	Graneros shale.		Dark-gray to black shale.	175
Cretaceous.	Upper Cretaceous.	Dakota sandstone.			Thin-bedded to massive hard buff sandstone.	60
Cretaceous.	Lower Cretaceous.	Fuson formation.			Shale and thin-bedded sandstone.	20
Cretaceous.	Lower Cretaceous.	Lakota sandstone.			Sandstone, in part conglomeratic, with some coal beds near the base.	199
Cretaceous (?)	(?)	Morrison formation.			Light-gray to pinkish shale.	130
Jurassic.	Upper Jurassic.	Sundance formation.			Light-gray to dark greenish-gray and pinkish sandy shale, with a 25-foot sandstone near the base.	346
Triassic (?)		Spearfish formation.			Gypsum and red clay beds in alternating succession ("Red Beds").	492
Carboniferous.	Permian (?).	Minnekahta limestone.			Light-gray to pinkish or purplish limestone.	34
Carboniferous.	Pennsylvanian.	Opeche formation.			Red sandy clay, purplish at the top.	74
Carboniferous.	Pennsylvanian.	Minnelusa sandstone.			Light-gray to buff calcareous sandstone.	851
Carboniferous.	Mississippian.	Pahasapa limestone.			White, pale-buff, pinkish, and gray limestone.	398

of the dome. It is apparently only 2 or 3 feet thick at the northwest end of the dome, but on the south end it includes about 15 feet of reddish to light-yellow sandstone associated with some carbonaceous shale. In the vicinity of Newcastle, where considerable oil seeps from this sand, it is about 35 feet thick and forms a ridge about 500 feet above the railroad. It continues as a very conspicuous ridge as far southeast as the L. A. K. ranch, on Stockade Beaver Creek, but from that point southward it becomes thinner, appearing only at intervals as lenses in the shale. It seems to be rather well developed, however, near the north end of the Old Woman anticline, about 12 miles southwest of the Mule Creek field. The conditions there are as follows: About three-quarters of a mile northwest of Wright's camp the Dakota sandstone forms a long dip slope. The sandstone is overlain by about 200 feet of dark shale. The shale is overlain by a succession of sandstones and carbonaceous shale beds which give rise to a very conspicuous ridge. This group of beds, the details of which are shown in the following section, is in part at least equivalent to the oil-bearing sand at Newcastle.

Section of sandstone and carbonaceous shale beds northwest of Wright's camp.

	Ft.	in.
Sandstone, very hard, forming east dip slope	2	6
Mainly black carbonaceous shale	9	0
Sandstone, yellowish brown, massive	6	6
Shale, sandy, carbonaceous		9
Sandstone, rather thinly bedded	7	0
Shale, black, carbonaceous	5	6
Sandstone, yellowish brown, hard and massive	4	6
Shale, sandy	1+	
	36+	

The group of sandy beds described above is doubtless widely distributed throughout Wyoming. It was recognized by the writer on the south slope of the Como Ridge, about 6 miles east of Medicine Bow, and is in all probability equivalent to the sand that occurs near the middle of the Thermopolis shale at different localities in the Big Horn Basin and is commonly known by drillers as the Muddy sand. These beds attain an unusual thickness at Newcastle and are oil bearing at that locality, so for convenience of description they are named the Newcastle sandstone member.

The beds immediately above the Newcastle sandstone are plainly exhibited along the north side of the Thornton dome, described in the report on the Upton-Thornton oil field. Encircling the sandstone in the Thornton dome is an area which is underlain by dark shale. The shale that overlies the Newcastle sandstone and gradually merges upward into the typical Mowry shale is about 50 feet thick. The upper half of the Mowry shale is exposed in the Mule

Creek field at the top of the western anticline, and for that reason the entire formation is described on succeeding pages along with the others which crop out in this field.

The section from the top of the Dakota sandstone down into the Morrison is well shown in the bore hole of the Antelope mine at Cambria, Wyo. At that locality, which is about 40 miles north of the Mule Creek field, the following section is exhibited:

Section in bore hole of Antelope mine at Cambria, Wyo.[2]

	Feet.
Dakota:	
Sandstone, thin bedded	20
Sandstone, hard, massive, buff	40
Fuson: Shale and talus	20
Lakota:	
Sandstone, light colored, conglomeratic in part	60
Talus and sandstone ledges	70
Sandstone, light gray, soft, fine grained	50
Coal	7
Sandstone, hard, light brown	5
Sandstone, soft, dark brown	2
Sandstone, light gray, moderately hard	1½
Coal with sandstone, shale, and pebbly layers	½
Sandstone, dark gray, soft	1
Coal, shales, and sandstone	2
Morrison:	
Fire clay, gray	3
Sandstone, light gray, moderately hard	1½
Fire clay	7½
Sandstone, gray, upper half very hard	4
Shales with some thin sandstones	54+

The deep-well boring at Cambria probably furnishes as detailed and reliable information regarding the underlying formations as can be obtained. This well was begun just below the 7½-foot bed of fire clay in the above section and was continued to a depth of 2,345 feet. The log of the well, as shown in figure 1, was compiled by N. H. Darton from samples sent to Washington and from a set of borings admirably preserved in glass tubes by Mr. Mouck, the superintendent of the Cambria mines. According to this log and the section from the bore hole of the Antelope mine there are 2,636 feet of beds between the top of the Dakota sandstone and the bottom of the deep well. In all probability there is a slight variation in the total thickness of the formations between Cambria and the Mule Creek field, but on the assumption that the total thicknesses are the same, the beds which occur at the bottom of the deep well at Cambria are about 2,900 feet below the surface at the top of the western anticline at Mule Creek and 3,770 feet below the surface at the top of the eastern anticlines.

[2] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 4, 1904.

A careful analysis of the logs of the bore hole and the deep well at Cambria shows that the principal sandstones beneath the surface in this region are included in the Dakota, Lakota, and Minnelusa formations. At the Antelope mine the Dakota is composed of an upper thin-bedded sandstone and a lower hard, massive buff sandstone. The Lakota formation is composed mainly of sandstone, in part conglomeratic, with coal beds near the base. The Morrison is composed mainly of light-gray to pinkish shale, with beds of sandstone and fire clay near the top. The Sundance formation is composed of light-gray to dark greenish-gray and pinkish sandy shales, including near its base one soft buff sandstone about 25 feet thick. Extending from the base of the Sundance down to the Minnekahta limestone is the Spearfish formation, commonly known as the Triassic "Red Beds," including alternating beds of gypsum and red clay. The Permian series is probably represented by the Minnekahta limestone, about 34 feet thick, and the underlying Opeche formation, composed of 74 feet of red sandy clay, somewhat purplish at the top. The Carboniferous from the base of the Permian series to the bottom of the deep well is composed essentially of sandstones and limestones. The Minnelusa formation, of Pennsylvanian age, consists almost entirely of light-gray to buff calcareous sandstones, the total thickness of which is 851 feet. From the base of this formation to the bottom of the well there is 398 feet of massive limestone.

FORMATIONS EXPOSED.

UPPER CRETACEOUS SERIES.

COLORADO GROUP.

The Colorado group in this locality includes the Niobrara formation, Carlile shale, Greenhorn limestone, and Granerous shale. The last three formations are equivalent to the Benton shale of other areas.

Graneros shale.—Overlying the Dakota sandstone in this region is a mass of soft, fine-grained deposits whose total thickness is about 885 feet. According to Gilbert[3] the name Graneros was first suggested by R. C. Hills for an equivalent group of beds exposed along Graneros Creek about 20 miles south of Pueblo, Colo. The greater part of the mass consists of dark-gray to black shale, which is very soft and which yields readily to the ordinary agencies of erosion. About 175 feet above the base of the formation there is commonly what may be called a sandy zone. This zone of sandy material—here named the Newcastle sandstone member, from Newcastle, Wyo., where it is conspicuously developed—varies in thickness and also in composition in different localities, as explained on pages 38–40, but it can generally be recognized by anyone reasonably familiar with their stratigraphy. It is commonly overlain by 25 to 50 feet of dark shale, which merges upward into the typical Mowry shale.

[3] Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 570, 1896.

The term "Mowrie beds" was first applied by Darton[4] in his description of the Big Horn region to a group of beds exposed along Mowry[5] Creek, northwest of Buffalo, Wyo. The Mowry shale in more or less typical form is exposed in this field at the top of the western anticline, where, as near as the writer could estimate, erosion has removed about one-half of the original thickness. Where the Mowry is upturned along the southwest flank of the Black Hills uplift it ordinarily includes about 150 feet of hard light-gray sandy shales, many of the individual plates of which exhibit fish scales. These shales, on weathering, become almost white, in strong contrast with the softer dark-colored shales above and below, and, owing to their superior hardness, they do not erode as rapidly as the overlying and underlying shales, so that the position of the Mowry shale member is commonly indicated by a more or less continuous ridge or by a succession of low hills covered by a moderately dense growth of evergreens. In this field some of the shale has been removed from the top of the western anticline, and certain thin layers of sandstone are laid bare for several hundred feet. The top of the Mowry shale is well exposed along the west side of the anticlines near the center of sec. 2, where it is marked by two 4-foot beds of bentonite separated by 8 feet of dark shale. This bentonite is a light-gray to yellowish fine-textured soft and massive clay. It is a hydrous silicate of alumina with certain other constituents in small proportions and is characterized by its highly absorbent qualities. The upper bed of bentonite is overlain by about 10 feet of dark-gray flaky shale, and this in turn by very black shale containing considerable heavy black, iron-stained material in thin layers and also in individual concretions. The bentonite and the associated beds are valuable horizon markers in eastern Wyoming because of their persistence over wide areas.

From the Mowry shale member up to the Greenhorn limestone the Graneros formation is composed essentially of dark shale containing scattered calcareous concretions.

Greenhorn limestone.—Immediately overlying the upper dark shale of the Graneros formation is a thin but very persistent series of beds of impure limestone known as the Greenhorn limestone. According to Gilbert,[6] this limestone first took its name from Greenhorn Creek and Greenhorn station, about 14 miles south of Pueblo, Colo. The entire limy series does not generally exceed 50 feet in thickness, but these limestone beds are so much harder than the beds above and below that they give rise to a more or less continuous ridge bordering the western anticline on the west and south and to a considerable extent on the east. They also give rise to a very prominent escarp-

---

[4] Darton, N. H., Comparison of stratigraphy of Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 400, 1904.

[5] Formerly sometimes spelled "Mowrie."

[6] Gilbert, G. K., op. it., p. 570.

ment extending from east to west along the north side of Cheyenne River. Where the resistant beds of impure limestone have not given rise to a well-defined ridge their outcrop is indicated on the surface by a narrow belt having a distinctly lighter color and curving in obedience to the gradual change in the strike of the beds. On weathering the thin layers of impure limestone become very hard and resistant, and where the beds dip steeply the outcrop is commonly marked by a series of thin slabs projecting above the surface. Many of these slabs contain numerous impressions of *Inoceramus labiatus*, a fossil that rarely occurs in other formations of Benton age.

Carlile shale.—The name Carlile shale was first applied by Gilbert[7] to a body of shale resting upon the Greenhorn limestone in the vicinity of Carlile Spring and Carlile station, about 21 miles south of Pueblo, Colo. In the more recent reports of the Geological Survey the same name is applied to a group of beds having the same stratigraphic position but differing considerably from those at the type locality. In the report on the Upton-Thornton oil field the writer calls attention to the fact that the lower 230 feet of the Carlile shale is composed essentially of soft sand and very sandy shale. These beds are all exposed in the railroad cut about 2 miles northwest of Thornton, Wyo. The lowermost 200 feet of the Carlile shale is not well exposed in the Mule Creek field, and hence that part of the formation is believed to be composed essentially of shale and imperfectly consolidated sandy beds. The upper portion of the section exhibited in the railroad cut near Thornton is represented in this field by a group of sandstones and carbonaceous shale beds about 35 feet thick. The beds of this series crop out in the western anticline a few hundred feet outside of the Greenhorn limestone and also along the gulches both east and west of the eastern anticlinal axis, and they occur at the surface at the producing well on the highest part of the eastern anticline. From the stratigraphic position of these sandstones and associated beds they are believed to represent the Wall Creek sandstone of areas farther west. The beds are well exposed in the NE. ¼ sec. 7, T. 39 N., R. 60 W., where the following section was measured:

Section showing the beds which constitute the Wall Creek sandstone member in the NE. ¼ sec. 7, T. 39 N., R. 60 W., Wyo.

	Feet.
Sandstones, yellowish brown, soft and very irregularly bedded......	7
Shale, dark, sandy, and carbonaceous..............................	4
Sandstone and dark carbonaceous shale, interbedded...............	5
Shale, dark, becoming very sandy near the top.....................	9
Shale, dark gray and very sandy, including numerous thin beds of sandstone..	10

[7] Gilbert, G. K., op. cit., p. 570.

The following species of invertebrate fossils were obtained from the above-described beds near the main road about a mile farther west, in the NE. ¼ sec. 12, T. 39 N., R. 61 W. They were examined by T. W. Stanton, who states that they belong to the Benton fauna and indicate a horizon within the Carlile shale.

Aporrhais sp.
Corbula sp.
Inoceramus fragilis Hall and Meek.
Lunatia sp.
Prionocyclus wyomingensis Meek.
Prionotropus sp. related to P. hyatti Stanton.
Scaphites warreni Meek and Hayden.

Throughout the eastern part of the Mule Creek field the sandy beds shown in the above section occur at or very near the surface, and either all or a large part of the upper portion of the formation is eroded, but in the western part of the field the upper portion is present. In that area the Carlile dips rather steeply beneath the Niobrara formation and, like that formation, presents very few exposures.

Niobrara formation.—The Niobrara formation rests unconformably upon the Carlile shale and is exposed throughout a narrow belt along the south and west sides of the field. This formation was first named in the reports of the Hayden Survey, and the type locality is along Missouri River near the mouth of the Niobrara, in northeastern Nebraska. At that locality the beds form vertical cliffs from 90 to 100 feet in height. In the Mule Creek field the characteristics of the formation are best exhibited east of the main road, at the south end of the field. It includes about 200 feet of soft shaly limestone or impure chalk containing more or less shale, fine sand, and clay. It also includes some thin beds of hard limestone which consists of aggregations of *Ostrea congesta,* a fossil very distinctive of the formation. The unweathered exposures of the formation are usually grayish, but the weathered outcrops are decidedly yellow. The formation is therefore very conspicuous, although the constituent beds are soft and give rise to few noticeable ridges.

STRUCTURE.

GENERAL FEATURES.

The Rocky Mountain Front Range and the Black Hills uplift are connected by what is commonly known as the Hartville uplift, an irregular arch whose axis is indicated by exposures of granite, schist, and limestone near Hartville and Lusk, at Rawhide Butte, and at a number of other localities. The position of the axis is also indicated by the Old Woman anticline, which brings to the surface the uppermost beds of the Sundance formation. The Mule Creek oil field lies in the direct continuation of this axis, about midway between the

Old Woman anticline and the rather steeply dipping beds along the southwest flank of the Black Hills. The great disturbance which brought the major uplifts into existence also resulted in the formation of two well-defined anticlines in the Mule Creek field, but the strata involved in these folds were uplifted relatively little in comparison with the arching of the same strata in the Old Woman anticline or the Black Hills uplift. The location and form of the two principal anticlines of the Mule Creek field are clearly shown on the accompanying geologic map (Pl. VII). The smaller one of the two lies south and east of the larger, and for want of better names they are called the eastern and western anticlines.

METHODS OF REPRESENTING STRUCTURE.

Different methods have been used from time to time by the Geological Survey for the purpose of conveying to the reader an adequate notion regarding the folding, or what is frequently referred to by drillers and others as the "lay" of the beds. The structure is ordinarily shown by means of either structure sections or structure contours. The structure section is based mainly upon the degree of inclination of the beds at the surface, upon measured stratigraphic thicknesses, and upon data from deep borings. It shows how a portion of the earth's crust would appear if it were cut by a vertical plane and the material on one side of the plane were removed. The structure section is an excellent aid in the explanation of structure where the beds dip steeply, but where they are inclined only a few feet to the mile it is difficult to bring out certain structural features without exaggerating the vertical scale more than is desirable. In oil and gas investigations, where the interpretation and representation of structure are extremely important, the method of representing structure by contours has been adopted because of its practical value and also because it is easily understood. The following explanation is offered for the benefit of those who are unfamiliar with the definition, degree of accuracy, and practical application of structure contours:

Structure contours are lines drawn on a map to show the elevation of some particular stratum above or below a certain datum plane, as, for example, mean sea level. They are designed to show the shape and magnitude of the folds and, in general, the irregular warping of the beds. In the preparation of the accompanying map (Pl. VII) it was decided to show, throughout the field, as accurately as the data available would allow, the elevation of the sand that yields oil in the Ohio Oil Co.'s producing well in the NE. ¼ sec. 24, T. 39 N., R. 61 W. Any particular contour is the line of intersection between that sand and a horizontal plane a certain distance (for example, 2,000 feet for the 2,000-foot contour) above sea level. Each structure contour represents a level 100 feet above or below that of the one adjacent, and hence it follows that where the contours are closely spaced the beds are steeply inclined, and where they are widely spaced the formation approaches much nearer to horizontality.

Structure contours furnish a convenient method for presenting to the reader a comprehensive idea regarding the structure of an entire field. Their practical value depends, of course, upon their accuracy, and their degree of accuracy depends upon the number of data available. In certain developed oil fields it is possible to obtain numerous well logs and recognize in them, either directly or from other beds, the position of the particular bed which it is desired to contour. After a structure-contour map is made for such a field the depth to the contoured bed at any point can be ascertained very accurately by subtracting from the surface elevation at that point the elevation of the contoured bed as shown by the structure contour. In other fields, where little drilling has been done and especially where many of the records were not preserved, it is necessary to depend almost entirely upon surface data, such as dips, measured intervals between beds, and elevations of traceable beds in making a structure-contour map. In such fields the structure contours are not likely to be drawn as accurately, but the demand for information is often so acute that it becomes necessary to sacrifice a certain degree of accuracy in order to insure more prompt publication. On the map of the Mule Creek field the structure contours are drawn mainly on the basis of dips, measured intervals, and elevations of traceable beds. At the Ohio Oil Co.'s producing well at the top of the eastern anticline, in the NE. ¼ sec. 24, T. 39 N., R. 61 W., the Wall Creek sandstone occurs at the surface and the oil sand occurs at a depth of 1,394 feet. Fortunately, it was possible to trace and determine the elevation of the Wall Creek sandstone throughout a large portion of the field and from it to determine the elevation of the oil sand. The top of the Greenhorn limestone is very close to 200 feet below the top of the Wall Creek sandstone, and therefore it is about 1,200 feet above the oil sand. It follows, then, that the top of the Mowry shale is about 570 feet stratigraphically above the oil sand if the thicknesses of the different formations and members are approximately those shown in the table of formations on page 39.

STRUCTURE OF THE MULE CREEK FIELD.

The structural relation of the Mule Creek field to the surrounding region is discussed on pages 45–46. As a result of the forces which were active in this region, two well-defined anticlines were developed in the Mule Creek field. The axes of these two anticlines trend nearly due north, and the more pronounced of the two is a little north and west of the other. The two anticlines are separated by a sharply curving syncline. As shown on Plate VII, the axis of the western anticline extends from sec. 23, T. 39 N., R. 61 W., to the northeast corner of the same township and from that point in a sweeping curve to the northeast corner of sec. 30, T. 40 N., R. 60 W., and in all probability for some distance farther east. The beds involved in this anticline are at most points inclined from 5° to 15°, but along the west side opposite the small area of Mowry shale they dip as steeply as 26°. East of the axis the beds are inclined from 14° to 16° at the south end, but farther north they become flatter as the fold broadens out. The axis of the eastern anticline extends from the synclinal axis southward to the Ohio and Midwest wells, at the top of the ridge near the west line of sec. 19, T. 39 N., R. 60 W., and thence it follows the township line closely for an indefinite distance southward. From this axis the beds are inclined at angles ranging from 3° to 6°. The axis of the syncline extends from the NE. ¼ sec. 23 to the SE. ¼ sec. 12, T. 39 N., R. 61 W., where it makes a sharp curve, and from that point it extends toward the middle of the north side of sec. 20, T. 39 N., R. 60 W.

When the two anticlines came into existence the same beds were forced up much higher in the western than in the eastern anticline, as is shown by the following facts. The Wall Creek sandstone, which crops out at the top of the eastern anticline, is about 236 feet higher than the Mowry shale, exposed at the top of the western anticline, but according to the thicknesses as given in the table of formations on page 39, there are about 900 feet of beds between the Wall Creek sandstone and the uppermost exposed beds of the Mowry. If the tops of the two anticlines were at exactly the same elevation, it is evident that the difference in elevation of corresponding beds would be equal to the stratigraphic interval, or 900 feet, but inasmuch as the top of the western anticline is 236 feet lower than that of the eastern anticline, it follows that any particular bed in the western anticline is 900 minus 236, or 664 feet higher than the corresponding bed in the eastern anticline. The reader should keep in mind, however, that this calculation is based on the log of the Ohio Oil Co.'s discovery well and the assumption that some of the formations are considerably thinner in the Mule Creek field than they appear to be in the Upton-Thornton field.

OIL AND GAS.

FACTORS THAT GOVERN THE ACCUMULATION OF OIL AND GAS.

A careful comparison of the structure of the rocks and its relation to concentrations of oil and gas in many parts of the world has given rise to the structural or anticlinal theory. The conditions that control the accumulation of oil and gas, according to this theory, are briefly as follows:

(*a*) A reservoir rock, commonly known as the oil "sand," although it may be a very sandy shale, a fractured rock of some kind, a loose conglomerate sufficiently porous to allow the accumulation of oil or gas, or a porous limestone or dolomite composed largely of interlocking crystals of calcite or oolitic grains.

(*b*) An impervious cap rock to seal over the reservoir rock and prevent the upward escape of the oil and gas.

(*c*) Folds in the rock favoring the accumulation and confinement of oil and gas in certain localities, these substances migrating from more extensive areas of adjoining beds that are less favorably situated for their retention.

(*d*) Saturation of the rocks by ground water, on which the oil and gas will move on account of their lower specific gravity and be forced along the more porous strata into the upper parts of the folds.

According to the anticlinal theory, if a porous rock containing gas, oil, and water is folded between other rocks which are nonporous, these substances, under the influence of gravity, separate and arrange themselves according to density in the porous zone. The gas, being the lightest, rises to the crest of the anticline, the oil separates out below, and the water occupies the deeper portions of the beds. It is a well-recognized fact that oil and gas have entered porous sands from adjacent beds and that they have in many areas migrated long distances to the points of concentration, but it is not absolutely demonstrated just what forces are the most active in causing oil, gas, and water to migrate from the fine clays and shales into the porous sands. Neither has it been proved beyond controversy to what extent gravity and capillary attraction influence the movement of those substances along porous sands that are inclined at an extremely low angle.

Detailed field observations have shown not only that many of the concentrations of oil and gas are intimately related to anticlines and domes, but also that gas, oil, and water adjust themselves in the strata in the manner stated above. Although the recognition of these facts has caused most geologists to accept the anticlinal theory in its broader aspects, many geologists are willing to accept it only in a modified sense, as recent study has shown that accumulations of oil and gas occur not only in the crowns of the arches but also in many places on the flanks of the folds where the dips are less steep for some distance, the local flattening forming structural terraces. Recent studies indicate also that the conditions of accumulation are entirely different in saturated and unsaturated rocks—that in thoroughly saturated rocks the oil and gas are borne upward on the sheet of underground water and are caught in the crowns of the arches, whereas in dry rocks the principal point of accumulation of oil may be near the bottoms of the synclines or at any place where the forces obstructing the movement of particles of oil are equal to or in excess of those which promote such movement.

In saturated rocks the ideal structural form is the dome which includes a thick bed of porous sand that is effectively sealed above and dips gently for considerable distances, but such a form is not common in nature. In many domes the dips are limited by other structural features, and in consequence the collecting area is small. The oil sands may be lenticular, or continuous sands may be offset along fault planes. If the fault remains partly open fluids migrating through the porous sands may rise to the surface and escape. It has been found that many oil seeps are characterized by deposits of asphalt. If the fault is sealed by clay, asphalt, or some other impervious substance the oil and gas may concentrate in the sand near the fault plane, and the result is practically the same as when the sand is lenticular. Thus an open fault fissure may prevent concentration at the top of an anticline or dome, and a fissure effectively sealed may produce local concentration at some point along the flank. The migration of oil, gas, and water through porous sands up along the flank of the most ideal structural feature may be retarded where the beds abruptly flatten or where the porosity of the sand decreases, and it may be entirely obstructed where a dike of igneous rock cuts across the sands. From the facts above outlined it is not surprising that some concentrations of oil and gas occur in places where, from all surface indications, the conditions are unfavorable, whereas some areas that appear to have the most favorable structure are barren. These conditions are mentioned briefly, not with the object of depreciating the value of the anticlinal theory as a working hypothesis, but merely to emphasize the necessity for making in every field a thorough study of all the conditions which may in any way retard the movement of fluids and result in concentration.

POSSIBLE PRODUCTIVE SANDS.

In an attempt to apply what has been said to the Mule Creek field certain facts become at once apparent. In the first place, a careful examination of the beds exposed along the southwest flank of the Black Hills shows that there are many porous beds in this field beneath the horizon of the Wall Creek sandstone and within reach of the drill. It is also apparent from the table of formations (p. 39) that many of these porous beds are overlain by impervious beds, and the geologic map (Pl. VII) shows plainly that the entire series has been arched upward, forming two well-defined anticlines. With these facts in mind we should attempt to ascertain, from experience in adjacent fields, which of these porous beds are the most likely to yield oil and gas.

In the description of the lowest beds exposed in the Mule Creek field (pp. 38–42) considerable emphasis is placed on the Newcastle sandstone, which at Newcastle occurs about 50 feet below the Mowry shale and about 225 feet above the top of the Dakota sandstone. These sandy beds are widely distributed throughout eastern Wyoming, and they exhibit considerable variation from one locality to another, even along the southwest flank of the Black Hills. They contain oil at Moorcroft and Newcastle and gas in the Big Horn Basin, and are probably the main oil and gas sands in the Lance Creek and Rock Creek fields. The Greybull sandstone member of the Cloverly formation produces most of the oil and gas of the Greybull field. In the Powder River field the approximate stratigraphic equivalent, which was designated the Dakota (?) sandstone, is the principal oil-bearing formation, but a small quantity of oil occurs in at least two sands in the Morrison, and it is also present in small quantity in the Sundance formation. The Carboniferous portion of the Embar group bears oil in the Lander field, and a 1,730-foot boring on the Old Woman anticline, about 15 miles southwest of the Mule Creek field, is reported to have found considerable oil, doubtless in the Minnelusa sandstone, also of Carboniferous age.

DEVELOPMENT IN THE MULE CREEK FIELD.

Attention was first directed to the Mule Creek field by the recognition of the western anticline, and the earliest development was in the nature of shallow drilling, mainly for the purpose of validating claims. As usual, the interested persons reported the "commercial discovery" of oil, but accurate records of the wells were apparently not preserved. The first important discovery of oil was made early in 1919 by the Ohio Oil Co. near the top of the eastern anticline, in the SE. ¼ NE. ¼ sec. 24, T. 39 N., R. 61 W. When the writer's field examination was completed this was the only producing well in the field, but since that time a number of other wells have been brought in near the axis of the eastern anticline. The writer is in possession of very little information concerning the recently completed wells, and consequently the detailed descriptions are omitted. The location and character of the recent wells, as shown on the geologic map (Pl. VII), are based upon a map furnished by the Ohio Oil Co. According to a statement in the Oil and Gas News of November 6, 1919, the producing wells at that time averaged from 125 to 150 barrels a day and the total production of the field exceeded 1,000 barrels a day. Like most of the oil obtained from that horizon in Wyoming, the Mule Creek oil is of low specific gravity and has a paraffin base. It is reported that the Illinois Pipe Line Co. has begun laying a pipe line from the field northeastward to Dakoming, a station on the Chicago, Burlington & Quincy Railroad near the line between South Dakota and Wyoming.

In order that the reader may become familiar with the stratigraphic position of the sand from which the oil is obtained in the discovery well, the log of that well is given below.

Log of Ohio Oil Co.'s producing well in the SE.¼ NE.¼ sec. 24, T. 39 N., R. 61 W., Wyo.

[Driller's interpretation.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy shale	300	300
Shell	1	301
Blue hard shale	274	575
Shell	2	577
Blue shale	16	593
Shell	2	595
Blue shale	55	650
Shell	2	652
Blue and gray shale	93	745
Sand; showing of gas	5	750
Blue shale (Newcastle sandstone horizon 175 feet above base)	385	1,135
Dry sand	25	1,160
Water sand	109	1,269
Blue-gray shale	22	1,291
Blue shale containing streaks of sand	23	1,314
Sand	57	1,371
Sandy shale resembling talc (oil sand)	23	1,394

The above log indicates that the drill penetrated more than 200 feet of sand before reaching the principal oil-bearing stratum. According to the thickness of the different members as shown in the table of formations accompanying the recent report on the Upton-Thornton field, the top of the Newcastle sandstone would be near the base of the "water sand" in the above log, but where the Newcastle sandstone crops out along the southwest flank of the Black Hills and in the Old Woman anticline it rarely exceeds 50 feet in thickness. In the Lance Creek field it is composed of an upper and a lower sandstone separated by hard shale, and the combined thickness of the three beds is probably not greater than 50 feet. Owing to the fact that the Newcastle sandstone is scarcely recognized immediately east of this area, where the beds are upturned in the vicinity of Edgemont, it seems reasonable to suppose that this sandstone is very thin in the Mule Creek field, and furthermore, that the "dry sand" and "water sand" noted in the above well log together constitute the Dakota sandstone, that the underlying blue-gray shale is equivalent to the Fuson shale, and that the oil is derived from an oil sand in the Lakota sandstone. In arriving at this conclusion it is necessary to assume that the formations above the Dakota are somewhat thinner at Mule Creek than they appear to be in the Upton-Thornton field, but nevertheless the field evidence seems to justify such a conclusion.

Considerable drilling has been done on the western anticline, mainly for the purpose of validating claims. Some of these wells, in all probability, were drilled below the horizon of the Newcastle sand. More recently considerable drilling has been done near the axis of the anticline by the Ohio, Sterling, and other oil companies. According to recent reports, the Ohio Oil Co. has drilled two wells as deep as the "Red Beds" (Spearfish formation). One of these wells is in the SE. ¼ sec. 11, T. 39 N., R. 61 W., and the other is near the southwest corner of sec. 36, T. 40 N., R. 61 W. The company is now (January, 1920) considering drilling the latter well still deeper for the purpose of testing some of the lower sands. Both of these wells are called dry holes, and both are well located with respect to the axis of the anticline. Having reached the "Red Beds," they have penetrated the sand that produces oil on the eastern anticline. The horizon of the oil sand is much higher in the western anticline, as explained on page 48, and there is an extensive collecting area to the north and west, but the results of drilling seem to be rather discouraging. The failure to obtain oil near the top of the western anticline is probably due to a change in the thickness or porosity of the oil sand, but additional subsurface data are necessary before the problem can be satisfactorily solved.